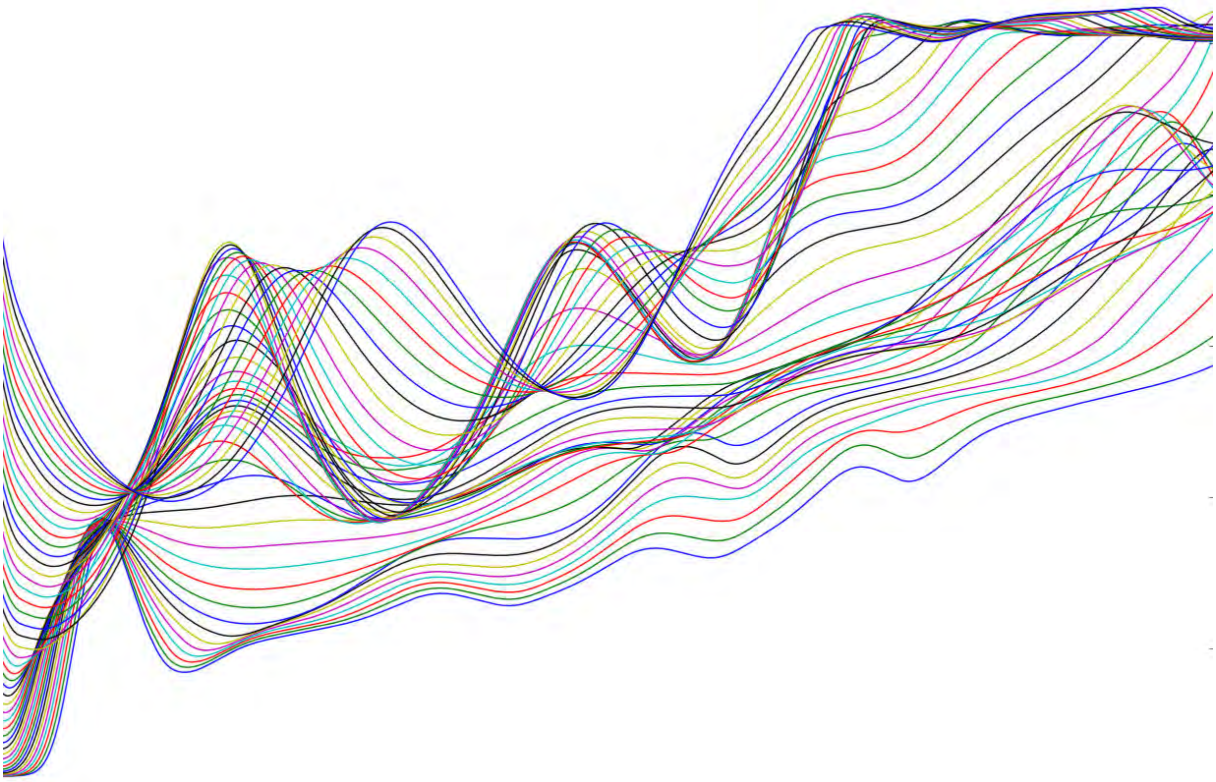
Small **System Dynamics** Models

for **Big Issues**

Triple Jump towards Real-World Dynamic Complexity



Erik Pruyt

1st time readers: start with intro | & 'e-book tour' | videos + preface |

↑ cover page ↓ info

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Cover and back cover image: sensitivity analysis using the EMA workbench and Vensim DSS of a slightly extended version of model 14.15
Picture on page 29: FloorFoto

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To Jikke, Mika & Jessica

Chapter 0

PREFACE

> 'The world certainly needs system dynamics now more than ever. While a cliché, it is certainly true that our social systems are more complicated, more interconnected and likely more fragile than at any previous point in the history of humankind. Worse, while we are ever more in need of a fundamentally holistic, systems-oriented perspective, there is good reason to believe that the theories and ideologies dominating social discourse are becoming more shortsighted and individualistic.' (Repenning 2003, p325)

0.1 System Dynamics

System Dynamics (SD) is a method to describe, model, simulate and analyze dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies. Quantitative SD modeling, simulation and analysis facilitates the (re)design of systems and design of control structures (Wolstenholme 1990). SD is in fact the application of the principles and techniques of control systems to organizational and social-economic-environmental-...problems. SD starts from the assumption that the behavior of a system is largely caused by its own structure. System structure consists of physical and informational aspects as well as the policies and traditions important to the decision-making process in a system (Roberts 1988). Hence, in order to improve undesirable behaviors, the structure of the system needs to be changed. SD allows to identify desirable system changes and test them in a 'virtual laboratory'.

The SD approach was developed at the end of the nineteen-fifties and the beginning of the nineteen-sixties by Jay W. Forrester, at the Sloan School of Management of the Massachusetts Institute of Technology (Forrester 1995; Forrester 1958; Forrester 1961; Forrester 2007a; Lane 2007). He argued that the traditional methods for solving problems provided insufficient understanding of the strategic processes involved in complex systems.

In his writing, Forrester scaled up from the company level in Industrial Dynamics (Forrester 1961) over the city level in Urban Dynamics (Forrester 1969) to the world level in World Dynamics (Forrester 1971). The latter work was the impetus to the well-known Limits to Growth report (Meadows et al. 1972) commissioned by the Club of Rome, and its successive updates. Beyond these important topics, SD is used today for almost any dynamically complex issue. Important application domains in SD are health policy, energy transitions and resources scarcity, environmental and ecological management, safety and security, public order and public policy, social and organizational dynamics, education and innovation, economics and finance, organizational and strategic business management, information science, and operations and supply chain management. Almost all of these domains are addressed in this e-book, but none of them deeply and broadly enough to do them right. Section 21.3 on page 276 therefore contains references to suggested reading in SD, and section 21.4 on page 277 to some good SD entries into each of these application domains.

0.2 Aim and Rationale

The Aim of this E-Book

Over the past seven years, I developed more than a hundred SD exercises and cases and hundreds of multiple choice questions for teaching and testing large SD courses (45+ and 200+ students per year) at Delft University of Technology. This e-book contains most of the fully specified exercises and cases I developed from 2007 until the summer of 2013[1]. These exercises and cases were developed in view of teaching basic/intermediate SD modeling and simulation skills. The emphasis of these introductory SD courses is on model building and simulation, and to a lesser extent on model conceptualization and (detailed and aggregate) diagramming, model testing and analysis, and policy testing and other model uses.

The e-book is in line with these courses: Its main aims are to allow anyone to learn basic and some intermediate SD modeling skills by means of a case-based blended-learning approach, and along the way, introduce the SD methodology and convey the necessary SD reflection skills. The explicit learning goals of the first part of the introductory courses this e-book was developed for are (*i*) to have basic knowledge of the SD field/philosophy/method, (*ii*) to be able to apply the SD method using SD software packages, (*iii*) to have a basic understanding of SD model use, and (*iv*) to have gained some SD modeling experience. There are no prerequisites for this e-book: although at Delft University of Technology, students enter the SD101 courses with a basic knowledge on differential equations and policy analysis, such prior knowledge may be useful, but is not required. What is required, though, is the desire to acquire these skills, and sufficient perseverance and discipline: the cases in this e-book require –because they are fully specified– 99-95% of transpiration, i.e. applying new skills, and only 1-5% of inspiration and insight. Open cases in the project part of these courses (see below) require about 50% transpiration and 50% inspiration and insight.

One of the courses for which these materials were developed is from 1 September 2013 on available as a fully certified Collaborative Online Learning (COL) course to external students and professionals enrolled for this SD course or the COL Policy Analysis program this course is part of. COL courses are online courses with a mix of online teaching, supervision, coaching, online collaboration and team work via online media. Blended COL courses alternate reading, short explanatory videos, hands-on activities (here: modeling and simulation), structured feedback, formative quizzes, targeted online lectures, online office hours and frequent evaluative testing. Contact hours are minimized through the blended-learning design, and students are supposed to work at least 5 times 10 hours for the first part of the course, although more is better. Given the diversity of activities, the limited number of contact hours, the difficulty of the subject matter, and the many exercises and cases available, it is imperative to offer a well-structured 'learning path'. This e-book offers one generic learning path and nine theme specific learning paths which hyperlink to all resources in the e-book and online resources.

The e-book was developed such that it is suited for self-teaching by anyone determined to acquire these skills but not enrolled in one of the regular or COL courses. Almost anybody with academic-level capabilities, the desire to acquire these skills, and sufficient perseverance and discipline could acquire these basic and some intermediate SD modeling skills in 1 intensive week (10 hours per day) or in 5 weeks (10 hours per week). Since guided hands-on practicing with targeted feedforward and learning-oriented feedback is in my opinion what it really takes to become a modeler, this e-book contains, on top of the material of a learning path, at least 10 times the amount of practicing materials that is necessary to acquire these basic to some intermediate modeling skills. Hence, there is also enough material for those with more time and willingness or need to practice.

The main aim of this e-book and associated online materials is thus to provide hands-on learner-oriented modeling materials to modelers *in spe* to help them acquire basic and some intermediate SD modeling skills in a minimum of about 50 to 70 hours.

[1]Exercises and cases developed from the summer of 2013 on will be added as online exercises and cases.

Most online materials will be available as Open Course Ware (OCW) materials from September 2013 on. Regular or COL course students nevertheless have some advantages over self-teaching students, namely the advantages of being able to access additional materials such as additional lecture notes and old exams, attend dedicated lectures and interactive feedback sessions, ask questions during (online) office hours, collaborate with peers, work for strict deadlines and tests, take part in exams to obtain a certificate and/or degree, and, most importantly, being coached by experienced supervisors during their SD project work.

Why this Introductory SD E-Book?

There are already quite some excellent introductory SD books with exercises (e.g. (Forrester 1968; Goodman 1974; Richardson and Pugh 1981; Richmond 1992; Coyle 1996; Sterman 2000; Warren 2002; Morecroft 2007; Ford 2009)), books introducing SD among other computational methods (e.g. (Shiflet and Shiflet 2006)), books introducing SD to support domain studies (e.g. (de Vries 2012)), introductions to SD (Randers 1980a), a series of Road Maps (self-study guides bringing together important papers, books, and modeling exercises), exercise/case oriented books (Goodman 1974; Ford 1999; Martín García 2006), open course ware materials from several universities, et cetera. Why then add another introductory SD book?

Because I believe that a case-based blended-learning approach, which to my knowledge does not exist yet, could help many to actively acquire basic SD modeling skills through learning by doing. From experience, I know that SD skills can be acquired through hands-on modeling with exercises from day one on and with near-real cases from day three on. I also believe that the SD philosophy and wisdom as well as more advanced modeling and analysis skills can best be taught along the way, not before hands-on modeling is ventured in on, again by means of cases of increasing methodological and applied complexity with case-related feedback, as well as by sharing experiences.

As stated above, I strongly believe that, in order to really acquire modeling skills, most people actually need a lot of hands-on practicing and experience – preferably along a smart learning path with insightful feedback and useful feedforward. Hence, hands-on quantitative modeling and simulation are, right from the start, at the center of the blended-learning approach offered here. The blended-learning approach –especially (*i*) the brief explanations in several short videos and introductory chapters preceding the case chapters, and (*ii*) the feedback to each exercise/case and the feedback in recap chapters and videos reviewing the main lessons learned over all exercises/cases in a chapter– accelerate the speed of learning. And although the core of this e-book consists of exercises and cases of increasing complexity and difficulty and with different lessons to be learned, together with the electronic resources and learning paths, it is much more than just a collection of cases: it is a full introductory SD course.

The cases in this e-book are more than just educational exercises: most of the cases deal with current real-world issues, although still in a simplified way. I think these cases are as actual and real as possible for an introductory hands-on modeling course. Actual cases are excellent tools for motivating students, for illustrating the relevance of SD modeling for real world problem solving, and for showing the way in which SD could be applied to real world cases. Although such 'hot' teaching cases may be more interesting, stimulating and challenging, they are also slightly more difficult and time consuming than purely didactic exercises: many cases in this e-book require about 2 hours for modeling novices.

Although this case-based blended-learning approach was inspired by some brilliant case-based SD books (e.g. (Goodman 1974; Ford 1999; Martín García 2006; Bossel 2007a; Bossel 2007b; Bossel 2007c)), it substantially differs from these sources of inspiration, both in style and learning approach. Like these other case-based books, this e-book may also be useful to colleagues by offering them many new cases and models. Since making teaching and testing cases is very time consuming, the best we can do is share our cases. Developing and sharing teaching and testing cases is, I believe, key in the further advancement of the SD field and model-based decision support. Hence, I am glad to share my cases, especially if it inspires others to share their cases too: *do ut des*! This e-book therefore also contains 126 links to new online exercises/cases to be added from the summer of 2013 on by, I hope, many colleagues around the globe that are willing to share their own cases.

0.3 Small Models for Big Societal Issues

Although most of the cases in this e-book are not as small as traditional educational exercises, they are still slightly smaller and simpler than real models. It is important to realize that these cases are still educational: none of the corresponding models could in their current form be used for real policy advice. I nevertheless strongly believe small models are much more useful than large models for real-world policy advice: in modeling, small really is beautiful! Proponents of small models argue that small models allow 'for exhaustive experimentation and sensitivity analysis, wise interpretation of parameters and parameter change' (Ghaffarzadegan et al. 2011; Pruyt 2010c). In fact, model parsimony is an important criterion of SD model quality (Saysel and Barlas 2006). Many modelers, especially novices, have a tendency to build unnecessarily large models (Barlas 2007; Repenning 2003; Forrester 1961), but '[l]arge models are not only difficult to build: they are also nearly impossible to understand, test (by the modeler or a third party), and evaluate critically' (Barlas 2007). I therefore believe it is important to teach novices to make small models, also of big issues.

This e-book mainly focuses on relatively big societal issues and important questions – often lacking a single and clear problem owner or decision maker. But that is not a major problem since for big issues, even those at the top of a hierarchy only *appear* to have influence (Forrester 2007b). Often, it is the underlying structure of a system that is important for its future dynamics, not the decision-makers at the top of the hierarchy: they may not be able to make a difference, unless they truly understand the issue/system and know how to change the system structure such that more desirable dynamics are endogenously generated by the system. I hope this e-book helps to diffuse a method that can be used to generate such understanding, and hence, to make such changes.

Exercises and cases are drawn from a variety of application domains full of big issues that need to be addressed. Cases are grouped in 9 themes: health and drugs policy, wildlife and ecosystem management, resource dynamics and energy transitions, safety/security and risk, policing and public order, urban planning and housing policy, education and innovation, economics and finance, and management and organization. There are also 9 thematic learning paths that allow one to work within one theme, although more could be learned from modeling and simulating cases across different themes.

Application domains and corresponding symbols used:

- Resource dynamics and energy transitions: dynamics of technology diffusion and energy transition, depletion of mineral/metal/fossil fuel resources, and resource nexus issues
- Environmental & ecosystem management: overfishing, ecosystem collapse,...
- Health and drugs policy: drug related problems, epidemics, health system management,...
- Crime fighting and policing: fighting burglaries, robberies, and human trafficking,
- Risk analysis and crisis management: radicalization, bank runs,
- Housing policy and urban planning
- Education and innovation: student and education system management, innovation,...
- Management and business: management of clients, production, supply chains, projects, human resources, businesses,

$ Economics and finance: macro-economics, bank & banking crises, economic development,

Technical exercises

0.4 Other Symbols Used

The leading principle of this e-book being hands-on training, many hyperlinked symbols are used. Three types can be distinguished: activity related symbols, e-book related symbols, and content related symbols.

Following activity related symbols are used in the remainder of the text and in exercises/cases:

- : (Link to) hands-on modeling or other model-related activities
- ∧ : Mandatory exercises (or at least strongly suggested)
- ∨ : Additional exercises (optional or additional training)
- : Link to video or streaming
- : Link to mandatory reading in this e-book or other non-mandatory reading
- : Link to a suggested special issue of a scientific journal
- : Link to useful tutorial(s)
- : Link to additional information or to suggested articles, books, etc.
- : Link to a lecture, a presentation, or an audio fragment
- : Hand in your assignment before the deadline!
- : Peer review (to be handed in 24h after simulating your own assignment)
- ? : Interactive Q&A session
- : Non-mandatory quiz or test
- : Quiz or test with mandatory effort and/or bonus
- : Quiz or test with mandatory result (full pass is required)
- : Quiz, test, exam (full pass / partial pass / fail)

Following e-book related symbols are used in the remainder of the text and in this e-book:

`Alt` ←: Go back to previous location (Note: this is a useful combination of keys, not a symbol)

: Go to the first page

: Go to and 'quickly cycle through'[2] the table of contents

: Go back to the general learning path

: Go to the Preface

: Go to Part I – Warm-up (simple and small qualitative SD exercises)

: Go to Part II – Run-Up (simple and small quantitative SD exercises)

: Go to Part III – Hop (simple and small technical SD exercises)

: Go to Part IV – Step (basic SD cases)

: Go to Part V – Jump (intermediate SD cases)

: Go to Part VI – Fly (SD project cases)

: Link to restricted resources (for COL and regular students only)

: Link to restricted resources (for approved lecturers only)

Following content related symbols are used in this e-book:

: Zoom-in or explanatory box

: Right thing to do!

: Watch out: Slippery! Dangerous!

: Important!

: Great insight, understanding, idea...

: Take care!

: Beyond the current level of difficulty (solve this part at a later point in time)

0.5 Structure, Exercises, and Cases

This e-book consists of this preface, 5 core parts, and a final part for bridging the gap with project cases and real-world modeling. Each part –except for the last part– consist of four chapters:

- A very brief theory chapter with links to additional online reading;
- A chapter with exercises/cases and links to additional online exercises/cases;
- A chapter with 15 right/wrong questions, 20 multiple choice questions, mostly graphic ones, and links to hundreds of online multiple choice questions;
- A recap chapter with the most important lessons to be learned from the exercises/cases in that particular part.

SD modeling and simulation skills are gradually ramped up to an intermediate level according to a triple jump approach. Before performing the triple jump, one needs to warm-up in Part I. The warm-up consists of building qualitative SD models – after all, this book focuses after all on quantitative modeling and simulation. These qualitative SD modeling skills are particularly useful for model conceptualization and model communication. Part II is the run-up: Its focus is on hands-on modeling and simulation of small and simple exercises. Part III is a technical part that allows one to hop to the next level. Part IV consists of cases that allow one to step forward using the functions and structures from the previous part. Part V contains many intermediate level cases: extensive hands-on practicing with these cases allows one to jump towards the next level. And part VI allows one to bridge the gap with project cases and real-world modeling and offers a sneak preview into more advanced modeling and simulation issues. That is, it allows one to fly away.

A more detailed overview of the exercises and cases in these six parts is provided below. The tables give an idea of the main themes exercises/cases are part of, their approximate level of difficulty (for students in a first SD course at the time of their exam), the indicative time required to solve them, their focus, and whether demonstration videos and background papers are available.

Part I: WARM-UP – Introductory Qualitative Exercises

This part is just a brief and superficial introduction to qualitative SD modeling, since quantitative SD modeling is the focus of this e-book, not stand-alone qualitative SD modeling. Qualitative modeling is introduced here for conceptualization and communication purposes in support of quantitative modeling. Students interested in stand-alone qualitative modeling are referred to that part of the SD literature. For this course, the time spent on this first part should be limited to about 5 hours. It is sufficient to do exercises 2.1, 2.2, 2.3, one from 2.4–2.12, and possibly 2.13 or 2.14.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time	Specifics	Demo /links
	2.1 p.50	Competition in the faculty	simple	0:05	qual.: unisolated loops	
	2.2 p.51	Managing assets & clients	simple	0:10	qual.: missing loops, control	
	2.3 p.51	Resource Dynamics	simple	0:05	qual.: aging chains and loops	
	2.4 p.52	Overly prescr. approach	simple	0:10	qual.: real policy advice	
	2.5 p.53	COLCs and MOOCs	simple	0:10	qual.: alt. diffusion models	
	2.6 p.54	Fish and Ships	simple	0:10	qual.: be trapped!	
	2.7 p.55	Housing policies	simple	0:10	qual.: housing cycles	
	2.8 p.55	Student passing policy	simple	0:15	qual.: CLDs versus ADs	
	2.9 p.56	Fighting high impact crime	simple	0:10	qual.: reinforced seasonality	
	2.10 p.56	Conflict in the Middle East	simple	0:15	qual.: intractability & policy	
$	2.11 p.58	Mapping bank runs	simple	0:15	qual.: alternative mechanisms	1
	2.12 p.60	Entrepreneurs & transitions	medium	0:15	qual.: successive mechanisms	1
	2.13 p.61	Soft Drugs Policies	medium	1:30	qual.: multiple perspectives	1 2
	2.14 p.63	Climate Change	medium	1:30	differences CLDs & SFDs	

Part II: RUN-UP – Introductory Quantitative Exercises

This part focuses on small and simple exercises. Given the fact that these exercises are extremely small and simple, time spent on this second part should be limited to a maximum of 5 hours. It is sufficient to model exercises 6.1, 6.2 and one of choice from exercises 6.3–6.11.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
	6.1 p.91	On cocaine	intro	0:05	1 stock, 1 loop	
	6.2 p.92	Muskrat plague	intro	0:15	2 stocks, 2+ loops	
	6.3 p.92	Econ. Overshoot & Collapse	simple	0:20	2 stocks, 6 loops	
	6.4 p.93	Management of societal aging	simple	0:20	aging chains	
	6.5 p.94	Feral pig plague	simple	0:20	small & simple	
	6.6 p.95	Gangs and Arms Races	simple	0:20	dynamics of escalation	
	6.7 p.96	Unin. fam. planning benefits	simple	0:20	aging chain	
	6.8 p.97	Pneumonic plague (A)	simple	0:15	SIR and diffusion	1
	6.9 p.98	System Dynamics Education	simple	0:30	multi-model/theory	
	6.10 p.99	Diffusion of micro-CHP	simple	0:25	S-shaped growth or nothing	
	6.11 p.101	Housing stock dynamics	simple	0:30	⟲ with delays ⇒ oscillations	

Part III: HOP – Technical Exercises

Many specific functions that are needed in subsequent chapters are introduced in this part. Time spent on solving these technical exercises should be limited to 5 hours. Additional debugging exercises may take another hour. After these exercises, one should be prepared for parts IV and V.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time	Specifics: technical	Demo /links
	10.1 p.123	Step, ramp, Time, sine	simple	0:05	exogenous inputs	
	10.2 p.124	Max, Min, MinMax	simple	0:10	hard floor & ceiling	
	10.3 p.124	Stock distortions	simple	0:15	stocks-flows dynamics	
	10.4 p.125	Material & Information Delays	simple	0:10	different delay types	
	10.5 p.126	Higher Order Delays	simple	0:10	different delay orders	
	10.6 p.127	(With) Lookups, Time Series	simple	0:10	Pneumonic Plague (B)	1
	10.7 p.127	Softmin, Softmax	simple	0:10	soft floor & soft ceiling	
	10.8 p.128	Pulses and Pulsetrains	medium	0:10	sudden & repetitive inputs	
	10.9 p.129	Random function vs sampling	medium	0:10	random nmbrs & parameters	
	10.10 p.130	Special Structures	medium	0:15	monitoring, testing,...	
	10.11 p.131	A Damped Mass-Spring System	medium	0:10	2nd order diff. equation	
	10.12 p.132	Shale Gas	simple	0:10	min, max, stock-flow	
	10.13 p.132	Mass starvation in OVP	medium	0:45	pulsetrains, randomizers	1
	10.14 p.134	Verification and Debugging	simple	0:10	floating points	
	10.15 p.134	Sensitivity and Uncertainty	simple	0:10	univariate, L.H.,...	

Part IV: STEP – Introductory Cases

This part is the first of two core parts. It consists of a set of relatively simple intermediate cases. Those with a time limit of 50–70 hours, should spend about 15 hours on this part.

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
	14.1 p.155	Managing a faculty	medium	0:45	small & simple	
	14.2 p.156	Supply chain management	medium	1:00	oscill. & bullwhip	
	14.3 p.157	Debt crisis in dev. nation	medium	1:30	bifurc. & phase plane	*
	14.4 p.158	Env. Mgt in Miniworld	medium	1:30	overshoot or not	*
	14.5 p.160	Next pandemic shock	medium	1:45	staged, SIR/SEIR	1 2 3
	14.6 p.163	New town planning	medium	1:45	clear sectors	1 2
	14.7 p.165	Tolerance, hate, aggression	medium	1:45	threshold & bifurcation	
	14.8 p.167	EVs and lithium scarcity	medium	1:00	staged, open end	1
	14.9 p.169	Cholera in Zimbabwe	medium	2:00	simpl. aqua. route	1
	14.10 p.171	Signalled bank run	medium	2:00	too simplistic	1
	14.11 p.174	Fighting HIC on nat. level	medium	2:00	reinforced seasonality	1
	14.12 p.176	Overfishing of NBF tuna	medium	2:00	staged	1
	14.13 p.178	Production Management	medium	2:00	oscill. & bullwhip	1
	14.14 p.180	District redevelopment	medium	2:00	abstract/aggreg.	1 2
	14.15 p.182	Mineral/metal scarcity I	medium	2:00	spec. functions	1 2 3
	14.16 p.184	De/Radicalisation I	medium	2:00	counterintuitive	1 2 3
	14.17 p.186	Fundamental behaviors	medium	1:00	core structures	

(*) based on (Bossel 2007a; Bossel 2007b; Bossel 2007c); (**) based on (Martín García 2006)

Part V: JUMP – Intermediate Cases

This part is the second of two core parts. Those with a maximum time budget of 50 to 70 hours, should spend a maximum of 20–30 hours on these cases and related online materials.

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
	18.1 p.210	Policy analysis, design, testing	simple	—	on previous exercises	
	18.2 p.210	Unemployment	medium	1:30	gov. sercives & debt	*
	18.3 p.212	Hospital Management	medium	1:30	correct for outflows	1
	18.4 p.214	Collapse on the Kaibab Plateau	medium	1:30	ecosystem collapse	**
	18.5 p.216	Prostitution & H.Trafficking	medium	2:00	± staged	1 2
	18.6 p.219	Seasonal flu	difficult	2:30	staged, SEIRS	1
	18.7 p.221	Real estate boom & bust	difficult	2:30	right/wrong	1
	18.8 p.224	DNO asset management	difficult	2:30	aggregated, gaming	1
	18.9 p.225	Fighting HIC regionally	difficult	2:30	waterbed effect	1
	18.10 p.228	Innovation in health care	difficult	2:30	subscripts & xls	
	18.11 p.228	Carbon and climate change	difficult	2:00	ST affects LT	*
	18.12 p.230	An Orchestrated bank run	difficult	2:30	operational	1
	18.13 p.232	De/Radicalisation II	difficult	2:30	counterintuitive	1
	18.14 p.234	Project management	difficult	2:30	staged	1
	18.15 p.237	Mineral/metal scarcity II	difficult	3:00	1 major loop	1
	18.16 p.239	Energy transition management	difficult	2:30	specification	1 2 3
	18.17 p.241	Fighting HIC across districts	difficult	2:00	regional waterbed	1
	18.18 p.244	Antibiotic resistance	difficult	2:00	thresholds & timing	1
	18.19 p.247	Globalization	difficult	2:00	effects free trade	*
	18.20 p.248	Higher education stimuli	difficult	2:30	batches, etc	1
	18.21 p.251	Housing market crisis	difficult	2:30	financial uncertainty	1
	18.22 p.254	Collapse of civilizations	difficult	2:00	from Maya to others	**

With a steep descend of the learning curve, one should be able to finish at least four to five cases and work through the materials suggested in the learning path.

Exam cases used in the introductory SD courses at Delft University of Technology are typically ‘difficult’ for an introductory modeling course and mostly relate to actual or otherwise important issues. During the exam, students have 3 hours to answer 15 multiple choice questions related to SD methodology/insight/..., and for solving an exam case with multiple choice questions and open questions ( ).

Part VI: FLY – Project Cases

The last part contains just two chapters: one chapter with advise before starting to model and simulate project cases or real cases, and one chapter with some (links to) pre-structured SD cases. However, one of the planned follow-up e-books will contain many more SD project cases as well as advanced SD topics. The other planned follow-up e-book will contain many ‘exploratory’ SD cases, that is, issues that are deeply uncertain and dynamically complex, as well as explanations on how to use the sampling and machine learning techniques and tools used in Exploratory System Dynamics Modeling and Analysis (E*SD*MA).

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
| |	22.1 p.279	Food or Energy?	difficult	5:00	closed ⇝ project	1 2
| |	22.2 p.284	Cod or not?	difficult	5:00+	open ⇝ project	1
| |	22.3 p.285	Wind Force 12	difficult	3:00+	closed ⇝ project	1
| |	22.4 p.294	Strategic Mgt & leadership	difficult	3:00+	partly open, gamimg	1
| |	22.5 p.298	Evidence-based HIC Fighting	difficult	5:00+	open, xls	1
| |	22.6 p.299	Heroin	difficult	3:00+	⇝ project	–

0.6 Materials: Cases and MCQs

Cases

Most of the exercises and cases consists of four versions of the case description (a standard case description in italics without guiding MC questions, a case description in italics and with guiding MC questions ( ), a case description without italics without guiding MC questions ( ), and a case description which consists of a short problem sketch and a research question ( )), links to videos showing the case being modeled and solved, to Forio simulators to compare models to, to pdfs with an indicative solution, to videos with case-specific feedback, to simulation models (different softwares), to pdfs with references and links to the literature....

Following symbols are used in the header of exercises and cases:

: Link to case description with level 1 support, i.e. with *italics* and MCQs

: Link printable level 2 description(s), i.e. with password, in *it*, wo MCQs

: Link to case description with level 3 support, i.e. without *italics* and MCQs

: Link to case description with level 4 support, i.e. the story and research questions

: Link to this exercise/case in Dutch and/or other languages if available

: Link to versions of the exercise/case written for other SD software packages

: keys, hints, clues, additional help

: Link to (a zip file with) simulation model(s) and/or other supplementary files

: Link to online simulators

: Link to a feedback document (pdf)

: Link to a feedback video

⊕ : Link to additional exercises and cases

Some of the teaching/testing cases in the table above were already made publicly accessible, albeit in just one format and without the online resources. Many cases were published either as cases or as part of research papers, mostly as proceedings articles of the ISDC available on the web site of the System Dynamics Society. Case descriptions are available in (Pruyt 2009c; Pruyt 2009a; Pruyt 2009d; Pruyt 2010a; Pruyt and Hamarat 2010a; Pruyt 2010a; Pruyt 2011; Pruyt 2012; Pruyt and Ribberink 2013; Pruyt 2013). Real-world analyses, i.e. beyond the case level, can be found in (Pruyt 2004; Pruyt 2007a; Pruyt 2008a; Pruyt 2008b; Pruyt 2009b; Pruyt 2009a; Pruyt 2009d; Pruyt and Hamarat 2010b; Pruyt 2010b; Pruyt and Hamarat 2010a; Pruyt and Kwakkel 2011; Pruyt et al. 2011; Pruyt and Kwakkel 2011; Pruyt et al. 2011; Kővári and Pruyt 2012; Hamarat et al. 2013; Pruyt and Ribberink 2013). Case 14.6 is based on George Richardson's URBAN1 model and case 18.14 on George Richardson's Project Management model. Case 2.14 is based on (Ford 1999, p92–96) and (Pruyt 2007a; Sterman and Booth Sweeney 2002; Houghton 2004; Fiddaman 2002). Exercises 6.1, 6.2, 10.11, and the first part of exercise 2.5 are adapted from (van Daalen et al. 2006). Exercises 6.10, 6.11, and the first part of exercise 14.2 were based on Vensim example models (Ventana Systems 2000). Exercises 6.3, 6.6, 14.3, 14.4, 14.7, 18.2, 18.11 and 18.19 are either based on, or adaptations from, cases by Hartmut Bossel (2007d), Bossel (2007a), Bossel (2007b), Bossel (2007c). Case 18.18 is based on (Homer et al. 2000), and 18.10 is based on Jakar Westerbeek's BSc thesis.

Multiple Choice Questions: Chapters and Online MCQ Bank

In this e-book, there are also five chapters with 15 right/wrong questions and 20 multiple choice questions (MCQs). The MCQs in the e-book are mainly graphical MCQs with graphs and diagrams, since they are somewhat more difficult to enter in the online question bank. The online resources contain MCQ banks with hundreds of formative MCQs, i.e. questions with hints and answers. They are organized in different ways to allow students to select the theme, category, methodological topic, and/or level of difficulty they would want to practice. The MCQs mainly relate to the cases dealt with in that part and to general issues from nine categories that are difficult to capture in exam cases:

1. SD Philosophy, SD Methodology, or 'SD speak'
2. SD Diagramming ('Count the loops', SFD to CLD to SFD conversion)
3. Specification (Delays, Special Functions, . . .)
4. Calculation, and basic Modeling and Simulation
5. Verification, Simulation Settings, Units
6. Validation, Sensitivity Analysis, Extreme Value Testing, and Uncertainty Analysis
7. Reading Graphs, Interpreting Behavior, Linking Structure and Behavior

8. Model Analysis and Use, especially Sensitivity Analysis and Policy Analysis
9. Applied Systems Thinking, and Archetypes

0.7 Generic Learning Path for the Theory/Practice Part

The course this blended COL approach was developed for in the first place consists of two parts: a theory/practice part and a project part. This e-book is most useful for the first part, but also for bridging the first and second part, and a little for supporting the project process in the second part (only for regular and COL students). One generic learning path and nine theme specific learning paths were developed for the first part. All those with broader interest than just one or two application domains are strongly recommended to follow the generic learning path. More can be learned from modeling and simulating rather different cases. Hopefully, new themes will be added in the near future. For a start, future theme 10 may be reached here. No matter what theme is followed, everyone is strongly advised to solve all MCQs and learn from the weekly/daily feedback across all application domains.

The following generic hyperlinked learning path is used for the first part[3]:

WEEK 1: INTRODUCTION TO SYSTEM DYNAMICS MODELING AND SIMULATION
|I| Video: Intro week/day 1

Chapter 1: Introduction to System Dynamics
- Qualitative SD modeling
  - || Tutorial introduction to SD software (1)
  - || Tutorial software interface (2)
  - || Tutorial hands-on example (3)
  - || Tutorial causal loop diagramming (4)
  - || Video: qualitative modeling
  - Introductory qualitative modeling exercises
    - ∧ ex.2.1, ex.2.2, ex.2.3
    - ∧ 1 exercise of choice from ex.2.4–2.12 (| | | | | | | | |$| | |)
    - ∨ all other exercises from ex.2.4–2.12 (| | | | | | | | |$| | |)
    - ∨ ex.2.13, ex.2.14, |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|
  - || Video feedback across all introductory qualitative exercises
  - || Written feedback across all introductory qualitative exercises
  - || MCQs in chapter 3
  - || MCQs in online quizzes
- Quantitative SD modeling
  - Chapter 5: Elementary System Dynamics Modeling
  - || Video: quant. model building (settings, stocks, flows, auxiliaries, simulation)
  - || Tutorial stock and flow diagramming (5)
  - || Tutorial building a simulation model (6)
  - Introductory quantitative SD exercises
    - ∧ ex.6.1, ex.6.2, 1 from ex.6.3–6.11 (|$| | | | | | | | | | | | | | | | |)

[3]The tutorial numbers correspond to the Vensim tutorials

∨ other exercises from ex.6.3–6.11 (|$| | | | | | | | | | | | | | | | |)
|⊕|: additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|
| | Video feedback across all introductory quantitative exercises
| | Written feedback across all introductory quantitative exercises
| | MCQs in chapter 7
| | MCQs in online quizzes

| | Test 1

|?| Q&A: Interactive Q&A and ramp-up session (on site and online)

WEEK 2: SYSTEM DYNAMICS MODEL FORMULATION

| II| Video: Intro week/day 2

Chapter 9: Basic System Dynamics Model Formulation

| | Video: model formulation: step, ramp, Time, sine
Exercise 10.1: step, ramp, Time, sine
| | Video: model formulation: min, max, minmax
Exercise 10.2: min, max, minmax
| | Video: model formulation: delays & smoothing
Exercise 10.3: stock distortions
Exercise 10.4: delays & smoothing
Exercise 10.5: higher order delays
| | Video: model formulation: lookups, with lookups, and time series
| | Tutorial building table functions (8)
Exercise 10.6: lookups, with lookups, and time series
| | Video: model formulation: softmin & softmax
Exercise 10.7: softmin & softmax versus min & max
| | Video: model formulation: pulses & pulsetrains
Exercise 10.8: pulses & pulsetrains
| | Video: model formulation: random sampling & randomizers
Exercise 10.9: randomizers & randomly sampled parameters
| | Video: model formulation: special structures
Exercise 10.10: special structures
| | Video: second order ODEs
Exercise 10.11: Damped Mass-Spring System

Exercises
∧ 10.12 (un/conventional gas), 10.13 (mass starvation in the OVP)
|⊕|: additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

| | Video feedback across all week/day 2 exercises and cases

| | Written feedback across all week/day 2 exercises and cases

| | MCQs in chapter 11

| | MCQs in online quizzes

| | Test 2

|?| Interactive Q&A and ramp-up session (on site and online)

WEEK 3: SYSTEM DYNAMICS MODEL BUILDING & TESTING

|III| Video: Intro week/day 3

- Chapter 13: Building & Testing System Dynamics Models
  - Model verification and debugging
    - | | Video: model verification and debugging
    - | | Tutorial function and simulation errors (7)
    - Exercise 10.14: Model verification and debugging
  - Sensitivity, uncertainty, scenarios, and robustness
    - | | Video: sensitivity, uncertainty, scenarios, and robustness
    - | | Tutorial Sensitivity testing (15)
    - | | Tutorial Uncertainty analysis (13+)
    - Exercise 10.15: sensitivity, uncertainty, scenarios, and robustness I
    - Exercise 10.16: sensitivity, uncertainty, scenarios, and robustness II
- Hands-on practice:
  - ∧ 1 case of choice from cases 14.1–14.8 (| | | | |$| | | | | | | | | | | | | | |)
  - ∧ 1 case of choice from cases 14.8–14.16 (| | | | |$| | | | | | | | | | | | | | |)
  - ∨ 1 case of choice from cases 14.1–14.8 (| | | | |$| | | | | | | | | | | | | | |)
  - ∨ 1 case of choice from cases 14.8–14.16 (| | | | |$| | | | | | | | | | | | | | |)
  - |⊕| additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|
- More model debugging to prepare for the exam:
  - | | Video: Practical advise regarding model debugging and testing for the exam
  - |⊕| additional debugging exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

| | Video feedback across all week/day 3 cases

| | Written feedback across all week/day 3 cases

| | MCQs in chapter 15

| | MCQs in online quizzes

| | Test 3

|?| Interactive Q&A and ramp-up session (on site and online)

WEEK 4: POLICY ANALYSIS, DESIGN & TESTING & ADVISE

|IV| Video: Intro week/day 4

Chapter 17: Using System Dynamics Models

- Video: on policy analysis, design, testing, and advise
- Tutorial customizing output (10)
- Tutorial input and output controls (12)

Policy Design and Testing on Previous Exercises & Cases: tech.ex.18.1

Video: feedback

Hands-on Practicing on New Cases

- ∧ 1 case of choice from cases 18.2–18.10 (|$| ...)
- ∧ 1 other case of choice from 18.2–18.10 (|$| ...)
- ∨ cases from ch18 (|$| ... |$| ... |$| ...)
- additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Video feedback across all week/day 4 cases

Written feedback across all week/day 4 cases

Test 4

Interactive Q&A and ramp-up session (on site and/or online)

WEEK 5: SYSTEM DYNAMICS MODEL USE AND COMMUNICATION

|v| Video: Intro week/day 5

Chapter 21: How to Fly

Video: on model use and communication

Hands-on practicing

- ∧ 1 case from 18.11–18.22 (... |$| ... |$| ...)
- ∧ 1 case from 18.11–18.22 (... |$| ... |$| ...)
- ∨ other ch18 cases (|$| ... |$| ... |$| ...)
- additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Video feedback across all week/day 5 cases

Written feedback across all week/day 5 cases

MCQs in chapter 19

MCQs in online quizzes

Final Interactive Q&A and ramp-up session (on site and online)

Exam preparation: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10| |11| |12| |13| |14| |15| |16| |17| |18| |19| |20|

Recent exams: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10| |11| |12| |13| |14| |15| |16| |17| |18| |19|

Exam part I: 15 MC questions

Exam part II: 1 new case on the computer with MC and open answers

New exercises and cases may be available per level via one of the following links:

|⊕| WARM-UP: Introductory (Qualitative) SD Exercises

|⊕| RUN-UP: Introductory (Quantitative) SD Exercises

|⊕| HOP: Technical SD Exercises

|⊕| STEP: Small and Simple SD Cases

|⊕| JUMP: Intermediate SD Cases

|⊕| FLY: SD Project Cases

0.8 Nine Thematic Learning Paths

In this version of the e-book, there are enough exercises and cases –some of them shared– to compose thematic learning paths for the following nine application domains:

|♥| Health Policy, Epidemiology & Drugs (p.17),

|| Environmental & Ecosystems Management (p.18),

|♻| Resource Dynamics & Energy Transitions (p.19),

|| Safety, Security & Risk (p.20),

|| Policing & Public Order (p.21),

|| Housing Policy & Urban Planning (p.22),

|| Education & Innovation (p.23),

|$| Economics & Finance (p.24), and

|| Management & Organization (p.25).

These thematic learning paths are elaborated on the following pages. Each time, the minimal thematic learning path is displayed in a box. The symbols are linked to the texts, tutorials, videos, exercises, cases, overall feedback videos, overall written feedback, and quizzes. The topics of the exercises and cases in the minimal thematic learning paths are displayed **in bold** below these boxes. Additionally, exercises and cases *in italics* are suggested: although they are not part of a particular minimal thematic learning path, they may be of interest to those interested in that particular learning path. Potential project cases beyond the purpose of this e-book are displayed in normal fonts, i.e. not displayed in bold nor in italics.

These thematic learning path pages can be reached from each and any page by clicking on the corresponding symbol at the bottom or the headers of exercises and cases. For example, those interested only in Environmental & Ecosystems Management can reach their thematic learning path page by clicking on ||. On the thematic page, click on the next activity in line (or an additional suggested exercise or case), do it, use the `Alt ←` combination or click on the theme symbol to go back to the learning path pages, and use the `Highlighted text` tool in the pdf reader to keep track of progress.

Since exercises and cases in a thematic learning path are often rather similar, it is recommended to also solve additional exercises and cases, or suggested exercises and cases from other themes of interest.

0.8.1 ♥ Health Policy, Epidemiology & Drugs

The Health Policy, Epidemiology & Drugs theme groups –as the name of the theme indicates– exercises and cases related to health policy, epidemiology & drugs. The main emphasis is on epidemiology and health system management. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.4| | | | | | | | |
|5| |2| |e| |f| |6.1| |6.2| |6.8| | | | | | | | | | | |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||10.6||7| |10.7|
|8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13|| || || || || ||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.5||14.9||14|| || || || || ||?|

W4: |IV| |17| |15| |k| |l| |18.1| | | |18.3| |18.6| | | | | | | | | | | |?|

W5: |V| |21| |16| |17| |18.10| |18.18| | | | | | | |?| | | | |

. . . : |22.6|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- ♥ 2.4 (p.52) **Overly prescriptive approach**
- ♥ 2.13 (p.61) *Soft drugs policies*
- ☆ 6.1 (p.91) **On cocaine**
- ♥ 6.8 (p.97) **Pneumonic plague (A)**
- 10.6 (p.127) **Lookups – Pneumonic plague (B)**
- ♥ 14.5 (p.160) **The next pandemic shock – A(H1N1)v**
- ♥ 14.9 (p.169) **Cholera outbreak**
- ♥ 18.3 (p.212) **Hospital management**
- ♥ 18.6 (p.219) **Seasonal flu**
- ♥ 18.10 (p.228) **Innovation in health care**
- ♥ 18.18 (p.244) **Antibiotic resistance**
- ♥ 22.6 (p.299) Heroin

|⊕| More health policy, epidemiology, drugs cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes may contain more exercises and cases of interest to those interested in this theme: Environmental & Ecosystems Management (| |), Management & Organization (| |), Safety, Security & Risk (| |), and Education & Innovation (| |).

0.8.2 Environmental & Ecosystem Management

The Environmental & Ecosystem Management theme groups –as the name of the theme indicates– exercises and cases related to environmental & ecosystem management. The main emphasis is on wildlife management and climate change. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| || |2.2| |2.3| |2.6| || || || ||
|5| |2| |e| |f| || || |6.2| |6.5| || || || || || |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7| |10.7|
|8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13||||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.4||14.12||14||||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| || |18.4| |18.11| || || || || || |?|

W5: |V| |21| |16| |17| |18.16| |18.18| || || || |?| || ||

. . . : |22.2|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.6 (p.54) **Fish and Ships**
- 2.14 (p.63) *Climate change*
- 6.2 (p.92) **Muskrat plague**
- 6.5 (p.94) **The threat of the feral pig**
- 10.13 (p.132) **Mass starvation in the OVP**
- 14.4 (p.158) **Environmental management in Miniworld**
- 14.12 (p.176) **Overfishing of bluefin tuna**
- 18.4 (p.214) **Predator-prey dynamics**
- 18.11 (p.228) **Carbon and climate change**
- 18.16 (p.239) **Energy transition management**
- 18.18 (p.244) **Antibiotic resistance**
- 18.22 (p.254) *Collapse of civilizations*
- 22.2 (p.284) Cod or not?
- |⊕| More environmental & ecosystems management cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in this theme: Resource Dynamics & Energy Transitions (||), and Health Policy, Epidemiology & Drugs (||).

0.8.3 Resource Dynamics & Energy Transitions

The Resource Dynamics & Energy Transitions theme groups –as the name of the theme indicates– exercises and cases related to resource dynamics & energy transitions. The main emphasis is on material scarcity and transitions of energy generation systems towards more renewable ones. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.12| | | | | | | | |
|5| |2| |e| |f| | | |6.2| |6.10| | | | | | | | | | | |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7|
|8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13|||||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.8||14.15||14||||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| | | |18.8| |18.11| | | | | | | | | | |

W5: |V| |21| |16| |17| |18.15| |18.16| | | | | | | |?| | | | |

. . . : |22.1| |22.3|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.3 (p.51) **Resource dynamics**
- 2.12 (p.60) **Entrepreneurs & transitions**
- 2.14 (p.63) *Climate change (qualitative)*
- 6.10 (p.99) **Diffusion of micro-CHP**
- 10.12 (p.132) **Un/conventional gas**
- 14.8 (p.167) **Lithium and the diffusion of electrical vehicles**
- 14.15 (p.182) **Mineral/metal scarcity I**
- 18.8 (p.224) **DNO asset management**
- 18.11 (p.228) **Climate change (quantitative)**
- 18.15 (p.237) **Mineral/metal scarcity II**
- 18.16 (p.239) **Energy transition management**
- 22.1 (p.279) Food or energy? Is that the question?
- 22.3 (p.285) Wind Power Potentiality: Wind Force 12
- |⊕| More resource dynamics and transitions cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Other themes of interest to those interested in this theme include: Environmental & Ecosystems Management (| |), Housing Policy & Urban Planning (| |), and Education & Innovation (| |).

0.8.4 Safety, Security & Risk

The Safety, Security & Risk theme groups exercises and cases related to risk assessment and risk management. This theme relates to all sorts of risks. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.10| || || || || |5| |2| |e| |f| || |6.2| |6.6| || || || || || |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7| |8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13||||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.7||14.16||14||||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| || |18.5| |18.13| || || || || || |?|

W5: |V| |21| |16| |17| |18.18| |18.22| || || || |?| || ||

. . . : |22.5|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.10 (p.56) **Conflict in the Middle East**
- 2.13 (p.61) *Soft drugs policies*
- 2.14 (p.63) *Climate change (qualitative)*
- 6.4 (p.93) *(Mis)management of societal aging*
- 6.6 (p.95) **Gangs and arms races**
- 14.5 (p.160) *The next pandemic shock*
- 14.7 (p.165) **Tolerance, hate, aggression**
- 14.16 (p.184) **Radicalization & deradicalization**
- 18.5 (p.216) **Prostitution and human trafficking**
- 18.11 (p.228) *Climate Change (quantitative)*
- 18.13 (p.232) **Activism, extremism and terrorism**
- 18.17 (p.241) *Fighting HIC across multiple districts*
- 18.18 (p.244) **Antibiotic resistance**
- 18.22 (p.254) **Collapse of civilizations**
- 22.5 (p.298) Evidence-based fight against HIC across districts

|⊕| More security, risk analysis & crisis management cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in this theme: Policing & Public Order (||), Health Policy, Epidemiology & Drugs (||), Resource Dynamics & Energy Transitions (||), Environmental & Ecosystems Management (||), Housing Policy & Urban Planning (||), and Economics & Finance (|$|).

0.8.5 Policing & Public Order

The main emphasis of the Policing & Public Order theme groups exercises and cases is on fighting High Impact Crime (HIC) and prevention of violence. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.9| || || || || |5| |2| |e| |f| || |6.2| |6.7| || || || || || |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7| |8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13|||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.7||14.11||14||||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| || |18.5| |18.9| || || || || || |?|

W5: |V| |21| |16| |17| |18.13| |18.17| || || || |?| || ||

...: |22.5|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.9 (p.56) **Fighting high impact crime** (qualitative)
- 2.13 (p.61) *Soft drugs policies*
- 6.7 (p.96) **Unintended family planning benefits**
- 14.7 (p.165) **Tolerance, hate, aggression**
- 14.11 (p.174) **Fighting HIC on the national level**
- 18.5 (p.216) **Prostitution and human trafficking**
- 18.9 (p.225) **Fighting HIC on the regional level**
- 18.13 (p.232) **Activism, extremism and terrorism**
- 18.17 (p.241) **Fighting HIC across multiple districts**
- 22.5 (p.298) Evidence-based fight against HIC across districts
- |⊕| More policing, crime fighting and public order cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in this theme: Safety, Security & Risk (||), Health Policy, Epidemiology & Drugs (||), and Housing Policy & Urban Planning (||).

0.8.6 Urban Planning & Housing Policy

The Housing Policy & Urban Planning theme groups –as the name of the theme indicates– exercises and cases related to urban planning and housing market policy. The main emphasis is on housing market dynamics, the influence of housing policies, and urban development. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.7| (|2.14|) | | | | | | | |
|5| |2| |e| |f| | | |6.2| |6.11| | | | | | | | | | | |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7|
|8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.6||14.14||14||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| | | |18.7| |18.8| | | | | | | | | | |

W5: |V| |21| |16| |17| |18.17| |18.21| | | | | | | |?| | | | |

. . . : |22.5|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.7 (p.55) **Mapping housing policies**
- 6.11 (p.101) **Simulating housing policies**
- 14.6 (p.163) **New town planning**
- 14.14 (p.180) **Redevelopment of social housing districts**
- 18.7 (p.221) **Real estate boom and bust**
- 18.8 (p.224) **DNO asset management**
- 18.17 (p.241) **Fighting HIC across multiple districts**
- 18.21 (p.251) **Financial turmoil on the housing market**
- 22.5 (p.298) Evidence-based fight against HIC across multiple districts
- |⊕| More housing policy and urban planning cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in the Housing Policy & Urban Planning theme: Resource Dynamics & Energy Transitions (| |), and Policing & Public Order (| |).

0.8.7 Education & Innovation

The Education & Innovation theme groups exercises and cases related to education, innovation, and transition processes. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.8| || || || ||
|5| |2| |e| |f| || |6.2| |6.9| || || || || || |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7|
|8||10.8||9||10.9||10.10||11||10.11||10.12||10.13||||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.1||14.8||14||||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| || |18.8| |18.10| || || || || || |?|

W5: |V| |21| |16| |17| |18.16| |18.20| || || || |?| || ||

. . . : |22.1| |22.3|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.1 (p.50) **Competition in the faculty**
- 2.8 (p.55) **Student passing policy**
- 2.12 (p.60) *Entrepreneurs & transitions*
- 6.9 (p.155) **System Dynamics Education**
- 14.1 (p.155) **Managing a faculty**
- 14.8 (p.167) **Lithium and the diffusion of electrical vehicles**
- 18.8 (p.224) **DNO asset management**
- 18.10 (p.228) **Innovation in health care**
- 18.16 (p.239) **Energy transition management**
- 18.20 (p.248) **Higher education stimuli**
- 22.1 (p.279) Food or energy? Is that the question?
- 22.3 (p.285) Wind Power Potentiality: Wind Force 12
- |⊕| More education and innovation cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in this theme: Housing Policy & Urban Planning (||), Resource Dynamics & Energy Transitions (||), Health Policy, Epidemiology & Drugs (||), Management & Organization (||).

0.8.8 $ Economics & Finance

The main emphasis of the Economics & Finance theme is on economic development, financial crises, and bank runs. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |$2.11| || || || || |5| |2| |e| |f| || || |6.2| |$6.3| || || || || || |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g||||7||10.7| |8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13|||||||||||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||$14.3||$14.10||14|||||||||||?|

W4: |IV| |17| |15| |k| |l| |18.1| || |$18.2| |$18.12| || || || || || |?|

W5: |V| |21| |16| |17| |$18.19| |$18.21| || || || |?| || ||

. . . : |$22.4|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

$ 2.11 (p.58) **Bank runs**

$ 6.3 (p.92) **Economic overshoot & collapse**

$ 14.3 (p.157) **Debt crises in developing countries**

$ 14.10 (p.171) **Managing a signalled bank run**

$ 14.4 (p.158) *Environmental management in Miniworld*

$ 18.2 (p.210) **Unemployment**

$ 18.12 (p.230) **Managing a concerted bank run**

$ 18.8 (p.224) *DNO asset management*

$ 18.19 (p.247) **Globalization & Liberalization**

$ 18.21 (p.251) **Financial turmoil on the housing market**

$ 22.4 (p.294) Strategic management and leadership

|⊕| More economics and finance cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Exercises 6.3, 14.3, 14.4, 18.2 and 18.19 are based on (Bossel 2007c). Economic models and accounting models can be found in (Yamaguchi 2013) and many papers in the ISDC proceedings.

Following related themes group more exercises and cases of interest to those interested in this theme: Management & Organization (||), Housing Policy & Urban Planning (||), and Education & Innovation (||).

0.8.9 Management & Organization

The Management & Organization theme groups –as the name of the theme indicates– exercises and cases related to management, business and organization. The main emphasis is on management of different types of organizations, processes, and issues. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: |I| |1| |a| |b| |c| |d| |1| |2.1| |2.2| |2.3| |2.5| | | | | | | | | |5| |2| |e| |f| | | |6.2| |6.4| | | | | | | | | | | |?|

W2: |II||9||3||10.1||4||10.2||5||10.3||10.4||10.5||6||g|| ||7||10.7| |8||10.8||9||10.9||10||10.10||11||10.11||10.12||10.13|| || || || || ||?|

W3: |III||13||12||h||10.14||13||i||j||10.15||14.2||14.13||14|| || || || || ||?|

W4: |IV| |17| |15| |k| |l| |18.1| | | |18.3| |18.8| | | | | | | | | | | |?|

W5: |V| |21| |16| |17| |18.12| |18.14| | | | | | | |?| | | | |

. . . : |22.4|

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.2 (p.51) **Customer and asset management**
- 2.5 (p.53) **Setting up COLs and MOOCs**
- 6.4 (p.93) **(Mis)management of societal aging**
- 14.2 (p.156) **Supply chain management**
- 14.13 (p.178) **Production management**
- 18.3 (p.212) **Hospital management**
- 18.8 (p.224) **DNO asset management**
- 18.12 (p.230) **Managing a concerted bank run**
- 18.14 (p.234) **Project management**
- 18.16 (p.239) *Energy transition management*
- 22.4 (p.294) Strategic management & leadership
- |⊕| More management and organization cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Following related themes group more exercises and cases of interest to those interested in the this theme: Economics & Finance (|$|), Housing Policy & Urban Planning (| |), Resource Dynamics & Energy Transitions (| |), Environmental & Ecosystems Management (| |), Health Policy, Epidemiology & Drugs (| |), Safety, Security & Risk (| |), Policing & Public Order (| |), Education & Innovation (| |). All other themes are in fact about management in particular application domains. Moreover, many introductory SD books, such as (Sterman 2000) focus on business and management.

0.9 Generic 'Project' Path

After taking the theory and practice part, on-site and COL students have to take a mandatory SD project part/course. During this 5 week project, pairs of students need to solve larger cases, either structured cases of 14-25 pages as the one in the appendix of (Meyers et al. 2010) or an 'open project', i.e. a project of their own choice. Students are supervised and coached on a weekly basis while doing so. The workload should correspond to about 2.5 ECTS or 75 hours of work. Where students acquire the SD language and technical modeling skills during the first 5 'theory and practice' weeks, they only really learn what modeling, simulation, and model-based policy analysis is in the project part of the course. The project phase of this course is crucially important. It requires good supervision and coaching in an environment in which failing is allowed and learning is the goal. Although the process of the second part of this course is outlined below, it is offered to on-site and COL students only. During these 5 project course weeks, pairs of students need to work independently, are peer reviewed and supervised/coached by experienced supervisors following the course schedule below.

WEEK 6: QUESTIONS AND CONCEPTUAL MODELS

- |I| Video: Beyond 'Introduction to SD' (project cases, advanced SD, real-world cases)
- |I| Video: SD Project – issues, research questions, information gathering, boundary choices, and conceptual model
- Issue choice, definition of research questions, information gathering, boundary choices, conceptual model, dynamic hypothesis
- Submission of lab report version 1
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 7: FIRST ITERATION QUANTITATIVE MODEL BUILDING

- |I| Video: Building your first iteration 'quick and dirty' simulation model
- first iteration 'quick and dirty' model building and simulation
- Submission of lab report version 2
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 8: SECOND ITERATION QUANTITATIVE MODEL BUILDING & TESTING

- |I| Video: Second iteration model building and model testing
- second iteration model building and testing
- Submission of lab report version 3
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 9: POLICY ANALYSIS, DESIGN AND TESTING

|I| Video: Third iteration model building and policy analysis

third iteration model building & use

Submission of lab report version 4

Peer review across themes/classes

Interactive feedback session per theme/class

WEEK 10: POLICY SUPPORT AND REPORTING

|I| Video: Interpretation, advise, reporting

interpret results, formulate advise, report

Submission of final (bullets) report + lab report + simulation models

Peer review and grading across themes/classes

Final individual feedback and grades

Materials beyond this 10 week/day introductory course briefly dealt with in the final chapters:

|I| Video: Beyond SD101

Chapter: Overview of Advanced System Dynamics

|| Tutorial 11

|| Tutorial 14

|| Tutorial 16

|| Tutorial 17

|| Tutorial 18

SD literature

⊕ Advanced SD cases

Chapter: Beyond SD. . .

The deliverables of the SD project are a SD simulation model, analyses performed with the simulation model, a bulleted report, and a very short presentation. Examples of conference papers based on open projects include (Kővári and Pruyt 2012; Howell and Wesselink 2013; Nassikas and Staples 2013; Rose and Kuipers 2013; Jaxa-Rozen and Handaulah 2013; Sharifi and George 2013; van Staveren and Thompson 2013).

Chapter 22 is a surrogate for those who do not have the opportunity to practice under supervision: it allows (i) students to practice on larger and more open ended cases before starting the project, and (ii) self-study students without supervision to practice on larger and more open ended cases. The latter is by no means a full substitute for a supervised project course.

After passing the SD project part of the course at Delft University of Technology, students are allowed to write a BSc thesis in SD, follow the Advanced SD course, take Simulation Master

Classes, and write a BSc or MSc thesis in SD, more or less as described in (Pruyt et al. 2009; Meyers et al. 2010).

0.10 Target Audiences

This e-book is aimed at students in the broadest sense: it can be used in introductory SD courses (semester or quarter), executive education (2 to 5 days), and self-study (minimum 5 days). At Delft University of Technology, it is used for the theory/practice part of the Introductory System Dynamics courses (5 weeks x 10 hours/week).

0.11 Rules of the Game: Copyright, Use, Contribution

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money –no matter how small– will be used to pay for the substantial costs incurred, for future development of new cases, for new editions of this book, and, hopefully, for writing follow-up books, e.g. an advanced book on Exploratory System Dynamics Modeling and Analysis and a Project Cases Book. However, if you are one of my on-site or COL students, or if you did not use this e-book, did not derive any value from it, did not learn from it, and did not enjoy it, or do not have money to spare, then please do not contribute and spend your money on something useful to you.

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0.12 About the Author

Let me briefly introduce myself: I'm Erik Pruyt. I am Dutch but studied in Belgium and Switzerland, obtained my PhD at the Free University of Brussels, and have, since 2007, been lecturing System Dynamics and other modeling courses at Delft University of Technology's Faculty of Technology, Policy and Management. I am heavily involved in research combining SD and Exploratory Modeling and Analysis for deeply uncertain dynamically complex issues.

My applied research interests include, but are not limited to, all the themes covered in this e-book. More information related to my research and the research of my research team colleagues and collaborators can be found online at simulation.tbm.tudelft.nl. I co-founded the Benelux Chapter of the System Dynamics Society, have chaired the Health Policy SIG of the System Dynamics Society, have organized several System Dynamics conferences, and do quite some real-world modeling. In July 2014, I will –together with my colleagues– host the International System Dynamics Conference at Delft University of Technology, Delft, The Netherlands (follow this link to the ISDC conference site).

0.13 Acknowledgements

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0.14 System Dynamics Software

For this course, one needs System Dynamics software. Several System Dynamics software packages are available. See for example following core packages. Other packages or online modeling and simulation interfaces are available too (see Wikipedia). Most packages have a free of charge version for learning purposes or are freely available for some time. These versions are good enough for most exercises and cases in this e-book. Exercises and cases have been made in Vensim keeping the other core packages in mind. All models are also provided, from the start on, in Vensim, and some other packages. Over time, I hope all exercises and cases will become available in most packages and online interfaces. For that, I need your help. Please send your models or links to your sims that correspond to the exercises and cases in this book and that were made with packages that are not yet provided in the online repository to smallsdmodels@gmail.com with subject title MODEL CONTRIBUTION TO SD101. Your contribution will be acknowledged.

0.15 Before Getting Started. . .

I wish you success and a lot of fun! Although this learning process will take time and will, at times, be painful and frustrating, you will not regret it in the end. Do not give up. You can do it!

Part I

WARM-UP

Chapter 1

Introduction to (Qualitative) System Dynamics Modeling

'Cuncta fluunt, omnisque vagans formatur imago.
Ipsa quoque assiduo labuntur tempora motu.' Ovidius

1.1 Systems, Boundaries, Variables, Causes, Feedback

Systems

Systems consist of the whole of closely interacting elements and their interactions[1]. In spite of the fact that the term 'system' is mostly used in System Dynamics (SD) and this e-book, SD models mostly focus on issues or problems, not on systems[2]. System dynamicists model the assumed/perceived underlying (material, informational, social, ...) structure of largely closed real-world systems. In SD terms, a causally closed system is a system which controls action based on the results from previous action (Forrester 1968) which means that closed systems generate their own behavior endogenously over time because 'the causes creating the behavior of interest lie within the system' (Forrester 1994, p254). The performance of purely open systems, on the other hand, is not influenced by their own past performance, but by external/exogenous events or driving forces. Although SD was primarily developed for systems that can be assumed to be causally closed, SD is often used to deal with complex real-world issues that are not fully closed nor entirely open. Modeling such partly open systems is a difficult equilibrium exercise between the inclusion and exclusion of elements, since on the one hand all important or potentially important elements have to be included in a useful model of the real-world system, but it is, on the other hand, impossible and undesirable to model 'the entire world'. This is one of the reasons why SD practice is generally highly issue-focused and goal-oriented and why SD modeling is often called a craft instead of a science, which is not to say that SD is not scientific: good SD adheres to the scientific method (Meadows and Robinson 1985).

Model Boundaries

It is very important to carefully delimit system and model boundaries. All (potentially) important elements which influence other parts of the system and are also significantly influenced by

[1] Ackoff (1994, p175) defines a system more precisely as: 'whole consisting of two or more parts *(i)* each of which can affect the performance or properties of the whole, *(ii)* none of which can have an independent effect on the whole, and *(iii)* no subgroup of which can have an independent effect on the whole. In brief, then, a system is a whole that cannot be divided into independent parts or subgroups of parts'.

[2] For a more detailed discussion of Issues, Systems, Models, readers are referred to this additional background chapter. From here on, the words issue, problem, system and model are used interchangeably.

elements of the system should be modeled as endogenous variables, all elements that (could) seriously impact the system –but that are not sufficiently influenced by the system– become exogenous variables, and all other elements omitted.

System dynamicists argue against model boundaries that are too narrow. System dynamicists and system thinkers promote a holistic and systemic view of issues under study: '[s]uccessful systems thinking is about being able to see the whole picture or context of a situation and its interconnections to its environment' (Wolstenholme 2003, p20). That way, '[s]ystem dynamics helps us expand the boundaries of our mental models so that we become aware of, and take responsibility for, the feedbacks created by our decisions' (Sterman 2002b, p505).

But boundaries do not only delimit the system from its environment, they also play an important part *within* systems. Wolstenholme (2003, p9) discusses why it is important to look for the boundaries within systems and models, and to represent them adequately in SD models: they lead to imperfect and asymmetric information, to unexpected reactions and behavioral strategies, and to unintended consequences (Wolstenholme 2003; Wolstenholme 2004).

System Elements and Model Variables

Systems consist of elements and relations between (some of) these elements. Models are simplified representations of issues or systems. They consist of variables and links between (some of) these variables. In SD models, diagrammatic distinctions are made between different types of variables (stocks, flows, auxiliaries, parameters and constants). Underneath, stocks are integral equations of the flows, flows and auxiliaries are equations of other variables and parameters/constants, and parameters/constants assume (constant) values over a simulation run.

Systems are said to be more than the sum of their constitutive elements. Likewise, SD models are more than a collection of different types of variables. The structure of a model –i.e. different types of variables, the links between them, and the feedback loops they form, together with their underlying equations and values– determines the behavior of the system. In order to fundamentally change the behavior of a model, one therefore needs to change the feedback and/or stock-flow structure, equations, and/or parameter values.

It is often assumed that, if the model and the real-world system correspond closely, the changes required to change the model behavior would also change the real-world system behavior. Every variable in a SD model needs to correspond closely to a real-world counterpart and the model itself needs to correspond to the real-world issue/system in ways important to the issue for this to be true. It is therefore good practice to unambiguously name variables after the real-world system elements. These names should be understandable and the interpretation of the corresponding dynamics meaningful. Note that this is less evident than it seems at first sight: models are often highly aggregated representations of not fully known real-world systems, and variable names are consequently less specific and more abstract than their real-world counterparts.

The above suggests that observation, conceptualization, aggregation, causal reasoning skills, and technical modeling skills are minimally required to make useful models of real-world systems. This e-book focuses explicitly on technical modeling skills. It is assumed the other skills –observation, conceptualization, aggregation, causal reasoning skills– were already acquired or will be acquired along the way by learning by doing or by coaching (e.g. in the project part).

Causal Links and Structures

Links between variables and parameters in SD models only represent direct causal relations. Hence, one needs to be able to perceive, identify or assume direct causal relations for SD to be of any use. If that is the case, then SD could be used to explore the interaction between the (assumed) structure and the dynamically complex behavior of these issues, for example to gain insights, and from these insights, transform structures to steer the system towards more desirable behaviors.

Feedback Loops

A *feedback loop* consists of two or more causal links between elements that are connected in such a way that if one follows the causality starting at any element in the loop, one eventually returns to the first element. For example, if a change in variable A directly causes a change in variable B which directly causes a change in variable C, which in turn directly causes a change of our initial variable A, then we are dealing with a feedback loop (see Figure 1.1). Variable A feeds back –after some time– to itself. Its behavior is therefore (partly) caused by its own past behavior. Feedback loops give rise to nonlinear behavior, even if all constitutive causal relationships are linear.

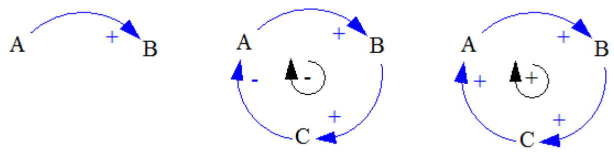


Figure 1.1: Causal links and feedback loops: a positive causal link (left hand side), a negative feedback loop (middle), and a positive feedback loop (right hand side)

There are two different types of feedback loops: positive and negative feedback loops.

- A feedback loop is called positive (+) or reinforcing (R) if an initial increase in variable A leads after some time to an additional increase in A and so on, and if an initial decrease in A leads to an additional decrease in A and so on. In isolation, such feedback loops are self-enhancing: they generate exponentially escalating behavior which could be (extremely) beneficial or (extremely) detrimental. The term '*positive*' should thus not be confused with its everyday meaning: vicious circles are in fact positive feedback loops, although highly undesirable ones.

- A feedback loop is called negative (-) or balancing (B) if an initial increase in variable A leads after some time to a decrease in A, and if an initial decrease in A leads to an increase in A. In isolation, such feedback loops generate balancing or goal-seeking behavior. They are sources of stability as well as resistance to change. The presence of a negative feedback loop in a system does not imply that the objective will be achieved nor that the process is under control. Negative feedback may also cause undesirable behavior, for example undesirable oscillatory behavior due to negative feedback loops with delays.

Feedback loops hardly ever exist in isolation: feedback loops are often strongly connected, and their relative strength changes over time. Indefinitely increasing growth does for example not exist in real world issues. Long before, the dominance of such positive feedback loops shifts to other (negative) feedback loops. Complex system behaviors often arise due to such shifts in the relative strengths of feedback loops, i.e. when dominant feedback loops lose strength and other loops start to dominate behavior.

Two or more connected feedback loops are called a feedback system (Roberts 1988). People are often unaware of the fact that they are a part of feedback loop systems. The larger the delays in loops and the more indirect the consequences are, the more difficulties people have in recognizing feedback loop structures (Roberts 1988).

As discussed above, boundaries in SD are set such that all important endogenous effects are included. That is, possibly important feedback loops need to be part of the feedback system. The combination of feedback system, stock-flow structures, and the underlying equations make up the structure of the model. Systems with similar structures can produce similar dynamic behaviors (Meadows 2009, p50).

1.2 SD Diagrams

Different types of diagrams are used in SD, both for model conceptualization, for model communication, and even for purely qualitative SD. Most often used are Causal Loop Diagrams (CLDs), Stock-Flow Diagrams (SFDs), Sector Diagrams, Bull's Eye Diagrams, Influence Diagrams (IDs), and Archetype Diagrams (ADs). They are briefly discussed below.

Causal Loop Diagrams

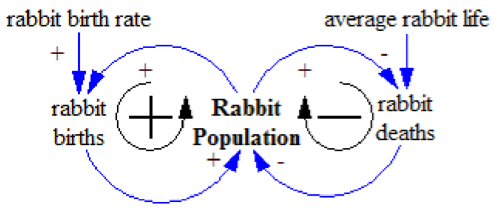


Figure 1.2: Example of a Causal Loop Diagram

System dynamicists mostly communicate feedback loop systems by means of CLDs like the one in Figure 1.2. The core building blocks of CLDs are variables and the direct causal relationships between them. These relationships are either positive or negative. The meaning of the terms positive and negative does not correspond to their everyday meaning. A link between two variables A and B is considered positive if *(i)* an increase in A causes B to rise above what it would have been otherwise and *(ii)* a decrease in A causes B to fall below what it would have been otherwise. A link between two variables A and B is considered negative if *(i)* an increase in A causes B to fall below the value would have had otherwise and *(ii)* a decrease in A causes B to rise above what it would have been otherwise (see Table 1.1) (Sterman 2000).

	Result in B:	
Change in A:	Rise above	Fall Below
Increase	+	-
Decrease	-	+

Table 1.1: Determining Link Polarity

The polarity of causal relations is visualized in CLDs by means of link polarities (+ or -) or by means of qualifications of the direction of the cause-effect relation (**S**ame or **O**pposite):

- $\xrightarrow[+]{}$ and $\xrightarrow[s]{}$ stand for a positive causal influence, i.e. an effect in the same direction;
- $\xrightarrow[-]{}$ and $\xrightarrow[o]{}$ stand for a negative causal influence, i.e. an effect in the opposite direction;
- $\xrightarrow[+]{/\!/}$ and $\xrightarrow[s]{/\!/}$ stand for a delayed positive causal influence, i.e. a delayed effect in the same direction;
- $\xrightarrow[-]{/\!/}$ and $\xrightarrow[o]{/\!/}$ stand for a delayed negative causal influence, i.e. a delayed effect in the same direction.

Positive and negative causal relations:

$\overset{\rightarrow}{+}$ A ***positive causal influence*** means that if the influencing variable increases (decreases), all things being equal, the influenced variable increases (decreases) too above (under) what would have been the case otherwise, or $A \overset{\rightarrow}{+} B \Rightarrow \frac{\partial B}{\partial A} > 0$. In other words, 'a positive arrow from A to B means that A adds to B, or, a change in A causes a change in B in the same direction' (Richardson 1997, p249).

$\overset{-}{\rightarrow}$ A ***negative causal influence*** means that if the influencing variable increases (decreases), all things being equal, the influenced variable decreases (increases) under (above) what would have been the case otherwise, or $A \overset{-}{\rightarrow} B \Rightarrow \frac{\partial B}{\partial A} < 0$. In other words, '[f]or a negative link from A to B one says A subtracts from B, or a change in A causes a change in B in the opposite direction' (Richardson 1997, p249).

CLDs allow to map systems, identify loops, determine their polarity ((+) and (R) or (−) and (B)), trace them, and communicate about specific loops or sets of loops. Loop polarity is determined as follows. If the net effect of the causal links in a loop is negative, the entire loop is negative or balancing ((−) and (B)). A simple way to determine the polarity of a loop is thus to count the negative signs. If the number of '-' signs in the feedback loop is uneven, then the feedback loop is negative, and if the number of '-' signs in the feedback loop is even, then the feedback loop is positive or reinforcing ((+) and (R)). The net effect could thus be determined by multiplying the signs of all connections in the loop. A better way to determine the polarity is to start at one point in the loop and 'read the loop' replacing $A \overset{\rightarrow}{+} B$ by "if A increases/decreases and everything else remains the same, then B increases/decreases beyond the value it would have taken without the increase/decrease in A" and replacing replacing $A \overset{-}{\rightarrow} B$ by "if A increases/decreases and everything else remains the same, then B decreases/increases beyond the value it would have taken without the increase/decrease in A".

A feedback loop does not contain the same variable twice, except for the first variable. And every feedback loop contains at least one stock or delay variable. The stock variable or delay variable functions as a memory in the loop, and hence, helps to avoid simulation problems caused by simultaneous equations, that is, mutually dependent equations that need to be calculated at the same time without starting point. Note however that traditional CLDs do not distinguish stock variables whereas hybrid CLDs do. See the box for useful guidelines and diagramming conventions to be respected when drawing CLDs.

Guidelines for drawing CLDs (largely based on (Sterman 2000, p135–190)):

- Make different types of CLDs for different purposes/audiences/uses (conceptualization, loop analysis, communication,...) and at different levels of aggregation.
- Choose the right level of aggregation (but never too detailed) dependent on the intended use/goal/audience.
- Iterate, use SD software to redraw your diagrams.
- Use nouns or noun phrases with a clear (positive) sense of direction as variable names. Choose variable names that, together with the causal links and link polarities, enable to easily 'read the loops'.
- Don't use/conjugate verbs in variable names. The arrows with their polarities perform the role of verbs when reading a CLD.
- Links between variables are causal and direct, not correlational nor indirect.

- Unambiguously label link polarities (split out links into different effects if polarities are ambiguous).
- Links should be drawn/interpreted under the *ceteris paribus* assumption, i.e. that everything else remains the same.
- Links are relative: they tell the value of the variable will be above/below what it would have been without the effect.
- Explicitly include the goals of goal-seeking loops.
- Distinguish between actual versus perceived conditions.
- Trace & unambiguously label loop polarities, and name loops such that they immediately convey their role, and that the names can be usd in texts/presentations.
- Indicate important delays on causal links.
- Use curved lines, make important loops circular, and minimize crossed lines.
- For communication purposes, don't use too large a diagram with too many loops.
- Don't try to make comprehensive or final CLDs: they will never be. They are either conceptualization tools or tools to communicate (specific) messages.
- Draw CLDs from different angles/perspectives and at different levels of aggregation.
- It is useful to integrate points of view in one and the same CLD, unless the points of view represent fundamentally different or irreconcilable world views. Then, different CLDs need to be drawn.

Stock-Flow Diagrams

SD simulation models are mostly displayed/constructed using Stock-Flow Diagrams (SFDs) as in Figure 5.1. These diagrams consist of stock variables (□), flow variables (⧖), auxiliary variables (no symbol or O), parameters and constants (◇ or O or no symbol), causal links between variables (→±) and causal links with delay signs (→±). Mostly, SFDs are not 'polluted' with other symbols (link and loop polarities, loop names, et cetera).

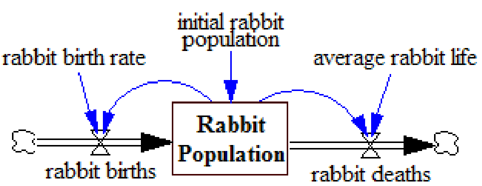


Figure 1.3: Example of a Stock-Flow Diagram

A stock variable –also called a level or a state variable– accumulates, i.e. integrates flows over time. Metaphorically, a stock variable could be seen as a 'bathtub' or 'reservoir'. During simulation, a stock variable can only be changed by ingoing and outgoing flow variables (also called rates). A stock can be increased by increasing its inflow rate as well as by decreasing its outflow rate. Stocks generally change slowly, even when the flows into or out of them change suddenly. Therefore stocks act as delays or buffers or shock absorbers in systems (Meadows 2009, p23).

There are two types of flow variables: inflows and outflows. Positive (negative) inflows increase (decrease) the content of the reservoir, and positive (negative) outflows decrease (increase) the content of the reservoir: ingoing flows correspond, metaphorically speaking, to taps or valves, and outgoing flows to drains. Flow variables regulate the states of stock variables. Flow variables are thus the variables that need to be targeted by strategies to improve the problematic condition/state of the more inert stocks variables. Stock variables also allow inflows and outflows to be decoupled from each other and to be independent and temporarily out of balance with each other (Meadows 2009, p24).

One way to distinguish between stocks and flows is to imagine what will happen if the entire system suddenly stops. Flows would then become nil or would cease to exist, while stocks would equal their values prior to halting the system. Technically speaking, each SD model could be built with stocks, flows and causal links only. In practice, SD models contain many auxiliary variables because good SD models are understandable, transparent, glass-box models of which all variables correspond to real-world elements or concepts: lumping all auxiliaries into the flows would result in opaque models with equations that are too complicated to be understood. It is also good practice to explicitly model all parameters, constants, and initial values. Hiding them in auxiliaries and flows makes models opaque and more difficult to use.

Guidelines for drawing SFDs:

- Explicitly represent important stock-flow structures.
- In case of large or highly interconnected SFDs, avoid spaghetti (as in Figure 1.4 for examples of spagetti in Vensim and in Powersim).
- Instead, use different views and/or sectors with different colors. And use shadow variables or snapshots and color them according to their provenance (view/sector).
- Use subscripts/arrays to replicate identical structures / submodels by means of vectors.
- Use predefined functions to reduce unnecessary structures. For example, use (higher order) delay functions instead of modeling (higher order) delay structures, unless information about the contents of each of the underlying stock variables is needed.
- Do not be afraid to redraw and restructure SFDs: it often takes several iterations to develop decent SFDs/models.
- Avoid polluting SFDs with unnecessary symbols (polarities, etc) except for delays.
- Link successive stocks by means of flows, but only if they are successive accumulations of the same.
- Aging chains, supply chains, etc. are easier and better represented with SFDs than with CLDs: make hybrid diagrams if necessary.
- Do not excessively reduce SFDs: variables should still relate to real-world elements or concepts and should be understandable and useful.
- If you need/want to discuss a model in detail, e.g. in a modeling report written for an audience of modelers, then first show the overall SFD with clear submodels for a big picture overview, followed by (well-organized) SFDs of each submodel to be discussed.

Use Hide/Unhide tools to hide/unhide parts of the model that are not necessary for the purpose at hand, e.g. for explaining the link between structure and behavior for a specific type of behavior.

(a) A Vensim model

(b) A Powersim model

Figure 1.4: How not to structure and communicate SFDs

Conversion, Correspondence, Competition between CLDs and SFDs

Figures 1.2 and 1.3 show a CLD and a SFD of the same simple system. In the SFD, stocks are represented by rectangles and flows by valves & pipes. Stocks and flows are not explicitly represented as such in the corresponding CLD (although in hybrid CLDs, stocks are represented with boxes but flows are not different from auxiliaries). In the SFD, sources or sinks, i.e. the system boundaries, are indicated by clouds on the flows. Outflows in SFDs are represented in CLDs by links with negative signs from the outflow variable to the stock variable. Inflows in SFDs are represented in CLDs by links with positive signs from the inflow variable to the stock variable. Delay structures or stock-flow structures that essentially represent delay structures are represented in (aggregate) CLDs by a single arrow with a delay sign.

Most system dynamicists construct both types of diagrams because each has strengths and weaknesses, and using both types of diagrams cushions the drawbacks of one or the other type of representation. Disadvantages of causal loop diagrams are for example that they *(i)* do not always explain well how flows influence stocks, *(ii)* could lead to mislabeling of loops, *(iii)* do not provide a sound basis for the rigorous deduction of behavior, and *(iv)* cannot explain some dynamic phenomena (Lane 2000a, p244). Some disadvantages of stock/flow diagrams are that they *(i)* make it difficult to grasp feedback loops *(ii)* make it difficult to grasp models in their totality, *(iii)* contain too many (technical) details, and *(iv)* do not allow to explain all dynamic phenomena (Lane 2000a, p244).

Influence Diagrams

Influence diagrams are slightly more sophisticated than causal loop diagrams: they contain solid lines for flows and dotted lines for influences from information, action or behavior, and different types of entities such as variables, players (or actors) and levers, and indicate the delays (Dn) and effectiveness (Es) (Coyle and Alexander 1997). Readers interested in IDs are referred to (Wolstenholme 1990; Coyle 1996).

Bull's-Eye Diagrams

Bull's eye diagrams provide a general overview of the elements modeled endogenously, of the elements modeled exogenously, and of all elements that were deliberately omitted. Moreover, bull's eye diagrams allow others to identify unintentional omissions at a glance. The bull's eye diagram in Figure 1.5 shows for example in a very simple way what is (to different degrees) included in, and deliberately omitted from, a rather large and complex simulation model of the technological battle in the European electrical power sector (see (Pruyt 2007a; Pruyt 2007b)).

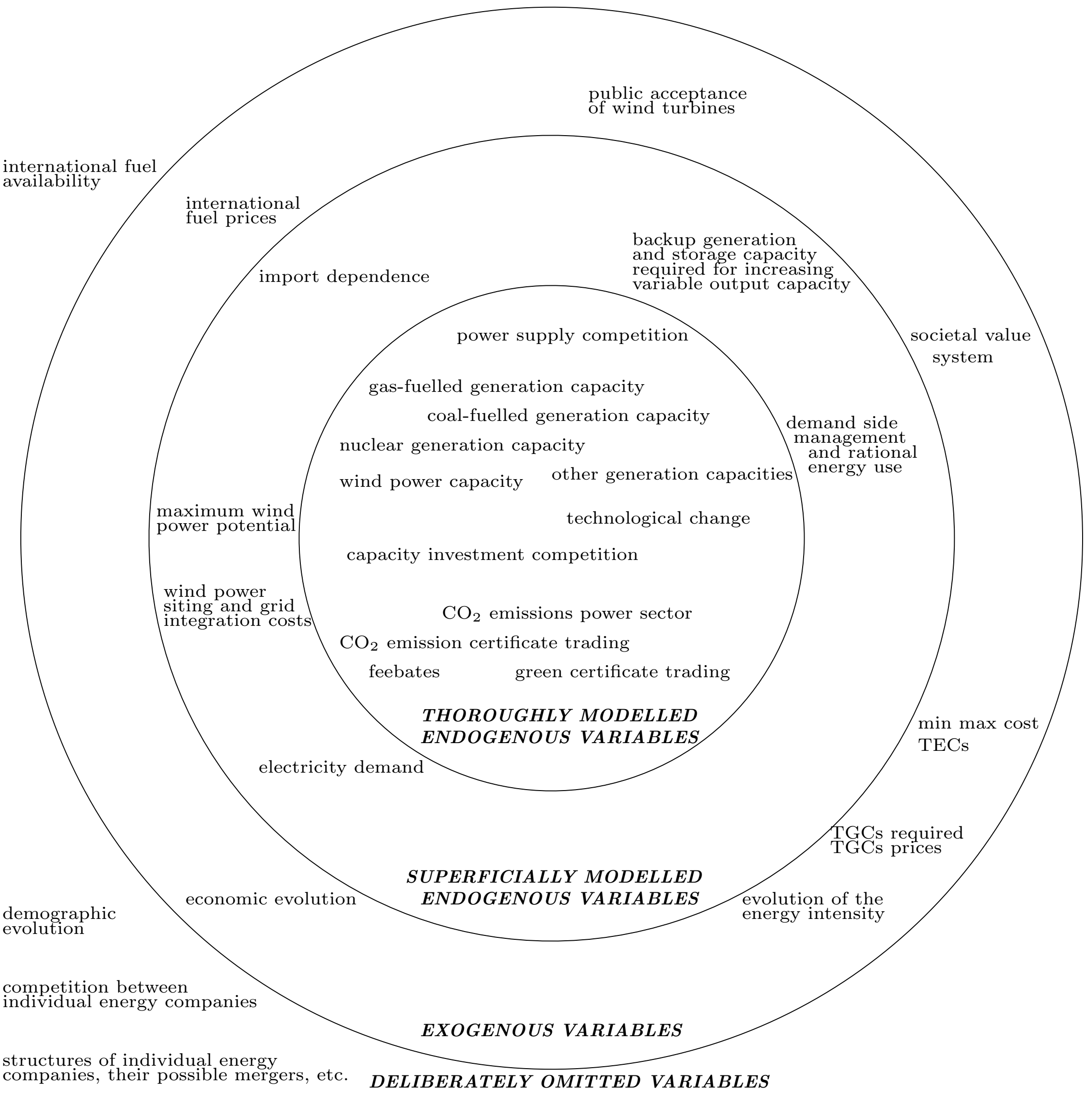


Figure 1.5: Example of a bull's eye diagram: What is missing?

Sector Diagrams

Sector Diagrams are aggregated diagrams that focus on the main sectors/clusters/submodels and the main relations between them, not on the relations within each of them. Sector diagrams are ideally suited to provide a big picture overview of issues or systems with sectors/clusters/submodels of variables with many relations between the variables within each of the sectors and few relations with variables in other sectors. Figure 1.6 shows a Sector Diagram of the fight against burglaries and robberies. The corresponding SFD of the model is too detailed to be shown for a big picture overview. And although CLDs can be used to illustrate different effects, such as the waterbed effect between types of high impact crimes or between different regions, for an overview of the whole model they would be too complex.

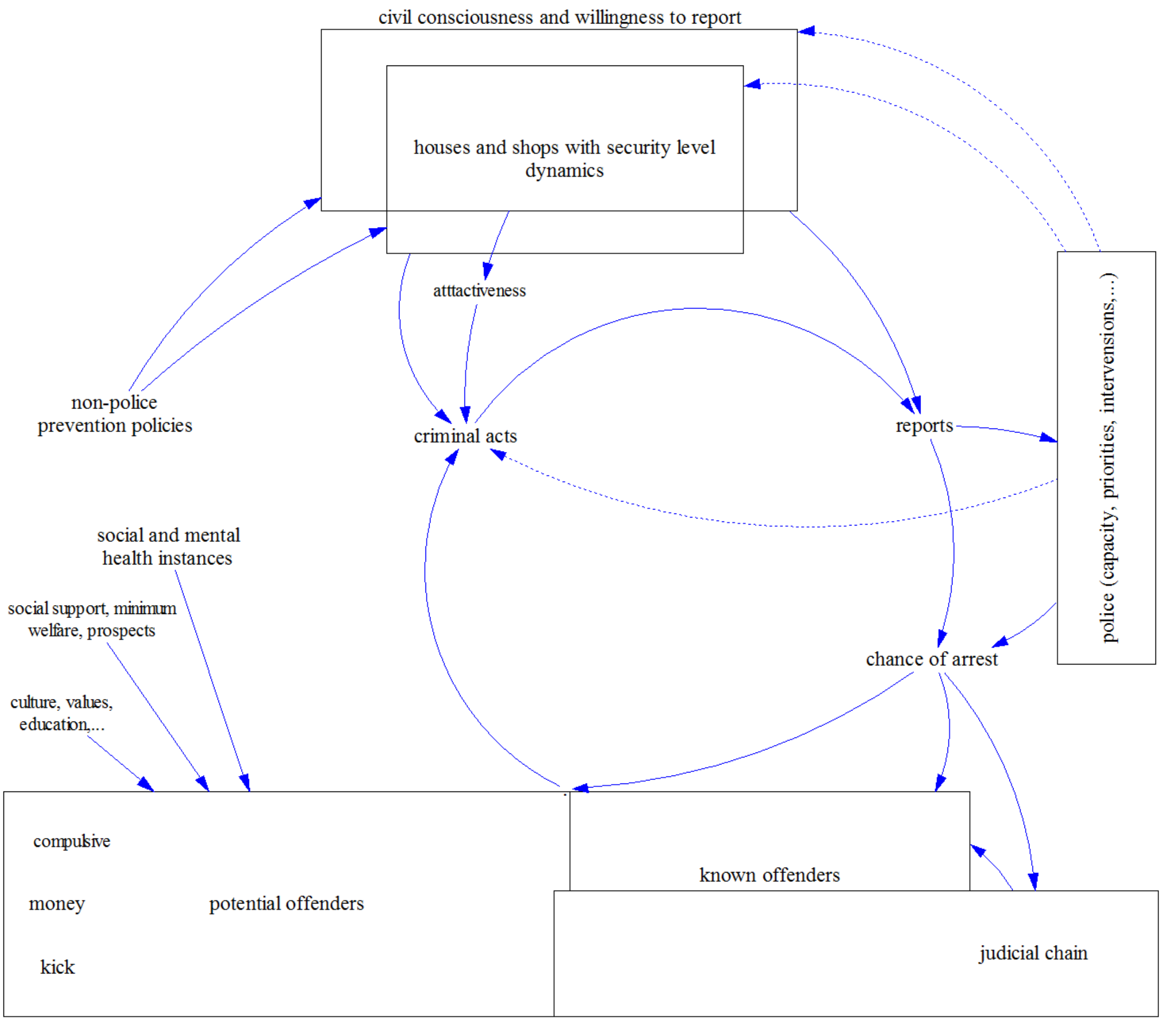


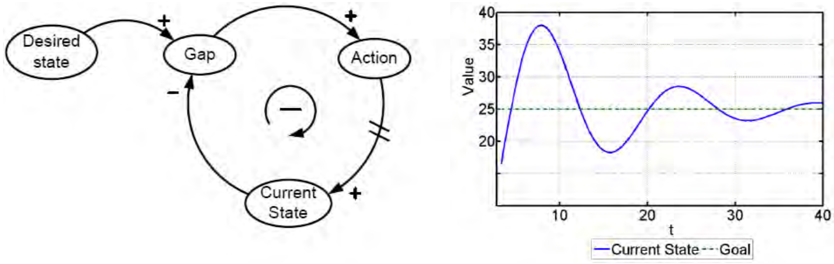
Figure 1.6: Example of a Sector Diagram.

Archetype Diagrams

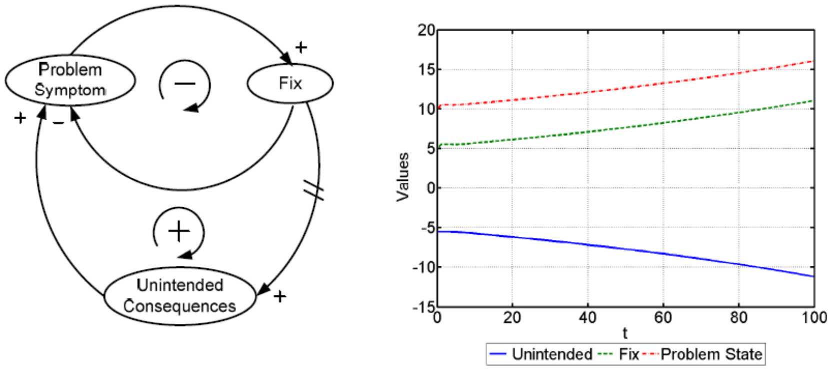
Archetypes, also known as *counter-intuitive system archetypes* or *generic system archetypes*, are typical situations encountered across different application domains caused by common underlying mechanisms encountered across these different application domains, with typical traps and solutions. Archetype Diagrams (ADs) are diagrams that are used to represent the essence of these archetypical situations. Although ADs resemble CLDs, they are not the same. ADs only show highly aggregated archetype mechanisms in isolation. The names of variables in ADs are more generic than in CLDs since archetypical situations are focused on. The following nine archetypes discussed by Senge (1990) are often used in SD:

- The *balancing process with delay* archetype (see Figure 1.7(a)) relates to systems characterized by regulation based on delayed feedback. Corrective interventions are often too strong and fast for the system, thus causing oscillatory behavior or insufficient results.
- The *fixes that fail* archetype (see Figure 1.7(b)) relates to fixes that result in substantial unintended/undesirable 'side' effects, and as such, instead of absolving the issue, creating new issues.
- The *shifting the burden* archetype (see Figure 1.7(c)) relates to short-term, symptomatic solutions used to correct problems, with seemingly immediate and positive results. As this solution is used more frequently, the more fundamental solution is used less frequently and after some time, the capabilities for the fundamental solution may even be rendered inoperative.
- The *eroding goals* archetype (see Figure 1.7(d)) relates to situations in which short-term solutions lead to adjustment of long-term goals.
- The *escalation* archetype (see Figure 1.8(a)) relates to situations in which two or more parties aim for relative advantages over the other party/parties, resulting in an escalation. Note that the two negative loops in Figure 1.8(a) jointly form one positive loop.
- The *success to the successful* archetype (see Figure 1.8(b)) relates to situations in which two parties or activities compete for the same limited resources and an even a small advantage results in more resources being allocated to the most successful party or activity, which reinforces the competition.
- The *limits to growth* archetype (see Figure 1.8(c)) relates to situations in which growth is followed –after reaching a limit– by stagnation, and possibly by a collapse.
- The *tragedy of the commons* archetype (see Figure 1.8(d)) relates to situations in which individual incentives lead to collectively catastrophic dynamics.
- The *growth and underinvestment* archetype (see Figure 1.9(a)), which is an extended version of the limits to growth archetype, relates to situations in which insufficient investments are made to sustain growth, after which expectations and goals are lowered.

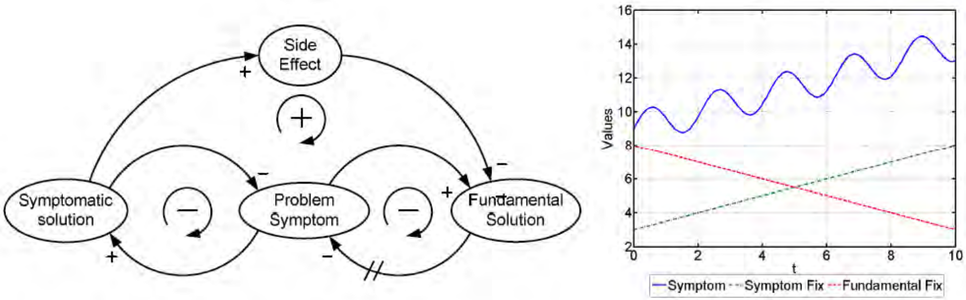
Wolstenholme further reduces the number of archetypes to core archetypes and stresses the importance of boundaries within archetypes and systems. For more on archetypes, read the additional online chapter on Archetypes, (Senge 1990) (especially appendix 2), as well as (Wolstenholme 2003; Wolstenholme 2004). Figures 1.7-1.9 are based on (van Daalen, Pruyt, Thissen, and Phaff 2007).



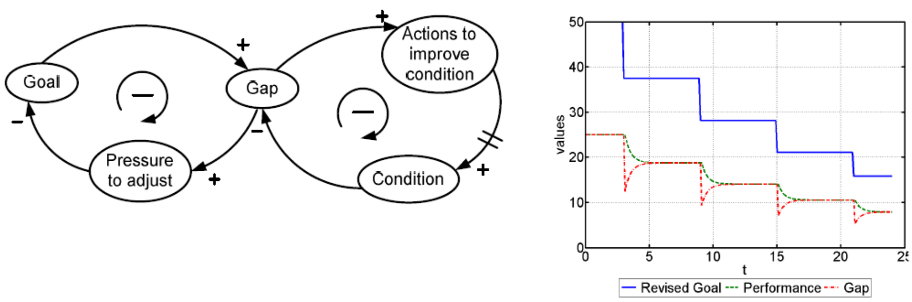
(a) AD of a balancing process with a delay and possible behavior



(b) AD of the fixes that fail archetype and possible behavior

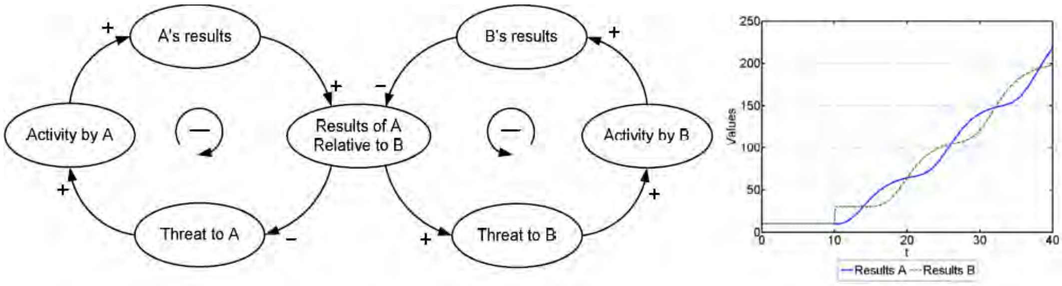


(c) AD of the shifting the burden archetype and possible behavior

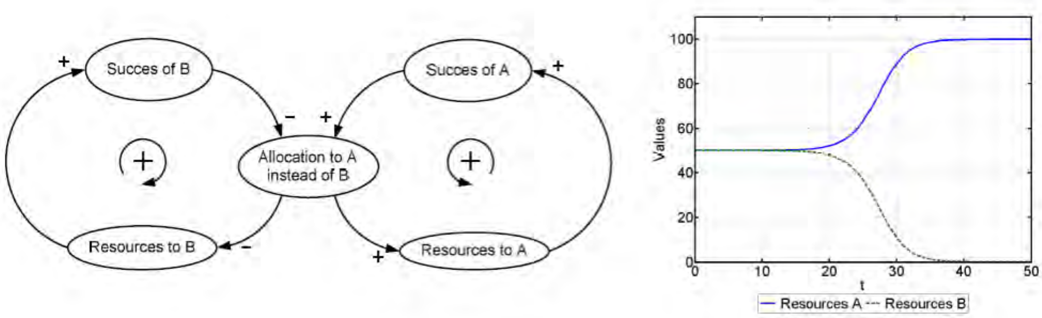


(d) AD of the eroding goals archetype and possible behavior for discrete goal adjustments

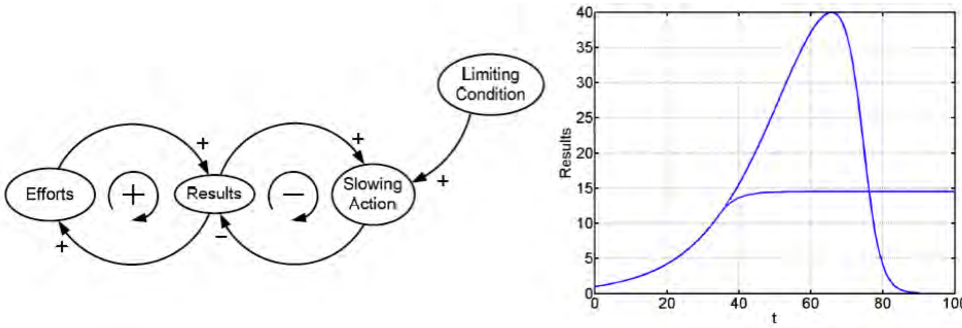
Figure 1.7: Archetype diagrams (1/3) with possible behaviors of systems that could be characterized by the respective archetypes. Source: (van Daalen et al. 2007)



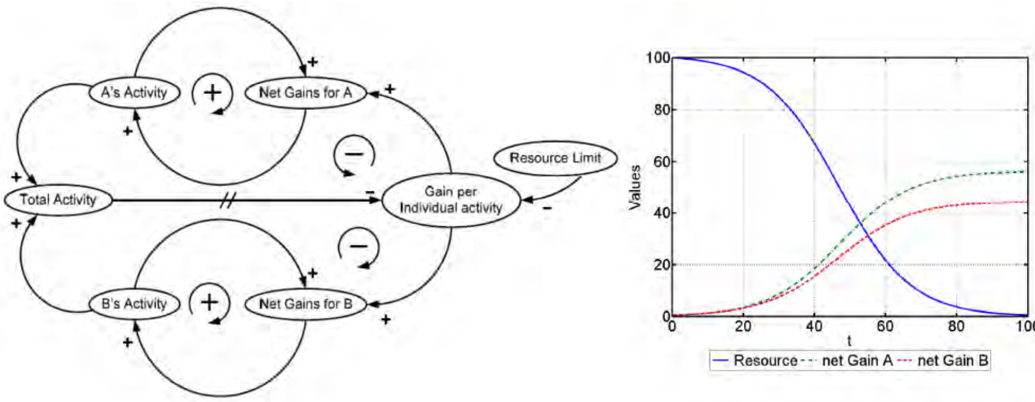
(a) AD of the escalation archetype and possible behavior (after perturbation of B's results at t=10)



(b) AD of the success to the successful archetype and possible behavior

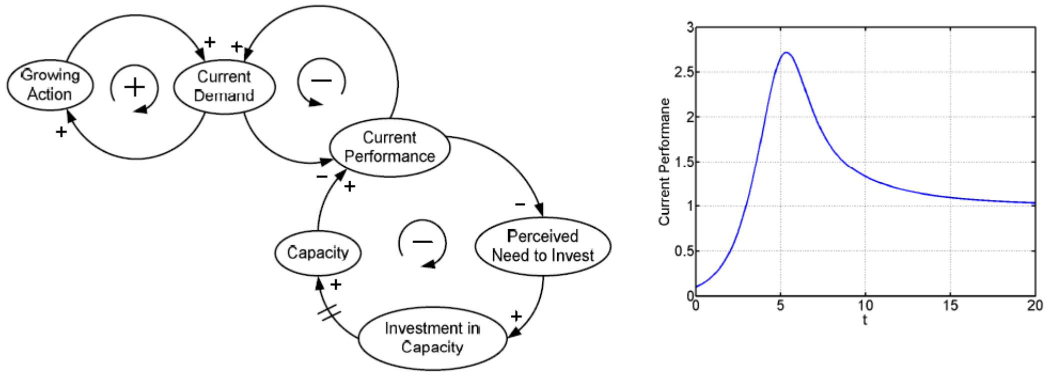


(c) AD of the limits to growth archetype and two possible behaviors



(d) AD of the Tragedy of the commons archetype and possible behavior

Figure 1.8: Archetype diagrams (2/3) with possible behaviors of systems that can be characterized by the respective archetypes. Source: (van Daalen et al. 2007)

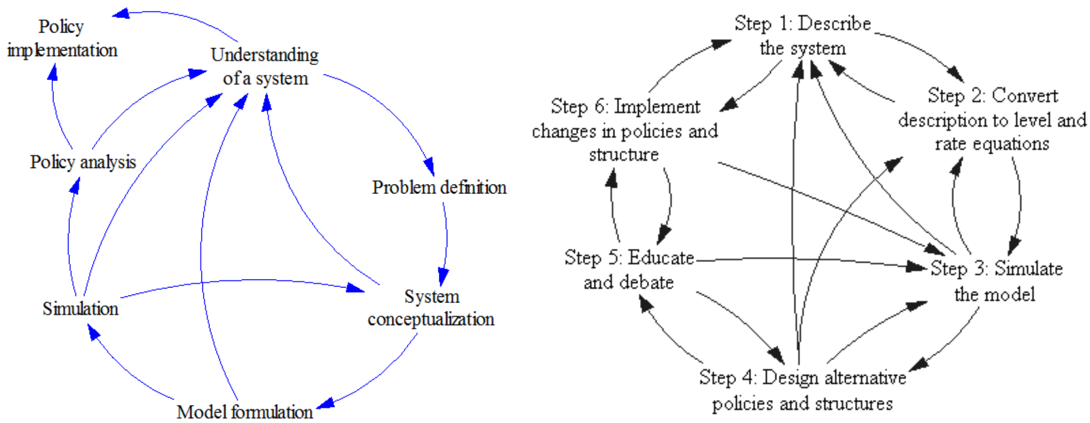


(a) AD of the growth and underinvestment archetype and possible behavior

Figure 1.9: Archetype diagrams (3/3) with possible behaviors of systems that can be characterized by the respective archetypes. Source: (van Daalen et al. 2007)

1.3 The SD Process: Iterative and Interactive

Different processes for model development have been put forward in the SD literature (e.g. (Randers 1980b; Richardson and Pugh 1981; Forrester 1994; Wolstenholme 1994; Sterman 2000).



(a) Overview of the SD modeling approach according to Richardson and Pugh (1981, p17)

(b) The SD methodology or process according to Forrester (1994, p245)

Figure 1.10: Two visualizations of the SD process

Although there are differences in naming and the activities covered by each phase, the SD modeling process could be summarized with the following phases:

1. Problem identification: identifying and articulating the issue to be addressed;
2. Model conceptualization: developing a causal theory about the issue;
3. Model formulation: formulating a SD simulation model of the causal theory;
4. Model testing: testing the model to assess whether it is fit for purpose; and
5. Model use, quite often model-based policy analysis: using the model to design and evaluate structural policies to address the issue.

Although the division of the modeling process in these phases is convenient for a first SD course (they are reflected in the learning paths on pp.0.7-), one should not think of SD modeling as a phase-to-phase waterfall process. SD modeling is extremely iterative in nature: every phase in the process may reveal the need to revise the model structure (Homer 1996), and modeling is an explorative process of knowledge generation which feeds back and forth between each of these phases (Richardson and Pugh 1981). The graphs in Figure 1.10, although expressing the iterative character of the SD process, do not even come close to showing how iterative modeling in practice really is. In practice, any of these phases is revisited several times during a SD modeling project, starting with a small model that is gradually extended until it is good enough for the purpose at hand. However, from a learning point of view, SD modeling processes are more important than the models resulting from these modeling processes(Forrester 1985).

Most SD modeling is also highly interactive, i.e. a high degree of participation of decision-makers and stakeholders is desirable and often necessary. A participative/interactive process allows to *(i)* exchange and aggregate information, knowledge and even emotions on existing and desired systems, *(ii)* gradually develop understanding, insight, confidence and commitment, and *(iii)* address factors excluded from the actual models (Forrester 1961; Forrester 1971; Lane 2000b).

1.4 Qualitative SD

Qualitative Stages in the Mainstream SD Process

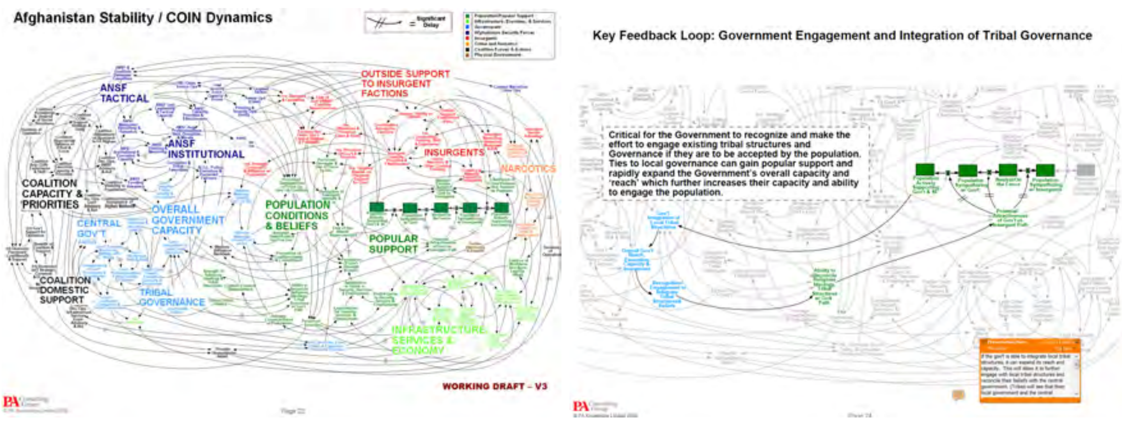
Several of the SD modeling phases in the process outlined by Richardson and Pugh (1981) are actually qualitative: the first three stages (understanding of a system, problem definition, system conceptualization) are qualitative, as is the interpretation of outcomes of SD-based policy analysis. SD model formulation, simulation, and model-based policy analysis on the other hand relate to, or require, quantitative models. Mainstream SD covers all stages, and is clearly qualitative-quantitative-qualitative: i.e. starting from qualitative information and diagramming, quantitative simulation models are developed and used, but the outcomes of these simulations and analyses, and the recommendations based upon them, are interpreted qualitatively. In mainstream SD, diagramming is mainly used for conceptualization, model building, and communication purposes.

The goal of the conceptualization phase of the modeling process is to capture the feedback structure that can offer a largely endogenous explanation of the problem (Sterman 2000). The steps of the model conceptualization phase are to:

1. determine the purpose/objective of the model,
2. define the model boundaries and identify the most important variables,
3. construct a conceptual model of important mechanisms and feedbacks in the system,
4. formulate a causal theory, aka dynamic hypothesis, i.e. a hypothesis on how (problematic) behavior is generated by the model structure. This causal theory, like all theories, exists to be tested and is constantly subject to change or abandonment.

In the conceptualization phase, CLDs are usually created to elicit the (assumed) feedback structure of a system or issue. These diagrams are made in consultation with the the decision-makers and possibly other actors involved in the problem/system. However, some prefer to work –already in the conceptualization phase– with SFDs, especially in case of typical 'stock-flow' problems.

CLDs are also interesting devices to summarize and communicate. SD diagrams are also used to facilitate the communication about models and the link between models and behaviors. One should nevertheless be careful when communicating CLDs and/or SFDs. Only formally trained system dynamicists, people closely involved in drafting a CLD, and some people without former training or close involvement to whom it was explained in full detail, are likely to be able to understand and appreciate a CLD or SFD. Large and overly detailed CLDs are easily ridiculed and may alienate anyone with a lack of time, anyone without proper training, anyone without close involvement, and/or anyone without deep knowledge of the issue.



(a) PA Consulting's 'leaked' COIN model (b) Key loop in PA Consulting's COIN model

Figure 1.11: PA Consulting's 'leaked' COIN model. Sources: msnbcmedia

In 2009, Richard Engel, NBC News' Chief Foreign Correspondent published the slide displayed in Figure 1.11(a) alongside his story 'So what is the actual surge strategy?' about the counter-insurgency strategy in Afghanistan. Soon after, this CLD was criticized on the internet and many newspapers, including the NY Times, as an example of both 'death by Powerpoint' and the inextricable situation in Afghanistan. Although SD and Powerpoint are of course not the same, and in spite of the Letter to the Editor by the PA Consulting's CEO, PA Consulting's reaction on their web site and the availability of the full slide pack including a gradual build-up and explanation of the CLD (see Figure 1.11(b)), harm was done.

Instead of the hybrid diagram in Figure 1.11(a), a highly aggregated version would have been better for the public at large if the public at large would have been the target audience in the first place (which was not the case). Although the most effective means for the public at large would in my opinion be a short well-structured newspaper article or report based on the CLD, or a conceptual model showing and explaining the main mechanisms at play and their (possible) consequences.

Purely Qualitative SD?

Mainstream system dynamicists often start with qualitative SD, then turn to quantitative SD. The results of which are interpreted in a qualitative sense and communicated using qualitative SD. And that in a single intervention. There are nevertheless system dynamicists who prefer qualitative SD modeling –mainly using CLDs and IDs, and sometimes ADs– over quantitative SD modeling. Proponents of purely qualitative SD modeling argue that if a close representation cannot be reached, the analysis should be restricted to the qualitative level (Coyle 2000) and that qualitative SD modeling is satisfactory when the 'insights from the diagram are so convincing [or] uncertainties in the numerical data are so great that a quantified model may contain such uncertainties and inaccuracies that it is not worth the effort of building' (Coyle and Alexander 1997, p206). Other arguments pro qualitative SD are that it is useful (i) for describing a problem situation and its possible causes and solutions, potential risks (Wolstenholme 1999, p424) and uncertainties[3], hypotheses and constraints, (ii) to 'capture intricacies of circular causality in ways that aid [. . .] understanding' (Richardson 1999, p441) (Wolstenholme 1999, p424), (iii) as

[3] uncertainties due to soft variables, parameter uncertainty, model uncertainty, and uncertainties related to different structural options and leverage points (Mayo et al. 2001, p269)

a medium by which people can externalize and share their mental models and assumptions (Wolstenholme 1999, p424), (iv) for the 'inference of modes of behavior by assisting mental simulation of maps' (Wolstenholme 1999, p424), (v) to show people the dynamic system they are part of, the strategic ramifications, and (vi) to propose solutions (Coyle 2000). It could create a common language and understanding of the structure and the feedback loops, reveal the big picture, hidden and different world views, hypotheses, constraints, structural problems (boundaries), uncertainties, threats, risks, opportunities, possible leverage points, policy variables and policy structures, and could therefore be seen as a problem structuring and discovery tool.

However, there are also good arguments against purely qualitative modeling and in favor of qualitative-quantitative-qualitative modeling, namely that: (i) maps are misleading (Richardson 1999, p441) and unreliable tools for behavioral inference (Homer and Oliva 2001; Richardson 1996), (ii) they do not enable estimation of the scale or speed of change of key items (Richardson 1999; Warren and Langley 1999), (iii) 'feedback based insights, especially those based on multiple loops of uncertain strength, can often be difficult things for people to understand and believe in' (Homer 1997, p307), (iv) they are 'less likely to lead to commitment, consensus or system changes than quantitative models' (Rouwette et al. 2002, p32), and (v) they are but 'tools for hypotheses generation without the systematic approach to falsify the hypothesis' (Oliva 2003).

Most system dynamicists would argue that simulation nearly always adds value (Homer and Oliva 2001, p347) but demands a deeper and more rigorous analysis than qualitative mapping (Wolstenholme 1999, p424), and hence, also much more time and resources. The question to be asked in each and any case is thus whether the additional effort of quantitative modeling is justified given the time and resources available.

Additional (non-mandatory) chapters:

- I. Systems and Models
- II. Hard and Soft Systems
- III. Introduction to System Dynamics
- IV. Model Conceptualization

Chapter 2

Introductory Qualitative SD Exercises

'Überhaupt lernt niemand etwas durch bloßes Anhören, und wer sich in gewissen Dingen nicht selbst tätig bemüht, weiß die Sache nur oberflächlich.' Johann Wolfgang von Goethe

2.1 Competition in the Faculty

Suppose that there are only two departments within a university faculty. One of these departments is slightly bigger and produces slightly more scientific papers (also because they write about less fundamental and less complex, but very actual issues). Until now, both departments have always received an equal amount of the budget because they were assumed to be equally important for the faculty.

Now, suppose that the Dean wants to increase the output of the faculty in terms of scientific papers. In order to do so, he decides to introduce some competition between the departments: from now on, the entire budget will be distributed between the sections in proportion to the number of scientific papers produced.

1. Make a CLD or AD of the new situation in order to explain the resulting dynamics.
2. What behavior do you expect? Will the total number of scientific papers increase? What is likely to happen to the two departments and the faculty?
3. Do you expect undesirable (side-)effects? If yes, which? If yes, how could you prevent these undesirable side-effects from happening? Is the Dean's idea overall a good idea?

2.2 Asset and Customer Management

The manager of a new fitness club wants to analyze and understand the (future) member dynamics. The fitness club has a specific number of fitness devices. The number of members –all members are assumed to be active– and the number of devices results in an average effective waiting time per device. Members have some sort of implicit maximum acceptable waiting time per device which could be seen as the 'desired waiting time' from the point of view of the fitness club. If the ratio of effective waiting time to desired waiting increases, then the satisfaction decreases, which leads over time to unsatisfied cancelations. Inversely, the more satisfied the members are, and the more members there are, the more positive mouth-to-mouth publicity there is which leads to an increase of the number of new members. Members pay a fixed monthly contribution and new members also pay a one-time registration fee.

1. Make a CLD (the modeling objective is to make a simulation model) of the member dynamics.
2. What behavior do you expect.
3. Do you expect undesirable (side-)effects? If yes, which?
4. The manager dislikes the decreasing satisfaction of the members, and asks you to suggest a dynamic policy to –using some sort of desired number of members– that regulates the number of members without decreasing the level of satisfaction of the members. Extend the CLD (use another color).

2.3 Resource Dynamics

Nowadays, Rare Earths Metals (REM) are extremely important. They are used, albeit in very small quantities, in modern appliances or applications. Let's use an aggregated variable, '*REM in goods*', for REM in all modern appliances or applications. *REM in goods* are lost after an *average lifetime in goods* of some 15 years (recycling of REM is very difficult and expensive). The *use of REM in the production of goods* depends on the *demand for REM* or –if the *available supply of REM* is smaller than the *demand for REM*– the *available supply of REM*. The *available supply of REM* only increases through *processing of REM* which follows *REM extraction*, i.e. the depletion of REM deposits.

1. Make a SFD, a complete CLD, and a strongly aggregated CLD of the description above.
2. Which of these diagrams is most useful? Why?

2.4 Prescriptive Approach to Health & Social Work

The Munro Report

The final report of the Munro Review of Child Protection was published in 2011 (Munro 2011). Qualitative SD in the form of CLDs was used for this report. This exercise is based on a CLD included in appendix A of the final Munro report. This CLD was developed in collaboration with Prof. Dr. David Lane.

The CLD

The CLD could be summarized as follows. An increase in the *prescription of practice* leads to a decrease in the *scope for dealing with variety of CYP*[1] *needs with professional expertise*, which, in turn, leads to a delayed decrease in the *quality of outcomes for CYPs* and a decrease in the *sense of satisfaction, self-esteem and personal responsibility*. A decrease in the *quality of outcomes for CYPs* also leads to a decrease in the *sense of satisfaction, self-esteem and personal responsibility*. A decrease in the *sense of satisfaction, self-esteem and personal responsibility* leads in turn to an increase in both the *staff absence or sickness rate* and the *staff turnover rate*. Both cause an increase in the *average caseload* of those that are still on the job. The increase of the *average caseload* results in a decrease in the average *time spent working with CYPs and families*. The same may be the case for changes in the *prescription of practice*: an increase in the *prescription of practice* may lead to a reduction of the *time spent working with CYPs and families*. A decrease in the *time spent working with CYPs and families* results in a lower *quality of the social worker relationship with CYP and family*, which all else remaining the same results, after a delay, in a reduced *quality of outcomes for CYPs*. The higher the *variety of needs of CYPs* is, the lower the *quality of outcomes for CYPs* will be.

1. Make a CLD based on the above description. Study the qualitative model and try to understand it.
2. How many loops are there? What is their polarity?
3. What are the unintended consequences illustrated in this CLD of the increase in rules and guidance governing child and family social work activity over the past two decades on the health of their profession and outcomes for vulnerable children and young people?
4. What policy changes do you suggest?

Back to the Munro Report

Note that the description provided above is my non-native 'direct translation' of the CLD into an introductory exercise. Munro and Lane show that the story told by the CLD could also be phrased eloquently:

> 'The quality of the outcomes for children and young people delivered by child protection services is heavily influenced by three factors. First, the wide variety of needs that children and young people have; the more variety, the harder it is to meet those needs.

[1] CYP stands for 'children and young people'.

> Second, professionals can only work within the scope that they are allowed for applying their professional expertise. If that scope is increased, alongside an investment in building social workers' capabilities, then it is likely that outcomes for children will improve. Third, outcomes are also improved when professionals establish and maintain high quality relationships with children, young people and their families.
>
> [T]oo much prescription of practice, which diminishes professional responsibility for judgments and decisions, has an unintended consequence of reducing the job satisfaction, self-esteem and sense of personal responsibility experienced by child protection workers. This leads to the further unintended consequence of increasing amounts of time taken off absent or sick. In fact, this goes on to create a reinforcing loop, R1 [...]: those still at work have to take on larger caseloads and in turn have less time to build relationships with children and families; in time, this reduces the quality of the outcomes for children and young people, which further reduces the sense of job satisfaction.
>
> Another unintended consequence of prescription is that dissatisfaction with the role causes high staff turnover. Again, this creates larger caseloads and reduced contact time with children, young people and families, so another vicious circle is created, R2.
>
> Two other influences are illustrated, each exacerbating the [unintended consequences]. Too much prescription reduces scope for professionals to respond appropriately to each individual case and, though it takes longer for the effect to play out, this reduces the quality of outcomes for children and families. In addition, the large amounts of time social workers are forced to spend on Integrated Children's System (ICS), reduces the time they can spend directly engaging with children, young people and families. Both of these can be seen as unintended consequences of burdensome rules and guidance. However, they also strengthen the two feedback effects (reduced job satisfaction due to increased caseloads as a result of absence and high turnover), making these loops even more damaging.'

Finally, another interesting CLD can be found in appendix II of the Munro review of child protection: part 1 – a systems analysis (Munro 2010), developed with Prof. Dr. David Lane too.

2.5 Setting Up COLs and MOOCs

The board of directors of a university would like to know whether it is a good idea to start a "traditional" online distance learning programme in addition to the regular on-site programme. The members of the board would like to gain an understanding of the likely dynamics of the number of online and on-site students over time. Similar programmes elsewhere show that:

Students enroll when entering the programme, and unenroll when finishing the programme or when quitting. The annual number of students that passes the programme is equal to a percentage of the total number of online students, which is lower than the percentage of on-site students passing. Students unenroll due to dissatisfaction with the programme. Dissatisfaction is mainly caused by the perceived quality of the teaching. Enrollment is directly proportional to the tuition fee, the perceived quality of the programme, and is highly dependent on word of mouth advertisement by current and former students. The more students there are in the online programme, the lower the costs per student.

The quality of the teaching/professors depends on experience, expertise, and motivation. Motivation is inversely proportional to their workload and the number of complaints. Complaints are the direct result of the deterioration of the quality. Improving the educational quality raises the cost per online student. And long term teaching overload results in loss of expertise.

A traditional online programme may attract students that would otherwise enroll in the on-site programme, and hence, cannibalize the on-site programme. The work related to the online programme would have to be done by the professors that teach the on-site programme, in addition to their high workload for the on-site programme.

1. Draw a CLD and a SFD related to this system. What do you advise the board of directors?
2. What if the online programme would be integrated in the on-site programme –as a Collaborative Online Learning course– such that it would not lead to doubling the classes on-site professors would have to provide?

But what if (*i*) new online courses would not cost professors any additional time after the materials have been developed, (*ii*) there would be no limit to the number of students that could follow the online course, (*iii*) there would almost be no costs per student, (*iv*) these cases would generate a lot of attention, and they would result in attracting brighter students in more advanced and fun courses to teach? Those are the promises of Massive Online Learning Courses or MOOCs.

3. Draw a CLD and SFD of this new system. Is this diffusion model fundamentally different?
4. Extend the CLD with side effects.
5. What do you advise the board to do? Should they invest upfront in such courses? Why?
6. Also draw a CLD of the global higher education system: how will COLs and MOOCs change the higher education system?

2.6 Fish and Ships

Below you find a description of a very simple fisheries model, also known as the basic Fish Banks model. The two main variables in a fisheries model are *fish* and *ships*.

Suppose the number of *fish* only increases through the *fish hatch rate* and decreases both through the *fish death rate* and the *total catch per year*. Suppose that the *fish hatch rate* equals the *fish* times the *hatch fraction*. The *fish death rate* is equal to the *death fraction* times the *fish*. The *death fraction* is a function of the *carrying capacity* and the number of *Fish*. The *total catch per year* depends on the number of *ships* and the annual *catch per ship* which is a function of the fish *density*. The *density* is defined as the amount of *fish* in the fishing area divided by the *area*.

Suppose that the number of *Ships* increases via the *ship building rate* which is a function of the *investment costs per ship*, *annual profits* and *fraction reinvested*. The *annual profits* are calculated as the *revenues* minus the *costs*. Assume that the *revenues* equal the *total catch per year* times the *fish price* and that the *costs* equal the *unit ship operating costs* times the number of *ships*.

1. Make a CLD of this model. What can be learned from it?
2. Make a SFD of this model. What can be learned from it?
3. Make a Sector Diagram of this model. What can be learned from it?
4. Make a Bulls Eye Diagram of this model. What can be learned from it?
5. In case of undesirable conclusions, change the diagrams to turn undesirable into desirable.

2.7 Housing Policies

Real estate demand in densely populated urban areas with sufficient land to extend is often rather price sensitive: declining property prices for instance caused by relative oversupply, i.e. real supply exceeding real estate demand, results in rapid demand rises. Construction companies often initiate new projects based on the demand for properties. Increased demand leads to new projects being initiated. Real estate construction projects are often completed with relatively long delays of about 2-3 years. Many construction companies tend to operate in these areas. And they are mostly unaware or do not keep track of construction projects initiated by others.

1. Make a CLD of this description.
2. What kind of dynamics would you expect to see in property prices?
3. What would be an adequate strategy of a smart construction company?
4. Extend the CLD with labor availability, construction costs, etc.
5. Make a CLD of real estate in your own country or city. Use it to identify potential problems.

2.8 Student Passing Policy

Suppose that last month, the Dean sent an internal memo to all lecturers and students announcing that the percentage of students failing a course should from now on be smaller than 10%, no matter how good or bad the students are in a topic. Otherwise the respective lecturer(s) will be fired. This would for example mean –given the average of 60% percent failures of all students participating in the exam of this course– that more than 86% of those who failed in first session need to succeed in the retake exam. . . which is of course not possible given the course goals, namely to allow only sufficiently good SD modelers to participate in the SD project. The consequence would be, indeed, a rather easy retake exam. . . and insufficiently good SD modelers being allowed to participate in the SD project. The rumor that almost all students succeed the retake exam would quickly spread. And since this year's retake exam is also the distributed example for next year's exam, new students will also think next year's exam will be easy. So next year's students will find the practice exam so easy that they will not study enough for the exam,. . . which will lead to an even easier retake exam next year to achieve the 90% quota, and so on.

1. Make a CLD or an AD of the situation in order to explain the resulting dynamic behavior.
2. Which archetype best fits this situation?
3. What behavior do you expect? What will happen over time in such a situation to the standards set out initially in the SD course?
4. What do you think: is this 90% quota a good idea for students in the long run? Why?
5. What could the lecturer do to avoid the undesirable behavior? Adapt the CLD.

PS: This is a hypothetical situation. . . the next exam of this course will be difficult as usual.

2.9 Fighting High Impact Crime

Suppose that burglaries are mainly committed by members of the organized crime (OC) and by occasional thieves. *Burglaries by members of the OC* and *burglaries by occasional burglars* then largely determine the *total number of burglaries*.

The Netherlands is such a small country and organized crime so well organized that the amount of *burglaries by members of the OC* depends largely on the *effective chance of being caught for burglary* in the Netherlands versus the *chance of being caught for burglary in neighboring countries*. The *effective chance of being caught for burglary* is proportional to the well-spent *police man-hours available for burglaries* and inversely proportional to the *total police man-hours required for burglaries*. Assume the police system is flexible but also rather inert: if *total police man-hours required for burglaries* increases/decreases, then so do the *police man-hours available for burglaries*, but with a delay.

Burglaries by occasional thieves mainly depend on the *percentage of houses with opportunities for burglaries*, which is seasonal (more in winter less in summer) and influenced by the *relative media attention with regard to burglaries*. The latter is proportional to the *total number of burglaries* divided by the *acceptable number of burglaries*.

1. Make a CLD of the description above.
2. What behavior do you expect based on this CLD?
3. Use the CLD to explain the link between structure and behavior.
4. Based on the CLD: What could different parties do reduce the total number of burglaries?

2.10 Conflict in the Middle East

Although few issues are as messy, and persistent as the Israelite-Palestinian conflict, using archetype diagrams, causal loop diagrams, and influence diagrams may help to shed some light on the inextricableness of the conflict and/or visualize opposing worldviews.

1. First, make a high-level archetype diagram of the following point of view.

Suppose more Palestinian *(suicide) bombings* are countered with more *measures* by the Israelis – such as walls, checkpoints, and economic measures– that are preventive in the short run. As a 'side effect', these *measures* are also repressive in the long term, likely causing further *marginalization, impoverishment, and despair*, and hence, both creating the *living conditions* which may well be a fertile breeding ground for terrorists (as they are called by one party in the conflict) or freedom fighters (as they are called by the other party in the conflict) and providing pretexts for more *(suicide) bombings*. These *(suicide) bombings* in turn damage efforts –such as peace talks, economic relations, and multi-cultural initiatives– aimed at reaching a *long-term fundamental solution to the conflict*.

2. What is the polarity of the loops? To which archetype does this diagram correspond? What could/should be done (by whom) according to this archetype in view of a long-term sustainable solution to the conflict?

3. Make another high-level archetype diagram displaying the conflict from a different angle. What could/should be done (by whom) according to this archetype in view of a long-term sustainable solution to the conflict?

At the time of the second intifada, a very heterogeneous group of students –some in favor of the Palestinians, some in favor of the Israelis, and most students neutral– participated in a group model building (GMB) session at the Free University of Brussels. The topic of the GMB was the conflict between Palestinians and Israelis. The following description corresponds to the CLD built by that particular group. The *living conditions of the Palestinians* are positively influenced by their *autonomy*, and negatively by *economic restrictions on the Palestinians*, by Israelite *security measures impacting the everyday life of Palestinians (e.g. walls)*, and *reprisals by Israelis on Palestinians* following *(suicide) attacks by Palestinians on Israelis.* Deteriorating *Palestinian living conditions* increase the *willingness to commit (suicide) attacks*, increasing –every else remaining the same– the number of *suicide attacks. Suicide attacks by Palestinians on Israelis* directly undermine the *trust of the Israelis in the Palestinians*, which almost instantly leads to more stringent *economic restrictions on the Palestinians*, Israelite *security measures impacting the everyday life of Palestinians (e.g. checkpoints)*, and a drop in *willingness to conduct constructive peace talks.* This willingness was also argued to be influenced positively by the *living conditions of the Palestinians* and the *trust of the Palestinians in the Israelis.* A reduced *willingness to conduct constructive peace talks* results in less *progress in the peace process* than would otherwise have been the case. Progress is also influenced positively by the *likelihood of success of the peace process* which is positively influenced by the *degree of equality in the peace talks.* The latter was argued to depend positively on the *living conditions of the Palestinians.* More *progress in the peace process* was believed to lead in the long term to more *autonomy of the Palestinians*, resulting in the even longer term in better *living conditions of the Palestinians.* And *reprisals by Israelis on Palestinians* were argued to be the prime cause of loss of *trust of the Palestinians in the Israelis.*

4. Replicate the CLD that corresponds to the CLD built in that particular GMB session. How many feedback loops of which kind are there? Can you further aggregate the CLD without losing crucial loops?

5. Extend the CLD with potential threats and potential solutions. What are the necessary conditions for a successful peace process?

6. Make your own CLD corresponding to your understanding of the current situation. How different is, according to you, the current situation from the one agreed upon years ago by the group of students? Extend your CLD with potential threats and solutions. What are the necessary conditions for a successful peace process now? Explain.

2.11 Mapping Bank Runs

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Although bank runs[2], banking panics[3] and even systemic banking crises[4] have since 2007 been the order of the day, they are not new. Bank runs and banking panics are of all times. Although each time, runs and panics seem to be different, they are essentially the same (Reinhart and Rogoff 2009). The core mechanisms of bank runs can easily be represented with causal loop diagrams. Let's draw causal loop diagrams of different types of bank runs and distill general conclusions regarding the core mechanism.

A Traditional Bank Run

A traditional bank run starts when (correct or incorrect) information about potential problems at a bank leads to *fear of a bank failure*. More fear leads to a higher *tendency to withdraw personal savings*. An increase of withdrawals leads to a decrease of the *perceived solvency of the bank* which leads to more *fear of a bank failure*. An increase of withdrawals also leads to a decrease of *liquid bank reserves* and hence to a lower *liquidity of the bank*. Banks then need to turn more and more illiquid assets into liquid assets (money) to have sufficient liquid assets to pay for (future) withdrawals. Due to the speed required to liquidate illiquid assets, huge losses are often made, resulting in a reduction of the *solvency of the bank*. The lower the solvency of the bank, the lower the *perceived solvency of the bank*, which leads to more *fear of a bank failure*. Weak or uncertain economic conditions result in more fear and lower perceived solvency.

1. Make a causal loop diagram of this description. This causal loop diagram should be similar to the ones described in (Richardson 1991; MacDonald 2002). How many feedback loops are there? What is their polarity?
2. What are the possible systems behaviors suggested by this CLD?

A Signalled Bank Run

In case of the crisis of the Fortis bank (case 14.10 on p.171), there was an interesting relation between the decrease of the stock market value and the increase of withdrawals. The stock market value functioned as a signal to depositors and lenders. An aggregated causal loop diagram of that particular 'stock market signalled bank run' would start with an *exogenous net worth loss* due to their Lehman Brothers positions, leading to a drop in *net worth*, followed by a fall in *perceived net worth*, and consequently a fall in *share price*. Falling *share prices* increase *depositor's and lender's fear of a bank failure* resulting in increases of *net liquid deposits and loans being lost*, in other words, in decreases of *net liquid deposits and loans being gained*. That leads, first of all, to a reduction of the *liquid assets* and later, when liquid assets fall below critical thresholds, to a reduction of the *fixed assets*, resulting –due to the fractional reserve banking systems and the losses incurred when being forced to sell fixed assets (e.g. in an illiquid market)– in *net worth* losses, and so on.

[2] Bank runs occur in fractional reserve banking systems when large numbers of customers withdraw their deposits from a financial institution because they fear a bankruptcy which leads to a self-fulfilling prophecy as more people will subsequently withdraw their deposits (Diamond 2007).
[3] Banking panics are financial crises that occur when many banks suffer runs at the same time.
[4] Systemic banking crises are financial crises in which entire financial systems break down or come to a halt.

3. Make a causal loop diagram of this description. How many feedback loops are there in this CLD? What is their polarity?
4. What are the possible systems behaviors suggested by this CLD?
5. How is it different from the previous CLD?
6. Extend the causal loop diagram: Add *net worth losses* and link it to the *net worth*. Add a 'general climate of fear on the financial markets' variable and a variable related to the percentage loss incurred when liquidating illiquid assets.
7. How many feedback loops are there now?
8. What are the possible systems behaviors suggested by this CLD?
9. What should the bank and/or central bank have done?

An Orchestrated Bank Run

In the case of the orchestrated run on the DSB Bank (case 18.12 on p.230), many depositors were *angry* because they were deceived by the bank (unacceptable sales practices had strongly impacted the financial position of many households and the bank refused to compensate these victims). Even more depositors feared the consequences of a failure because –although deposits up to €100000 are guaranteed– *hinderance from a bank failure* due to the temporary inaccessibility of deposits was still fresh in the collective memory.

At some point, someone called for a bank run on national TV, which resulted in a sudden outflow of funds deposited at the bank which lasted for a few days. The *liquid deposits and loans lost* reduce the stock of *liquid deposits and loans*. More *liquid deposits and loans lost* also lead –depending on the *liquidation premium*, i.e. the penalty paid at unplanned liquidation of fixed assets– to more *assets lost*, thus reducing the stock of *liquid assets*. Assume that the *perceived likelihood of a liquidity failure* is determined by the amount of *liquid assets* and that the *liquid assets lost* are a proxy for the *perceived likelihood of a solvency failure*. Suppose the *perceived likelihood of a bank failure* can be determined by the *perceived likelihood of a solvency failure* and the *perceived likelihood of a liquidity failure* since a bank failure can be caused by a lack of liquid assets (liquidity failure) and/or a shortage of assets relative to liabilities (solvency failure).

Banks always vehemently deny any imminent failure. The higher the *credibility of these denials* the lower the *perceived likelihood of a bank failure* is. However, denials are very often not very credible. The higher the *perceived likelihood of a bank failure* is, the larger the *liquid fraction running* will be. The *liquid deposits and loans* subsequently *lost* depends on the *liquid fraction running* times the *liquid deposits and loans*, the (in this case) *anger*, and the expected *hinderance of the bank failure*.

10. Make a CLD of this description. How many feedback loops are there in this CLD? What is their polarity?
11. What are the possible systems behaviors suggested by this CLD?
12. How is it different from the previous CLDs?
13. Extend the CLD with the following information: Backed by assets, banks can borrow at the European Central Bank (ECB facilities) for dealing with (short-term) liquidity problems. But the ECB applies a 'haircut', i.e. it all of a sudden reduces the ECB facilities of the bank, if the asset basis decreases. This haircut is often delayed and applied rather suddenly and discretely. Extend the CLD with this 'haircut' mechanism that finished off the DSB Bank.

14. How many feedback loops are there now? What is their polarity?
15. What are the possible systems behaviors suggested by this CLD?
16. What should the bank and/or the central bank have done?

Summarize all CLDs: Draw up a generic CLD with regard to Bank Runs.

2.12 Entrepreneurs & Transitions

Energy Transitions are dynamically complex: they are governed by many feedback effects and long delays. Energy transitions are also deeply uncertain: major uncertainties –related to individuals, particular technologies, the entire system, and hence for policy/decision makers in the energy field– are omnipresent. Energy technologies face many uncertainties and need to overcome many hurdles, even before becoming commercially viable and entering the energy technologies battlefield. One of these hurdles is the so-called 'valley of death'. That is, quite often, entrepreneurs and technology developers bring a new technology to the *pre*-commercial stage, but due to a lack of investments, it does not survive the phase between (subsidized) entrepreneurial technology development and large-scale commercial take-off in which subsidies are (often) forbidden. It is hard to predict which promising technologies will actually make it, and hence, which might possibly become the technologies of the future.

Ineke Meijer and colleagues studied the influence of uncertainty on entrepreneurial motivation and entrepreneurial action related to the pre-battlefield stage in energy transitions (Meijer 2008; Meijer et al. 2010a; Meijer et al. 2010b). In SD terms, her PhD thesis could be summarized as follows:

Many *self-reinforcing uncertainties* influence *perceived certainty* related to each new technology. The lower the *perceived certainty*, the higher the *perceived risk* and the lower the *entrepreneurial willingness to acquire knowledge/experiment/lobby/...* in order to bring a technology to the point where it would be considered a good investment. *Resources for actions to reduce uncertainty* may actually help to take this hurdle and may lead to more *perceived certainty* and raise *perceptions about the potential success of the technology*. This in turn reinforces (intrinsic) *entrepreneurial motivation*, resulting in more *willingness to act*.

A reduction of the *perceived risk* and an increase of the *entrepreneurial motivation* are the preconditions to further the state of development and increase the *willingness to invest* of entrepreneurs and risk-taking energy companies, which in turn leads to more real *investments*, contributing to the *success of the technology*, reinforcing the *willingness to invest*, etc.

1. Make a CLD of the pre-battlefield struggle. How many loops are there? What is their polarity? What would be appropriate names?
2. What policy recommendations could be derived from this CLD?

After surviving the valley of death, technologies enter –from a technologies point of view– the technology battlefield. The outcomes of the battle is also uncertain and impossible to predict. But even though the outcomes of the energy technologies battle may be unpredictable, plausible dynamics may be 'explorable' by explicitly focusing on these uncertainties. Case 18.16 on page 239 deals with the dynamics on the energy technology battlefield.

2.13 Soft Drugs Policies

On 21 November 2008, a highly mediatized 'Soft Drugs Summit' ('*wiet top*') was held in the Netherlands to discuss the future of the Dutch policy of tolerance with regard to soft drugs, also known as '*het gedoogbeleid*'. At that time, there were about 700 '*coffeeshops*' (soft drug bars) in The Netherlands. They had been tolerated since 1976, the year in which the then Dutch government decided to separate soft drugs and hard drugs in order to get soft drugs out of the underworld (the criminal circuit). At that time, it was clear that rules and regulations about the supply of these coffeeshops had to be made some time later. However, the supply of these coffeeshops has never been regulated. All activities related to the supply of coffeeshops were/are consequently illegal, but some activities were/are winked at.

In 2008, most Dutch citizens and policy makers agreed that this policy of tolerance needed to be revised. Dutch society was nevertheless strongly divided about the direction of the revision. The Dutch soft drug debate was –broadly speaking– dominated by two groups (splitting the cabinet, opposition, and population in two large groups) with almost opposite points of views:

- The proponents of a stricter soft drugs policy wanted the abolishment of *het gedoogbeleid*, the closing of coffeeshops, and more severe punishments for soft drugs trade and use.
- The proponents of a better regulated but looser soft drugs policy wanted the further legalizing of soft drugs cultivation and use, or at least the regulation and legalization of the supply of coffeeshops, and only the closure of these coffeeshops that were causing serious nuisance. They argued that banning soft drugs would only pass soft drugs cultivation and trade into criminal hands and would therefore not resolve soft drugs-related problems.

Suppose you were at the time (becoming) a SD expert, and were invited to join a meeting of proponents of a further legalizing of soft drugs cultivation and use in order to map their ideas in a CLD. At the meeting, following opinions/ideas were expressed:

A policy of more *illegalizing and repression* leads –according to the proponents of a further legalization– to more *illegality of soft drugs cultivation, sales and use*, which, all else remaining the same, results in an increasing *soft drugs price*, more *street dealing* and more *small criminality*. More *street dealing* and *small criminality* leads immediately to more *societal nuisance*.

An increasing *soft drugs price* leads to an increasing *profitability of the illegal soft drugs business*, which results –after some time– in an increase of the *size of the illegal soft drugs business*. The proponents of a further legalization assume that an increase of the *size of the illegal soft drugs business* leads after some time to an increase in the (financial) *power of soft drugs criminals* [or 'business men'], which in turn results in an increase of *big crime* [or at least black money].

An increase of *societal nuisance on the street* and an increase of *big crime* both lead to more *societal resistance against the illegal soft drug business*, which leads to a *stronger call for more soft drugs policy*.

It is often assumed by proponents of legalization that an increasing *illegality of soft drugs business and use* leads to an increasing *attractiveness of occasional soft drugs use*, which leads to an increasing *soft drugs use*, both directly and indirectly (an increase of the *attractiveness of occasional soft drugs use* leads after some time to an increase of *addicted soft drugs use*). The *soft drugs use* drives the *soft drugs demand*. An increase of the *soft drugs demand* leads, all else remaining the same, to an increase of the *soft drugs price*.

An increase in the *size of the illegal soft drugs business* leads to an increase of *illegal soft drugs cultivation*. That, in turn, increases the *total soft drugs supply*. And an increase of the *total soft drugs supply* leads, ceteris paribus, to a decrease in *soft drugs price*.

The proponents of a further legalization think of course that increasing calls for *calls for more soft drugs policy* should lead to more policies focused on decreasing *illegality and repression*, which means (more) *legal soft drugs cultivation* such that the *total soft drugs supply* increases in a legal (and controlled) fashion, and more *control over coffee shops* which means less *societal nuisance caused by coffee shops* (dotted lines).

1. Summarize the ideas of the proponents of a further legalization in an extended CLD.
2. How many feedback loops does this extended *causal loop diagram* contain if you take the link between *demand for soft drugs policy* and *illegalization and repression* as well as the policy of *legal soft drugs cultivation* into account?
3. Mentally simulate the model. What behavior will the system display with this policy if it can be assumed that a decrease of the *illegal soft drugs cultivation* will be more than compensated by an increase of the *legal soft drugs cultivation* such that the *soft drugs price* will not increase significantly. Sketch the expected system behavior.
4. Make an extremely aggregated CLD that would allow you to explain the link between structure and behavior of this system in about 30 seconds to politicians and laymen.
5. Describe this link between structure and behavior of this system in maximum two sentences.
6. The opponents of a further legalization argue that an increasing *demand for soft drugs policy* needs to be answered with stricter policies (more *illegalization and repression*). That also means that legal soft drugs cultivation is unacceptable. Use another color to indicated on the extended *causal loop diagram* how that changes the structure of the extended *causal loop diagram*. The adapted diagram represents the policy of the opponents of a further legalization from the point of view of proponents of a further legalization (which should not be confused with the policy of the opponents of a further legalization from their own point of view).
7. Mentally simulate the model. What behavior will the system display with this policy if you assume/accept that –in case of an increasing soft drugs price– illegal soft drugs cultivation will never increase to such an extent that the soft drugs price will decrease significantly. Sketch the expected system behavior.
8. Make an extremely aggregated *causal loop diagram* that would allow you to explain the link between structure and behavior of this policy & system (the policy of the opponents of legalization from the point of view of the proponents of a further legalization) in about 30 seconds to politicians and laymen.
9. Describe this link between structure and behavior of this system in maximum two sentences.
10. List two important assumptions specific to the world view of the proponents of a further legalization (not shared by opponents).

Note that the opponents of legalization do not share this world view. The world views of both groups and the effectiveness of different policies in both world views is analyzed in (Pruyt 2009b).

2.14 Climate Change (Qualitative)

This case was written in early 2007 based on (Ford 1999, p92–96) and (Sterman and Booth Sweeney 2002; Fiddaman 2002; Houghton 2004; Pruyt 2007a).

Introduction

The climate –the average weather over a long period of time– is currently changing very rapidly compared to past changes, and it is expected to change even more rapidly/drastically in the future. This exceptional climate change is quite generally believed to be caused by the increasing concentrations of atmospheric greenhouse gases which absorb outgoing infrared radiation and therefore warm the atmosphere and the surface of the earth as a radiation blanket. The higher atmospheric concentrations since the beginning of industrialization are mainly the result of unprecedented greenhouse gas emissions –carbon dioxide (CO_2) and some other gases– related to human activities such as fossil fuel burning, land use changes, and cement production. This human induced greenhouse effect which reinforces the natural greenhouse effect is called anthropogenic climate change or global warming. Currently the CO_2 emitted remains on average between 100 and 200 years in the atmosphere before being taken up by oceanic (algae photosynthesis) processes and biological (green plants) processes[5], enhancing the greenhouse effect during its atmospheric lifetime, but indirectly influencing the climate for thousands of years. The CO_2 concentration continues to increase exponentially because of increasing annual emissions which were at the time of writing more than double the amount of CO_2 annually absorbed/recycled by natural processes. The natural absorption is only one of many complex natural feedback effects at play, reinforcing or balancing global warming, many of which are characterized by very long delays, many non-linear and possibly irreversible processes, and high degrees of uncertainty/risk.

The maximum global average temperature rise in order to avoid dangerous and irreversible climate change has recently been estimated at ±2°C, which corresponds to an atmospheric CO_2 equivalent (CO_2eq) concentration of 450ppm, which might be reached in little more than a decade... Avoiding dangerous and irreversible climate change therefore requires rapid and drastic reductions in the order of 60-80% of current emissions by 2050 and even 80-90% in the longer term. Reductions in the Western World need to be even more drastic if developing countries start emitting their fair share of CO2eq emissions. Anthropogenic climate change is thus a very complex, urgent, intergenerational/ intragenerational issue of major importance.

An important question is whether such drastic CO_2eq emission reductions are possible. The answer seems to be yes, but not immediately and not just like that: 'many technical, economic, political, cultural, social, behavioral and/or institutional barriers [...] prevent the full exploitation of the technological, economic and social opportunities of [...] mitigation options' (IPCC 2001a, p11). Drastic emission reductions require real gradual societal and technological transition processes, which are also characterized by inertia/delays, complex feedback effects and many uncertainties/risks. It is therefore impossible to look for an unambiguous optimal solution/policy. Global/individual action is required very urgently in many policy domains because of these very long societal/technical/natural delays.

In order to understand the climate change issue, decision makers need to understanding at least the basic biochemical/physical processes at play. CLDs are very useful to convey that message.

[5]With small temperature increases, the activity of these oceanic and terrestrial biological processes is assumed to increase.

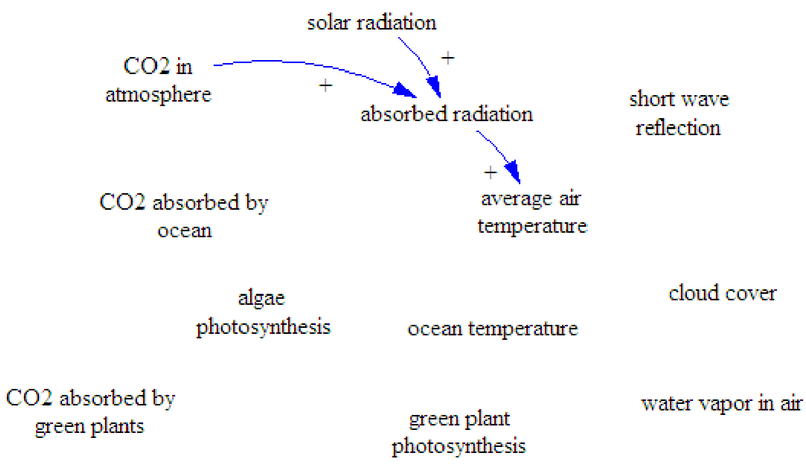


Figure 2.1: Causal Loop Diagram to be completed

> 1. Complete the CLD in Figure 2.1: add causal links, polarities, delays and analyze the feedback loops.

In the *causal loop diagram* above, water vapor in the air leads to short wave reflection, dampening the absorption of radiation. But water vapor is also another –even stronger but short-living– greenhouse gas, absorbing long wave radiation, reinforcing the absorption of radiation. This is known as the water vapor feedback effect: higher temperatures leads to more water vapor in the atmosphere, which has a very strong greenhouse effect.

> 2. Different effects involving the same variables should be split out as much as possible in CLDs. Add therefore another feedback loop to capture this effect.

Anthropogenic climate change might also activate other possible non-linear natural climate change effects. Potent(ial) feedback effects that need to be taken into account include:

- the melting of the permafrost which also reflects radiation and contains enormous amounts of methane (CH_4) and the slow release of methane with higher temperatures currently trapped in hydrate form.
- the reinforcing ice-albedo[6] feedback: less ice and snow cover leads to less reflection of incoming solar radiation which leads to more warming. This effect could be of the order of 20%.
- the weakening of the thermohaline ocean circulation[7].
- the reinforcing effect of respiration by microbes in soils.
- the predominantly reinforcing blanketing effect of high clouds and predominantly balancing reflectivity effect of low clouds, and the effects of aerosols.

[6] The albedo of an object is the reflectance of the object over all wave-lengths.

[7] The thermohaline circulation is a large-scale density driven circulation in the ocean caused by differences in temperature and salinity (Houghton 2004, p339) which transports enormous amounts of heat from the equator to the polar regions. The amount of heat transported this way to the north Atlantic Ocean is over 1000 terawatt (Houghton 2004, p95) equivalent to the output of one million large power plants.

3. Add these feedback loops too. Complete the CLD: add causal links, polarities, delays and analyze the feedback loops. What are your conclusions?

The biochemical cycle is even more complex and uncertain than outlined above. The future additional uptake by several feedback effects[8] balancing the increase in atmospheric CO_2 concentration is far from guaranteed because of the complex and uncertain interplay of many climate change feedbacks, some of which *balance* (slowing down or reducing) the increased emissions of greenhouse gases and hence global warming, and some of which *reinforce* the increased emissions of greenhouse gases and hence global warming. The balancing CO_2 fertilization feedback effect[9] might for example be countered by a reduction of growth and die-back of forests caused by too rapidly changing climatic conditions for species and ecosystems to adapt or migrate, whereas the balancing effect of the biological pump[10] might be reduced by the reinforcing plankton multiplier effect[11] which might both lead to a declining atmospheric removal rate with increasing temperatures and might even switch one day 'from being part of the solution to being part of the problem' (European Environmental Agency 2005, p82).

4. Extend your CLD to include the main points of this additional information.

So, although much is known and certain, many direct and indirect effects related to greenhouse gas sources and sinks, aerosols[12], clouds, oceans and ice-sheets feedbacks, the timing and magnitude of regionally varying patterns of climate change, and so on, remain scientifically uncertain or unknown, which makes that the outcomes of the models dealing with these effects are also uncertain.

And on top of such 'natural' uncertainties come many other uncertainties such as social-economic-energetic uncertainties related to population, economic and energetic development paths and pressures. All these uncertainties make any deterministic prediction worthless. Scenarios, simulation models, projections and ranges are therefore mostly developed in this domain, instead of deterministic optimization models and point predictions. Such projections are mostly generated by means of very complex simulation models (detailed physical-chemical Atmosphere-Ocean General Circulation Models and broader but less detailed Integrated Assessment models). These 'climate models do a reasonably good job of capturing the essence of the large-scale aspects of the current climate and its considerable natural variability on time scales ranging from 1 day to decades' (Mahlman 1997).

5. Make your own CLD about the human aspects (causes and effects) of climate change.
6. Could both CLDs –the bio-chemical and the human-societal ones– be merged without losing transparency and clarity? What are your conclusions both methodologically and applied?

An advantage of CLDs is that it helps to capture feedback loop effects, but there are also some disadvantages related to CLDs. Stock-flow diagrams are for example much better tools to visualize the (closed) carbon cycle.

[8] See (Stocker et al. 2001).

[9] higher CO_2 concentrations $\Rightarrow$ increased plant growth

[10] The biological pump is the 'process whereby carbon dioxide in the atmosphere is dissolved in sea water where it is used for photosynthesis by phytoplankton which are eaten by zooplankton. The remains of these microscopic organisms sink to the ocean bed, thus removing the carbon from the carbon cycle for hundreds, thousands or millions of years' (Houghton 2004, p333).

[11] Less cooling of the upper layer of the ocean reduces the depth of the mixed layer which might lead to less plankton growth and hence a weaker biological pump.

[12] direct effect: sulphate particles (cooling), aerosols (cooling), black carbon from fossil fuel burning (warming), organic carbon from fossil fuel burning (cooling), mineral dust (cooling or warming); indirect effect: more water drops (no effect or cooling) and decreasing precipitation (unknown effect)

Now, on geologic or intergenerational time scales, carbon is not destroyed but dynamically redistributed between carbon reservoirs. This redistribution cycle is called the carbon cycle. The atmospheric 'reservoir' currently contains about 760 gigatonnes carbon (GtC), but the biosphere and ocean reservoirs contain much larger quantities of carbon (fossil fuel reserves not included), some 39000 GtC in the oceans and some 2500 GtC in biomass/soils. The amount of carbon stored in the form of fossil fuels are estimated to amount to some 1549 GtC of reserves[13], some 3410 GtC of resources[14] and some 16521 GtC additional occurrences.

7. Make an elementary stock-flow diagram of the carbon cycle.

For several thousands of years before the beginning of industrialization around 1750, the atmospheric CO_2 concentration was 280 ± 10ppm (Prentice et al. 2001), and '[a]t no time in the past 650000 years is there evidence for levels of carbon dioxide or methane significantly higher than values just before the Industrial Revolution' (Brook 2005)[15] and likely not in the past 20 million years (IPCC 2001b). Since then, the atmospheric CO_2 concentration has continuously risen to reach about 375ppm in the year 2005. The anthropogenic emissions of the other greenhouse gases such as CH_4, N_2O and fluorocarbons have increased their respective atmospheric concentrations such that their warming impact currently corresponds to a further 50ppm of CO_2eq (European Environmental Agency 2005, p63). Currently the atmospheric concentration of carbon rises each year by about 1.5ppm on average, which is equivalent to an additional 3.3GtC per year (Houghton 2004, p31). This amount corresponds to about 45% of the amount of anthropogenic carbon emitted into the atmosphere each year most of all by the burning of fossil fuels and to a lesser extent the production of cement (6.3 ± 0.4GtC/yr between 1990 and 1998 –of which about 160MtC/yr for cement production– which is about 75% of the total anthropogenic CO_2 emissions) and the emissions due to land-use changes (about 25% of the total anthropogenic CO_2 emissions with tropical deforestation of about 1 to 2GtC/yr), because currently, about 55% of the annual emissions are taken up additionally by the oceans through dissolution (the so-called *solubility pump*) and biological processes (the so-called *biological pump*), and by land biota (through increased plant growth).

The net runoff sedimentation from the land to the oceans is about 0.4 Gt/yr. The air/ocean exchange is about 90 Gt/yr with a net ocean uptake of about 2.3 ± 0.8 Gt/yr. The air/land exchange is about 60Gt/yr with a net land uptake of about 0.7 ± 1 Gt/yr.

8. Complete the SFD with this additional information.
9. Analyze the carbon cycle. Analyze the SFD. What are your conclusions?
10. What are your main applied and methodological conclusions?

[13] identified and measured as economically and technically recoverable with current technologies and prices

[14] occurrences with less certain geological and/or economic characteristics, but which are considered potentially recoverable with foreseeable technological and economic developments

[15] See also (Siegenthaler et al. 2005) and (Spahni et al. 2005)

2.15 Additional Exercises in Online Repository

All remaining cases and exercises (except for technical exercises) require SFDs, CLDs, sector diagrams, and/or bulls eye diagrams to be drawn. Additionally, another 21 exercises are available online:

- |⊕| Add. ex. 1
- |⊕| Add. ex. 2
- |⊕| Add. ex. 3
- |⊕| Add. ex. 4
- |⊕| Add. ex. 5
- |⊕| Add. ex. 6
- |⊕| Add. ex. 7
- |⊕| Add. ex. 8
- |⊕| Add. ex. 9
- |⊕| Add. ex. 10
- |⊕| Add. ex. 11
- |⊕| Add. ex. 12
- |⊕| Add. ex. 13
- |⊕| Add. ex. 14
- |⊕| Add. ex. 15
- |⊕| Add. ex. 16
- |⊕| Add. ex. 17
- |⊕| Add. ex. 18
- |⊕| Add. ex. 19
- |⊕| Add. ex. 20
- |⊕| Add. ex. 21

Chapter 3

MCQs Part I

'Man begreift nur, was man selber machen kann, und man fasst nur, was man selbst hervorbringen kann.' Johann Wolfgang von Goethe

Which of the following statements are right and which are wrong?

1. In SD, it is assumed that exogenous data largely determines system behavior.
2. The presence of a negative feedback loop means that a system always shows goal-oriented behavior.
3. The polarity of a feedback loop is negative if it contains exactly 1 negative link polarity.
4. System Dynamicists often use soft variables to model ill-known quantitative relationships.
5. Multiple CLDs may be consistent with one and the same SFD.
6. CLDs are good devices to communicate the feedback loop structure of complex systems.
7. Black-box models with better predictive precision are always better than insight generating glass-box models.
8. Precise reproduction of real-world system behavior is an important property of SD models.
9. Transparency is one of the most important characteristics of good SD models.
10. The desired level of aggregation of a model depends on the goal or function of the model.
11. SD models ought to comprise cognitive motives and political influences if they are important.
12. An outflow leaving a stock variable in a SFD corresponds in a detailed CLD to a negative causal link from the outflow variable to the stock variable.
13. For material-flow systems, CLDs are better representations than SFDs because they visualize how the material flows through feedback loops.
14. CLDs can be used to map and visualize multiple perspectives or intractable messes as long as causal assumptions can be elicited.
15. Complex issues are often characterized by more than one archetype.

Multiple Choice Question 1

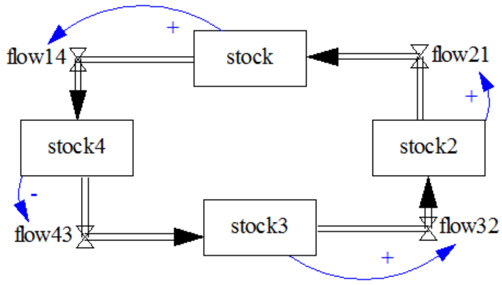
How many feedback loops (of each kind) are there in the SFD on the right? Hint: draw the CLD.

a. 3 negative loops and 1 positive loop

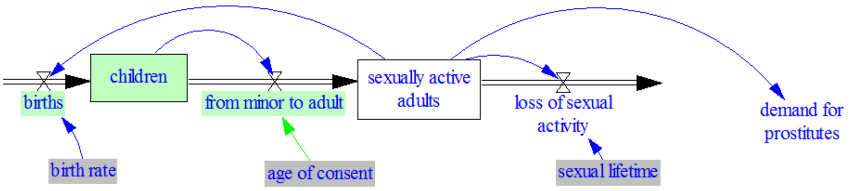
b. 1 negative loop and 3 positive loops

c. 2 negative loop and 3 positive loops

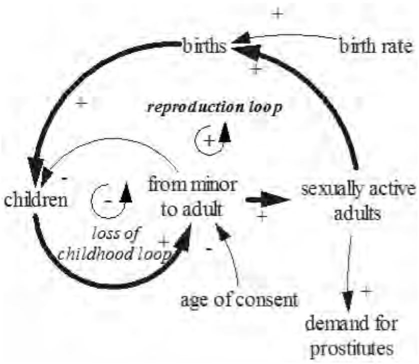
d. none of the previous answers is correct



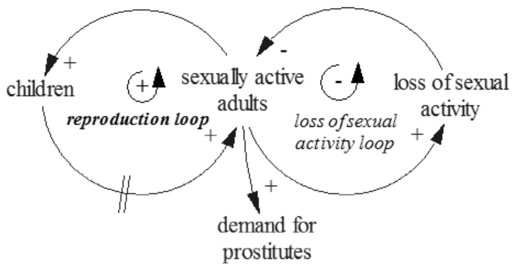
Multiple Choice Question 2



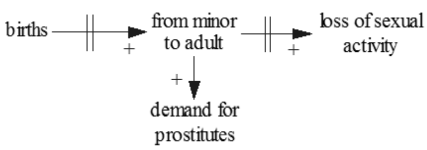
Consider the SFD of the population submodel of a model related to *prostitution and human trafficking* displayed above. Which of the following CLDs is the best *aggregated* CLD corresponding to this submodel?



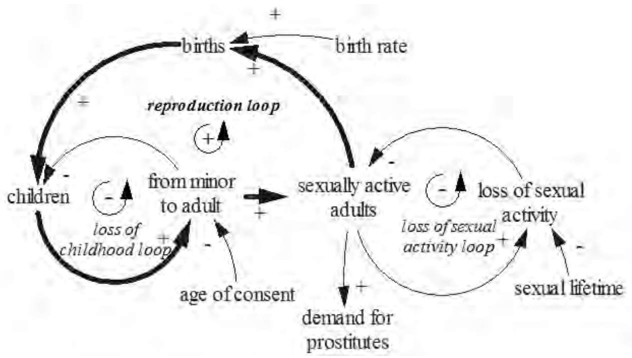
(a)



(b)

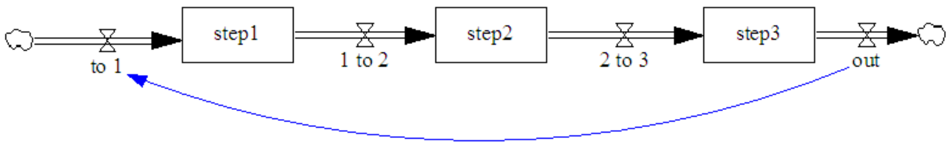


(c)

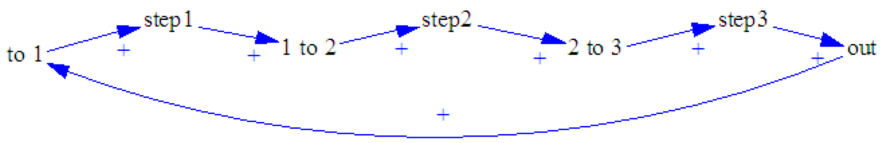


(d)

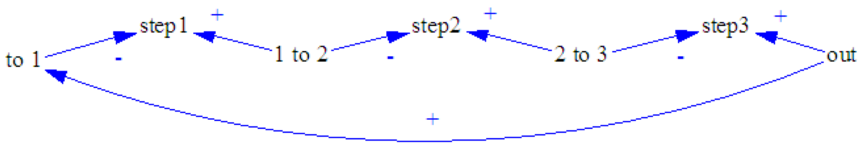
Multiple Choice Question 3



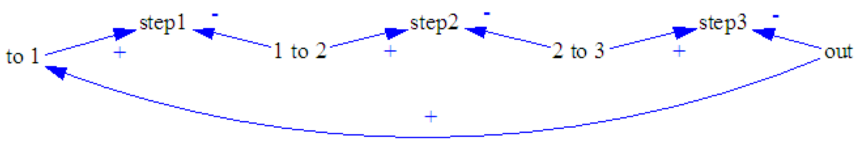
Which of the following CLDs corresponds best to the SFD displayed above?



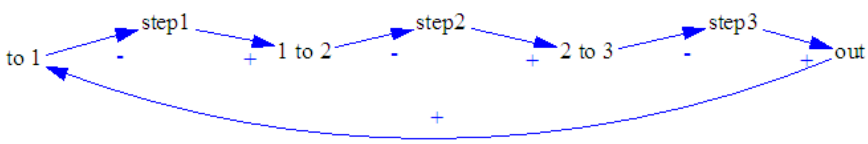
(a)



(b)



(c)



(d)

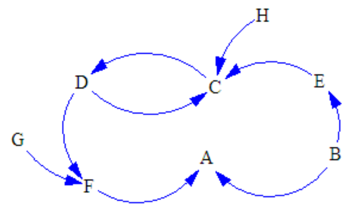
Multiple Choice Question 4

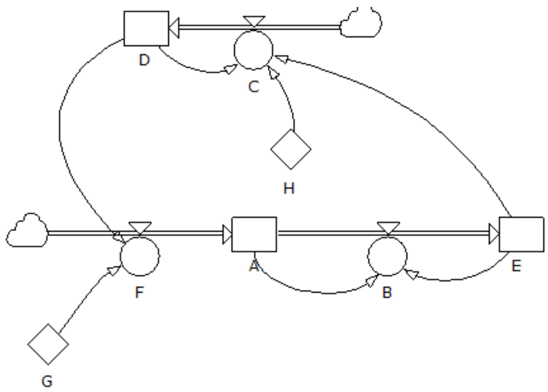
The unit of time in a model concerning the large-scale introduction of electrical vehicles (EVs) is expressed in *month*. The production capacity of a company that produces EVs is modeled as a stock variable with units expressed in $EV/month$. The enormous growth of the expected demand for new EVs leads to an increase of the production capacity of EVs. What unit needs to be used for this increase of the production capacity?

a. $\frac{EV * month}{1}$; b. $\frac{EV}{month}$; c. $(\frac{EV}{month})^2$; d. $\frac{EV}{month^2}$.

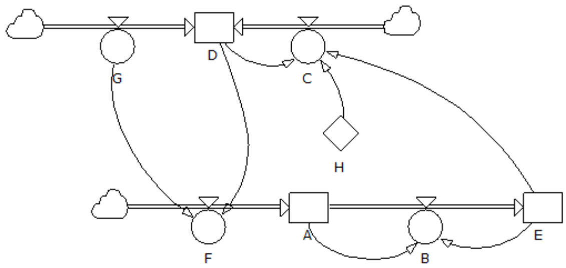
Multiple Choice Question 5

Consider the CLD (without loop polarities and link polarities) on the right. Which of the SFDs displayed below is compatible with this CLD?

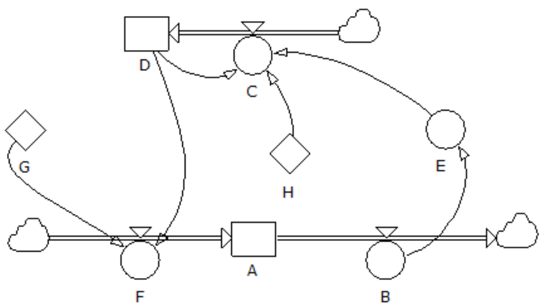




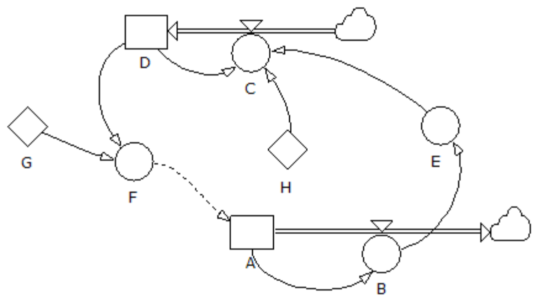
(a)



(b)



(c)



(d)

Multiple Choice Question 6

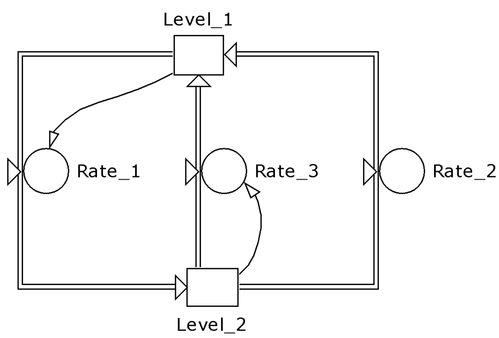
How many feedback loops (of each kind) are there in the SFD on the right? Hint: draw the CLD.

a. 0 feedback loop

b. 2 feedback loops

c. 4 feedback loops

d. None of the previous answers is correct



Multiple Choice Question 7

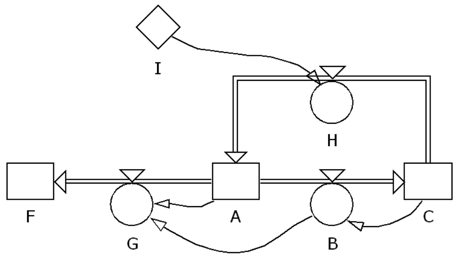
How many feedback loops (of each kind) are there in SFD on the right? Hint: draw the CLD.

a. 1 feedback loop

b. 2 feedback loops

c. 3 feedback loops

d. None of the previous answers is correct



Multiple Choice Question 8

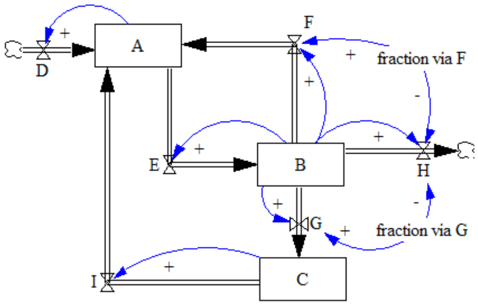
How many feedback loops are there in the SFD on the right? Hint: draw the CLD.

a. 6 feedback loops

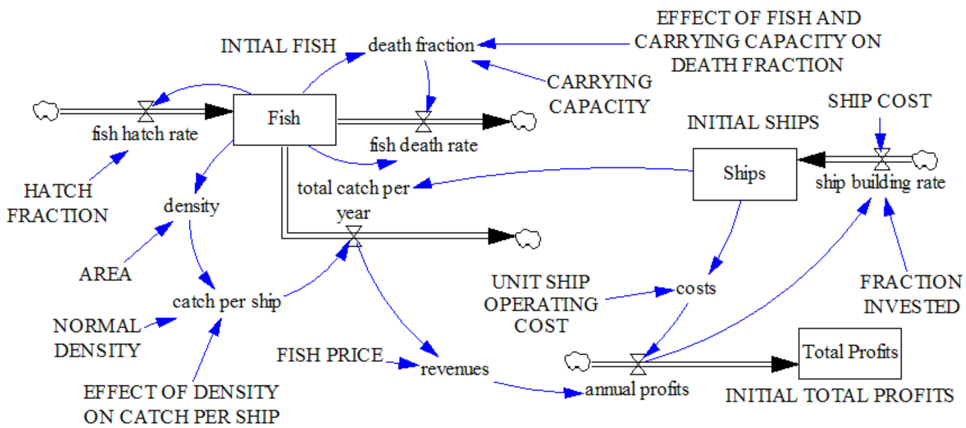
b. 7 feedback loops

c. 8 feedback loops

d. none of the previous answers is correct



Multiple Choice Question 9



How many feedback loops are there in the SFD displayed above?

a. 5 feedback loops b. 6 feedback loops c. 7 feedback loops d. None of the answers is correct.

Multiple Choice Question 10

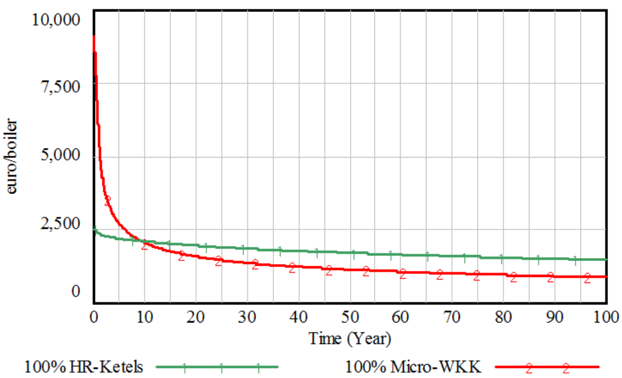
At first sight, it seems as though the crisis in the euro zone hurts Germany. At closer inspection, that may not be entirely true: as the value of the German currency depends –since the introduction of the euro– in part on the (poor) performance of the other euro-countries, it does not increase as much as the increase of the German exports to non-euro countries which makes the German economy ever more competitive. The doubling of the German export since 1999 is mainly due to the dampening effect on the currency of the Euro-Mediterranean countries: German exports to the euro zone were 55% higher in 2011 than in 2000 but have stagnated since 2007. However, exports to the 'BRIC' countries have increased fivefold in the same period... German exports to China even grew at an average 17.7% per year between 1996 and 2011. Euro zone-wide this export boom must have been compensated by other countries with decreasing exports or deteriorating capital balances.

Hence, the German export miracle protects the euro from a drastic decline which would be desirable for weakly performing euro countries, making them even less competitive. In other words, higher Germany exports lead to a reduction in competitiveness of weakly performing euro-countries, and conversely, the worse the performance of the weaker euro-countries is, the better German exports will be. Which of the following archetypes matches this situation best?

a. Success to the successful b. Growth & underinvestment c. Fixes that fail d. Eroding goals

Multiple Choice Question 11

Suppose you must decide, as the manager of a large Dutch housing corporation, about the types of boilers that will be installed by the housing corporation over the next 100 years. Suppose you can only choose from two types of boilers: High Efficiency Boilers (HE-boilers) or micro-CHP installations. Micro-CHP installations are still very expensive to buy, €9100 per unit (one unit corresponds to one boiler), but recent cost reductions have been spectacular. Experience with micro-CHP so far, 20000 micro-CHP units in total, shows that the '*progress ratio*' equals 0.75. HE-boilers nowadays only cost €2500 because of years of experience (equivalent to 7.5 million installed HE-boilers), and are characterized by a '*progress ratio*' of 0.75 too.



The graph on the left shows a perfect prediction of the cost reduction of both types of boilers if all 14 million boilers to be installed in the next 100 years by your housing corporation are either of the micro-CHP type (red curve) or of the HE-boiler type (green curve). The red curve is much steeper because micro-CHP is new and there is still much room for descending the learning curve, resulting in strongly decreasing marginal costs.

The 'learning curve effect' is the relationship between production costs and the cumulative production over time: the *progress ratio* provides insight into the cost reduction for each doubling of cumulative production. So, if a boiler has a progress ratio of 75% and it costs €10000 to produce the 1000th unit, then it will cost €7500 to produce the 2000th unit.

The red (green) curve in the graph is thus the perfectly predicted production cost per micro-CHP device (HE-boiler) if you install 100% in micro-CHP (HE-boilers) over the next 100 years. Note: the surfaces between the curves provide insight into the cumulative cost advantages of one technology over another.

Suppose that you are the only one installing boilers (hence, the destiny of your housing corporation is fully under control), and the future is perfectly foreseeable (no surprises, perfect foresight), and discounting is not required (€1 now is worth as much as €1 in 100 years and at any time in between), which of the following strategies then minimizes the total investment costs over the full 100 years (or 14 million boilers)?

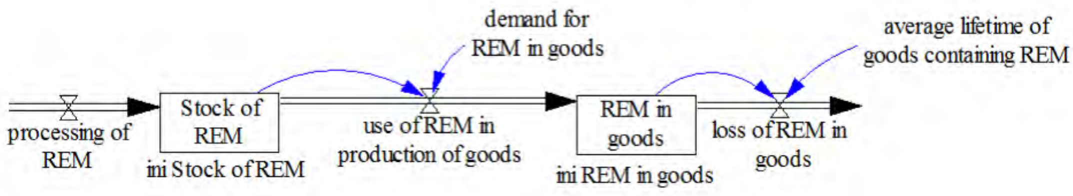
a. 100% in HE-boilers: HE-boilers are cheaper and will always be cheaper;

b. 100% in micro-CHP: the surface of the area to the right of the intersection point is much larger than the surface of the area to the left;

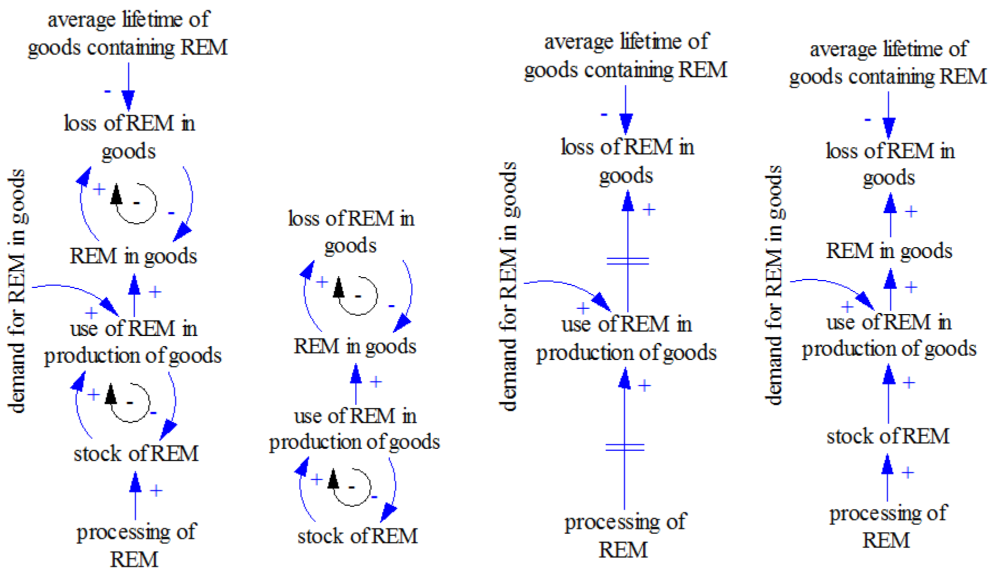
c. 100% HE-boilers for the first 10 years and 100% micro-CHP afterwards in order to take advantage of the lowest cost over the full 100 years;

d. not 100% in HE-boilers nor 100% in micro-CHP, but somewhere in between (which could be calculated), in order to take full advantage of the evolution of both technologies.

Multiple Choice Question 12



Consider the sub-model with regard to rare earth metals displayed above. Which of the following corresponding CLDs is the most appropriate *aggregate* CLD?



(a) (b) (c) (d)

Multiple Choice Question 13

Suppose there is a positive causal link from variable x to variable y, i.e. $x \overset{\rightarrow}{+} y$. Someone tells you that y increases when x increases, but also when x decreases. Which of the following statements is true?

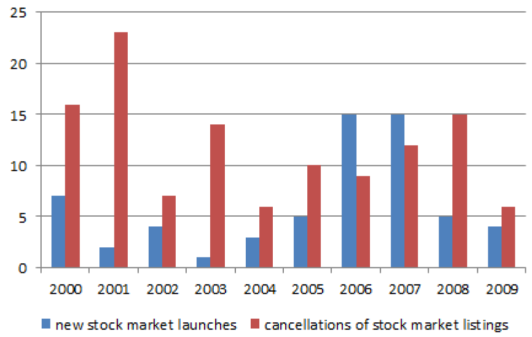
a. What that person says must be wrong.

b. y must be a lookup variable.

c. x must be a flow variable.

d. y must be an auxiliary variable.

Multiple Choice Question 14



The stock exchanges of Amsterdam, Brussels and Paris announced in the year 2000 that they would merge into Euronext. In 2007, Euronext merged with the New York Stock Exchange. The graph on the left shows what happened in the meantime in terms of the annual number of IPOs and annual cancelations of stock market listings in Amsterdam, also called the Damrak. Which of the following statements is correct?

a. In **2000** there were more companies listed on the Damrak than in subsequent years.

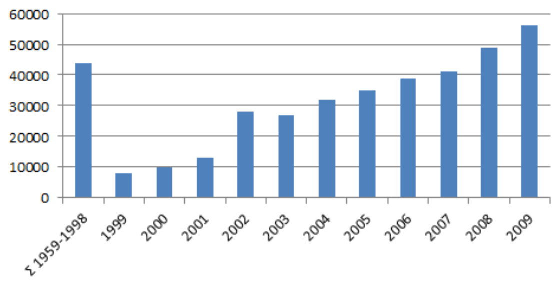
b. In the year **2007** there were more companies listed on the Damrak than in previous years (from 2000 on) and the following years (until the end of 2009).

c. The year **2001** was the absolute low point: In 2001, the fewest companies were listed on the Damrak over the period 2000 to 2009.

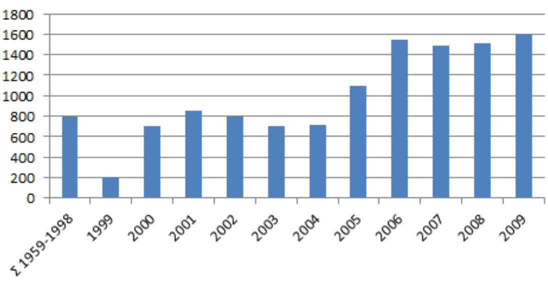
d. Either none of the above statements is correct, or all of the above statements are correct.

Multiple Choice Question 15

The European Court of Human Rights is an international court established by the European Convention on Human Rights which it needs to supervise. In spite of the fact that less than 8% of the complaints are judged admissible, i.e. the court assesses the content in less than 8% of the cases, and half of these remaining cases are in fact repetitive cases (similar to cases treated previously), the Court has a considerable backlog with respect to complaints of citizens who believe their human rights have been violated. Given are the graphs of the total number of new complaints and the number of judgments summed until 1998 and for each year between 1999 and 2009. Given the two graphs below: How big was the backlog of pending cases at the beginning of 2010 knowing that $2/3^{rd}$ of all new complaints is immediately judged inadmissible (and therefore removed from the list of pending cases)?



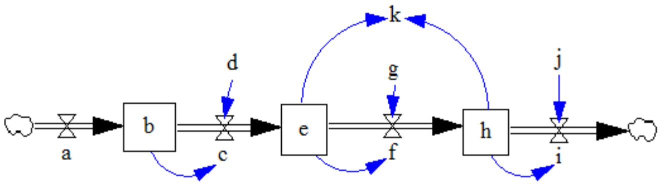
(a) New complaints per year



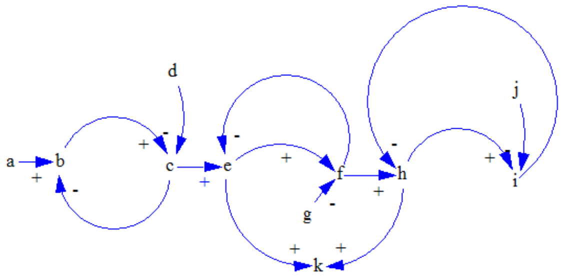
(b) Judgments per year

a. 11800 cases; b. 18600 cases; c. 119300 cases; d. 380000 cases.

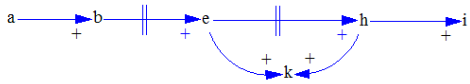
Multiple Choice Question 16



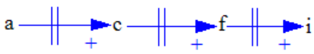
Consider the SFD above. Suppose that variable k is not important. Which of the following (incomplete) CLDs is the most appropriate ***highly aggregated*** CLD corresponding to the SFD above?



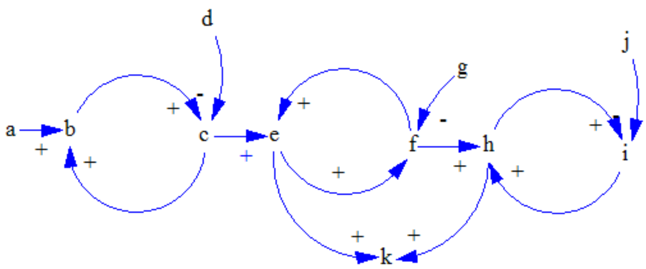
(a)



(b)

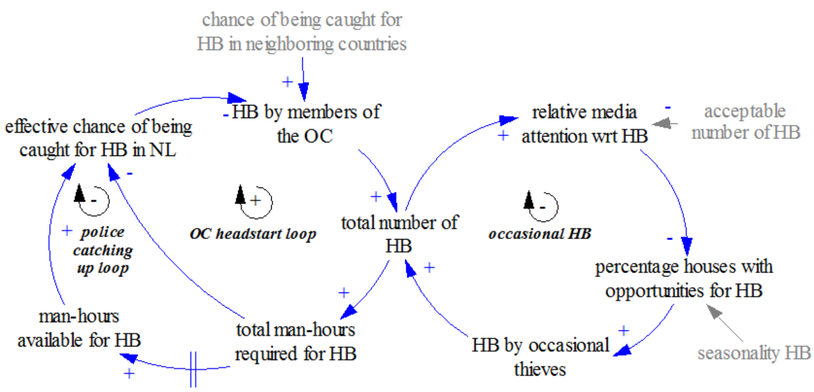


(c)



(d)

Multiple Choice Question 17



The CLD displayed above summarizes the structure of a model on burglaries (HB stands for Burglaries in Houses as opposed to Burglaries in shops and businesses, and OC stands for Organized Crime). Which of the following statements about possible behaviors of the model/system cannot be explained by this causal loop diagram:

a. The number of burglaries will go down if the acceptable number of burglaries goes down.

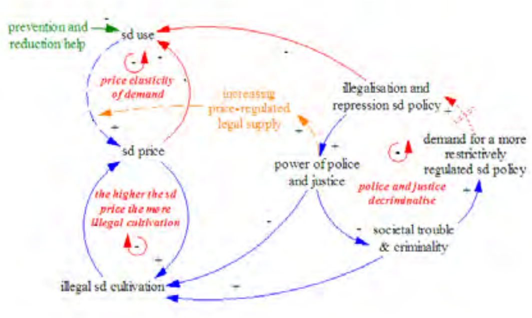
b. If the chance of getting caught in neighboring countries goes down, so will the burglaries committed in the Netherlands, resulting in a fewer opportunistic burglaries since there will be fewer opportunities due to increased vigilance through media attention.

c. Organized crime has a strong interest in committing burglaries during peaks of burglaries by opportunistic burglars. The chance of being caught is lowest during these peaks since the police is likely to be understaffed for these peaks.

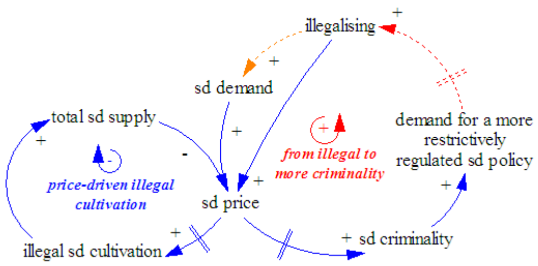
d. Opportunity burglars have good reasons to commit burglaries when the opportunity is highest and vigilance is lowest, which is seasonal and dependent on media attention given to many or spectacular burglaries.

Multiple Choice Question 18

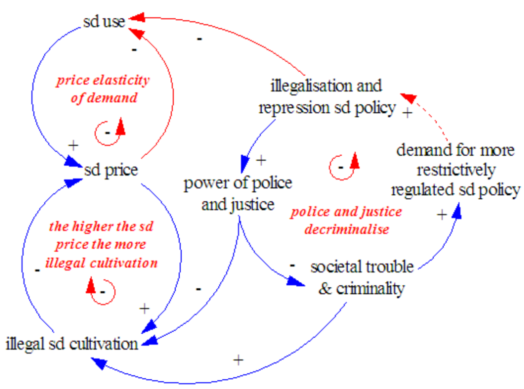
The CLDs below summarize perspectives on soft drugs policy. Which of the following CLDs has not been drafted from the point of view of proponents of a more tolerant soft drugs policy with regard to their own perspective or to the perspective of their opponents? In other words: which diagram (not policy!) does not make any sense to proponents of a more tolerant soft drugs policy?



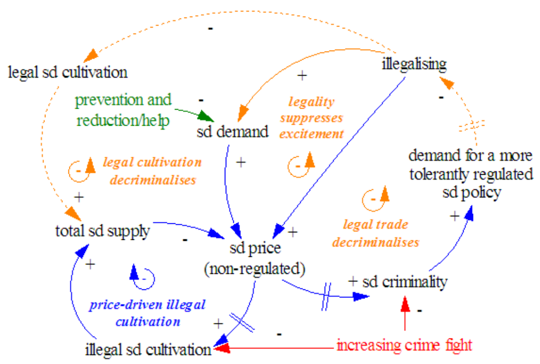
(a)



(b)

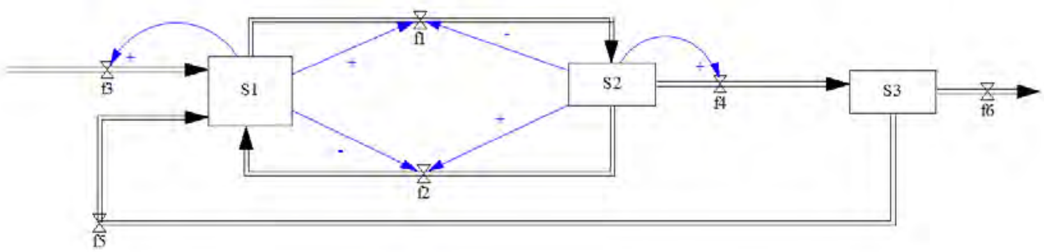


(c)



(d)

Multiple Choice Question 19



How many feedback loops are there in the stock-flow diagram displayed above?

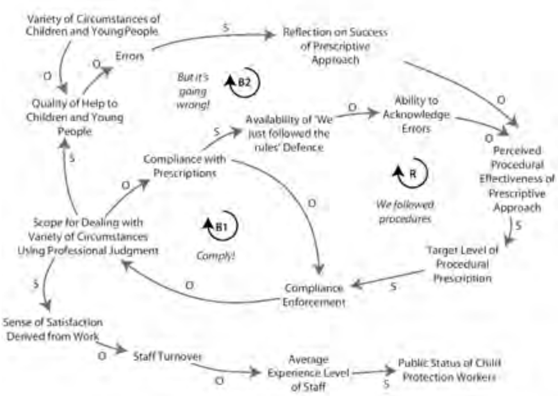
a. 2 feedback loops: 1 ⊕ and 1 ⊖

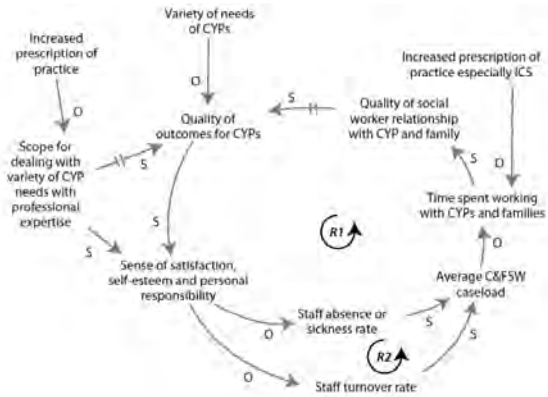
b. 6 feedback loops: 1 ⊕ and 5 ⊖

c. 7 feedback loops: 2 ⊕ and 5 ⊖

d. None of the previous answers is correct

Multiple Choice Question 20





Both CLDs displayed above are taken from reports that are part of the Munro Review of child protection in the UK. Systems Theory and qualitative System Dynamics were used in this review to examine what conditions have caused the system to become over-bureaucratized and focused on compliance instead of an expertise-centered system focused on the safety and welfare of children and young persons (CYPs). Based on an improved understanding of the undesirable evolution of the system and root causes, the final Review Report formulates proposals for reform in order to create the necessary conditions for professionals to be able to make the best judgments about the type and amount of help to be given to children and young people, as well as their families. The CLD on the left is a preliminary CLD and the diagram on the right is a simplified CLD communicated in the final review. What is the most important difference between these CLDs?

a. All loops in the CLD on the left are clockwise and all loops in the CLD on the right are counter-clockwise.

b. The main dynamic hypothesis in the CLD on the right relates to endogenous HR dynamics whereas the main dynamic hypothesis in the CLD on the left relates to the organizational ability to acknowledge errors and reflect on the success of the prescriptive approach.

c. The dominant balancing loops in the CLD on the left cause the system to be pulled into more and more prescription, whereas the reinforcing loops in the CLD on the right cause the system to be pushed away from less prescriptive approaches.

d. The CLD on the left consists of 3 feedback loops and the CLD on the right only consists of 2 feedback loops.

Link to the answers to the 15 right/wrong questions & 20 multiple choice questions in this chapter.

Links to web based quizzes: | | | |

Chapter 4

Recap I – Lessons to be Learned

'We do not learn from experience ... we learn from reflecting on experience.' John Dewey

Case-Based Lessons from Part I

2.1 The main lesson from the Competition in the Faculty exercise is that:

- Feedback loop systems should be analyzed, not loops in isolation: dominance and dominance shifts between loops drive system behavior.

2.2 The main lessons from the Assets and Customer Management exercise are that:

- Reference modes are helpful to identify loops that are minimally required;
- Systems are often implicitly regulated by undesirable control loops –the system in this exercise is regulated through customer dissatisfaction;
- Implicit policy loops with undesirable effects may be alleviated by means of purposefully designed closed-loop policies.

2.3 The main lessons from the Resource Dynamics exercise are that:

- For material flow subsystems, SFDs are more useful than detailed CLDs;
- For material flow subsystems, aggregate CLDs are more useful than detailed CLDs.

2.5 The main lessons from the COLs & MOOCs exercise are that:

- Breaking limiting feedback loops may lead to fundamentally different dynamics;
- The higher education system will radically change over the next 15 years.

2.4 The main lessons from the Overly Prescriptive Approach to Health and Social Work exercise are that:

- Even well-intended closed-loop policies may, in combination with 'external' factors / conditions / realities, drive systems towards undesirable states and/or may generate undesirable (unintended) consequences;
- Relatively simple and small CLDs may –if accompanied by a brief diagrammatic explanation– be powerful means to communicate 'ripple effects' to parties involved as well as to policymakers.

2.6 The main lessons from the Fish and Ships exercise are that:

- CLDs and/or SFDs may, even without simulation, help to identify structures that generate problematic behavior;
- Issues may be caused / trapped by underlying structures;
- Fisheries problems are typical examples of the tragedy of the commons archetype.

2.7 The main lessons from the Housing Policies exercise are that:

- Systems often cause their own undesirable behavior;
- Oscillations are often generated in opaque systems characterized by important delays by many individuals without systemic perspective that have the same incentive at about the same moment in time to take advantage of opportunities caused by these delays.

2.8 The main lessons from the Student Passing Policy exercise are that:

- CLDs and ADs are complementary: ADs may be more useful to make the general point to those that do not (need to) know the mechanisms and details, whereas CLD, being more specific, may be more appealing to those that know the mechanisms and details.
- Multiple CLDs could be drawn regarding the same issue, possibly shedding different lights on the same issue;
- It takes recognition, understanding, strength and determination to resist the pressure of eroding goals. . .

2.9 The main lessons from Fighting High Impact Crime exercise are that:

- Reactive actions may reinforce seasonal phenomena;
- Well thought-out proactive actions may counter seasonal phenomena;
- Even good policies are likely to meet policy resistance due to balancing feedback effects in the system.

2.10 The main lessons from the Conflict in the Middle East exercise are that:

- Even intractable issues can be mapped using CLDs;
- CLD may help to identify critical mechanisms;
- CLD and IDs are useful tools to map (re)actions of parties that cause the system to behave the way it does.

$ 2.11 The main lessons from the Bank Runs exercise are that:

- Bank runs can be caused by multiple underlying mechanisms;
- Integrating all underlying mechanisms in the same CLD allows to point at knock-on effects.

2.12 The main lessons from the Entrepreneurs & Transitions exercise are that:

- CLDs and IDs can be used to map the key mechanisms that are required for transitions and those that could keep transitions from happening.
- Even intrinsically motivated entrepreneurs may need help, but help should not be given to entrepreneurs that are not intrinsically motivated;
- Technologies developed by entrepreneurs need to survive the valley of death before entering the technological battle field.

2.13 The main lessons from the Soft Drugs case are that:

- Different CLDs are needed to visualize opposing worldviews;

- CLDs may be useful to show that policies that are acceptable in one world-view may not hold in opposing worldviews.
- CLDs are useful tools to analyze the fit between worldview and closed-loop policy;
- Aggregating CLDs is an art. Communicating about complex systems and dynamics, and heir causes and effects, is difficult and time consuming.

♻ 2.14 The main lessons from the Qualitative Climate Change case are that:

- For typical stock-flow problems, SFDs are more useful than CLDs;
- For typical feedback loop problems, CLDs are more useful than SFDs;
- For mixed stock-flow feedback loop problems, hybrid diagrams are most useful.

Link to the feedback video related to all WARM-UP exercises.

Part II

RUN-UP

Chapter 5

Elementary System Dynamics Modeling

'Our social systems are far more complex and harder to understand than our technological systems. Why, then, do we not use the same approach of making models of social systems and conducting laboratory experiments on those models before we try new laws and government programs in real life? The answer is often stated that our knowledge of social systems is insufficient for constructing useful models. But what justification can there be for the apparent assumption that we do not know enough to construct models but believe we do know enough to directly design new social systems by passing laws and starting new social programs? I am suggesting that we do indeed know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase. But I am confident, and substantial supporting evidence is beginning to accumulate, that the proper use of models of social systems can lead to far better systems, and to laws and programs that are far more effective than those created in the past.' (Forrester 1971, p126)

5.1 Elementary Model Building

As argued in chapter 1, SD is an iterative method for modeling –using mental models and specific structural elements (positive and negative feedback loops and causally linked stock/flow/delay structures), hard and soft variables, and logical parameter estimates– and simulating the dynamic behavior of problem/client-centered models to study, explain and/or manage the complex dynamic behavior of aggregate social-technical systems in order to dissolve problematic aspects of complex issues. Let us focus now on some of the building blocks in view of building small and simple models.

The Constitutive Elements

Stocks

Stocks are state variables, i.e. they are the memory of the system and of each individual feedback loop. At least one stock –or a delay which consists of at least one stock– is needed in each feedback loop since equations in a loop need to be calculated in each numeric integration step from starting points or system memories. Stocks start from an initial value but are, during a simulation run, only affected by their inflows and outflows: they can be increased by increasing their inflows as well as by decreasing their outflows, and they can be decreased by decreasing their inflows as well as by increasing their outflows (Meadows 2009, p22). Stock variables are thus defined by their inflows, outflows, and initial values. A stock variable is in fact the accumulation of its inflows minus its outflows over time, starting from its initial value. Mathematically speaking, stocks are thus integral equations: the stock variable x in Figure 5.1 is equal to the amount in the stock x_0 at t_0 plus the integral over the difference of the inflow(s) ax and outflow(s) bx over the time interval considered:

$$x = x_0 + \int_{t_0}^{t} (+ax - bx)\ dt$$

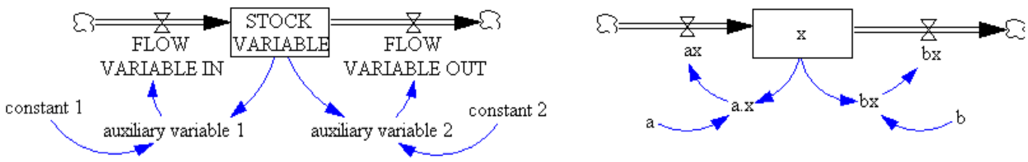


Figure 5.1: A basic stock/flow diagram with a stock, a flow, an auxiliary variable and a constant

The behavior of stock variables differs from the behavior of other flow and auxiliary variables precisely due to the fact that they are integral equations. They generally change slowly, even when their inflows or outflows change heavily or abruptly. Stocks thus buffer and delay. They could consequently be used as shock absorbers (Meadows 2009, p23) both to the inflow side and to the outflow side: stocks allow inflows and outflows to be independent, decoupled and temporarily out of balance with each other (Meadows 2009, p24).

The number of independent stocks (and delays) determines the order of the system. Endogenous oscillations require at least a second order system. Hence, systems with just 1 stock or delay cannot oscillate endogenously.

Flows

Only flows that enter or leave a stock variable affect it during simulation. Although these flows are preferably labeled and visualized either as inflows or as outflows, they can also –unless protected for example with a max(. . . ,0) or softmax function (see chapter 9)– become negative, thus turning an outflow into an inflow and vice versa. Flows can also connect two stock variables, flowing out of a first stock and flowing into a second stock. Since a stock variable corresponds to the integral of all its inflows and outflows, the inverse is also true: the net flow, i.e. the sum of all flows connected to a stock, describes the state changes of the stock over time. That is, the net flow corresponds to a differential equation in spite of the fact that it is not written as a differential equation in the equation editor. In fact, a normal equation must be specified for each flow variable. Following flow equations are often used:

1. $flow = (variable - stock)/constant$. This is a classic *flow* proportional to a deficit involving the corresponding *stock*. The *variable* could for example be a desired level that is aimed for or information that is smoothed. And the *constant* could for example be the smoothing time.

2. $flow = coefficient * stock$. This is a *flow* proportional to the corresponding *stock*. The *coefficient* could for example be $1/average\ residence\ time$ in the stock.

3. $flow = normal\ flow + effect$. This is an additive *flow* independent from the corresponding *stock*. Note that the *normal flow* and the *effect* have the same units as the *flow*.

4. $flow = normalflow * effect$. This is a multiplicative *flow* independent from the corresponding *stock*. Note that the *normal flow* has the same units as the *flow* and that the multiplicative *effect* must be dimensionless. This equation is often used for percentage changes and/or when it should be possible to shut the flow down ($coefficient = 0$).

Flow equations are not limited to these 'common' flow equations. Special functions such as the ones discussed in chapter 9 are commonly used in flow equations too. Be careful though with complicated equations and net flows, especially in case of multiplicative effects. In fact, it is wise to work as little as possible with net flows. Also avoid causal links between flows, except in case of co-flows and delay functions using stock-flow structures (see chapter 9). Finally, all flows into and out of the same stock variable need to have the same units.

Auxiliaries

Auxiliary variables help to keep flow equations simple and understandable. Moreover, use of auxiliary variables which closely correspond to real world system elements allows one to keep models understandable. Auxiliaries require equations to be specified, often with special functions such as the ones in chapter 9. They are called hard variables if the relations are well known and completely determined, else they are called soft variables. System dynamicists believe it is better to include soft variables than to omit them. For including them using assumptions, allows one to explore the effects of assumptions, and hence, generate insights and understanding. Omitting them is equivalent to 'saying they have zero effect – probably the only value that is known to be wrong!' (Forrester 1961, p57).

Parameters and Constants

Although there are only few real constants, like real physical constants, there are many variables that can be assumed to remain about constant over a simulation run for a particular model and for a particular time horizon[1]. Examples are conversion factors (e.g. 'productivity'), reference values (e.g. the 'normal delivery delay'), average lifetimes or residence times, adjustment times, et cetera. They can be included in a model by means of exogenous parameters if they are not or hardly influenced by other model variables.

Their values can be distilled from real data and from knowledge about processes. However, mostly they are uncertain or inaccurate as are models and systems. Hence, it is recommended to test the sensitivity of the model to small and even large parameter changes (see chapter 13). The same is true for initial values. They are mostly inaccurate or uncertain and require –especially for highly non-linear/chaotic models– sensitivity and uncertainty analyses.

Elementary Model Building and Model Specification

Stock variables are usually very important variables. Hence, it makes sense to first model a stock variable or a set of stock variables, then connect inflows and outflows that influence this/these stock variable(s), as well as separately modeled initial value(s). Subsequently add auxiliaries and parameters/constants that influence the flows, and connect them by means of causal links. Simultaneously or subsequently specify the equations. And then simulate and test the first iteration model (see next two subsections).

It is best to build models iteratively: start with a very small model, and gradually extend it. Ways to keep this iterative way of modeling manageable are to: (i) model/simulate/test one subsystem at a time and gradually include other subsystems, (ii) gradually build in submodels, that is, first include a submodel as an exogenous parameters/variable, then replace the exogenous parameter/variable by an endogenous variable (e.g. a graph function), and finally, turn the endogenous variable into a full submodel if needed, and (iii) first use simple structures and functions and gradually refine them (most likely making them more complex) along the way.

[1]Depending on the time horizon, one and the same process or element of a system could be modeled as a constant (for short time horizons compared to the inherent time horizon of the process), as a stock variable (for simulation time horizons that are similar to the inherent time horizon of the process), or as an auxiliary variable (for simulation time horizons that dwarf the inherent time horizon of the process). Constants do not, or hardly, change compared to the time horizon considered, stocks change slowly compared to the time horizon considered, and auxiliaries change instantly compared to the time horizon considered. For example, large glaciers hardly change on a daily time scale, change slowly on a time horizon of decades to centuries, but change rapidly/instantly on geological time scales.

In fact, it is good practice to include as little as possible, but not less than necessary. System dynamicists try to distil the very essence of issues (Coyle and Alexander 1997, p213), capture the essence in a structure of the model that is as small as possible by eliminating superfluous details and aggregating what could possibly be aggregated.

5.2 Elementary Model Simulation

SD allows the simulation of systems and policies over time in such a way that the behavior of the model unfolds continuously over time. Only the dynamics of extremely small and/or well-known systems (of up to three stocks, and only few feedback loops) could possibly be solved analytically, be assessed without simulation, or be derived by analogy to similar 'archetypes'. The dynamics of large and/or ill-known systems requires numerical simulation. Hence, most SD models require numeric integration.

Attention needs to be paid to the combination of the numerical integration method and the step size used. Numerical integration methods commonly included in SD packages are Euler, Runge-Kutta4 (RK4), and Runge-Kutta4 auto (RK4 auto). Euler is best for models with very discrete functions. But for many models and patterns, Euler is insufficiently precise unless a very small time step is chosen. RK4 is best for continuous models with, possibly, oscillatory behavior without large changes in the speed of dynamics. And RK4 auto is best for continuous models with large variations in the speed of dynamics.

There are a few rules of thumb for choosing an appropriate step size given the numeric integration method. Moreover, the step size should be chosen such that time is fully covered, that is, if time is n periods of length dt from t_0 then time should be equal to $t_0 + n * dt$. The step size should be such that crucial simulation times are 'visited', e.g. if a very discrete pulse occurs at $t = 0.25$, then the time step should be smaller or equal to 0.25 and t=0.25 should be calculated, as would be the case with a time step of 0.125, or 0.0625, et cetera. It is even better to start with a time step of less than 1/4th the smallest time constant or delay time in the model and simulate it. Then cut the time step in half and run the model again. If the two behaviors are identical or almost fully converge, then the largest of the two time steps was good enough, else the smallest time step should be halved again, et cetera. If there are delays in the model, then the time step should also be smaller than the delay constant divided by 4 times the order of the delay. The step size should not be chosen arbitrarily small: smaller step sizes take more time to compute and for small step sizes there is a trade-off between integration errors and round-off errors. The largest acceptable time step should thus be determined, chosen, and tested.

Apart from the integration method and the time step, one also needs to specify the start time and final time of the simulation. With regard to the total time horizon, i.e. Final Time - Initial Time, SD is oriented towards the very long term future, that is, very long term for the system under study[2]. Hence, it remains to be tested whether the time horizon chosen is actually too short by also simulating beyond the assumed long term time horizon.

Simulating the model numerically, one obtains the behavior of a run. System dynamicists are interested in this overall pattern of behavior of a run or an ensemble of runs, not so much in exact point or path predictions:

> '[System dynamicists] are much more interested in general dynamic tendencies; under what conditions the system as a whole is stable or unstable, oscillating, growing, declining, self-correcting, or in equilibrium' (Meadows and Robinson 1985, p34).

The overall dynamic behavior of a run strongly depends on the dominance of feedback loops and the shifts in dominance between them. The dynamic complexity of real systems arises because

[2] In relation to the time problem of SD models (especially the issue of choosing a time horizon), Perelman (1980, p79) argues that a very broad time perspective needs to be taken because of the fact that '[t]he cause of a current problem may lie in the distant past, and therefore may be insoluble by current actions[, that t]he solution to a problem within one future time horizon may contain the seeds of catastrophe in a longer time horizon[, that] a near-term disaster may be the best hope for the long-term future'.

systems are dynamic, tightly coupled, governed by feedback, nonlinear, history-dependent, self-organizing, adaptive, counterintuitive, policy resistant and characterized by trade-offs (Sterman 2000, p22).

5.3 Elementary Model Testing

Before starting to interpret the behavior of a model and/or performing policy analyses with the model, one first needs to turn to model testing. Model testing is a process to uncover errors, improve models, learn, and build confidence in the usefulness of models for particular purposes and in the recommendations that follow from modeling studies. Model testing is not about 'proving' a model is right –after all, all models are wrong (Sterman 2002a). However, some models may not just be wrong, they may be erroneous, may be used erroneously, or may simply be useless for the intended purpose. Identifying erroneous modeling and simulation are among the purposes of model testing. Another purpose of SD model testing is to test whether SD models generate the right outputs for the right reasons, for SD models are supposed to be operational causal models. That is, all model variables need to correspond to system elements and each relation is assumed to be causal. However, the most important purposes are to learn and to build confidence in the model and its usefulness for the intended purpose.

Model testing consists of model verification and model validation. Model verification refers to testing whether the model is incorrectly coded or simulated incorrectly, that is, whether it has been coded incorrectly (equations, submodels, and the whole model), whether the units are inconsistent (dimensional analysis[3]), or whether there are numerical errors (due to the use of an inappropriate combination of numeric integration method and step size).

Model validation refers to the entire range of tests to check whether a model meets the objectives of the modeling study. As such, validation is really about building confidence in its fitness for purpose, that is, confidence of the modeler/analysist as well as of the client/audience. Hence, clients, model users, and users of model results should somehow be involved in model validation. Some of the main questions to be addressed together with the clients/audience are:

- Are the boundaries, structures and parameters adequate?
- Does the model allow to generate the behaviors it should be able to generate for the right reasons?
- Does the model generate plausible behaviors under extreme conditions?
- Does the sensitivity of the model to changes in parameters, functions, boundaries, et cetera correspond to the sensitivity of the real system to corresponding changes?

There are many validation tests. Extremely important ones are boundary and in/direct structure assessment tests (are the boundary and structure appropriate?), extreme condition tests (does the model make sense under extreme conditions?), and sensitivity analysis (is the model sensitive to small changes in parameters, functions,. . . ?). For more on model testing, see chapter 13.

5.4 Elementary Policy Analysis, Design and Testing

Important objectives of most SD studies are to enable virtual experimentation, to learn from these experiments and to design system structures and policies that result in improved system behavior. When designing policies to improve system behavior, one should be creative within the real world boundaries and structural limits, and only change in the model what could also be changed in the real world.

[3]Dimensional analysis, i.e. analyzing the units of left hand side and right hand side of the equation, is very easy and useful for identifying missing factors/terms and detecting potential errors.

There are several approaches for designing and testing policies. Iteratively and interactively[4] changing structures and parameters and testing the effects of these changes is by far the easiest approach from a technical point of view, but not necessarily the most informative from a policy analytical point of view. Other approaches rely heavily on mathematics, control engineering, sampling and machine learning, and/or optimization techniques. These techniques are beyond the introductory level of this e-book and will be dealt with in a follow-up book. The intuitive/interactive/iterative approach of changing loops, structures and parameters is focused on here.

Intelligently playing with policies and models is a function of experience with the real system as well as of experience with SD modeling and simulation. Innovative structural policies can very often be distilled from the structure of a model. Possible model-based structural changes –in decreasing order of effectiveness– include:

1. adding/breaking/changing feedback loops related to information flows, decision routines, boundaries of responsibility,. . .
2. adding/breaking/changing (physical) stock-flow structures;
3. strengthening/weakening feedback loops and/or flow variables;
4. changing high leverage policy parameters, i.e. parameters that can be controlled by those involved and that have large effects for relatively small changes. The latter can be identified by means of sensitivity analysis (see chapter 13).

5.5 Elementary Interpretation

A SD model is 'a simplification of reality designed to be a *tool for thought about questions*' (Coyle 2001, p357). Model runs, scenarios, and policy runs could thus be used to support reflection and dialogue, they should not be used as truth sayers, or in the words of Barabba (1994): 'never say a model says'. SD model runs are interpreted in terms of their behavior patterns, which are in fact qualitative in nature. The most important outcomes of the modeling process are often increased insight and deeper understanding. And policies are mostly assessed in terms of their capacity to significantly and robustly improve behavior patterns.

Additional (non-mandatory) chapters:

III. Introduction to System Dynamics

V. Model Formulation

[4]by using the experience and intuition of both system actors and analysts

Chapter 6

Introductory Quantitative SD Exercises

'One good way to learn something new is through specific examples rather than abstractions and generalities, so here are several common, simple but important examples of systems that are useful to understand in their own right and that will illustrate many general principles of complex systems.' (Meadows 2009, p35)

6.1 Cocaine

The monthly change in the total quantity of *cocaine* in a country depends on the monthly quantity of *cocaine imports*, the monthly quantity of *cocaine used* and the monthly quantity of *cocaine confiscated* by the police. In a highly simplified model, we assume that 3000 kg of cocaine is used per month. The import of cocaine is constant and amounts to 4000 kg per month. And the monthly quantity of cocaine confiscated by the police is equal to 10% of the cocaine in the country. Suppose there was an initial amount of 3000 kg of cocaine in the country.

1. Make a *causal loop diagram* of this problem. What behavior do you expect?
2. Write down the corresponding differential equation. What kind of equation is this? What do you know then about the behavior of this system over time, even before simulation? What is the corresponding integral equation? What is the analytic solution?
3. Make a SD simulation model of this system. How would the *total quantity of cocaine in the country* evolve over time if initially there was 3000 kg of cocaine in the country? How would the *total quantity of cocaine in the country* evolve over time if initially there was 20000 kg of cocaine in the country? And how would the *total quantity of cocaine in the country* evolve over time if initially there was 10000 kg of cocaine in the country?
4. Does the behavior of this simulation model correspond to the analytical solution.

For SD models related to cocaine see (Homer 1993; Homer 1996; Homer 1997) or (Homer 2012).

6.2 Muskrat Plague

Suppose there is a muskrat plague in a particular area. At first, there were 100 *muskrats*. The autonomous increase in the number of muskrats per muskrat per year amounts to an average of 20 muskrats per muskrat per year. Suppose that each year, 10 licences are granted to set muskrat traps. The *licences* are only valid for one year and each person holding a licence may set 10 *traps*. Assume the number of *muskrats caught per trap* is proportional to the number of muskrats and a *catch rate per trap* which is close to 0.2, say, on average 0.2, minimally 0.195, and maximally 0.205.

1. Draw a *causal loop diagram* of the problem.
2. Write the corresponding balance equation.
3. Represent the system in your SD software, simulate the model with proportionality factors 0.195, 0.200 and 0.205, and make a graph of the muskrat population over a period of 10 years.
4. Compare your model structure and behavior with the example model (| | | | | |).
5. See what happens for different values of the proportionality factor and try to explain this.
6. Design and test an open-loop policy.
7. Given the uncertainty (of the proportionality factor, of the initial amount of muskrats, and of the number of muskrats), design a better –more specifically a dynamic closed-loop– licensing strategy that allows to stabilize the size of the population. Modify your initial simulation model, and compare the outcome of your dynamic closed-loop policy with the outcomes of the open-loop policy.

6.3 Economic Overshoot and Collapse

|$|

This exercise was inspired by Zoo System model Z416 developed by Hartmut Bossel (2007c) (follow this link to the zip file containing all Zoo models).

Overshoot and collapse is a phenomenon found in many application domains. In this exercise, one needs to build and analyze a simple overshoot and collapse model related to renewable resource exploitation by an autarchic population, for example the population on an isolated island in ancient times.

Suppose that the *population* initially amounts to 1 million persons and that the initial *renewable resources* amounts to 5 million units of the resource (for example tons of fish or acres of arable land). Suppose that the *births* flow is proportional to the *population*, the *per capita renewable resource availability* and the *normal birth rate* of 0.35% person per person per year. Suppose that the *deaths* flow is proportional to the *consumer population* and inversely proportional to the *resource availability dependent lifetime*. The latter is equal to the *normal lifetime* times the *per capita renewable resource availability*. Add `MAX(15,MIN(100,` in front of and `))` behind this equation to ensure the maximum average adapted lifetime is 100 years and the minimum average adapted lifetime is 15 years.

Per capita renewable resource availability is of course equal to the stock of *renewable resources* divided by the size of the *population*. *Renewable resources* only increase through *regeneration* and decrease through *resource use*. *Regeneration* consists of the sum of the *minimum regeneration* and the *resource dependent regeneration*. The *minimum regeneration* amounts to the *carrying capacity* times the *minimum regeneration rate*. Approximate the *resource dependent regeneration* with the following function: $regeneration\ rate * renewable\ resources * (renewable\ resources/carrying\ capacity) * (1 - renewable\ resources/carrying\ capacity)$.

In times of abundance, the *resource use* is equal to the *population* times the *renewable resource consumption per capita*, but in times of scarcity it is limited to the amount of *renewable resources* divided by the *rapid resource depletion time*. The *resource use* equation could thus be written as: $MIN(\frac{renewable\ resources}{rapid\ resourcedepletion\ time},\ renewable\ resource\ consumption\ per\ capita * population)$

Assume the *regeneration rate* amounts to 120%, the *carrying capacity* to 7500000 units of the resource, the *minimum regeneration rate* to 1% per year, the *rapid resource depletion time* to 1 year, and the *renewable resource consumption per capita* to 1 unit of resource per person per year.

1. Make a SD model of this description.
2. What dynamics in terms of the population and the renewable resources do you expect? Simulate the model. What dynamics in terms of population and renewable resources do you get?
3. What happens if the *minimum regeneration rate* is 10% per year?
4. Make a CLD that could be used to explain the link between structure and behavior and do it: use the CLD to explain the link between structure and behavior.

6.4 (Mis)Management of Societal Aging

Mismanagement of societal aging is –according to the World Economic Forum– one of the biggest risks to many developed and several developing countries.

Chinese, Western European and South American governments are concerned by the forecasted rise in the ageing population. Suppose a small Western European nation commissions a (rather simplistic) SD model related to its population dynamics. You are the lucky one assigned to this job. Make a simulation model based on the following information:

In 2010 there are, initially, 9 million *adults*, 3 million *retirees*, and 4 million *children*. Suppose that only *retirees* die after an *average retiree period* of 20 years. *Adults* retire after an *average adult period* of 40 years. And *children* mature (and hence become adults) after an *average childhood period* of 22 years. Suppose furthermore that the *average birth rate per adult* amounts to 20 children per 1000 adults per year.

The '*burden per active adult*' could be defined as the *inactive population* divided by the number of *adults on the labor market*. The *inactive population* equals the sum of the *children*, *retirees*, and the *adults not on the labor market*. The number of *adults not on the labor market* and the number of *adults on the labor market* depend of course on the *average adult participation ratio*.

Suppose that this ratio amounts to 50%. The '*grey pressure*' could be defined as the fraction of *retirees* on *adults*.

1. Make a SD model corresponding to this description.
2. Simulate the model. What is the evolution in terms of the *grey pressure* and the *burden per active adult*? Is this evolution desirable?
3. Design and test policies to improve the evolution.
4. The model is rather simplistic: what needs to be changed to substantially improve it?

6.5 The Threat of the Feral Pig

Many American Departments of Natural Resources have adopted the position that *feral pigs* (Latin: *sus scrofa*) are exotic, non-native wild animals that pose significant threats to both the environment and to agricultural operations. See for example the web site of the Southeastern Wisconsin Invasive Species Consortium on which information this exercise is partly based. Due to feral pigs' tramping and rooting behaviors, many American wildlife biologists and institutions are becoming increasingly concerned about the devastation these 'exotic' animals can cause to ecologically sensitive native habitats, particularly native plants and rare, threatened or endangered species. Feral pigs can transmit diseases and parasites to livestock and people. Farmers are especially worried about the potential spread of exotic diseases to their domestic livestock. Of primary concern are diseases such as pseudorabies, brucellosis and tuberculosis. Many farmers are also troubled by potential crop losses. As mentioned above, feral pigs can be extremely destructive to recently planted fields and can damage pastures, facilities and fences, resulting in serious financial losses. Their wallows can affect ponds and wetlands by muddying the water, creating algae blooms, destroying aquatic vegetation and lowering overall water quality. Digging and rooting activity of feral pigs near a watercourse leads to bank erosion. All of this activity can lead to decreased livestock use and poor fish production.

Suppose one of the Departments hired you to develop a SD simulation model of the feral pigs population to assess the dynamics of the population over time given the departmental gaming rules.

In this region, feral pigs may be removed any time throughout the year as long as those choosing to pursue them possess a valid licence. Each year, 10 *licences* are granted to set feral pig *traps*. The licences are only valid for one year. Each person holding a licence may set 10 *traps*. The number of *feral pigs caught per trap* is proportional to 15% to 17% of the feral pigs.

Assume that, at this moment, there are about 20000 feral pigs in the area, that feral pigs can mate any time of the year, that sows produce on average 4 litters per year with each litter consisting of 8 piglets on average, and that half of the pig population consists of sows.

1. Draw a simple CLD of the feral pig problem.
2. Make –on the computer– a simple SD simulation model of the feral pigs population to assess the dynamics of the population over time given the departmental gaming rules.
3. Make a graph of the number of feral pigs over time. Show what happens in the graph for different values of the proportionality factor (15%, 16% and 17%).

4. Verify and validate your model.
5. Given the uncertainty (of the proportionality factor, of the initial amount of feral pigs, and of the number of new pigs), design a better (dynamic) licensing strategy that allows to stabilize the size of the feral pig population to less than 25000 units.

6.6 Gangs and Arms Races

Arms races are escalation processes between two (or more) nations or parties in a conflict that 'watch each other and [both] respond to [uncertain] arming activities of their opponent with [relatively greater] arming activities of their own' (Bossel 2007c, p36). The amount of weapons held by one party may actually deter the other party from attacking and vice versa, resulting in a situation of escalating armed peace. This exercise is based on the escalation model described in (Bossel 2007c, Z507) (follow this link to the zip file containing all Zoo models). Arms races are escalation processes between two (or more) nations or parties in a conflict that 'watch each other and [both] respond to [uncertain] arming activities of their opponent with [relatively greater] arming activities of their own' (Bossel 2007c, p36). The amount of weapons held by one party may actually deter the other party from attacking and vice versa, resulting in a situation of escalating armed peace. This exercise is based on the escalation model described in (Bossel 2007c, Z507) (follow this link to the zip file containing all Zoo models).

Suppose there are two gangs, gang A and gang B. Initially, the *arms stock of gang A* amounts to 100% of the weapons needed to destroy gang B, and the *arms stock of gang B* amounts to 100% of the weapons needed to destroy gang A. The *arms stock of gang A* only in/decreases via the *arming of gang A* and the *arms stock of gang B* only in/decreases via the *arming of gang B*. Suppose that the arming of both gangs depends on an autonomous arming rate due to their intrinsic interest in arms and arming –the *autonomous arming rate A* and *autonomous arming rate B* respectively– and on an arming rate relative to the expected first order arming of the adversary, that is, the arming of gang B from the point of view of gang A without consideration of the arming of gang A and vice versa. This *relative arming rate of gang A* –in terms of the weapons needed to destroy gang B– then equals the product of the *overassessment factor of gang B arming by gang A*, the *arms obsolescence rate of gang A*, and this *arms stock of gang B* minus the *arms obsolescence rate of gang A* times the *arms stock of gang A*. The same applies to gang B: the *relative arming rate of gang B* –in terms of the weapons needed to destroy gang A– equals the product of the *overassessment factor of gang A arming by gang B*, the *arms obsolescence rate of gang B* and the *arms stock of gang A* minus the *arms obsolescence rate of gang B* times the *arms stock of gang B*. Assume that the *autonomous arming rate of gang A* and the *autonomous arming rate of gang B* are both equal to 5% of the weapons needed to destroy the other gang per month and that both *arms obsolescence rate*s equal 10% of the weapons needed to destroy the other gang per month.

1. Suppose that gang A overassesses the arming of gang B by 10%, i.e. the *overassessment factor of gang A arming by gang B* is 110%, and that gang B correctly assesses the arming of gang A, i.e. the *overassessment factor of gang A arming by gang B* is 100%. Model the arms race. What behavior do you expect? Simulate the model over a period of 100 months. What behavior does the simulation show? Why?

2. Suppose that gang A underestimates the arming of gang B by 50%, i.e. the *overassessment factor of gang B arming by gang A* is 100%-50% or 50%, and that gang B correctly assesses the arming of gang A, i.e. the *overassessment factor of gang A arming by gang B* is 100%. Change the parameter, rename the run, and simulate the model again over a period of 100 months. What behavior do you expect and what behavior does the simulation show? Why?

3. Make a CLD or AD of arms races between two gangs. Use it to explain the link between structure and behavior.

6.7 Unintended Family Planning Benefits

Levitt and Dubner (2006, chapter 4) argue in Freakonomics that dropping crime rates (i.a. in New York) are in fact an "unintended benefit" of legalized abortion. In this exercise, we will build a simplistic, purely hypothetical, simulation model to simulate the first-order effects on crime statistics of a sudden drop in the birth rate of families with multiple problems[1] –be it by voluntary abortion or by successful family planning measures.

Let's focus on families with multiple problems only, and let's assume that individuals born in families with multiple problems are indeed trapped, but that they do not necessarily resort to crime. Model an aging chain of *kids*, *youngsters*, *adults* and *retirees*. Initially, there are 1 million *kids*, 1 million *youngsters*, 3 million *adults*, and 750000 *retirees* within these families with multiple problems. Suppose for the sake of simplicity that only *retirees* die, on average after an *average time as retiree* of 15 years, i.e. *deaths* equals *retirees* divided by *average time as retiree*. Similarly, *adults* flow after an *average time as adult* of 40 years *from adults to retirees*, *youngsters* after an *average time as youngster* of 12 years *from youngsters to adults*, and *kids* after an *average time as kid* of 12 years *from kids to youngsters*. Both *adults* and *youngsters* give birth: the *birth* inflow is thus the sum of the *adults* times the *annual fertility rate of adults* of 3 percent per adult per year and the *youngsters* times the *annual fertility rate of youngsters* of 0.3% per youngster per year.

Suppose 6 million crimes are committed annually by others, that is, by criminals that are not part of families with multiple problems. Apart from these *crimes by others*, *crimes* are committed by *criminal kids* at a rate of 2 *criminal acts per criminal kid* per year, by *criminal youngsters* at a rate of 4 *criminal acts per criminal youngster* per year, by *criminal adults* at a rate of 12 *criminal acts per criminal adult* per year, and by *criminal retirees* at a rate of 4 *criminal acts per criminal retiree* per year. Suppose that, in these families with multiple problems, the *percentage of kids with criminal behavior* amounts to 5%, the *percentage of youngsters with criminal behavior* amounts to 50%, the *percentage of adults with criminal behavior* amounts to 60%, and the *percentage of retirees with criminal behavior* amounts to 10%.

1. Make a SD simulation model of this description and verify it. Simulate a base run over a period of 50 years.

[1] Troubled families or families with multiple problems are families that struggle with complex social issues, difficult spousal and parent-child relationships, economic housing pressures, mental illness, and the judicial system. Turning around these messy multi-problem situations is so difficult that, without proper sustained help, multiple generations may be trapped.

2. Now assume that due to *successful voluntary family planning measures*, the *birth* flow is 75% lower, that is, 25% times the sum of the *adults* times the *annual fertility rate of adults* of 3 percent per adult per year and the *youngsters* times the *annual fertility rate of youngsters* of 0.3 percent per youngster per year. Change the name of the run, and run it.
3. Compare the behavior of the latter run to the behavior of the base run. How much time do you think it would take before people would notice something is going on?
4. This simulation model only focuses on the first order effects, that is, the reduction of individuals. The biggest gains, however, are likely to relate to higher order effects such as the better socio-economic circumstances of those children that are born in families with less children that need to be taken care of. Make a highly aggregated CLD of the simulation model and extend it with higher order effects. Use the CLD to explain the problem and possible solutions.

6.8 Pneumonic Plague (A)

Introduction

On 3 August 2009, media reported about an outbreak of pneumonic plague in north-west China:

> "A second man has died of pneumonic plague in a remote part of north-west China where a town of more than 10,000 people has been sealed off. [...] Local officials in north-western China have told the BBC that the situation is under control, and that schools and offices are open as usual. But to prevent the plague [from] spreading, the authorities have sealed off Ziketan, which has some 10,000 residents. About 10 other people inside the town have so far contracted the disease, according to state media. No-one is being allowed [to] leave the area, and the authorities are trying to track down people who had contact with the men who died. [...] According to the WHO, pneumonic plague is the most virulent and least common form of plague. It is caused by the same bacteria that occur in bubonic plague – the Black Death that killed an estimated 25 million people in Europe during the Middle Ages. But while bubonic plague is usually transmitted by flea bites and can be treated with antibiotics, [pneumonic plague, which attacks the lungs, can spread from person to person or from animals to people], is easier to contract and if untreated, has a very high case-fatality ratio." (BBC 03/08/2009)

Modeling a Pneumonic Plague Outbreak

You are asked to make a SD model of this outbreak. Use the following assumptions: The *total population* of Ziketan amounted initially to 10000 citizens. New *infections* make that citizens belonging to the *susceptible population* become part of the *infected population*, which initially consists of just 1 person. The number of *infections* equals the product of the *infection ratio*, the *contact rate*, the *susceptible population*, and the *infected fraction*. Initially, the *normal contact rate* amounts to 50 contacts per week and the *infection ratio* to a staggering 75% per contact. The *infected fraction* equals of course the *infected population* over the sum of all other subpopulations. If citizens from the *infected population* die, they enter the statistics of the *deceased population*, else they are quarantined to recover. The *recovering* could be modeled simplistically as $(1 - fatality\ ratio) * infected\ population/recovery\ time$. Suppose for the sake of simplicity that the average *recovery time* and the average *decease time* are both 2 days. The *fatality ratio* depends on the *antibiotics coverage of the population* which –in this poor part of China– is 0% at first.

The fatality ratio is 90% at 0% *antibiotics coverage of the population* and 15% at 100% *antibiotics coverage of the population*. Assume for the sake of simplicity that those belonging to the *recovering population* do not pose any threat of infection, either because they are really quarantined or because they are not contagious any more.

1. Make a SD simulation model of a local pneumonic plague epidemics. Verify the model.
2. Assume in your basecase simulation that the *antibiotics coverage of the population* remains 0%. Simulate the model using a time horizon of one month. Make graphs of the evolution of the *infections*, the *deaths*, the *recovering population*, and the *deceased population*.
3. Assume now that *antibiotics coverage of the population* is 100%. Compare the evolution of the *infections*, the *deaths*, the *recovering population*, and the *deceased population* with those obtained in the previous question.
4. Make a detailed as well as a highly aggregate CLD of this model.
5. Could the epidemics be stopped? Explain based on the structure of the model.

6.9 System Dynamics Education

Since the 1960s, the SD field has been growing at a moderate but steady pace. Let's make a few extremely simplified models regarding the expansion of the SD field, and let's use them to investigate the effects of potential measures to expand the field at a much faster pace. To do so, assume this issue can be addressed with a continuous model (e.g. professors are expressed in terms of FTEs, student numbers do not need to be integers, et cetera).

In 1962, there was just 1 *SD professor*, Jay W. Forrester, and in 2012, there were about 500 *SD professors*. First of all, assume there is no outflow of SD professors (being a SD professor is awesome and enlightened SD professors live much longer than average human beings). Hence, the number of SD professors only increases through the inflow of *new professors teaching SD*. The number of *SD students entering* SD programs equals the number of *SD professors* times the *average SD student cohort size per professor* of, say, 25 persons per professor per year. Initially there were about 10 *SD students in SD programs* in 1962. Suppose the *average time to finish SD studies* amounts to 7 years (BSc + MSc (+ PhD) + accumulating experience). Suppose, again for the sake of simplicity, that no one quits. After all, SD is awesome. Model the flow *SD students finishing* as the number of *SD students* divided by the *average time to finish SD studies*. After finishing, SD students join the club of *SD trained*.

So far, no information has been given about how the number of *SD professors* increases. Suppose you do not have that information and would still like to complete this model and simulate it. Let's make three different models with three simple assumptions. Assume in the first version of the model that the inflow of *new professors teaching SD* is constant over time (simply calculate it). Assume in the second version of the model that the increase of *SD professors* at any time over the last 50 years was equal to 12.5% of the number of *SD professors*. Assume in the third model that *new professors teaching SD* is equal to the rate of *SD students finishing* times a constant *percentage of SD students finishing that become SD professors* of about 1%. Assume for the sake of simplicity that there is no delay involved.

1. Build these three SD simulation models. Save them. Simulate them from 1962 until 2012. What would be the resulting number of *SD professors*, *SD students* and *people trained in SD* in 2012 in each of these models? Write down these numbers.

2. Change the settings of these three models: Set the initial time of the model to 2012 and the final time to 2020. Adapt the initial conditions of the stocks to the values obtained in question 1. Now simulate these three models again. What would be the resulting number of *SD professors*, *SD students* and *people trained in SD* in 2012 in each of these models now? Write down these numbers.

3. Which model is most desirable? Which model is least incorrect? Is the best assumption made about the past development also valid for the future development of the field?

4. What happens in these three models if from 2014 on the *average SD student cohort size per professor* increases with 1000 persons per professor per year? In order to simulate this, change the *average SD student cohort size per professor* into: 25 + STEP(1000, 2014).

5. Which model is most useful for assessing the future expansion of the academic field of SD? What needs to be changed for this/these models to be used for forecasting purposes?

6. Think, for each of the models, of another policy that may help to significantly expand the SD field. Implement it and test it.

6.10 Diffusion of micro-CHP

'Micro Combined Heat and Power' is an extension of the now well established cogeneration technology to the single family home. You just bought the Dutch franchise of the best domestic Micro-CHP technology of which the potential market equals the number of Dutch households (7.3 million households). The product will most likely sell itself through normal mouth-to-mouth publicity. But how will sales actually happen over time? Make a SD simulation model to investigate the potential diffusion of Micro-CHP.

Assume, simplistically, that every citizen will only buy the product once. To start up the mouth-to-mouth publicity, you distribute 100 of these Micro-CHP devices for free, turning these 100 *potential clients* from the outset into *clients*.

Existing *clients* are rather enthusiast and social, and hence, have some 50 contacts with other people with whom they talk about the product per month. The variable *contacts with clients* influences the variable *contacts of potential clients with clients*. The variable *contacts of potential clients with clients* equals the *contacts of clients* times the variable *potential client concentration*, which in turn equals the number of *potential clients* divided by the *total market* of 7.3 million Dutch households. Not every household is immediately convinced of the new product: the *convincing degree* is just 1%. Those who are convinced almost instantly buy a Micro-CHP appliance.

1. Make a simple System Dynamics simulation model. Simulate it. Make graphs for the dynamics of the number of *potential clients*, the number of *new clients*, and the number of *clients*.

2. Compare your model structure and behavior with the example solution (| | | | | |). Test the model using other tests too.

3. How many months does it approximately take to capture 99% of the market?

4. Make a CLD of the system and use it to explain the link between structure and behavior.

6.11 Housing Stock Dynamics

After taking this SD course, you make a wise decision and start to work as a System Dynamics modeling consultant (you don't know it yet, but SD will become your passion soon). One of your first clients is the Dutch minister of housing. Initially there are 5,000,000 *houses* in the Netherlands. After a period of dynamic equilibrium in the housing system, the minister foresees the need to expand the number of *houses* to 5,050,000.00 (an increase of 50,000.00 houses) and wants to understand the medium term dynamics (about 8 years ahead) of this expansion of the housing stock after raising the *desired housing stock* with 50,000 units in month 20.

The minister wants you to make a SD simulation model of the current situation. As already said, the system is currently in dynamic equilibrium. The *houses* have an *average house lifetime* of 100 years after which the houses are demolished. The *demolishing* flow equals the number of *houses* divided by the *average house lifetime*. All demolished houses are actually replaced. This takes place in two steps and takes some time. First of all, the number of houses that are being demolished per month also enter a *planned houses* stock via a *planning* flow. The initial value of the *planned houses* stock equals the *planning* times a constant *average time from planning to building* of 3 months. The *planned houses* stock is emptied by a *building* flow that feeds the *houses under construction* stock. Model the *building* flow as the *planned houses* divided by the *average time from planning to building*. As initial value of the *houses under construction* you could take the *building* flow times the *average time to build houses* of 6 months. The *completion* flow –which equals the stock of *houses under construction* divided by the *average time to build houses*– empties the *houses under construction* stock and feeds the *houses* stock. Check whether this model is in equilibrium.

If the model is indeed in equilibrium, then extend it as follows to test the expansion of the housing stock: Add a variable or constant *desired number of houses* and add a variable called *housing gap*, which is equal to the *desired number of houses* minus the number of *houses*. The *housing gap* divided by the *average time to respond to the housing gap* of 8 months should now be added to the existing *planning* flow. Add the additional 50,000 desired houses with a STEP function.

1. Make a simple SD model, simulate it and assess the dynamics of the system. How long (more or less) does it take before the system is back in dynamic equilibrium?
2. Make graphs for the number of *houses*, the *demolishing* flow, the *houses gap*, the number of *planned houses* and the number of *houses under construction*.
3. Test your model. Is it appropriate for a 'quick and dirty' exploration.
4. Draw a simple CLD of the system and use it to explain the link between the structure and the behavior of the system. Or in other words: how could this behavior be generated by its structure?
5. However, contrary to the foreseen rise in the *desired number of houses*, things turn out differently: the housing market collapses due to an economic-financial crisis. Instead of raising the *desired number of houses* with 50000 houses, the minister decides to reduce the *desired number of houses* with 50000 houses (in the Netherlands, building permits are strongly regulated and social housing is huge). What happens?
6. Twenty months later –that is, in month 40– the same minister realizes that the underlying issue, i.e. housing for all (future) Dutch households, has not changed fundamentally. He

suddenly decides to raise the level of houses to 5,050,000, i.e. with 100,000 at the beginning of month 40. What are the consequences?

6.12 Additional Exercises in Online Repository

|⊕| Add. ex. 1
|⊕| Add. ex. 2
|⊕| Add. ex. 3
|⊕| Add. ex. 4
|⊕| Add. ex. 5
|⊕| Add. ex. 6
|⊕| Add. ex. 7
|⊕| Add. ex. 8
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|⊕| Add. ex. 10
|⊕| Add. ex. 11
|⊕| Add. ex. 12
|⊕| Add. ex. 13
|⊕| Add. ex. 14
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|⊕| Add. ex. 19
|⊕| Add. ex. 20
|⊕| Add. ex. 21

Chapter 7

MCQs Part II

'It's so much easier to suggest solutions when you don't know too much about the problem.'
Malcolm Forbes

Which of the following statements are right and which are wrong?

1. The value of a stock variable can only be changed, during a simulation, by its flow variables.
2. An inflow cannot be negative.
3. The behavior of a stock is described by a differential equation.
4. If two causally linked variables show exactly same behavior as a function of time, then one of these variables is a stock.
5. A stock variable always needs to be embedded in at least one loop.
6. Plugging a SD model with correction factors that do not have any relation to the real world system is not considered good SD practice.
7. If a hypothetical sheet of paper that could be folded infinitely is about 0.1mm thick and the maximum distance between the earth and the moon is 405500 km, then folding the paper 42 times more than bridges the maximum distance between earth and moon.
8. The units of inflow variables and outflow variables of the same stock variable always have the same units.
9. Non-linear functions, feedback loops, or their combination can generate non-linear dynamics.
10. Underlying SD models, there is exactly one differential equation for each feedback loop.
11. Diffusion and transition models always have the same feedback loop structure consisting of one (+) or (R) and one (-) or (B) .
12. Quantitative System Dynamics simulation results need to be interpreted qualitatively.
13. If $A \underset{+}{\rightarrow} B$, both variables A and B were increasing until time t, and variable A starts to decrease at time t, then variable B may either start to decrease or keep on increasing but at a reduced rate of increase.
14. If a potentially important variable is not reliably quantifiable, it should be omitted from a SD model.
15. In SD studies, conclusions can only be drawn validly if they are based on simulations.

Multiple Choice Question 1

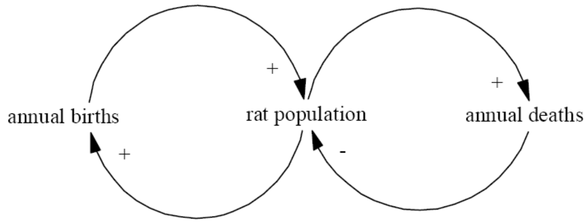
The equation for the CLD on the right –with *p(t)* = size of the rat population, g the annual number of births per rat, and s the annual number of deaths per rat– is:

a. $p(t) = gp(t) - sp(t)$

b. $p(t) = g(t)/s(t)$

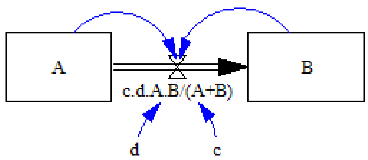
c. $dp(t)/dt = gp(t)$

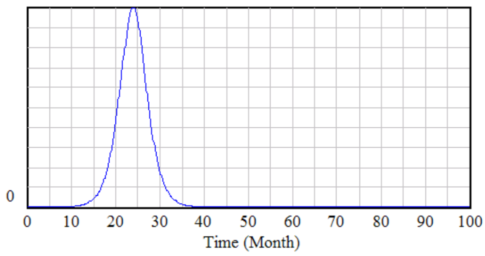
d. $dp(t)/dt = gp(t) - sp(t)$



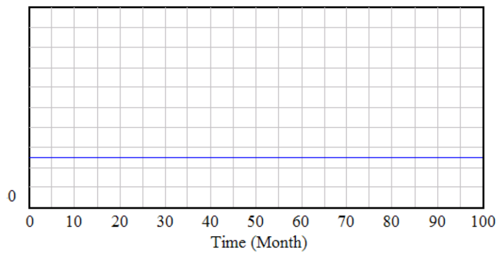
Multiple Choice Question 2

Consider the SD model displayed on the right, with $c > 0$, $d > 0$, $A_0 > 0$, en $B_0 > 0$. The formula of the flow variable is equal to $c.d.A.B/(A+B)$. Which behavior corresponds to (*stock*) variable B?

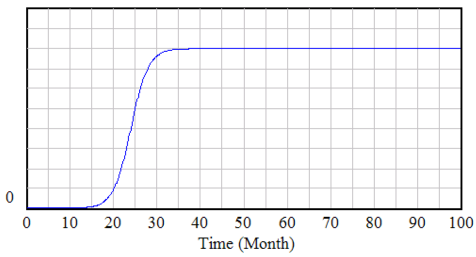




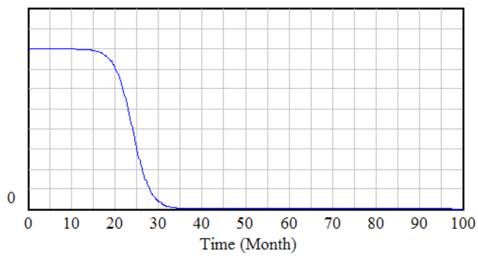
(a)



(b)



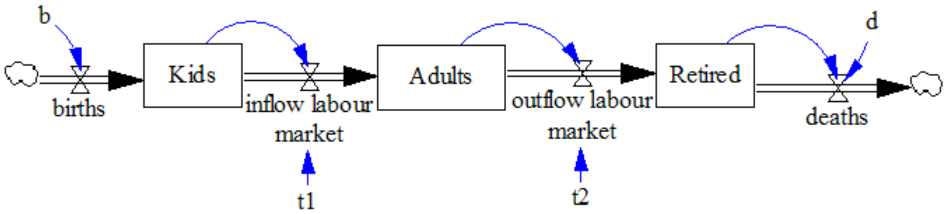
(c)



(d)

Multiple Choice Question 3

Many European countries consider raising the retirement age to keep the social security system financially healthy. To study this issue in its most basic form (that is: all adults work, only the retired die, first-order delays are good approximations, etc.), three groups need to be discerned: the kids K, adults younger than the retirement age A, and retirees R (see the incomplete stock-flow diagram below).



Which of the following systems of differential equations is best suited for studying the sustainability of the security systems? [death rate of the Retired = m; birth rate per adult = b; average residence time in group $K = t_1$ and in group $A = t_2$].

a. $\begin{cases} \frac{dK(t)}{dt} = bK(t) - t_1K(t) \\ \frac{dA(t)}{dt} = t_1K(t) - t_2A(t) \\ \frac{dR(t)}{dt} = t_2A(t) - R(t)/m \end{cases}$

b. $\begin{cases} \frac{dK(t)}{dt} = \frac{K(t)}{t_1} - \frac{A(t)}{t_2} \\ \frac{dA(t)}{dt} = \frac{K(t)}{b} - \frac{K(t)}{t_1} \\ \frac{dR(t)}{dt} = \frac{A(t)}{t_2} - mR(t) \end{cases}$

c. $\begin{cases} \frac{dK(t)}{dt} = bA(t) - \frac{K(t)}{t_1} \\ \frac{dA(t)}{dt} = \frac{K(t)}{t_1} - \frac{A(t)}{t_2} \\ \frac{dR(t)}{dt} = \frac{A(t)}{t_2} - mR(t) \end{cases}$

d. $\begin{cases} \frac{dK(t)}{dt} = bK(t) - \frac{K(t)}{t_1} \\ \frac{dA(t)}{dt} = \frac{K(t)}{t_1} - \frac{A(t)}{t_2} \\ \frac{dR(t)}{dt} = \frac{A(t)}{t_2} - mR(t) \end{cases}$

Multiple Choice Question 4

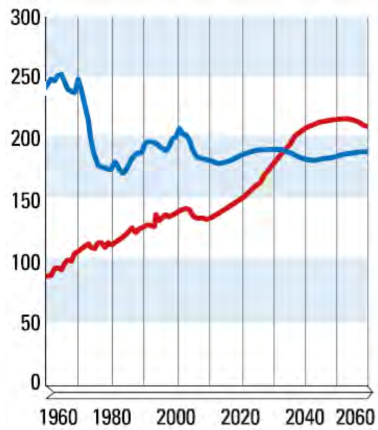
The graph on the right contains data and projections of the CBS (Dutch Central Bureau of Statistics) concerning the births (blue) and deaths (red) in the Netherlands between 1960 and 2060. Assuming there is no net migration in this period, it means that:

a. the Dutch population remained more or less constant between 1980 and 2000 because births and deaths developed more or less in parallel;

b. the Dutch population is projected to decrease between 2000 and 2032 because the number of deaths increases faster in that period than the number of births;

c. the Dutch population is projected to keep on growing till 2032 – nevertheless with a decreasing growth rate, because the number of deaths remains larger than the number of births;

d. none of the statements above is correct.



Blue: births x1000; Red: deaths x1000; Source: CBS in NRC Handelsblad 17/12/2010 p4.

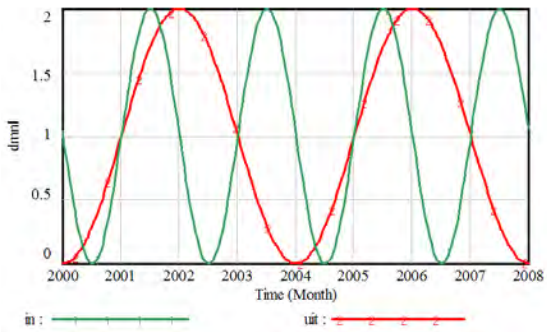
Multiple Choice Question 5

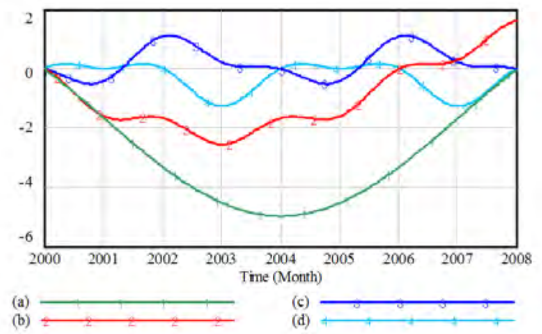
The unit of time in a model concerning the large-scale introduction of wind turbines is expressed in *months*. The production capacity of a company that produces wind turbines is modeled as a stock variable with units expressed in *turbine/month*. The enormous growth of the demand for new wind turbines, leads to an increase of the production capacity of the company. Which unit needs to be used for the increase of the production capacity of the company?

a. *turbine* b. *turbine/month* c. $turbine/month^2$ d. $(turbine/month)^2$

Multiple Choice Question 6

The green curve in the left hand side graph is the only inflow '*in*' into a *stock* variable, and the red line is the only outflow '*uit*' out of the same *stock* variable. Which of the behaviors in the right hand side graph corresponds, given the '*in*' and '*uit*' flows, with the behavior of the *stock* variable?

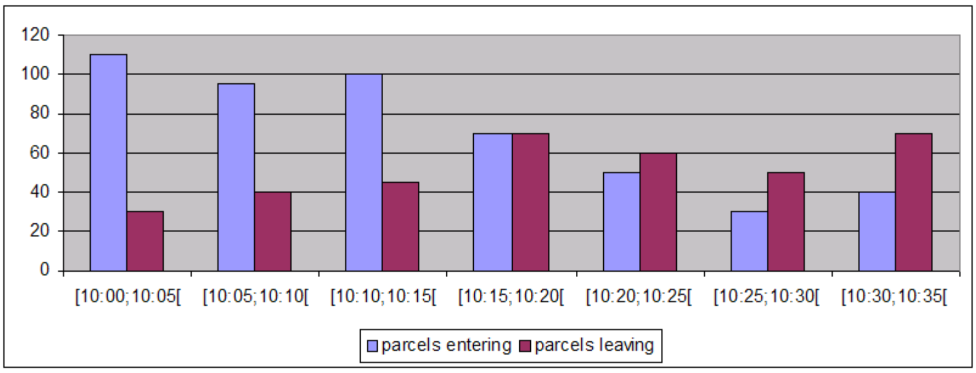




a. curve 1 (green) b. curve 2 (red) c. curve 3 (dark blue) d. curve 4 (light blue)

Multiple Choice Question 7

The graph below shows the number of parcels entering and leaving a warehouse between 10:00am en 10:35am in time intervals of 5 minutes. It is unknown how many parcels there were in the warehouse before 10:00am. It is unknown how many parcels left the warehouse after 10:35am. In which time interval between 10:00am and 10:35am was the smallest number of parcels inside the warehouse?



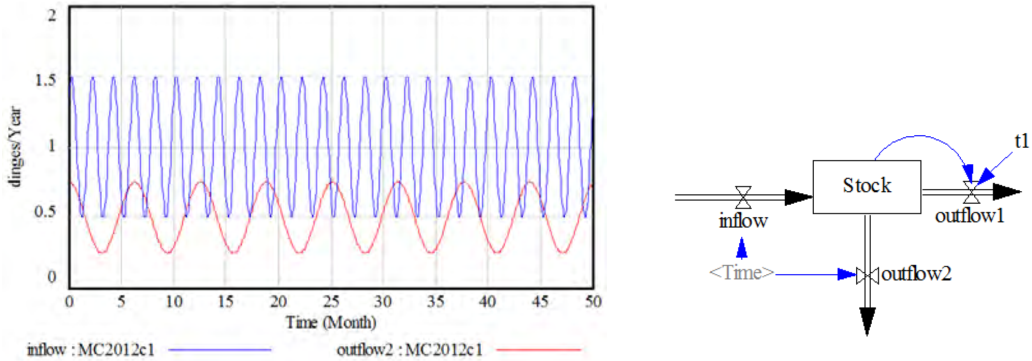
a. The number of parcels inside was smallest at 10:00am or 10:05am.

b. The number of parcels inside was smallest at 10:15am or 10:20am.

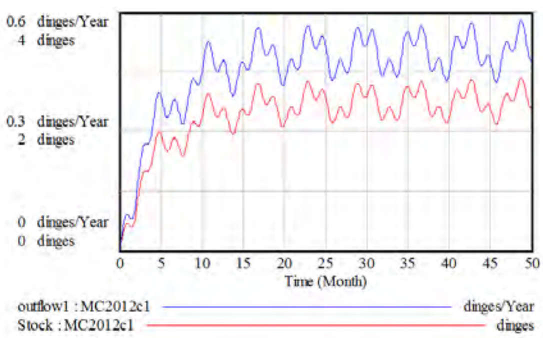
c. The number of parcels inside was smallest at 10:30am or 10:35am.

d. That cannot be determined with the information provided here.

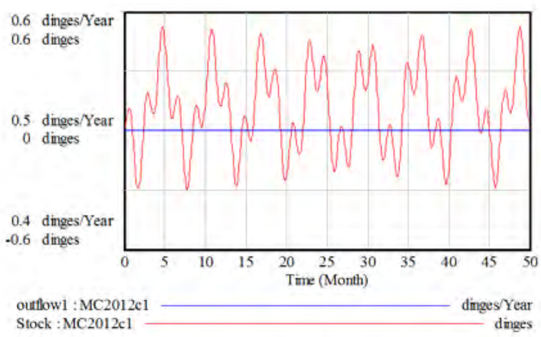
Multiple Choice Question 8



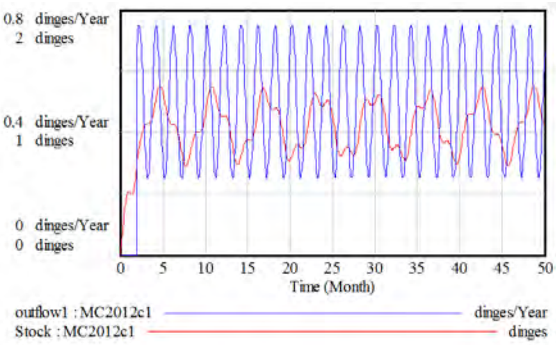
The left hand side graph in the above figure shows the behavior of two out of three flows of the stock-flow diagram displayed on the right. The third flow is proportional to the *Stock*. Which of the following figures displays possible behaviors for the *Stock* and *outflow1* that could have been generated with the above structure?



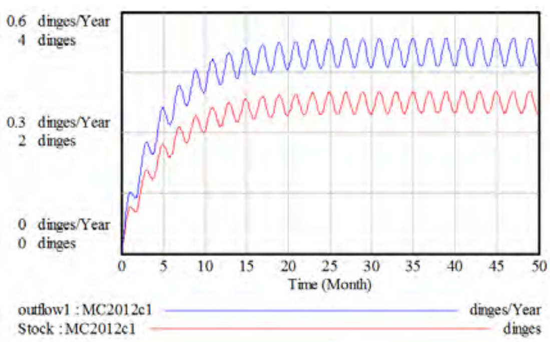
(a)



(b)



(c)



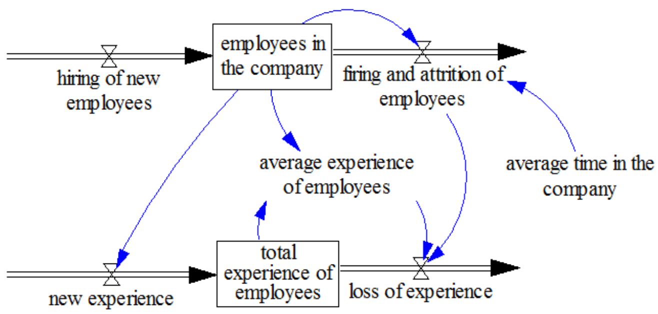
(d)

Multiple Choice Question 9

What was long predicted, happened in the second quarter of 2010: China's economy became bigger than Japan's. The Japanese economy amounted in the second quarter to $ 1290 billion, against $ 1340 billion for China. Economists point out that Japanese welfare is still much higher than Chinese welfare. The average Japanese income ($ 37800 per capita) is about 10 times higher than the average Chinese income. Measured in Gross Domestic Product per year, the top five currently looks –according to the figures of the IMF– as follows: the United States of America are the largest economic power (€10995 billion), far ahead of China (€4319 billion), Japan (€4053 billion), Germany (€2486 billion) and France (€1921 billion). Practically all analysts predict that China will take over the lead from the USA – the only question seems to be when. When will China take over the lead from the USA if China keeps on growing at a rate of 11,9% per year as in the first quarter of 2011, and the USA at 2% per year?

a. 2019; b. 2021; c. 2023; d. 2027.

Multiple Choice Question 10



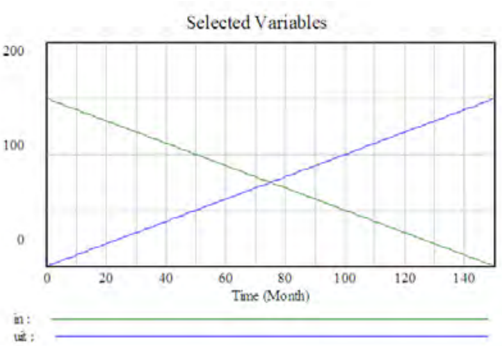
Given is the fully displayed sub-model of a company with a large number of employees on the left. The model is about gain and loss of experience, which is measured in weeks. The SD model aggregates the experience of all employees in the company. All relevant variables are displayed; no constants or parameters are used that are not shown.

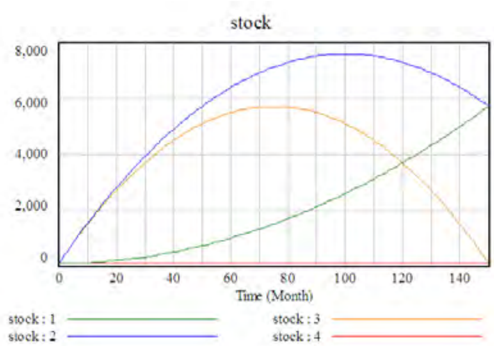
Employees gain experience over the course of time. If an employee leaves the company, then it is assumed that the employee leaves with his/her experience which equals the average experience. The formula for *loss of experience* is equal to the *firing and attrition of employees* times the *average experience of employees*. The formula for *average experience* is equal to the *total experience of employees* divided by number of *employees in the company*. The number of employees is expressed in 'person', the unit of time is expressed in 'week'. What units should be used for the *average experience of employees* and the *total experience of employees*?

a. week; person * week; b. Dmnl; person; c. week; person; d. Dmnl; week/person.

Multiple Choice Question 11

The green line in the graph on the left is the only inflow '*in*' into a *stock* variable. The blue line with the positive slope is the only outflow '*uit*' out of this same *stock* variable. Which of the patterns of behavior on the right could, given the '*in*' and '*uit*' flows, correspond to the *stock* variable?

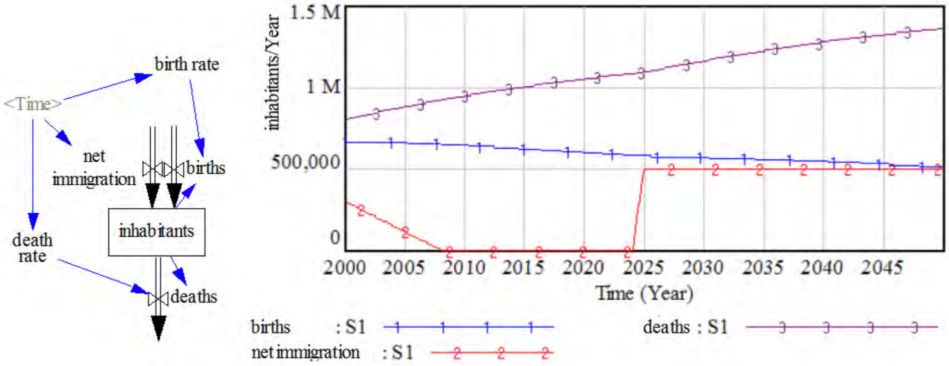




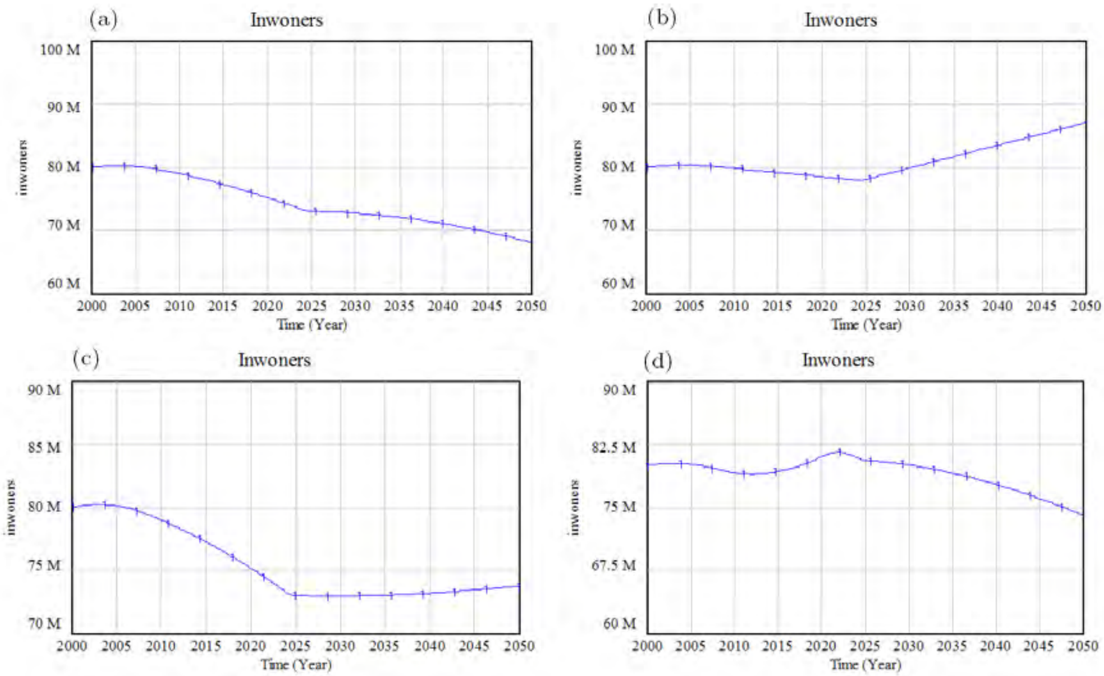
a. pattern 1 (green) b. pattern 2 (blue) c. pattern 3 (orange) d. pattern 4 (red)

Multiple Choice Question 12

The SD model below could be used to calculate demographic scenarios. Suppose one uses the model to project the expected demographic developments in Germany starting from following assumptions about the flow variables (see also the graph below): The net immigration decreases from 300000 in 2000 to 0 in 2008 and remains constant at that level until the year 2025 after which an annual amount of immigrants equal to 500000 are admitted. The birth rate decreases linearly from 0.0083 in 2000 to 0.0075 in 2050. The death rate increases linearly from 0.01 in 2000 to 0.02 in 2050.



Given these assumptions and the model displayed above, what would be the expected evolution of the stock variable ‘Inhabitants’?



Multiple Choice Question 13

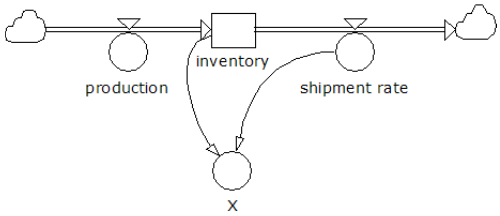
Consider the model below. Assume that it is in equilibrium. *Inventory* is measured in 'item', the time unit of the model is days. The variable X is defined as $X = inventory/shipment\ rate$. What is the unit of X? What would be a good name for X?

a. dimensionless, average residence time

b. day, average residence time

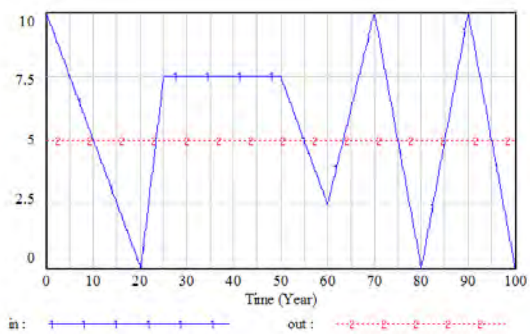
c. day, residence coefficient

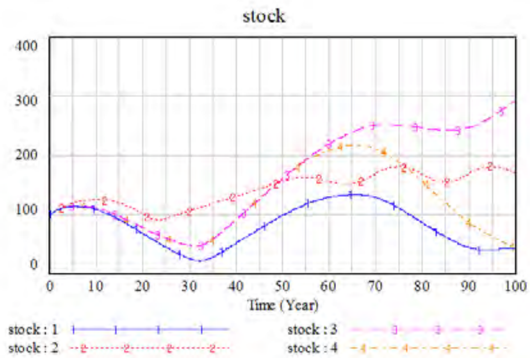
d. 1/day, day



Multiple Choice Question 14

Pattern 1 in the graph on the left shows the only inflow '*in*' into a stock variable and pattern 2 its only outflow 'out'. Which pattern of behavior on the right belongs to the stock variable?

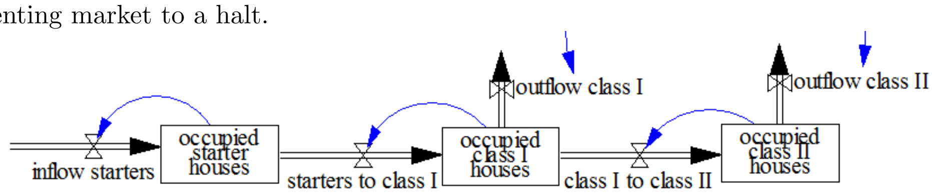




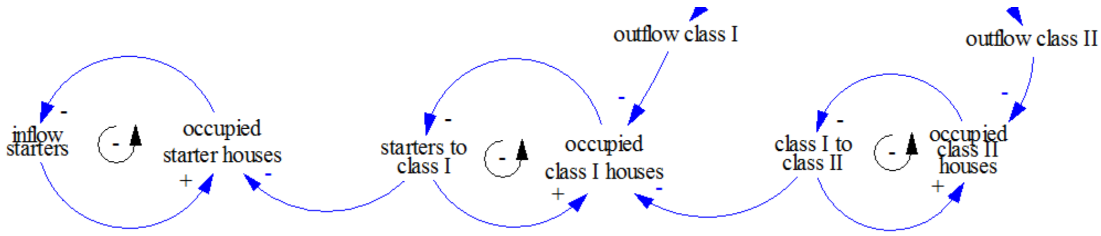
a. pattern 1 (blue) b. pattern 2 (red) c. pattern 3 (pink) d. pattern 4 (orange)

Multiple Choice Question 15

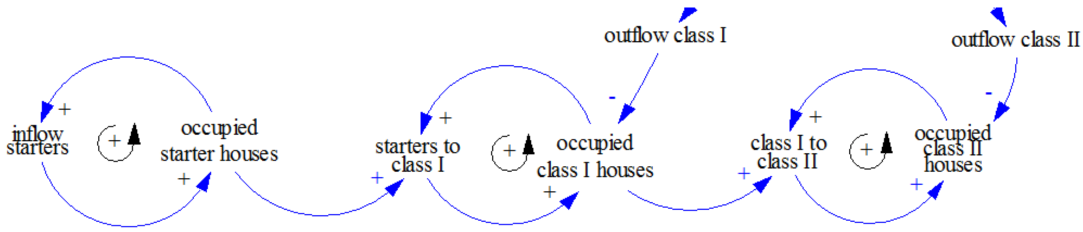
Different parts of the Dutch housing market have been under attack from different sides for the past few years. The social housing market too. According to the European Commission, the rules and organization of the Dutch corporation system did not correspond to the purpose of social housing. That is, the social rental market was not restricted to the poor. Although nobody complained, the European Commission argued that the Dutch rental market did not comply with the rules of free competition, creating a situation of unfair competition with the private rental market, resulting in a distorted housing market. After long negotiations, the Dutch government and the European Commission agreed that after 1/1/2011, 90% of all social housing vacancies would be allocated to families with incomes up to €28475 per year – which is below modal. However, no agreement was reached about the majority of above modal income families in the social housing sector, resulting in the situation that above modal income families were not allowed to move (upward or sideways) inside the social housing sector any more. For them, moving meant, from then on, leaving the social housing sector, i.e. buying or renting on the (excessively expensive) private market. Before 1/1/2011, the housing market was a pull system: after an attractive house had become vacant, another social housing family would soon move to the vacant house, freeing up their own house, which would soon be filled up by yet another social housing family, until finally, a 'starters house' would become vacant and would be occupied by young entrants into the social housing system. Due to these regulations, higher income families stay put, which brought the dynamics on the social renting market to a halt.



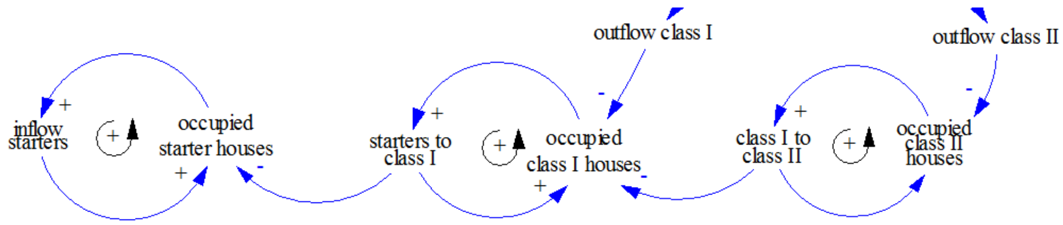
Consider the SFD of a Dutch social housing simulation model displayed above. Which of the following CLDs corresponds to this SFD?



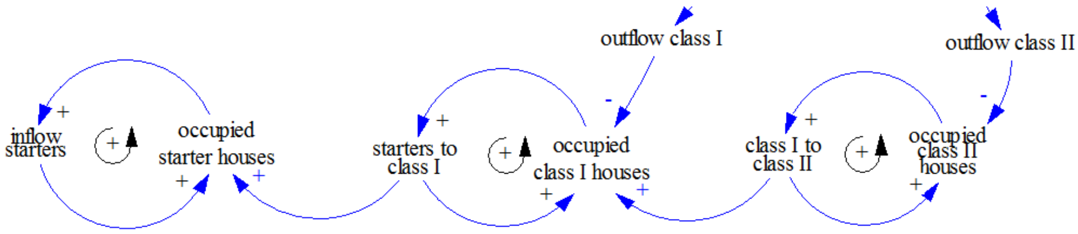
(a)



(b)

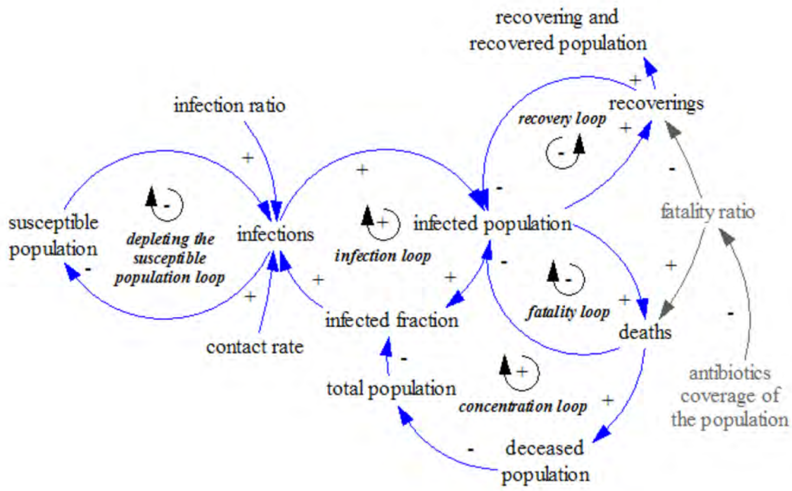


(c)

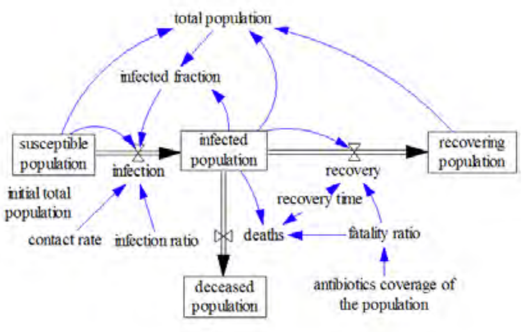


(d)

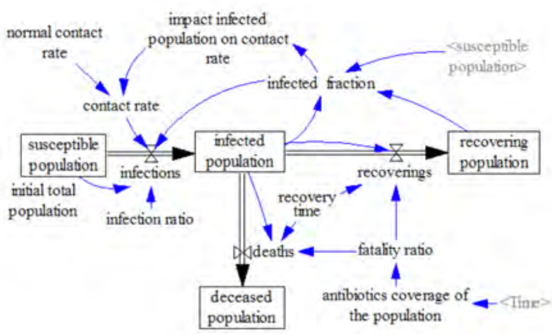
Multiple Choice Question 16



Consider the detailed CLD on the outbreak of a disease displayed above. Which of the following SFDs corresponds best to this CLD?



(a)



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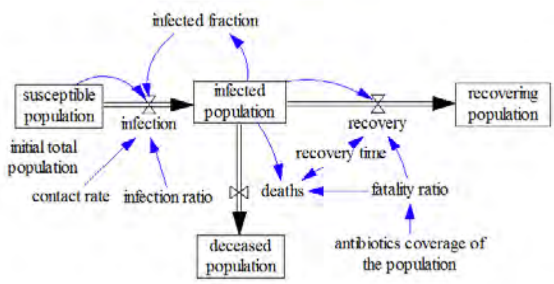

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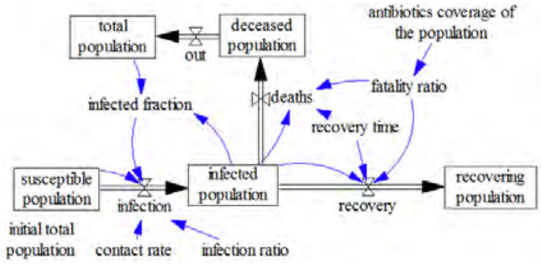
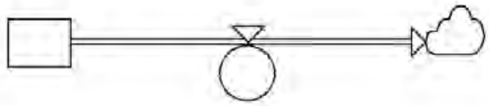
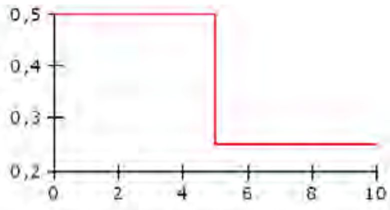


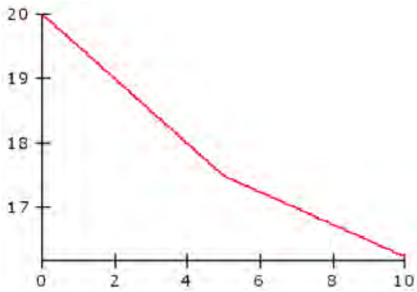
(d)

Multiple Choice Question 17

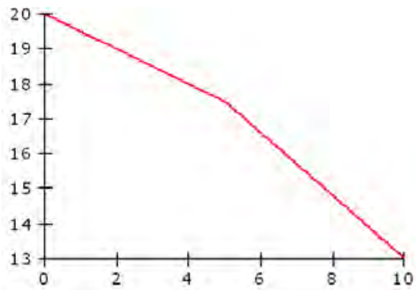




Consider the above simulation model and behavior of the *flow* variable. What is the corresponding behavior of the *stock* variable?



(a)



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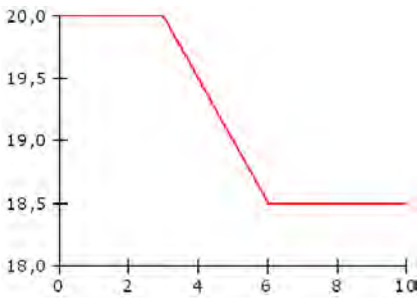

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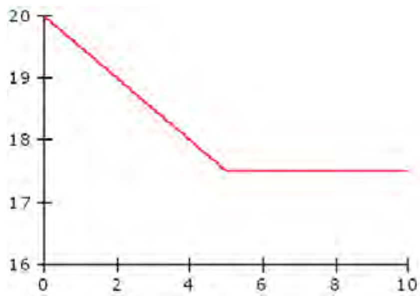


(d)

Multiple Choice Question 18

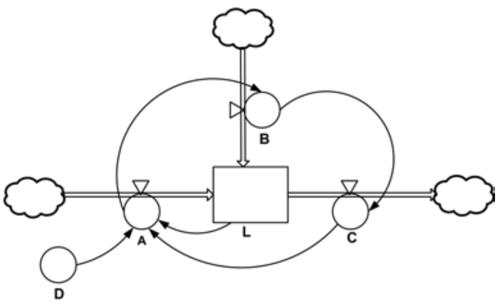
What is wrong with the SFD on the right?

a. There are too many inflows into the stock.

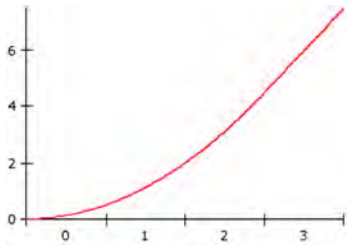
b. There is a variable in the diagram that is not influenced by other variables, hence it should have been modeled as a constant.

c. There is a loop in the diagram without a stock variable, which is not allowed.

d. The diagram is correct.

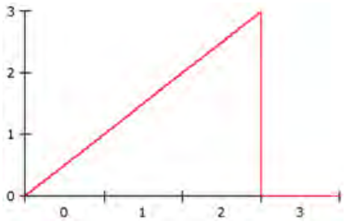


Multiple Choice Question 19



Suppose a stock variable displays the behavior over time displayed above. If the stock variable only has one flow variable, more precisely an inflow, then what is the corresponding behavior of the inflow?

(a) none of the behaviors below



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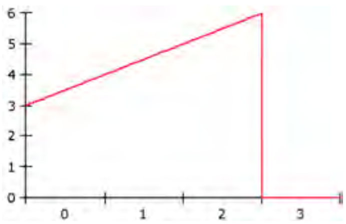

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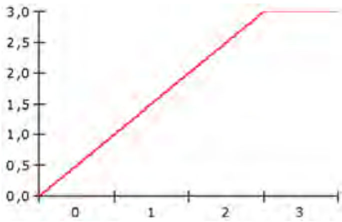
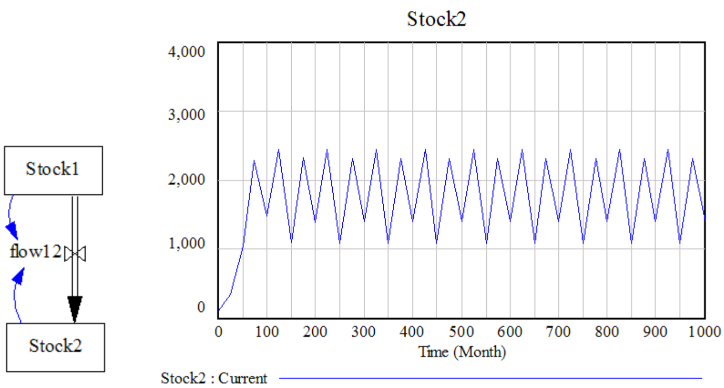


(d)

Multiple Choice Question 20



Suppose you made the model on the left. By simulating the model, you obtained the behavior on the right. What can you say about the link between model and behavior?

a. You found the critical variable values that make model behave chaotically.

b. It is impossible to obtain this behavior with that model since it is a model with only one independent stock variable.

c. You have chosen a bad time step: the output shown is due to a numeric solution error.

d. The model has complex eigenvectors.

Link to the answers to the 15 right/wrong questions & 20 multiple choice questions in this chapter.

Links to web based quizzes: | | | |

Chapter 8

Recap II – Lessons to be Learned

'Fresh understanding of the regularities underlying complex systems offers us a new perspective on sustainability, stability, and crisis-prevention methods.' (Van Santen et al. 2010, p5)

Case-Based Lessons from Part II

6.1 The main lessons from the simplistic Cocaine model are that:

- Feedback loops dominate system behavior;
- Negative loops in isolation generate balancing behavior.

6.2 The main lessons from the simplistic Muskrat Plague model are that:

- Feedback loop systems, i.e. loops that are not in isolation, can generate different types of behaviors;
- Equilibria may be stable or unstable;
- Closed loop policies may fundamentally change modes of behavior;
- Under uncertainty, closed-loop policies are more powerful than open loop policies.

$ 6.3 The main lessons from the Economic Overshoot and Collapse model are that:

- Overuse of renewable resources leads to medium to long term scarcity;
- Renewable resource systems require well thought-out flow-oriented policies.

6.4 The main lessons from the Societal Aging model are that:

- Even slow and inert processes can cause crises if solutions take time to affect the system;
- Although societal aging is a well-understood and slow phenomenon, it is also uncertain, and therefore hard to predict accurately;
- Accurate and exact prediction is not necessary to design robust adaptive policies.

6.5 The main lessons from the Threat of the Feral Pig model are that:

- Feedback loop systems can generate different types of behaviors depending in the strength and shift in relative strength of the different feedback loops;
- Equilibria may be stable or unstable;
- Closed loop policies may fundamentally change modes of behavior;
- Under uncertainty, closed loop policies are more powerful than open loop policies.

- 6.6 The main lessons from the Gangs and Arms Races model are that:
  - Reactive balancing structures may generate escalating behavior too;
  - It takes a systemic meta-perspective to demine a potentially explosive situation.
- 6.7 The main lessons from the Unintended Family Planning Benefits model are that:
  - Delayed underlying phenomena are hard to identify as causes of relatively sudden effects;
  - Although extremely simplistic models may be useful to shed some light on an issue and show a theory may be plausible, larger and more detailed modeling is mostly necessary to really test a causal theory.
- 6.8 The main lessons from the Pneumonic Plague model are that:
  - Infectious diseases may be very explosive, requiring immediate intervention, and thus, strategic stocks of vaccines, antibiotics and other medication;
  - Infectious disease models are –structurally speaking– closely related to diffusion models and aging/recycling chains.
- 6.9 The main lessons from the SD Education model are that:
  - Multiple models / dynamic hypotheses may fit the same issue and (poor) data set;
  - Reference modes may be useful in formulating dynamic hypotheses;
  - Different models / dynamic hypotheses may generate different but also very similar types of behavior;
  - Collecting detailed data may be useful to eliminate models / dynamic hypotheses from consideration for explanatory purposes;
  - Historic behaviors do not guarantee the correctness of dynamic hypotheses;
  - Policies that perform well over all plausible hypotheses and data are robust;
  - SD education needs a different diffusion model to really make a world-wide impact.
- 6.10 The main lessons from the simplistic Micro-CHP Adoption model are that:
  - Shifts in dominance of feedback loops may lead to changes in modes of behavior;
  - S-shaped growth requires at least the shift in dominance of a positive feedback loop to a negative feedback loop;
  - For generating S-shaped growth one needs at least one independent stock and connected flow, and one positive and one negative feedback loop connecting the stock and its complement to the flow.
- 6.11 The main lessons from the simplistic Housing Stock model are that:
  - Abrupt changes in goals may lead to complex dynamics, even in rather inert systems;
  - Classic n^{th} order aging chains show behavior similar to n^{th} order delays, since classic aging chains are concatenations of first order delays;
  - One of the first steps in building highly aggregated CLDs from SFDs is to replace all first (and higher) order delays into links with delay signs ($\overset{//}{+}$ or $\overset{//}{-}$).

Link to the feedback video related to all RUN-UP exercises.

Part III

HOP

Chapter 9

Basic System Dynamics Model Formulation

'He who would learn to fly one day must first learn to stand and walk and run and climb and dance; one cannot fly into flying.' Friedrich Nietzsche

This chapter is written for Vensim users. If you are not using Vensim: check here whether this chapter is available for the software you are using.

9.1 Some Predefined Functions

Following simple functions are extremely useful in SD models[1]:

- `Time` is a predefined system variable which can be included as a shadow/snapshot variable. Time is equal to `Initial Time` plus the time that has elapsed since the start of the run. `Time` is especially useful together with `SIN()` to simulate (exogenous) seasonal phenomena, and in combination with `With Lookup()` to simulate time series.
- `STEP(stepsize, steptime)` is a predefined function that allows to step up or down with a particular stepsize at time = `steptime`.
- `RAMP(slope, ramp start time, ramp end time)` is a predefined function that allows to ramp up linearly with a particular `slope` between the `ramp start time` and the `ramp end time`, e.g. RAMP(2, 5, 20) is 0 until t=5, then a linear function from 0 to 30 between t=5 and t=20, and 30 afterwards.
- `SIN(arg)` is the predefined SINE function. It is particularly useful in combination with `Time` to simulate exogenous seasonal phenomena.
- `MAX(x,y)` returns the largest of two arguments. MAX(x,0) could be used as a floor at 0.
- `MIN(x,y)` returns the smallest of two arguments. MIN(B, x) could be used as a ceiling at B.
- `ZIDZ(A,B)` stands for Zero If Divided by Zero. It returns A/B unless if B is smaller than 1E-6, then it return 0.0.

[1] Vensim notations and definitions are followed here. Other packages have equivalent as well as different functions. Equivalent versions of this chapter written for other packages are available online.

- `XIDZ(A,B)` stands for X If Divided by Zero. It returns A/B unless if B is smaller than 1E-6, then it return X.
- `MIN(B,MAX(x,A))` could be used to return values between a lower bound A and an upper bound B.
- `IF THEN ELSE(condition, arg if true, arg if false)` is a traditional `if` statement that returns the first argument (arg if true) if the condition is true, and the second argument (arg if false) if the condition is false. Note that IF THEN ELSE functions are extremely discrete.
- SoftMin and SoftMax are less discrete, i.e. more continuous, structures using table functions to set soft ceilings or soft floors.
- `PULSE(start,width)` returns the value 1 starting from a `start` time on for a time interval equal to `width`, and returns 0.0 at all other times.
- `PULSE TRAIN(start,width,tbetween,end)` returns the value 1 starting from a `start` time on for a time interval equal to `width`, and then repeats this pattern every `tbetween` time until the `end`, and returns 0.0 at all other times.
- `RANDOM` functions, e.g. Random Uniform(), returns a pseudo random number from a particular distribution at each successive invocation during a run.
- Random sampling draws a pseudo random number for a parameter or initial value from a particular distribution for a parameter at each new run, not within the same run.
- Table functions (`LOOKUP` and `WITH LOOKUP` functions in Vensim, different types of GRAPH function in Powersim,...) allow to easily specify non-linear relationships between two variables. They can be entered graphically or using couples. Specific points that require attention are the y and x values equal 0 and 1 and as well as extreme values. For multiplicative effects, the normal y value is equal to 1 and for additive effects, the normal y value is equal to 0. Using a *with lookup* function and Time allows one to introduce time series.

Note that many more predefined functions are available in most SD software packages. Note also that depending on the purpose, functions could be used in a supplementary way. Following alternative functions could for example be used for STEP-like behaviors: STEP, RAMP, PULSE with a memory structure, IF THEN ELSE, WITH LOOKUP, GET XLS DATA, GET XLS LOOKUP. Similarly, SIN, PULSE TRAIN, STEP-STEP, WITH LOOKUPS, IF THEN ELSE with MODULO(Time) with/out delays, GET XLS DATA, GET XLS LOOKUP could be used in alternative formulations for fluctuations or seasonal behaviors. And XIDZ, ZIDZ, MIN, MAX, MINMAX, Softmin, Softmax, and IF THEN ELSE are alternatives for setting floors and/or ceilings. The least discrete functions that allow for good enough a representation of the real effect should be chosen. Often, submodels could be formulated that endogenously generate the effect of exogenous functions.

9.2 Delaying and Smoothing

First Order Material and Information Delays

For this introductory SD course/book, there are two important types of delays: the 'material delay' type and the 'information delay' type, also known as smoothing. The main differences between them are (i) their different model structures, and (ii) that material delays conserve whatever is delayed whereas information delays do not. In practice however, they generate the same output as long as the delay times are equal and invariable. Variable delay time cause the behavior of

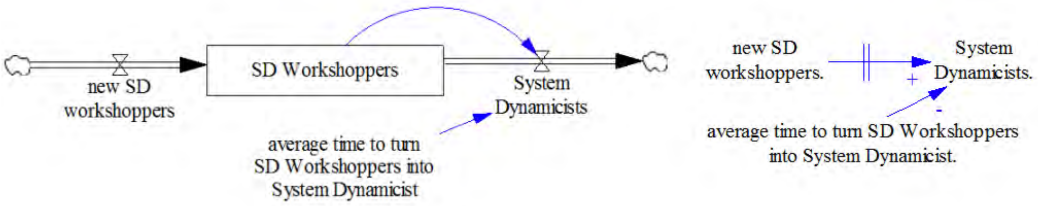


Figure 9.1: A 1^{st} order material delay as a stock-flow structure (left) and as a function (right)

material delays and information delays to differ significantly, due to their fundamentally different structures and conservation principles.

Figure 9.1 shows a first order material delay structure. The input of the delay structure is the inflow of *new SD workshoppers*. The output of the delay structure is the outflow of new *System Dynamicists* which is equal to the value of the stock divided by the delay time *average time to turn SD Workshoppers into System Dynamicists*. The output of this first order delay thus corresponds to a traditional outflow which is proportional to the perfectly mixed stock value and inversely proportional to the delay time. Instead of modeling a delay structure, one could also use the corresponding delay function. Predefined delay functions are especially useful for higher order delays, which are mostly used since first order material delays are generally speaking less appropriate for representing real world delays than 3^{rd} order delays or other, more complex, delays. Note that, normally, the inflow of a material delay needs to be nonnegative.

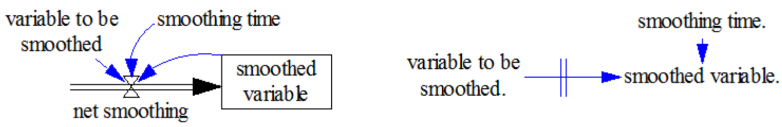


Figure 9.2: A 1^{st} order information delay as a stock-flow structure (left) and as a function (right)

Figure 9.2 shows a first order information delay structure. The *smoothed variable* is the smoothed equivalent of the *variable to be smoothed*. The flow equation is the same as the flow equation of the classic flow equation: (variable to be smoothed - smoothed variable)/smoothing time. Smoothing averages out information (e.g. oscillations) but it also delays. The most recent information receives more weight. The larger the smoothing time, the more smoothing occurs. There is no conservation of the material/mass/information that goes in. And the input does not need to be nonnegative.

Higher Order Material and Information Delays

Higher order delay and smoothing structures are obtained by cascading 1^{st} order delay structures or 1^{st} order smoothing structures. A 3^{rd} order material delay is thus the cascading of 3 1^{st} order delays with their delay time divided by the order. The same is true for higher order smoothing: Figure 9.3 shows a 3^{rd} order smoothing structure and a 1^{st} order and 3^{rd} order smoothing function. Figure 9.4 shows that the 3^{rd} order function and 3^{rd} order structure generate the same behavior for a random input whereas the 1^{st} order smoothing function shows less smoothing.

The higher the order of a delay, the slower the initial response, but the closer the replication of the input by the delayed response. Very high orders almost entirely replicate the input, although with a delay equal to the delay time. A material delay of infinite order, aka Delay Fixed (Vensim) or Pipeline delay (Powersim), delays the input exactly with the delay time. That is, individual items exit after the same delay time in the exact same order they entered. For more about delays,

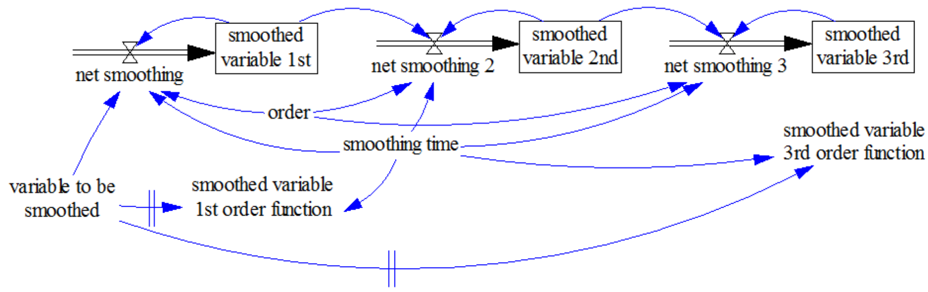


Figure 9.3: A 3^{rd} order smoothing structure, and 1^{st} order and 3^{rd} order smoothing functions

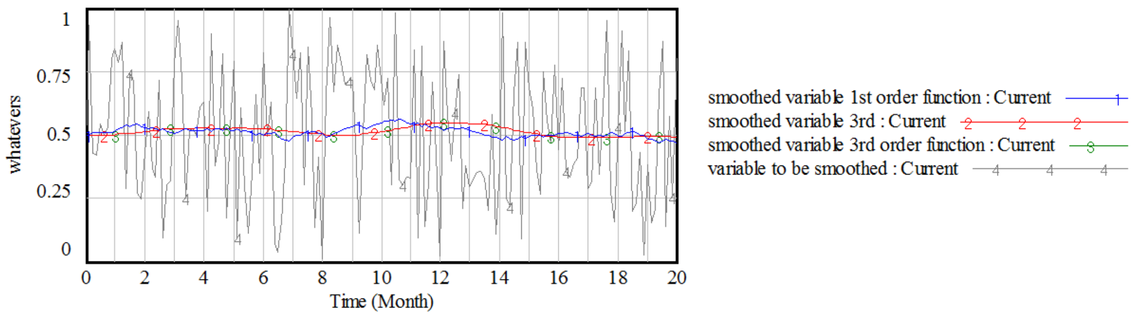


Figure 9.4: Response of a 3^{rd} order smoothing structure and 1^{st} order and 3^{rd} order smoothing functions to a random normal input

see e.g. (Forrester 1961, Chapter 9, App D and H), (Hamilton 1980) and exercise 10.4 on page 125.

The typical behaviors generated by different orders and types of delays are not shown here on purpose: in exercise 10.4 you have to discover for yourself what the effects of all sorts of delays on all sorts of inputs are.

9.3 Core Model Structures

Many models contain archetypical stock-flow and feedback loop structures that are very similar for very different topics. Examples are: Aging chains and recycling chains; Co-flow structures; Diffusion / Infection / Adoption / Transition structures; Learning curve structures; Demand with price elasticity and substitution structures; and Second order oscillatory structures. They will be pointed out in the feedback to individual, and in the feedback across, exercises/cases of a chapter.

9.4 Non-linearities

SD models and SD model behaviors are (almost always) nonlinear. Nonlinearities are often included in SD models by means of non-linear (table) functions. However, even if all equations in models with one or more feedback loops are linear, then the behaviors are almost always nonlinear. Nonlinearity is experienced and explored in almost all exercises and cases in this e-book.

Additional (non-mandatory) chapters (from the old lecture notes):

- V. Model Formulation
- Ap Mathematics for SD

Chapter 10

Technical SD Exercises

'The righter one does the wrong thing, the wronger one becomes. If one corrects an error in the pursuit of the wrong thing one becomes wronger. Therefore, it is better to do the right thing wrong than the wrong thing right because it offers the possibility of improvement.' (Ackoff 2001, p345)

10.1 Step, Ramp, Time, Sin

This technical exercise allows you to get familiar with some pre-defined functions.

1. Open a new model, change the model settings such that the model simulates from 0 to 20 years with a time step of 0.125 and use the RK4 Auto numerical integration method.
2. Use the auxiliary variable tool to add an auxiliary variable named *cte*. Give it a constant value 5 and dimensionless units (Dmnl). Simulate the model. Select the variable and visualize its behavior with the graph tool.
3. Use the auxiliary variable tool to add an auxiliary variable named *step up*. Add a STEP function to it which forces a discrete step with 6 units at time 10, i.e. STEP(6,10), and units Dmnl. Simulate the model. Select the variable and visualize its behavior with the graph tool.
4. Use the auxiliary variable tool to add an auxiliary variable named *step down*. Add the function 10 - STEP(6,5) - STEP(3,15) to it, and units Dmnl. Simulate the model. Select the variable and visualize its behavior with the graph tool.
5. Use the auxiliary variable tool to add an auxiliary variable named *ramp up*. Add a RAMP function to it that grows from time 10 till time 20 with a slope of 1 per year, and units Dmnl. Select the variable and visualize its behavior with the graph tool.
6. Use the shadow variable tool to add the predefined variable *Time*. Select the variable and visualize its behavior with the graph tool.
7. Use the auxiliary variable tool to add an auxiliary variable named *sine* with units Dmnl. Add a SIN function to it that is a function of *Time*. In other words, link a *Time* shadow variable to the sine variable, open the equation editor and add the equation: 5 + SIN(Time). Select the variable and visualize its behavior with the graph tool.

8. Now select all auxiliaries (hold the shift button) and visualize them all, except for the *Time* shadow variable.

10.2 Min, Max, MinMax, MaxMin

This technical exercise helps you to get familiar with different Max and Min constructs. Open the previous model (ex.10.1).

1. Use the auxiliary variable tool to add an auxiliary variable named *max cte and step up*. Open the equation editor and add the following function: MAX(*cte*, *step up*). Simulate the model. Select the three variables (*cte*, *step up*, *max cte and step up*) and visualize their behavior with the graph tool. What does the MAX function do?
2. Now build a function that takes the maximum of all ex.10.1 variables. Note: since max functions can only take two arguments, you will need to build nested max functions.
3. Use the auxiliary variable tool to add an auxiliary variable named *min step down and sine*. Open the equation editor and add the following function: MIN(*step down*, *sine*). Simulate the model. Select the three variables (*step down*, *sine*, *min step down and sine*) and visualize their behavior with the graph tool. What does the MIN function do?
4. Now build a function that takes the minimum of all ex.10.1 variables. Note: since min functions can only take two arguments, you will need to build nested min functions.
5. Use the auxiliary variable tool to add two constants named *floor* and *ceiling* respectively. Set the *floor* equal to 4 and the *ceiling* to 6. Add three auxiliary variables called *sine with ceiling*, *sine with floor*, and *truncated sine*. Suppose that the *sine with ceiling* equals MIN(*sine*, *ceiling*), that the *sine with floor* equals MAX(*sine*,*floor*), and that the *truncated sine* equals MAX(MIN(*sine*,*ceiling*),*floor*). Simulate the model and visualize the behaviors of these three variables. Conclude: what could MIN and MAX functions be used for?

10.3 Stocks

This technical exercise helps you to get familiar with the effects of stock variables. It builds on the previous two exercises. Open the previous model (ex.10.2).

1. Use the stock variable tool to add a stock variable named *Material1* with initial value equal to 0. Connect an inflow *MaterialIn* and an outflow *MaterialOut* to this stock. The outflow *MaterialOut* equals the stock variable divided by a *depletion time* of one year. Set the *MaterialIn* inflow equal to each of the variables in exercise 10.1: *cte*, *step up*, *step down*, *ramp up*, *Time*, and *sine*. Compare each time the behavior of the inflow and outflow of the stock. What happens?

2. Do the same for the variables added in exercise 10.2. Set the *MaterialIn* inflow equal to each of the variables in exercise 10.2: *max cte and step up*, *min step down and sine*, *sine with ceiling*, *sine with floor*, and *truncated sine*. Compare each time the behavior of the inflow and outflow of the stock. What happens?
3. Use the stock variable tool to add a stock variable named *CumulativeIn* with initial value equal to 0. Add an inflow called *CumulativeInflow*. Equate the inflow to each of the variables in exercise 10.1: *cte*, *step up*, *step down*, *ramp up*, *Time*, and *sine*. Compare each time the behavior of the inflow and stock variable. What happens?
4. Use the stock variable tool to add a stock variable named *CumulativeOut* with initial value equal to 100. Add an outflow called *CumulativeOutflow*. Equate the inflow to each of the variables in exercise 10.1: *cte*, *step up*, *step down*, *ramp up*, *Time*, and *sine*. Compare each time the behavior of the outflow and stock variable. What happens?
5. Conclude: what is special about stock variables?

10.4 First Order Material & Information Delays

This technical exercise builds on exercise 10.3. It helps you to get familiar with first order material delays and with first order information delays.

1. The stock with an inflow and outflow proportional to the stock in exercise 10.3 is in fact a first order material delay structure: the inflow is the input and the outflow gives the response or output of the delay. Now, let's build a first order information delay: add another stock variable *Information1* with initial value equal to 0, an inflow *Information1In*, an auxiliary *In1*, an auxiliary *Out1*, and a *Delay Time* of one year. The auxiliary *Out1* should be equal to the stock variable *Information1*, the inflow *Information1In* should be equal to: (*In1* - *Information1*)/*Delay Time*. Replace the variable *Depletion Time* in the first order material delay by the *Delay Time*. Equate the auxiliary *In1* to each of the variables in exercise 10.1: *cte*, *step up*, *step down*, *ramp up*, *Time*, and *sine*. Simulate and compare the inputs and outputs of this first order information delay with the first order material delay. Conclude: what does the information delay do? Do the responses of the material delay and information delay differ?
2. Now change the constant *Delay Time* into the following function over time: 1 + STEP(3,5) - STEP(2,10) - RAMP(0.1,15,20). Compare the effect on the first order material delay and the first order information delay. What happens? Do the responses of the material delay and information delay differ now? What could be concluded?
3. Why do you think the names material delay and information delay are used? What could material and information delays be used for?

10.5 Higher Order Delays

This technical exercise builds on exercise 10.4. It helps you to get familiar with higher order material delays and higher order information delays. This exercise allows you to simulate and analyze the consequences of different delays (information and material), of different orders (1^{st} order, 3^{rd} order, 10^{th} order, and pipeline delays aka delay fixed), for different inputs, and for fixed and variable delay times.

1. Select the material delay structure, the information delay structure, and the *step up* variable from the model developed in exercise 10.4, copy them, open a new model, paste them, and adapt your model settings. Change the *delay time* into a constant 1 year. Name the simulation run, e.g. '1^{st} order', and simulate the model.

2. Extend both structures to a second order delay by copying these structures linking the output variables to the input values and adding a variable *delay order* and *delay time divided by delay order*. The formula of the variable *delay time divided by delay order* is of course equal to the *delay time* divided by the *delay order*. Rename the simulation run, e.g. '2nd Order', set the *delay order* equal to 2, and simulate the model again. Visualize and compare the 1^{st} order and 2^{nd} order outputs of the material delay and the information delay. What is the difference between the 1^{st} order and 2^{nd} order delays? What is the difference between material delays and information delays?

3. Do the same for a 3^{rd} order delay: extend the stock-flow structures, change the order, change the run name, simulate, and compare their behaviors.

4. Delays can also be specified with predefined functions. Make a new variable called *MaterialDelayFunction* and a new variable called *InformationDelayFunction*. Open these variables with the equation editor and select the function DELAY3I for the *MaterialDelayFunction* and SMOOTH3I for the *InformationDelayFunction*. Select the same input *In*, *delay time*, and initial value 0 as before. Simulate the model and compare the outputs of the *MaterialDelayFunction* and the 3^{rd} order material delay stock-flow structure. Do the same for the outputs of the *InformationDelayFunction* and the 3^{rd} order material delay stock-flow structure.

5. Now change the constant *delay time* into the following function over time: 1 + STEP(3,5) - STEP(2,10) - RAMP(0.1,15,20). Compare the effect on the 1^{st} order material delay and the 1^{st} order information delay. What happens? What could be concluded?

6. Change the 3^{rd} order delay function and 3^{rd} order smooth function into DELAY N and SMOOTH N which can be selected in the 'all' functions class. These functions do the same, but now the order can to be set too. Choose for example a 10th order. Rename the run, simulate it and compare the response. Double the order, rename the run, simulate it, and compare the output. What could be concluded?

7. Add another auxiliary variable *MaterialDelayfixed*, specify its function as DELAY FIXED (Vensim) or Pipeline Delay (Powersim) and simulate it. Compare the output to the highest order material delay function. What could be concluded: what is and what does a delay fixed aka pipeline delay do?

8. Copy-paste the other inputs from the model developed in exercise 10.1, connect them, and compare the responses of the delay and smooth structures with the corresponding inputs.

9. What are your overall conclusions regarding material and information delays? Why do you think the names material delay and information delay are used?

10.6 Lookups, With Lookups, Time Series

If you solved exercise 6.8 on page 97 related to the outbreak of Pneumonic Plague in China, then open your model, and set the *antibiotics coverage of the population* back to 0%. If you have not solved exercise 6.8 on page 97 yet, then read the description and open the corresponding model here.

1. The fatality ratio is 90% at 0% *antibiotics coverage of the population* and 15% at 100% *antibiotics coverage of the population*. Add a table function (WITH LOOKUP or LOOKUP in Vensim and one of the GRAPH functions in Powersim) *effect of antibiotics coverage on fatality ratio* to include this effect.
2. The outbreak of an extremely contagious deadly illness such as pneumonic plague actually causes the *contact rate* to drop (because of panick and illness). Adapt the model by closing the 'loop' between the *infected fraction* and the *contact rate*. Create a function *impact of the infected fraction on the contact rate* that, multiplied with the *normal contact rate* (the one without epidemic and panick), gives the effective *contact rate*. The function takes a value of 1 at an *infected fraction* of 0%, of 0.5 at an *infected fraction* of 10%, of 0.25 at an *infected fraction* of 20%, 0.125 at an *infected fraction* of 30%, of 0.0625 at an *infected fraction* of 40% , of 0.03125 at an *infected fraction* of 50%, and so on. Simulate the model over a time span of 1 month. Make graphs of the evolution of the *infections*, the *deaths*, the *recovering population*, and the *deceased population*. Does this reduction of the natural contact rate result in the desired effect?
3. Suppose that the *antibiotics coverage of the population* increases linearly in de first week of the epidemics from 0% to 100%. Add a table function to simulate this effect. What is the consequence on the *deceased population*?

10.7 SoftMin & SoftMax versus Min & Max

Solve this exercise right after solving exercise 10.12 on page 132.

The hard min/max functions in exercise 10.12 may not be appropriate if the behavior near the max/min values matters. In such cases, it is better to use Softmin/Softmax functions. One way to include Softmin/Softmax functions is with a nonlinear table function that specifies the way the process (e.g. depletion) works under normal conditions as well as near the limit.

1. Open exercise 10.12.
2. Replace the max/min functions that determine the way depletion happens when the stock is nearly depleted by softmax/softmin functions.

3. Simulate the model and compare it to the behavior of the previous model.
4. Do you need to replace all max/min functions with softmax/softmin functions? Explain.

10.8 Pulse and Pulse Train

Let's start with an exercise on PULSE functions, that is, the Vensim variant. Powersim's PULSE function corresponds to a PULSE TRAIN in Vensim, which will be addressed afterwards. Vensim's PULSE function can be replicated in Powersim with a step-up-step-down construct (+Step(,)-Step(,)).

1. Make a simple model consisting of a *stock* with an initial value of 0 units, and an *inflow* equal to a PULSE that starts at time 10 with a duration of 0.5. Set *Initial Time* to 0, *Final Time* to 40, and use RK4 with a *Time Step* of, say, 0.125. Simulate the model. What happens?
2. Set the duration to 1. Simulate again and compare.
3. Suppose we want this inflow to add 10 units to the stock during the pulse. How can we do that without changing the duration? Do it.
4. Now suppose we want this inflow to add 10 units to the stock, no matter what the duration of the pulse is. How can we do that using the pre-specified variable *Time Step*? Do it.
5. Add an *outflow* proportional to the *stock* that is active during a PULSE with a duration equal to 1. That is, specify the equation as follows: PULSE(20,1) * *stock*. Simulate the model. What happens?
6. Suppose we want the outflow to empty the stock entirely during the PULSE, whatever the duration of the PULSE is. How can we do that using the pre-specified variable Time Step? Do it.
7. Vary the simulation settings to check whether indeed both PULSE functions do what they need to do.
8. So, how exactly do PULSE functions work?

Now, let's change the PULSE functions into PULSE TRAIN functions in Vensim or PULSE functions in Powersim.

9. First, change the function of the *inflow* into PULSE TRAIN(5, 0.5 , 2 , 35). What do you think this function with these parameters does? Simulate. What happens?
10. Adapt the function such that it always adds 2 units for each pulse and that the duration of each pulse is as long as the *Time Step*.
11. Second, change the *outflow* such that it empties the stock entirely (no matter how large it is) starting at each even simulation time from $t = 6$ on. Verify that the stock is indeed periodically emptied. What is the formulation of your *outflow* function?

10.9 Randomizers and Randomly Sampled Parameters

The difference between randomizers, randomly sampled parameters, and randomly sampled randomizers is explored in this exercise. This exercise is written for Vensim users, although other packages have similar functionalities. Variants for other packages will be added online (||).

Let's start with random functions, also known as randomizers.

1. Open a new model and add four variables: *random variable 1*, *random variable 2*, *seed*, and *difference between random variables*. Use the same predefined RANDOM UNIFORM(0, 1, seed) functions for the two random variables, set the seed to 1234, and specify the *difference between random variables* as *random variable 1 - random variable 2*.
2. Set the Final Time to 10, the Step Size to 0.25, use RK4 (or another integration method), and simulate the model. Study the behavior of *random variable 1*, *random variable 2*, and the *difference between random variables*. What can be concluded?
3. Change the function of *random variable 2* into RANDOM UNIFORM(0, 1, 1111). Rename the run and simulate the model again. Compare the outputs once more. What could be concluded?

Now we will add randomly sampled parameters to this model and explore the difference between randomizers and random sampling. Moreover, we will also study the effect of random sampling on randomizers. Note however, that, for Vensim users, PLE+ or higher is required for the rest of the exercise since we will need to use the sensitivity analysis tool.

4. Add two parameters *randomly sampled variable 1* and *randomly sampled variable 2*. Give both of them a value 1. And add a variable *difference between randomly sampled variables* which is equal to *randomly sampled variable 1 - randomly sampled variable 2*.
5. Now, click on the Simulation Control button, edit the Sensitivity Control, and change the settings to 2 simulations using Latin Hypercube with a noise seed of 1234. Select the two variables *randomly sampled variable 1* and *randomly sampled variable 2*, and choose RANDOM UNIFORM distributions between 0 and 1 for both. Add them, and click on OK. Now make a Sensitivity Save List and add *randomly sampled variable 1*, *randomly sampled variable 2*, *random variable 1*, *random variable 2*, *difference between random variables* and *difference between randomly sampled variables* to it.
6. Then click on the Sensitivity button. Two runs will be executed and different values will be sampled in each run for *randomly sampled variable 1* and *randomly sampled variable 2* from the corresponding distributions.
7. Click right on the Sensitivity Graph button, select the individual traces option, confirm. Then click left on each of the variables and sets of variables, and analyze what has happened. What could be concluded with regard to the randomly sampled variables? What could be concluded with regard to the randomizers?

In some cases, one may want to use random randomizers. Let's make one now.

1. Go to the simulation control and add the *seed* parameter to the list of sampled parameters. Use a RANDOM UNIFORM distribution between for example 1001 and 1999.
2. Change the number of runs to be simulated to 50, confirm, and click on Sensitivity. Use the Sensitivity Graph tool to look at the effect on all variables, and conclude.
3. What is a random randomizer? Why and when would one want to use one?
4. What is a seed?

There are many predefined random functions. Readers who lack formal training in statistics, may want to read about the differences between these distributions and what they may be used for, for example in the online software documentation.

10.10 Special Structures

Sampled Noise with an Interval

Ford (2009, p175-176) describes a structure that allows one to sample noise and hold the sampled values for a noise interval. The structure can be downloaded here. Test and compare it to the outputs generated in exercise 10.9.

White and Pink Noise

Sterman (2000) provides as structure that transforms White Noise into Pink Noise. Pink Noise is first-order autocorrelated noise. It provides realistic noise inputs to models in which the next random shock depends in part on previous shocks. The structure is such that the user needs to specify the mean, standard deviation, and noise seed for the white noise that drives the pink noise process. The white noise input follows a standard normal distribution, scaled such that the standard deviation of the resulting pink noise is equal to the parameter specified by the user. The structure can be downloaded here. Test it.

State Space Diagrams

Hartmut Bossel (2007a, Z115) developed a model structure that allows to plot a 2D state space diagram or phase plot that allows one to assess the influence of 10x10 initial conditions for pairs of stock variables with uncertain initial conditions. The structure can be downloaded here or from his web site.

1. Open model Z114. It is a model of a linear oscillator of the second order.
2. Simulate the model. Perform a Latin Hypercube sensitivity analysis on the initial conditions of *state 1* and *state 2*. Let INITIAL STATE 1 and INITIAL STATE 2 vary between -1 and 1. What could be concluded?
3. Change the values of the *COUPLING FACTOR 1 to 2* to 1 and *SELFCOUPLING FACTOR 2* to -1. Simulate the model. Perform a Latin Hypercube sensitivity analysis on the initial conditions of *state 1* and *state 2*. What could be concluded now?
4. Open a new version of Vensim. Open model Z115. The top-most structure is the same as model Z114. Compare the changes in the equation between *state 1* and *state 2* between the two models.

5. Make sure the settings of MIN STATE 1, MAX STATE 1, MIN STATE 2, and MAX STATE 2 correspond to the upper and lower limits specified above.

6. Also set the COMPUTE LENGTH at 1. The total simulation period (FINAL TIME - INITIAL TIME) must be at least 100 times this COMPUTE LENGTH. Set the FINAL TIME therefore equal to 100, the INITIAL TIME equal to 0, and the TIME STEP equal to 0.05.

7. Simulate the model. Open the Control Panel. Select the graph and display it. If you do not see dots, then change your graph settings to dots (left click on graph tool). If you see dots, what could be concluded?

8. Change the values of the *COUPLING FACTOR 1 to 2* to 1 and *SELFCOUPLING FACTOR 2* to -1. Simulate again, display the graph and interpret. What could be concluded?

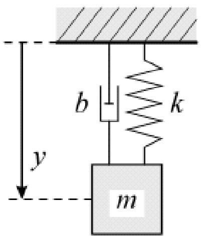
9. Note: The easiest way to use this module is to copy your model into it. Then connect the most important stocks as was the case with *state 1* and *state 2*, change the MAX STATE an MIN STATE variables, simulate, visualize, and interpret.

10.11 Damped mass-spring system

The behavior of the damped mass-spring system displayed in the graph on the right can be described by the following second-order differential equation:

$$y'' = g - \frac{k}{m}y - \frac{b}{m}y'$$

with $y(t_0) = y_0$ and $y'(t_0) = 0$.



$m = 1$
$b = 0.5$
$k = 2$
$y_0 = 10$
$g = 9.81$

1. Transform it into a system of two first-order differential equations. Then make a SD model of this initial value problem related to a damped mass-spring system that is released at time 0. Use the values displayed next to the figure of the damped mass-spring system. Simulate the model (i.e. numerically solve the system of differential equations).

2. Make a graph of y over time for each of the numerical solution methods below and compare the graphs.

a	Euler	step size = 1	start = 0	stop = 20
b	Euler	step size = 0.1	start = 0	stop = 20
c	Euler	step size = 0.01	start = 0	stop = 20
d	RK4	step size = 1	start = 0	stop = 20
e	RK4	step size = 0.1	start = 0	stop = 20
f	RK4	step size = 0.01	start = 0	stop = 20

3. Discuss the results. What step size and integration method would you recommend? Why?

4. Validate your model.

5. Calculate the roots of the characteristic equation. What can you say about the exponents in the solution? What does this mean for the behavior of the system as a function of time? Does that correspond to the simulated behavior?

10.12 Un/Conventional Gas

Until recently, the prospects for gas looked pretty dim: currently known conventional gas reserves will be depleted within 40 years if the demand for gas keeps on increasing by 2% per year.

However, technological developments related to shale gas may turn that dim future into a bright one. Shale gas is natural gas produced from shale[1]. Shale gas has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential gas shales in Canada, Europe, Asia, and Australia. Note however that shale gas is also strongly contested.

1. Model the conventional gas demand and supply. Make sure that modeled gas reserves are depleted in 40 years.
2. Extend the conventional gas model with shale gas. Suppose that adding shale gas to the conventional reserves/resources would double them.
3. How many years would it take then before the total gas reserves/resources are depleted if the demand for gas keeps on increasing by 2% per year?
4. Replace hard Max and/or Min functions if you used any.

10.13 Mass Starvation in the OVP

Introduction

The swampy natural reserve the 'Oostvaardersplassen' (OVP) –approximately the area between Almere and Lelystad in South Flevoland, the Netherlands– was created when it was decided –some time after the impoldering– to create a large area where geese could pass the molting season. Large herbivores were needed in order to keep the area free of willows and other brushwood. Hence, a small group of Heck cows were introduced in 1983, followed by Konik horses in 1984 and red deer in 1992. The area was supposed to bring back Dutch primal nature: the area would be left to nature – no hunting would be allowed.

The three populations of herbivores increased prosperously, at the beginning even exponentially, as could be expected with herbivores without natural enemies on such a large pasture area. However, the last couple of years, a large fraction of the large herbivores did not survive the winter. Movies of many of the animals dying of starvation caused major public outrage and discussions whether the area should be managed or not and whether animals should be shot or not, and if so, when (just before the winter season or just before dying).

[1] Shale is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite.

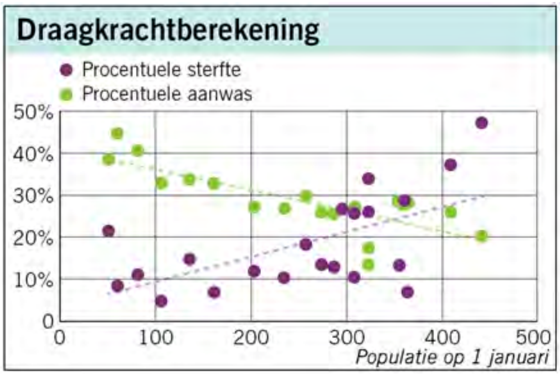
Modeling the Large Herbivore Population

Make a System Dynamics simulation model about the large herbivores in the Oostvaardersplassen based on following information.

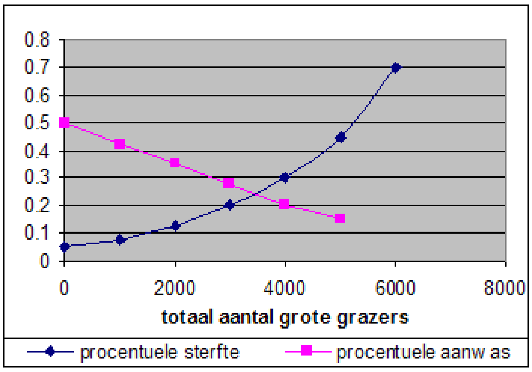
Suppose that there were 75 *large herbivores* in the Oostvaardersplassen in 1985. One could model the *births* as the product of the number of *large herbivores*, the *percentage birth rate*, the *birth season* and the *birth randomizer* divided by the *length of the birth season*. And one could model the *deaths* as the product of the number of *large herbivores*, the *percentage death rate*, the *death season* and the *death randomizer* divided by the *length of the death season*.

Model the *birth season* with a pulse train starting in 1982.5 with the *length of the birth season* and a frequency of 1 year until the final simulation time. Model the *death season* with a pulse train starting in 1982 with the *length of the death season* and a frequency of 1 year until the final simulation time. Make your model such that the *length of the birth season* and the *length of the death season* are equal to the time step.

Suppose that you obtain the information in Figure 10.1(a) regarding past assessments of two aspects of the carrying capacity of the area for Heck cows and that you generalize the information regarding Heck cows to all large grazers in the Oostvaardersplassen as in graph 10.1(b). Use the estimates displayed in Figure 10.1(b) to model the *percentage birth rate* of the *large herbivores* and the *percentage death rate* of the *large herbivores*.



(a) Carrying capacity for Heck cows in the OVP – Source: NRC Handelsblad 11/12/2010



(b) Generalized carrying capacity curves for all large herbivores in the OVP

Figure 10.1: Carrying capacity and generalized carrying capacity for the OVP

Also add a *birth randomizer* distributed normally between 0 and 2 with average 1 and standard deviation 0.5 and seed 2 (the seed is a number from which a (pseudo-)random number is generated). And add a *death randomizer* distributed uniformly between 0.5 and 3 with seed 3.

The information related to the three output indicators of interest (number of *herbivores*, *births* and *deaths*) still needs to be smoothed for at least two reasons:

- Since the OVP reserve is a rather large UR-wildlife reserve, it is impossible to monitor the exact numbers of births, deaths and the number of large herbivores over time: assessment of these evolutions could, at best, be made based on periodic assessments (right before and right after the *birth season* and *death season*) and some additional calculations/smoothing.
- Rather discrete modeling constructs used in the description above may lead to discrete flow behaviors that need to be turned back to continuous evolutions.

Add therefore a variable *smoothed info on large herbivore births* to smooth the *births* according to 3^{rd} order exponential smoothing with a delay of 1 year. Do the same for the variables *smoothed info on large herbivores* and the *smoothed info on large herbivore deaths*.

1. Make a SD simulation model based on the description and information provided above.
2. Test the model: list two useful validation tests (except for sensitivity analysis – see below), perform them, and briefly describe your results/conclusions.
3. Simulate the model and plot the evolution of the births and deaths (in the same graph), as well as the number of *large herbivores*. Simulate the model again with a different 'seed' and plot the results once more. Do this again, and again, and again. Generalize and conclude.
4. Perform the necessary sensitivity analyses. To which parameters and assumptions is the model behaviorally sensitive? Briefly describe the analyses performed and draw only the interesting outcomes.
5. Make complete and aggregate CLDs of this model and use one of these CLDs to explain the link between structure and behavior.
6. What would be an appropriate policy for this problem? Implement it in the model and test it. What is your conclusion? Why?

10.14 Verification and Debugging

1. Debug model 1.
2. Debug model 2.
3. Debug zipped models.

10.15 Sensitivity, Uncertainty, Scenarios & Robustness I

Revisit the Muskrat Plague model from exercise 6.2 (p.92 – ||):

1. There are several uncertainties in the model(s). List them.
2. Conduct a manual sensitivity analysis: manually change all uncertain parameters with ± 10% and test whether they have a significant influence on the behavior.
3. Conduct an automated Sensitivity Analysis / Risk Analysis: use Latin Hypercube sampling and assume that all uncertain parameters are independent.
4. What conclusions are there to be gained from these sensitivity analyses?
5. Do the same for the model with the closed-loop policy. Do your conclusions regarding the sensitivity of the model and policy change?
6. Now perform an uncertainty analysis on the model with the closed-loop policy. What could be concluded? Is the closed-loop really policy robust?

Revisit the micro-CHP Diffusion model from exercise 6.10 (p.99 – ||):

7. There are several uncertainties in the model(s). List them.
8. Conduct a manual sensitivity analysis: manually change all uncertain parameters with ± 10% and test whether they have a significant influence on the behavior.
9. Conduct an automated Sensitivity Analysis / Risk Analysis: use Latin Hypercube sampling and assume that all uncertain parameters are independent.
10. Now perform an uncertainty analysis. What could be concluded?
11. What conclusions can you derive from these analyses?

10.16 Sensitivity, Uncertainty, Scenarios & Robustness II

1. Open the burnout model developed by Jack Homer (1985) (download the paper here).
2. Test the sensitivity and conclusions of the model to small parameter changes (up to 10%). What could be concluded?
3. Test the robustness of the conclusions to the largest plausible parameter ranges. What could be concluded?
4. Test the sensitivity and conclusions of the model to changes in all lookup functions and parameters. What could be concluded?
5. Which uncertainties have the strongest effect on higher values of the accomplishments to date?

10.17 Additional Exercises in Online Repository

|⊕| Add. ex. 1
|⊕| Add. ex. 2
|⊕| Add. ex. 3
|⊕| Add. ex. 4
|⊕| Add. ex. 5
|⊕| Add. ex. 6
|⊕| Add. ex. 7
|⊕| Add. ex. 8
|⊕| Add. ex. 9
|⊕| Add. ex. 10
|⊕| Add. ex. 11
|⊕| Add. ex. 12
|⊕| Add. ex. 13
|⊕| Add. ex. 14
|⊕| Add. ex. 15
|⊕| Add. ex. 16
|⊕| Add. ex. 17
|⊕| Add. ex. 18
|⊕| Add. ex. 19
|⊕| Add. ex. 20
|⊕| Add. ex. 21

Chapter 11

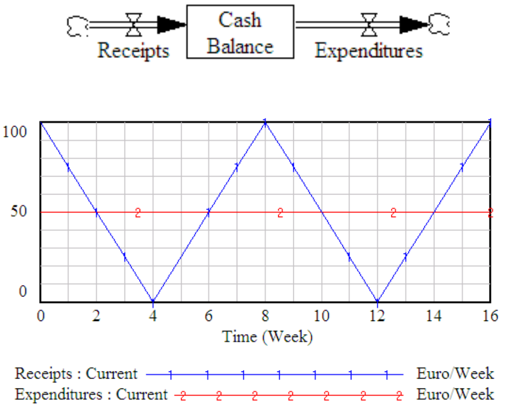
MCQs Part III

'[A]ll models are wrong, but some are useful' (Box and Draper 1987)

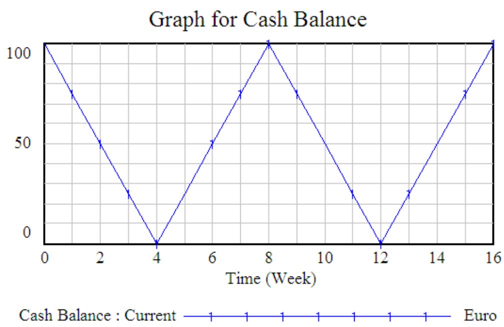
Which of the following statements are right and which are wrong?

1. The smaller the smoothing time, the smaller the oscillations in the smoothed response are.
2. A seed is a number from which a pseudo-random number is generated.
3. The number of feedback loops in a CLD equals the order of the system being modeled: e.g. a feedback loop system with 2 loops corresponds to a 2^{nd} order system.
4. In models containing discrete functions, Euler is the most appropriate integration method.
5. For a given step size, Runge-Kutta(4) will always outperform Euler in a purely continuous model with oscillatory tendencies.
6. SD models are continuous models: a model with discrete functions cannot be called a SD model since it is not continuous.
7. In SD models, using softmin/softmax structures is always better than min/max functions.
8. It is possible that the same real-world system element –for various levels of aggregation and time horizons of interest– is modeled as a constant, a stock, a flow, or an auxiliary.
9. A softmin is a smoothed min function in a soft variable.
10. Two step functions can substitute a pulse function, and a pulse function in an inflow plus a stock variable can substitute a step function.
11. Using random sampling is a substitute for using randomizers.
12. Unexpected runaway behavior could be caused by a sign error in a stock equation, e.g. INTEG(-inflow, initial) or INTEG(+outflow, initial).
13. Floating point errors indicate that even though all equations can be computed, values to be computed are too big. They are often caused by positive feedback loops or divisions by 0.
14. If the eigenvalues of a 2^{nd} order SODE are complex with a negative real part, then the behavior is asymptotically stable in the equilibrium points.
15. PULSE TRAINS can be replicated with a combination of Time, Modulo and PULSE functions.

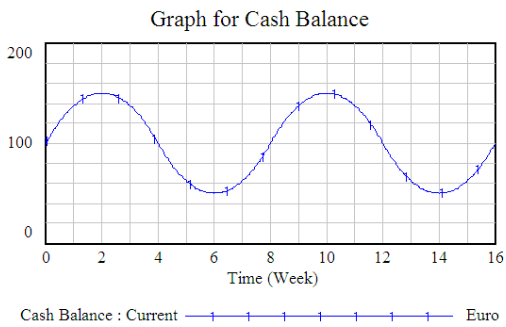
Multiple Choice Question 1



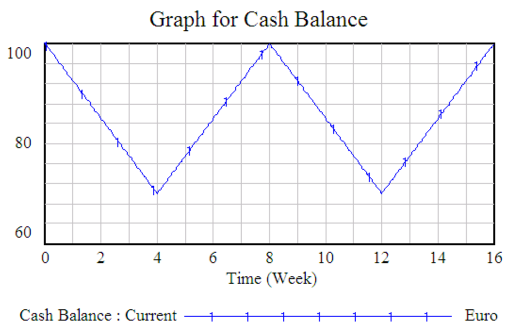
Consider the cash balance model of a company on the left. Receipts (blue –1–) flow into the balance at a particular rate, and expenditures (red –2–) flow out at a particular rate as is displayed on the right. The graph on the right shows the evolution of the receipts and expenditures over time. Given this information and assuming that the initial cash balance equals €100, what is the behavior of the firm's cash balance?



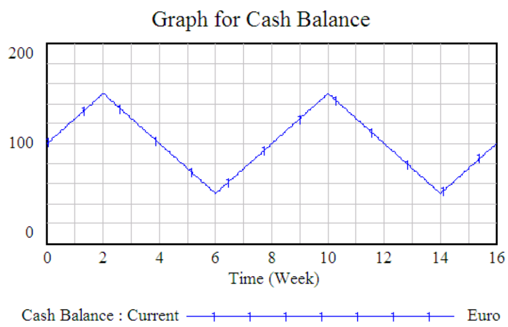
(a)



(b)



(c)



(d)

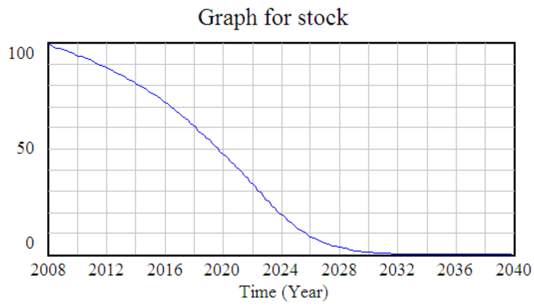
Multiple Choice Question 2

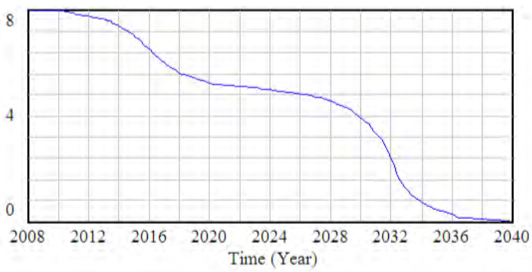
Using a simplistic SD model one can foresee that the currently known gas reserves will be depleted within 40 years if the demand for gas keeps on increasing by 2% per year.
Suppose that gas reserves are just half as large as expected. How many years would it take then before the gas reserves are depleted if the demand for gas keeps on increasing by 2% per year?

a. ± 16 years; b. ± 23 years; c. ± 30 years; d. None of the previous answers.

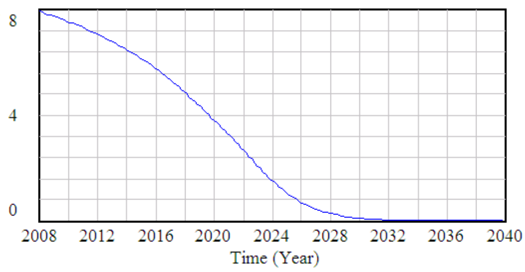
Multiple Choice Question 3

Consider the behavior over time of the stock variable on the right. This stock variable has 1 outflow and no inflow. By which of the outflow behaviors displayed below could the behavior of the stock variable be caused?

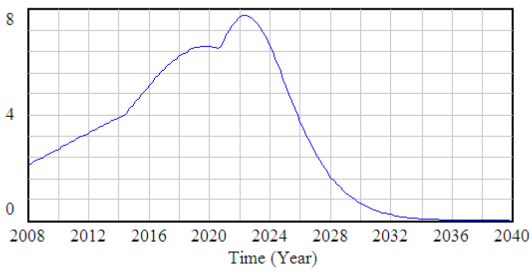




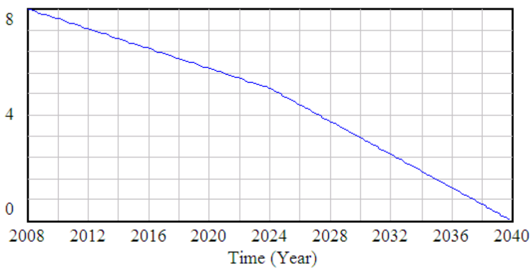
(a)



(b)



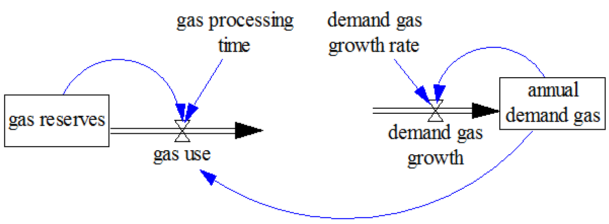
(c)



(d)

Multiple Choice Question 4

Given the model on the depletion of '*natural gas*' displayed on the left, what are the units of the variable *demand gas growth* if the units of *gas use* are $m^3/Year$?



a. $m^3/Year$

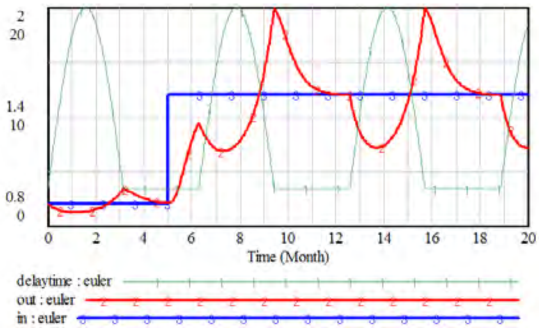
b. $m^3/Year^2$

c. m^3

d. None of these answers is correct

Multiple Choice Question 5

Consider the behavior of an input (blue curve) and its delayed output (red curve) in the graph on the right. The input increases according to a STEP function at $t = 5$ and the delay time varies following the green curve. Which type of delay of which order could cause this behavior?



a. a 1^{st} order information delay

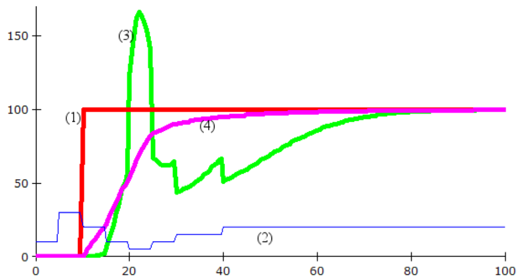
b. a 3^{rd} order information delay

c. a 3^{rd} order material delay

d. none of them could cause this behavior

Multiple Choice Question 6

Consider the graph below. A step function input (1) is delayed with variable delay time (2). Which of following statements related to the delayed responses (3) and (4) could be true?



a. (3) is a 3^{rd} order material delay, (4) is a 1^{st} order information delay

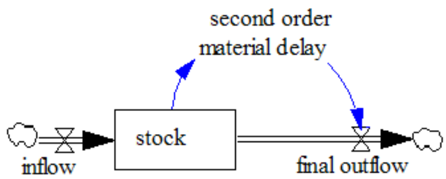
b. (3) is a 3^{rd} order information delay, (4) is a 1^{st} order material delay

c. (3) is a 1^{st} order material delay, (4) is a 3^{rd} order information delay

d. (3) is a 1^{st} order information delay, (4) is a 3^{rd} order material delay

Multiple Choice Question 7

Consider the SFD on the right. Which of the following statements concerning this model could possibly be correct?



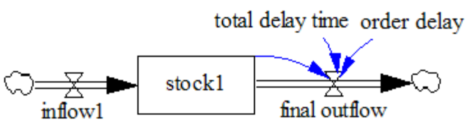
a. This structure combines a first-order material delay with a second-order material delay, which together make a 3^{rd} order material delay. The *final outflow* is therefore a 3^{rd} order material delay of the *inflow*.

b. This structure combines a first-order material delay with a second-order material delay, but by means of blue information arrows, which does not make a 3^{rd} order material delay. The *final outflow* is therefore *not* a 3^{rd} order material delay of the *inflow*.

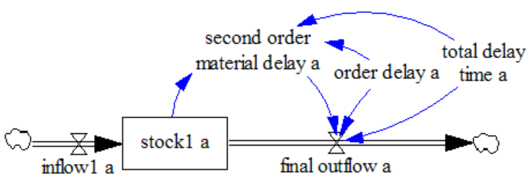
c. This structure combines a first-order material delay with a second-order material delay, but is *not* a 3^{rd} order material delay. This structure can generate oscillatory behavior of the *final outflow* even if the *inflow* is not oscillatory.

d. None of the statements above could possibly be correct.

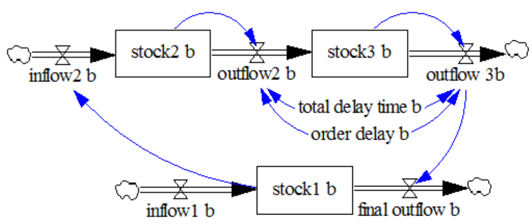
Multiple Choice Question 8



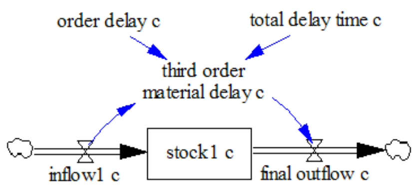
Suppose you are asked to turn the 1^{st} order delay structure on the left –without too many changes (e.g. by using a function)– into a 3^{rd} order delay structure. Which of the following adapted stock-flow structures could be used to simulate a 3^{rd} order delay if all variables –except for some constants– are visualized?



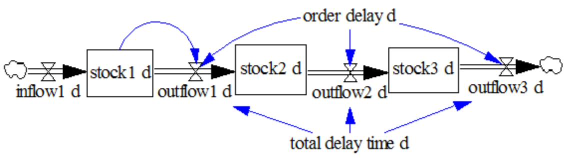
(a)



(b)



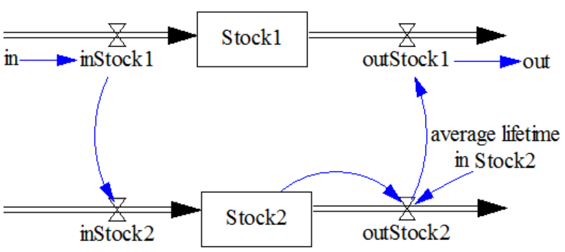
(c)



(d)

Multiple Choice Question 9

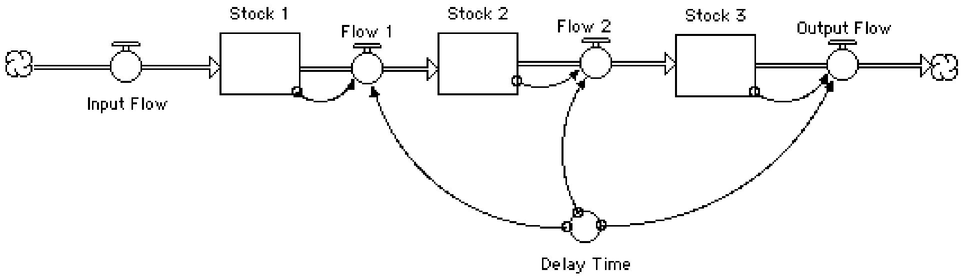
Consider the following model in which $inStock2 = inStock1 = in$ and $out = outStock1 = outStock2$. What does this structure correspond to?



a. The first tier in a bull-whip structure
b. A negative feedback loop with a delay
c. A 1^{st} order material delay
d. None of the previous answers is correct

Multiple Choice Question 10

A 3^{rd} order material delay structure is given below. The system with a *Delay Time* of 5 months is observed to be in equilibrium. If the *Input Flow* to this structure is 10 cars/week, which of the following is true about the *Output Flow* and/or the value of the stock variables?



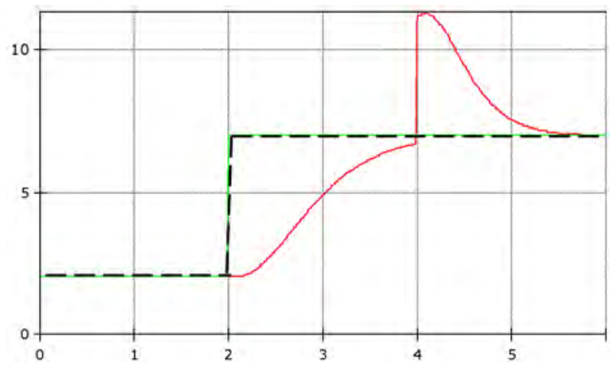
a. The stock values cannot be calculated.

b. All stock values are equal.

c. The output flow is equal to 2 cars/week.

d. *Stock 3* has a value of 2 cars.

Multiple Choice Question 11



Consider following graph representing the behavior of an input (dashed green) and the behavior of the delayed output (red). The input steps up at $t = 2$, and the time constant changes abruptly at $t = 4$. What order and type of delay could cause this behavior?

a. a 1^{st} order material delay

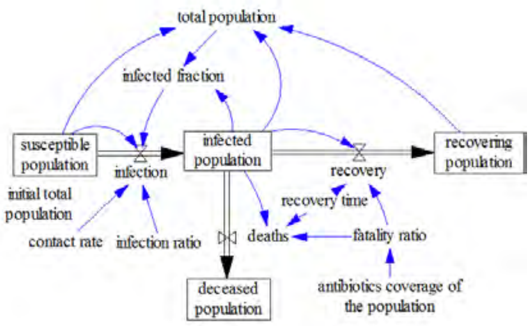
b. a 3^{rd} order material delay

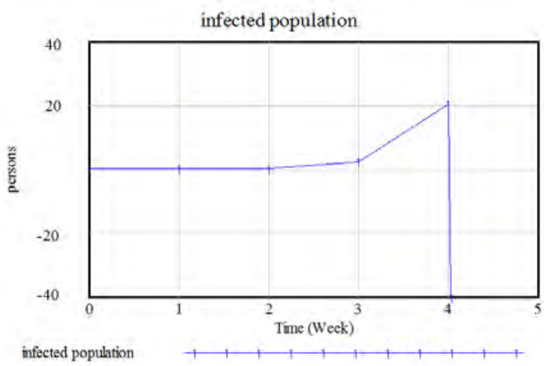
c. a 1^{st} order information delay

d. a 3^{rd} order information delay

Multiple Choice Question 12

The simple SD model below is about the outbreak of pneumonic plague in an isolated community (more precisely a remote Chinese village with 10000 inhabitants). The behavior on the right hand side of the Stock-Flow Diagram is generated with this model. Which of the following statements is correct?





a. The model is wrong because of a specification error: the *infection* flow must be modeled as non-negative.

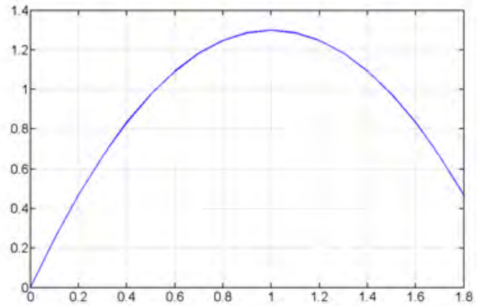
b. The model is wrong because of a numeric integration error: it looks as though the Euler integration method is used with too big a time step.

c. The model is wrong because of a numeric integration error: it looks as though the Runge-Kutta4 integration method is used with too small a time step.

d. The model is wrong because of a specification error: the *recovery* flow and *deaths* flow should have been modeled as non-negative flows.

Multiple Choice Question 13

Which of the following statements regarding the table function displayed below is incorrect?



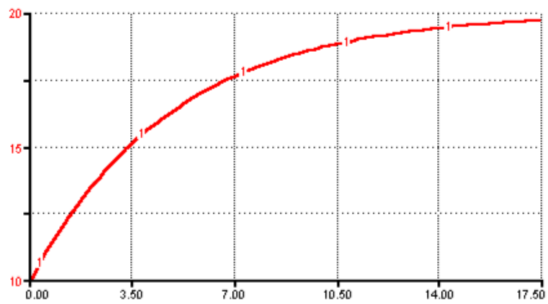
a. If this graph represents an additive effect, the reference point is (0,0).

b. The modeler should check whether this single graph function can be modeled as the combination of two different effects.

c. This graph cannot represent a multiplicative effect.

d. If this graph represents a multiplicative effect, then it has two reference points.

Multiple Choice Question 14



Examine the behavior of a stock variable on the left (assume the stock converges to a level of 20 in the long-run). What is the constant *doubling time* or *half-life time*?

a. A constant half-life of 3.5 time periods

b. A constant half-life of 7 time periods

c. A constant doubling time of 17.5 periods

d. None of these answers is correct

Multiple Choice Question 15

Which of the following statements concerning stock variables is wrong?

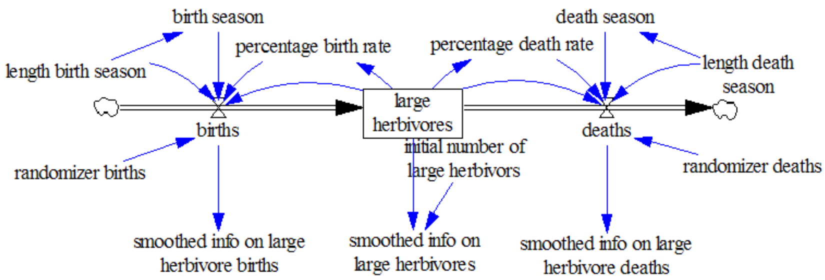
a. Stocks allow flows to be decoupled.

b. A stock can be increased by decreasing its outflow rate.

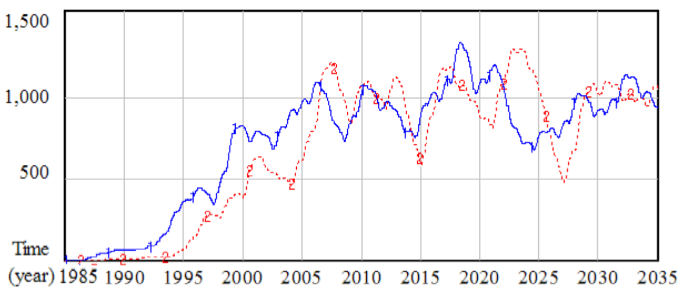
c. Stocks change relatively slowly, even when their flows change suddenly and/or rapidly.

d. Stocks would become nil or would cease to exist if systems would be paused.

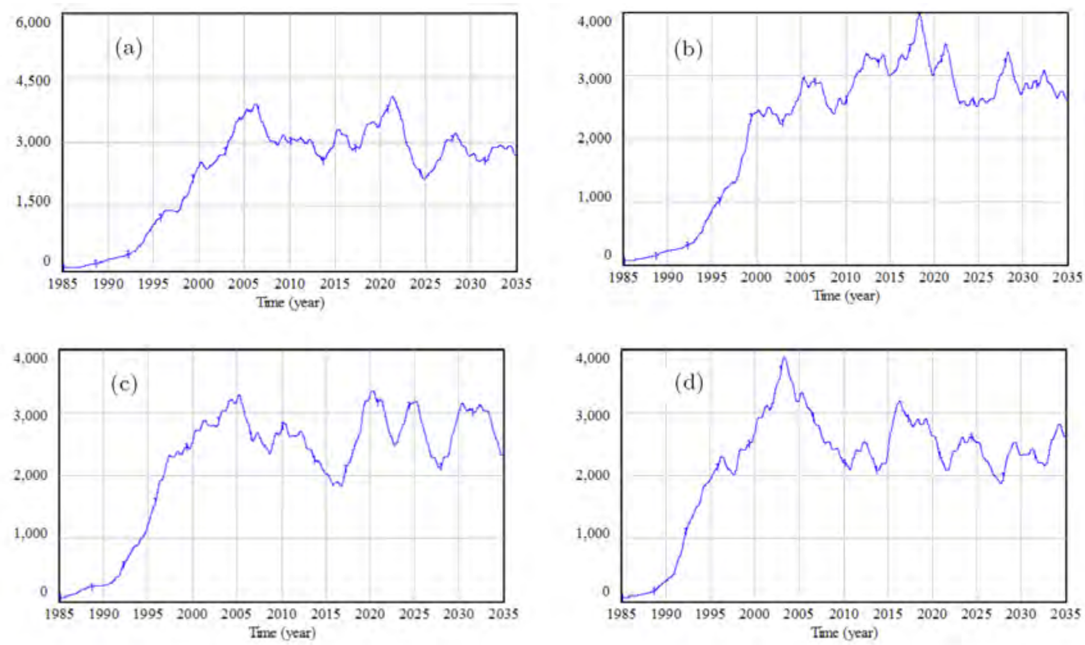
Multiple Choice Question 16



Suppose you made a SD model (as displayed above) concerning the large herbivores population in the 'Oostvaardersplassen' (OVP), and that you used the carrying capacity calculation displayed in Figure 10.1 on page 133.



The graph on the left shows the 3rd order smoothed response of the *flow* variables (in blue: *smoothed info on large herbivores births*; in red: *smoothed info on large herbivores deaths*). Which of the following graphs could then be the graph of the corresponding smoothed *stock* variable *smoothed info on large herbivores*?



Multiple Choice Question 17

Case 10.13 on page 132 and the previous MCQ deal with massive starvation in the OVP. In the guiding questions, one is asked to simulate the model with different '*seeds*' for the two randomizers. What could be concluded from these simulations with different seeds?

a. The significant difference in dynamics show this model is strongly behavior pattern sensitive and policy sensitivity for changes in the values of these seeds. It could therefore be concluded that changing the seed is an interesting policy measure.

b. The simulated dynamics are numerically different which indicates that the model is numerically sensitive to changes in the values of the seeds, but not behavior pattern sensitive. If the model is an appropriate model of the dynamics of large herbivores in the OVP, then it could be concluded that the situation in the OVP could not have been foreseen.

c. The simulated behavior patterns are hardly different in a qualitative sense: the model is not numerically sensitive to changes of the *seeds*.

d. None of the previous conclusions is correct.

Multiple Choice Question 18

Following up on the previous two MCQs regarding the OVP model (case 10.13 on page 132) displayed above: which of the following specifications does not allow –if applied to a further correctly specified model– to generate this behavior? In other words, which formula is surely wrong?

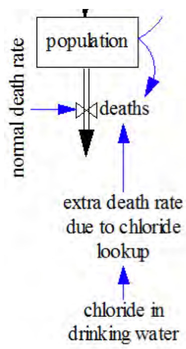
a. *births large herbivores* = DELAY FIXED(*large herbivores* * *percentage birth rate* * *birth season* / *length birth season* * *randomizer births*, 2, *large herbivores* * *percentage birth rate* * *birth season*/*length birth season* * *randomizer births*)

b. *percentage birth rate* = WITH LOOKUP(*large herbivores* ; ((0, 0.05), (1000, 0.075), (3000, 0.2), (4000, 0.3), (5000, 0.45), (6000, 0.75)))

c. *birth season* = PULSE TRAIN(1982.5, *length birth season*, 1, FINAL TIME); with *length birth season* = TIME STEP

d. *smoothed info large herbivores* = SMOOTH3I(*large herbivores*, 1, *initial number of large herbivores*)

Multiple Choice Question 19



The normal death rate of inhabitants of a country amounts to 6 deaths per 1000 inhabitants per year. However, the future death rate may increase due to significant deterioration of the drinking water quality. Large quantities of chloride per liter drinking water are harmful to public health: the death rate is 1 per 1000 inhabitants higher in countries with 50mg chloride per liter drinking water than in countries without chloride-polluted drinking water, and is even 5 deaths per 1000 inhabitants higher in countries with 100mg chloride per liter drinking water.
Suppose you included this effect in the model displayed on the right. The '*additional death rate through chloride lookup*' function connects following couples: (0,0), (50,0.001), (100,0.005). Which of following specifications for the *deaths* flow is then best?

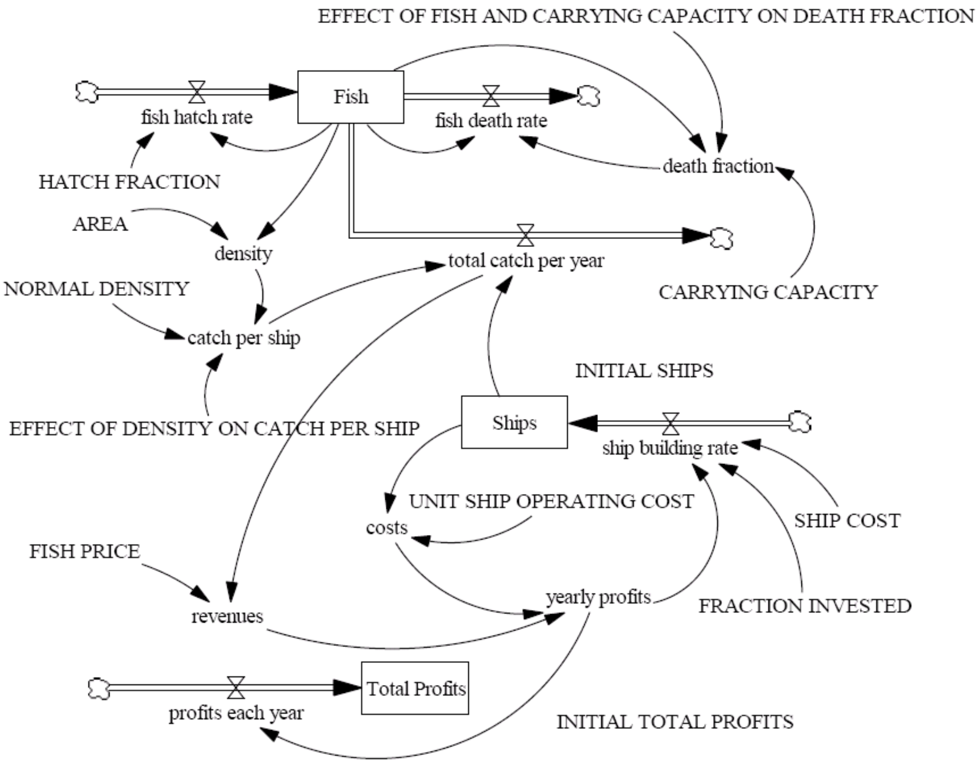
a. *deaths* = *inhabitants* * (*normal death rate* + *additional death rate through chloride lookup*); with *additional death rate through chloride lookup* a function of *chloride in drinking water*

b. *deaths* = *inhabitants* * *normal death rate* * (1 + *additional death rate through chloride lookup*; with *chloride in drinking water* being the argument of *additional death rate through chloride lookup*

c. *deaths* = *inhabitants* * *normal death rate* + *additional death rate through chloride lookup* * *chloride in drinking water*

d. *deaths* = *inhabitants* * *normal death rate* + *additional death rate through chloride lookup*; with *additional death rate through chloride lookup* a function of *chloride in drinking water*

Multiple Choice Question 20



Consider the fisheries model displayed above. Which *Fish* stock behavior could be expected if the model starts with a very small number of ships, the ship building rate is always ≥ 0, all ships are used to fish, ships are not decommissioned, and the *Fish* stock starts far below equilibrium?

a. continuous exponential growth

b. sustainable S-shaped growth

c. growth, overshoot, and collapse

d. continued cyclic behavior

Link to the answers to the 15 right/wrong questions & 20 multiple choice questions in this chapter.

Links to web based quizzes: | | | |

Chapter 12

Recap III – Lessons to be Learned

'A new type of thinking is essential if mankind is to survive and move toward higher levels.'
Albert Einstein

Case-Based Lessons from Part III

♻ 10.12 The main lessons from the simplistic Shale Gas exercise are that:

- From a SD perspective, this model is not a good model: it is too small, some Min and/or Max functions should be changed into Softmin and/or Softmax functions;
- However, it allows to reflect on the type of variables, the units, and the use of special functions.

10.13 The main lessons from the Mass Starvation in the OVP case are that:

- From a SD perspective, this model is not a good model: the carrying capacity/vegetation should be modeled endogenously, and the births and deaths should be modeled in a more continuous way;
- However, it is rapidly built and is very useful for quickly simulating and assessing the uncertain consequences of environmental *laissez-faire* in a relatively small and confined area.

Link to the feedback video related to all technical HOP exercises.

Part IV

STEP

Chapter 13

Building & Testing System Dynamics Models

'[T]esting is often designed to "prove" the model is "right", an approach that makes learning difficult and ultimately erodes the utility of the model and the credibility of the modeler. [...] Model testing should be designed to uncover errors so you and your clients can understand the model's limitations, improve it, and ultimately use the best available model to assist in important decisions.' (Sterman 2000, p.845-846)

13.1 Model Testing

Model Debugging

If errors made in the model specification phase show up during the first test simulation, then model debugging becomes a necessary –often rather frustrating– activity. Model debugging consists in tracing errors that keep the model from simulating properly and correcting them. Model debugging is an art that can be learned/trained. Following errors are common for novices:

- faulty combinations of numeric integration method and step size (too large a step size is often chosen given a model and integration method) which leads to inaccurate calculations and/or faulty –even totally impossible– behavior ⇒ reduce the time step and reflect on the appropriateness of the integration method;
- wrong signs within stock equations, especially in case of net flows, which often leads to runaway behavior in the opposite direction (e.g. goal seeking ↦ exponential increase) and to floating point overflows ⇒ get rid of net flows and check all signs in stock equations;
- loops without stock or delay/smoothing functions with initial conditions, which leads to simultaneous equations ⇒ (temporarily) add delays with initial values to loops without stocks, and/or (temporarily) break loops;
- floating point overflows which indicate that variables can be calculated but their values got too big, either due to positive loops or to divisions by very small numbers ⇒ track down the large/small values and correct the problems, or –if that does not work– (temporarily) add floors or ceilings (ZIDZ, XIDZ, (soft)MAX, (soft)MIN);
- very discrete implementations, which may lead to strange behaviors ⇒ replace discrete elements such as IF THEN ELSE functions by more continuous alternatives;

- erroneous structures and equations, such as outflows that are not connected to the stock they should empty or the use of special functions in stock equations ⇒ check all equations and structures.

While debugging, keep track of all temporary changes/hacks such as floors and ceilings, figure out what is going on, fix the real problem, then try to relax all temporary hacks – one at a time.

Model Verification

Model verification activities correspond to a large extent to model debugging activities. The difference is that in case of model debugging one knows there are bugs, whereas in case of model verification, one is looking for errors without knowing whether there are any. Model verification consists mostly of testing the appropriateness of the combination of numeric integration method and step size, checking all equations and inputs for errors, testing submodels and structures, and testing the dimensional consistency (i.e. test unit consistency e.g. to see whether variables are missing in equations).

A useful tool for model verification is Argonne National Laboratory's SDM-doc tool. This tool is actually a documentation tool. Use it for that purpose too: SD modeling and simulation needs to be understandable, transparent and fully replicable (see (Rahmandad and Sterman 2012)). It is also good practice –apart from using this tool– to keep track of all choices and decisions made during the modeling process in a lab report or notebook.

Model Validation

Validation in many research areas corresponds largely to testing whether a model reproduces past real data. In SD, reproduction of historical patterns is just one of many tests that may be needed depending on the model/modeling purpose. Comparing model behavior with past data is almost never a goal in itself, especially not for SD modeling about the future. . . due to the types of systems and problems studied and SD-specific model uses, SD validation goes beyond this more traditional concept of validation.

Two common uses of SD modeling are (i) to explore plausible futures, and (ii) to study the implications of different policies. Comparing model output with data from the past does not guarantee a good fit with future developments. Traditional validation in the sense of 'objective demonstration of the truth of a model' is in these cases, and many other cases, impossible. Another common use of SD modeling is to learn about a system and the link between system structure and behavior. For that use, most can be learned from reflective modeling, i.e. unprotected experimentation with models to uncover and learn, not to force the model to replicate past system behavior. For this purpose, a model that does not produce a good fit with past data may be more useful than a model that does. SD validation is actually all about building confidence in the usefulness of models for the purpose at hand (Sterman 2000). Valid models/modeling are therefore models/modeling that are believed to be useful for their intended purpose.

Model validation tests are applied in each iteration of the modeling process – from rough to refined: in the first iterations, rough tests are good enough, and later, more refined tests are required. There is a large set of tests that could help in establishing confidence in the usefulness of a model or modeling process for its intended purpose. As mentioned before, they can be categorized into (i) 'direct structure tests' in which the structure is tested without simulating the behavior, (ii) 'structure-oriented behavior tests' which allow to test the structure indirectly by running the model and comparing its behavior to real/anticipated behavior in order to find, again, errors in the model structure, and (iii) 'behavior reproduction tests' which allow to statistically compare model output with past behavior of the real system.

With respect to investigating the structure of the model (structural validation), a distinction could thus be made between direct structure tests and structure-oriented behavior tests. In the first type, the model is not simulated, whereas in the second type it is. Direct structure tests are used to check whether the relations and assumptions in the model are based on accepted theories and that all important variables are included in the model. It is also important to check whether the equations and model hold under extreme conditions.

Structure-oriented behavior tests are used to test whether the modes of behavior, frequencies and mechanisms causing the behavior and other characteristics correspond to what one would expect. Unexpected results and responses to extreme conditions are then explored in detail. Sensitivity analysis is a very important structure-oriented behavior test for identifying parts of the model to which model behavior is particularly in/sensitive (i.e. parameters, functions, structures,... that have a minor/major influence on the behavior when slightly changed). These model in/sensitivities should be compared to real system in/sensitivities if information about real system in/sensitivities is available.

Replicative validation, i.e. investigating whether the values of the variables calculated by the model correspond to known or historical data, should be performed, but only in addition to structural validation. In the absence of real data, model results can sometimes be compared to results of other models developed in the same (or a similar) area. This might, for example, include other models in which a sub-problem is analysed in detail and to which the calculated variables can be compared with a number of the variables in the model under study.

It should furthermore be verified whether the model focuses on the problems and questions deemed important by clients and stakeholders, that the model itself is comprehensible and that the use of the model stimulates the understanding of the behavior of the system.

After the model has been used, one could investigate whether the model was useful and whether the real-world situation was improved as in the model. This information could be used for ex-post evaluation which may further increase confidence in the model.

Validation tests partly based on (Sterman 2000, chapter 21):

- Direct structure tests
  - Direct boundary adequacy test: test whether boundaries are adequate (e.g. large enough to endogenously capture carbon leakage in a climate change policy model);
  - Direct structure assessment test: test whether the structure is conform the real system and laws of nature (e.g. irreversible decisions are irreversible);
  - Theoretical/empirical structure/parameter confirmation test: test whether structures and parameters have real world counterparts and are consistent with knowledge about the system;
  - Direct extreme conditions test: test without simulation (*i*) whether structures and equations make sense under assumed extreme conditions, or (*ii*) what the limits are for the model to be plausible/useful;
  - Face validation: test whether domain experts find the model structure and equations appropriate for the intended purpose.
- Structure-oriented behavior tests
  - Extreme conditions behavior test: test through simulation (*i*) whether the model responds plausibly under extreme conditions, or (*ii*) what the limits are for the model to be plausible/useful;
  - Sensitivity analysis: manual and/or automated testing whether relatively small changes in parameters, initial values, (graph) functions, alternative model structures and boundary choices lead –in decreasing order of importance– to a modified order of preference of policies (policy sensitivity), to changes in modes of behavior (behavior mode sensitivity), or to mere 'numerical sensitivity';
  - Qualitative features analysis: test under specific test conditions whether the model generates particular qualitative features (modes, frequencies, trends, phasing, amplitude, phase relation between pairs of variables, et cetera);

- Behavior anomaly test: test whether changing or deleting assumptions leads to anomalous behaviors;
- Family member test: test whether the model can generate all plausible types of behaviors that are observed in other instances of the same system or that could be imagined;
- Surprise behavior test: test whether the model generates surprising behavior, and if so, whether these behaviors are plausible.

• Behavior reproduction tests: test statistically whether the model generates the behavior of interest.

Validity in the sense of usefulness can only be assessed in view of the intended purpose, and hence, from the points of view of client/audience and modelers/analysts. In fact, clients and audience need to be involved in some of the validation testing or need to be informed about, or ask questions in order to test, the appropriateness and effects of choices made with regard to boundaries, time horizons, levels of aggregation, inclusion/exclusion of theories and (explicit and implicit) assumptions, and types of data used. The effects of these choices should be clarified.

13.2 Sensitivity & Uncertainty Analysis, and Scenario Discovery

Sensitivity Analysis

'Sensitivity Analysis is the computation of the effect of changes in input values or assumptions (including boundaries and model functional form) on the outputs' (Morgan and Henrion 1990, p39). Defined like this, Sensitivity Analysis (SA) refers to the analysis of the effect of relatively small changes to values of parameters and functions on the behavior (behavioral sensitivity) or preference for a particular policy (policy sensitivity), starting from a base case[1]. In SD, the term SA is often[2] used and mostly refers to a mixture of Sensitivity Analysis and Uncertainty Analysis (see below) as defined by Morgan and Henrion (1990). In this e-book I follow their distinction. SA defined in this strict sense could be used, following Pannell (1997) and Tank-Nielsen (1980), for:

- searching for errors in models;
- increasing the understanding of relationships between inputs and outputs, and in the case of SD, generate insights about the link between structure and behaviour;
- identifying candidates for uncertainty reduction efforts, and hence, direct further work on parameters and structure;
- identifying inputs for which the output is insensitive because dynamic limits may have been reached or non-linear thresholds crossed;
- identifying highly sensitive policy levers;
- testing the local robustness of results in the proximity of a base case scenario.

[1] Three types of sensitivity to (small) changes in a model are commonly distinguished: numerical sensitivity (just a small numeric change), behavior mode sensitivity (change in behavior pattern), and policy sensitivity (change in the preference order of policies). Only the last two types really matter.

[2] See for example (Graham 1976; Tank-Nielsen 1976; Sharp 1976; Tank-Nielsen 1980; Richardson and Pugh 1981; Ford 1983; Clemson 1995; Sterman 2000; Moxnes 2005)

Both univariate and multivariate SA are performed in SD, both manually at many moments throughout the SD modeling process (Tank-Nielsen 1980) and in automated mode by means of Monte Carlo sampling (Fiddaman 2002), Latin Hypercube Sampling (Ford 1990), and Taguchi methods (Clemson 1995).

However, rigorous theories and procedures for performing SA do not exist (Meadows 1980, p36), nor do tools for comprehensive sensitivity analysis. Sensitivity is therefore performed by hand as well as with sampling techniques, first one at a time, followed by combinations of parameters, initial values, etc. The sensitivity of the key performance indicators of a model should however not only be tested for changes in parameter values, initial values, in table (graph/lookup) functions, ... also to modifications of functions, model structures, and boundaries.

Sensitivity can be desirable as well as undesirable. High sensitivity is often undesirable if it cannot be controlled and could negatively influence key performance indicators. High sensitivity is on the other hand desirable if it can be controlled and opens up more desirable dynamics. SA is therefore essential, both in model testing and in policy analysis. In model testing, one would like to know which small changes to the model lead to large changes in behaviors, whereas in policy analysis, one would like to know where the largest policy leverage can be found.

Uncertainty Analysis

'Uncertainty Analysis is the computation of the total uncertainty induced in the output by quantified uncertainty in the inputs and models, and the attributes of the relative importance of the input uncertainties in terms of their contributions' (Morgan and Henrion 1990, p39). Uncertainty Analysis (UA) thus refers to the exploration of the influence of the full range of uncertainty deemed plausible. UA could be used for systematically:

- evaluating plausible effects of uncertainties in parameters, lookups, functions, structures, submodels, models, boundaries, methods, and possibly controversial/disputable perspectives;
- generating many plausible scenarios / behavior patterns (see for example (Kwakkel and Pruyt 2013; Pruyt and Kwakkel 2012a));
- exploring and analyzing ensembles of scenarios/runs and uncertainty spaces using advanced machine learning algorithms (Kwakkel et al. 2013; Pruyt et al. 2013), analytical tools, and statistical screening (Ford and Flynn 2005; Taylor et al. 2010);
- evaluating the appropriateness of models under uncertainty similar to testing models under extreme conditions where it is often easier to review whether the model is plausible or not (Tank-Nielsen 1980, 189) and triangulating/comparing sets of alternative models[3] (Pruyt and Kwakkel 2012b);
- directly searching the uncertainty space for limits, tipping points, best fits, implausible results, or high leverage points using optimization techniques;
- searching the uncertainty space for particular behaviors and densely concentrated regions thereof, identifying joint root causes of behaviors with particular characteristic (un/desirable dynamics, un/desirable end-states, or undesirable side-effects) with dynamic scenario discovery and selection techniques (see (Kwakkel and Pruyt 2013; Kwakkel et al. 2013));
- supporting the design of adaptive robust policies (Hamarat et al. 2013);

[3] Loosely following Lane's definition of a SD model, i.e. 'the assembly of causal hypotheses about relationships between variables [...]' (Lane 1998, p938), models are considered different here if there are differences in system boundaries, model structures, functions, internal and external parameter values and other input data, and model implementation (e.g. different simulation methods). A model is thus not the same as a model file: one model file which contains switches between alternative structures thus contains many different models.

- testing and comparing the absolute and relative robustness of conclusions and policies (Sterman 2000; Lempert et al. 2003; Kwakkel and Pruyt 2013);
- identifying candidate parameters and structures for model simplification in highly non-linear models, i.e. model inputs and structures that do not significantly affect output.

A major difference between SA and UA is that SA necessarily starts from a base run/scenario, which is not the case for UA. In addition, SA is a means to explore the sensitivity of a model to small perturbations whereas UA is a means to virtually explore plausible real world effects of assumptions over their plausible uncertainty sets/ranges. Technically speaking there is a large overlap between SA and UA and both are extremely useful for SD. Using them in tandem –SA followed by UA– is most insightful for model-based studies. Advanced UA techniques beyond sampling techniques will be dealt with in the follow-up book on ESDMA.

Scenario Generation and Discovery

Scenarios are often useful to communicate a few different behavior patterns without having to communicate all plausible behaviors. Scenario discovery is the identification of potentially interesting scenarios. Scenarios can be generated by setting inputs such that different behaviors are generated. Another approach is to use UA to generate a large ensemble of runs and then use time series classification and/or machine learning techniques to identify different scenarios of interest (Kwakkel and Pruyt 2013; Kwakkel et al. 2013). In this e-book, we will stick to the former intuitive approach, just simulating different consistent sets of inputs. The latter approach will be dealt with in the follow-up book on ESDMA.

Additional (non-mandatory) chapters: VI. Model Testing

Chapter 14

Small and Simple SD Cases

'The ultimate objective of model understanding is to provide a basis for improved policy. To gain such understanding, the model should be tested over an unusually wide range of changes in both parameters and structure. Only a very wide range can reveal the inherent dynamics of the model.' (Tank-Nielsen 1980, p189)

14.1 Managing a Faculty

A new Dean has recently been appointed at the faculty. He would like to understand how the faculty will develop in the following months in terms of the number of professors. Since you follow a SD course, you should be able to investigate this issue by means of a SD model. He accepts your proposal to make a continuous SD model –instead of a discrete or agent-based model– in order to investigate the dynamics of the faculty. You obtain the following information:

The number of *professors* working at the faculty could be increased by an inflow of *new professors hired* and decreased by an outflow of *professors leaving* the faculty. The *percentage of leavers* amounts to 10% of the number of *professors* per year. The number of *new professors hired* equals the difference between the *desired number of professors* and the number of *professors*, divided by the *average hiring time* of 12 months. The *desired number of professors* equals the *available money for salaries* divided by the *average professor salary*. Initially, the number of professors at the faculty amounts to 25 full time equivalents. The amount of money received for all teaching activities of all professors together, the lump sum *teaching fee*, currently amounts to €150.000,00 per month. The *available money for salaries* could be increased by the inflow consisting of the *teaching fee* and the *earnings from papers* and could be decreased by the outflow of *money spent on salaries*. Initially, the *available money for salaries* amounts to €500000. The *money spent on salaries* equals the number of *professors* times the *average professor salary* of €3500,00 per professor per month. The *earnings from papers* equals the average *number of papers published* times the *earnings per published paper* of €4000 per paper. The average *number of papers published* equals the number of *professors* times the *number of papers per professor*. Professors produce on average 6 papers per person per year.

1. Make a simple SD model on your computer and simulate this model for about 100 months. Save it as your base model.

2. Verify and validate the model. Briefly describe the validation test you performed and –in case of corrections– the corrections you made to the model.

3. Sketch the behavior of the number of professors and the money available.
4. Draw a CLD of the system. Briefly explain the link between structure and behavior.
5. Does the variable number of *Professors* show behavior converging to a dynamic equilibrium? If yes, then how long does it (more or less) take before the system is in dynamic equilibrium and how many professors would there be in equilibrium?
6. The new Dean is very ambitious: how could he drastically change the number of professors working at the faculty? He would be interested in a change in the mode of behavior of the number of professors, not just a slight increase. What do you recommend? Why?

14.2 Supply Chain Management

Introduction

After following this SD course, you decide to start working as a model-based business analyst. Your first job consists in helping out the manager of a luxury car company that produces hand-made sports cars. The company faces severe *inventory*, *production* and *workforce* fluctuations following *sales* fluctuations. The manager wants you to make a model to understand the interactions between *production*, *inventory* and *workforce* in order to be able to reduce these fluctuations.

Modeling a Company

Smart as you are, you decide to make, first of all, a model in equilibrium with constant *sales* of 100 cars per month. These *sales* empty the stock of *inventory*. The inventory initially consists of 300 cars and is replenished by a *production* inflow which equals the size of the *workforce* (i.e. the employees) times the *productivity* of an average worker. The average *productivity* is currently 1 car per person per month.

The *target inventory* currently equals the *sales* times an *inventory coverage* of 3 months. This *target inventory* is used to calculate the *inventory correction* which is used to calculate the *target production*. The *inventory correction* is calculated as: (*target inventory* - *inventory*)/*time to correct inventory*. The *time to correct inventory* is currently 2 months. The *target production* is then the *sales* plus the *inventory correction*.

The *target production* divided by the *productivity* of the average worker results in the *target workforce*. The discrepancy between the *target workforce* and the actual *workforce* currently drives the 'hiring and firing' strategy of the company as follows: *net hire rate* = (*target workforce* - *workforce*)/*time to adjust workforce* of 10 months. The *workforce* could be modeled as a stock variable regulated by the *net hire rate*. Since you will start out from equilibrium, you could take the *target workforce* as the initial value of the *workforce*.

1. Make a simple SD simulation model, simulate it over a period of 100 months. Check whether your model is in equilibrium.
2. Now change the *sales* after 20 months from 100 cars per month to 150 cars per month. Make graphs to show the behavior of the *sales*, the *inventory* and the *workforce*.
3. How long does it (more or less) take before the system is back in dynamic equilibrium?

Modeling the Supply Chain

Now, suppose that the company you work for is part of a supply chain consisting of 3 manufacturing companies, all three with the (same) structure developed in the first part. In fact, you are working for the assembler who sells the final product to the final customers. This assembler is supplied by a tier one supplier, and the tier one supplier is supplied by the tier 2 supplier. The tier 2 supplier faces extremely undesirable oscillations in demand and production.

1. Suppose that the production of the assembler constitutes the demand for the tier 1 supplier, and that the production of the tier 1 supplier constitutes the demand for the tier 2 supplier. Model the system: assume that the internal structures of these suppliers are exactly the same as the internal structure of the assembler. Assume that supply shortages are not solved with back-orders.
2. What is the resulting dynamics for the three companies? What is the name of this effect?
3. What could be done do to solve (or reduce) this undesirable effect for the entire supply chain?
4. Use the model to find at least 1 simple policy to reduce the internal volatility of each of the companies.

14.3 Debt Crisis in a Developing Country

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This case is based on an adapted version of the Debt Crisis model developed by Hartmut Bossel (2007c, Z607) (follow this link to the zip file containing all Zoo models). In this case, one needs to build a simplistic economic model of a developing country consisting of just two endogenous stock variables (*production plants* and *debt*) in order to test under which conditions developing countries could/cannot avoid the debt trap.

The values in this model are relative values, e.g. all state variables are standardized to 100% or 1. Assume that all production plants in the model function at full capacity, i.e. *production* is equal to the stock of *production plants* times their *specific production* of 100%. The stock of *production plants*, initially equal to 0, increases over time through addition of *new production plants* and decreases over time through *deterioration*. Define *deterioration* simply as the stock of *production plants* times a 5% *deterioration rate*. The addition of *new production plants* follows the *investments* times an *investment effectiveness* of, say, 50%. *Investments* are financed by means of exogenous *credits* and *endogenous investments*, i.e. reinvested profits. *Endogenous investments* are equal to the non-negative gap between *net revenues* and debt *repayments*, times the re*investment fraction* of 50%. *Net revenues* correspond to *revenues* minus *interest payments*, i.e. the outstanding *debt* times the *interest rate* of, say, 7%.

Model the *revenues* as the *sales* times a *price factor* with the *sales* in this model being equal to *production*. And model the *price factor* as a function of *production* over *demand* connecting the following couples: (0, 2), (0.2, 2), (0.4, 2), (0.6, 2), (0.8, 1.4), (1, 1), (1.2, 0.6), (1.4, 0.1), (1.6, 0.1), (1.8, 0.1), (2, 0.1). Model the *repayment* variable such that it is equal to the *debt repayment fraction* times the *net revenue* if *net revenue* and *debt* are both greater than 0, else *repayment* is 0. Further, assume that the *demand* is 100, that the *debt repayment fraction* is 50%, and that initial *debt* is 0.

Debt decreases via *repayments* and increases through new *credits* and through *additional debt due to interest payments* (added if interest payments exceed revenues). The latter variable could be modeled as: MAX(-*net revenue*, 0). Add a *credit* variable such that a *credit amount* of 100 per year is provided from year 4 until year 10 (included), after which it falls back to 0 until the end of the simulation time.

Also add the following three key performance indicators: *profits*, *cumulative profits*, and *cumulative interest payments*. Calculate the *profits* as the *endogenous investments* times (1 - *investment fraction*) divided by the *investment fraction*.

1. Build a SD model following the description provided above. Verify the model.
2. Simulate the model over a period of 100 years. Plot the behavior of *production plants*, *debt* and *profits*.
3. Perform automated sensitivity analyses (Latin Hypercube) in view of detecting behavior mode sensitivity to changes of the initial values of *production plants* (from 0 to 200) and *debt* (from 0 to 2000). What could be concluded?
4. Couple this model to the state space model developed by Hartmut Bossel (2007a, Z115). Copy your model, open a cleaned version of Z115, paste your model into that model, and rename it. Set the *credit amount* to 0 (to avoid time-dependent forcing of the system), set the *compute length* to 100, set the *Final Time* to 100 * 100, and set the *Time Step* to 0.5. Connect *production plants* to *status 1*, *debt* to *status 2*, *limit 1* and *new state 1* to *production plants*, and *limit 2* and *new state 2* to debt. Furthermore set *min state 1* to 0 and *max state 1* to 200, and *min state 2* to 0 and *max state 2* to 2000. Generate the state diagram. What could be concluded? Compare your results to (3).
5. Broaden the analysis. Perform sensitivity/uncertainty analyses in view of detecting behavior mode sensitivity to changes of the *investment effectiveness*, *credit amount*, *investment fraction*, and *debt repayment fraction*, first one at a time, followed by all together. Start with manual analyses but perform automated analyses too. What could be concluded?
6. Try to use the state diagram version of the model to the same purpose. What could be concluded?
7. What could be concluded regarding the analyses using Latin Hypercube sampling versus state space analysis?

⚠ Get rid of normalized standard values: choose a country, collect the necessary data, adapt the model, add proper units, and perform the analyses for that country.

14.4 Environmental Management in Miniworld

This exercise is based on a strongly adapted version of the Miniworld model. The original Miniworld model was developed by Hartmut Bossel (2007c, Z605). This exercise allows one (i) to build a very simplistic world model that exhibits similar behavior as more complex global models, and (ii) to compare similar models about the same issue.

The values in this model are relative values, e.g. all state variables are standardized to 100% or 1. Hence, the *population* at the start of the simulation is therefore equal to 100% or 1. It only increases through *births* and only decreases through *deaths*. The variable *births* could be modeled as the product of the *normal birth rate* of 3%, the *population*, the *environmental quality* and the *consumption level*. Assume furthermore that the variable *deaths* is proportional to the *population*, the *normal death rate* of 1.5%, and to the delayed –with some 10 years and following a 3^{rd} order delay– influence of *environmental pollution*.

Assume that production capacity is always fully used. That is, the *consumption level* equals the *production capacity*. And the *production capacity* is the accumulation of all *net capacity increases*, starting from an *initial capacity* of 100%. Suppose that *net capacity increases* can be approximated by the product of the *normal growth rate*, the *consumption level*, the *environmental quality*, the *population*, and (*consumption goal* - *consumption level* * *population* * *environmental quality*) / *consumption goal*, with a *consumption goal* equal to 400% or 4 times the initial consumption, and a *normal growth rate* of 4%.

Suppose that the *environmental quality* shows a typical 3^{rd} order delay response –with a delay time of 20 years– of the fraction $\frac{\textit{damage threshold}}{\textit{environmental pollution}}$. Make sure the latter fraction cannot exceed 1. Assume that the *damage threshold* is 200%. *Environmental pollution* only increases over time through *degradation* and only decreases over time through *regeneration*, starting from an *initial pollution* level of 100%. Suppose that *regeneration* is proportional to the level of *environmental pollution* and a *normal regeneration rate* of 2%. Suppose also that *degradation* can be modeled as the product of the *population*, the *consumption level*, and the *normal degradation rate* of 2%.

1. Construct the model. What behavior do you expect? Verify the model. Simulate it over a period of 500 years. What behavior do you obtain?
2. Play with the model: test the influence of parameters on some key performance indicators. Is the model behavior mode sensitive to parameter changes?
3. Also test the influence of different formulations, e.g. different orders for the delays and different flow formulations. List the different formulations tested. Is the model behavior sensitive to these changes?
4. Draw a CLD of the model and use it to explain the link between structure and behavior.
5. What policies would be appropriate? Test them using your model.
6. Download the zipped zoo models here and open the original Miniworld model (Z605.mdl) and/or use Bossel's equations displayed below to compare the two models. In what sense do these two models differ? Would you expect different simulation results? Do you obtain different conclusions?

- ⚡ Given these different models, what would be appropriate policy recommendations? Test these recommendations in both models (and possibly in some other variants). Are these recommendations robust?
- ⚡ System Dynamicists generally do not like 'normalized' stock models. Adapt the model to the real world: collect data and turn the model into a model with real units and values that correspond to real world counterparts. Use the new model for the same purpose. What do you conclude?

population = INTEG (*births* - *deaths*, *initial population*)
births = *birth rate* * *population* * *quality of environment* * *consumption level* * *birth control*
birth control = 1 ; *birth rate* = 0.03 ; *initial population* = 1

deaths = *death rate* * *population* * *environmental pollution*
death rate = 0.01

quality of environment = *damage threshold*/*environmental pollution*
damage threshold = 1
environmental pollution = INTEG (+*degradation*-*regeneration*, *initial pollution*)
regeneration = IF (*quality of environment* > 1, *regeneration rate* * *environmental pollution*, *regeneration rate* * *damage threshold*)
degradation = *degradation rate* * *population* * *consumption level*
initial pollution = 1 ; *degradation rate* = 0.02 ; *regeneration rate* = 0.1

consumption level = *production capacity*
production capacity = INTEG (capacity increase, *initial capacity*)
capacity increase = *growth rate* * *consumption level* * *environmental pollution* * (1 - (*consumption level* * *environmental pollution* / *consumption goal*))
initial capacity = 1 ; *growth rate* = 0.05 ; *consumption goal* = 10

14.5 The 2009-2010 Flu Pandemic / Next Pandemic Shock

The government asks you to make an experimental SD model related to the potential evolution of the Mexican Flu, also known as H1N1, or swine flu. Model and analyze the Mexican flu, first as a epidemic in the Western World, and then, as a worldwide epidemic or pandemic in the Western World and the densely populated developing world. Keep in mind during your analyses that the Western World was especially concerned about potential disruptions of society and the economy if more than 30% of the active population simultaneously has the flu.

The Mexican flu as an epidemic in the Western World

Infections make that people from the *susceptible population* (initially equal to 600.000.000 persons) get the flu and migrate from the *susceptible population* to the *infected population* (initially equal to 10 persons). The number of *infections* equals the product of the *susceptible population*, the *contact rate*, the *infection rate*, and the *infected fraction*. The *infected fraction* equals the *infected population* divided by the *total population*. The average *infection rate* of this flu variant in the Western World is estimated at first to amount to 10% infections per close contact. Suppose that the *contact rate* in de Western World amounts to 50 close contacts per person per month.

Members of the *infected population* flow after an average *recovery time* of 2 weeks to the *recovered population* (initially empty). Assume for the sake of simplicity that the entire infected population recovers. That is, there are no flu deaths.

1. Make a SD model of the above described epidemic. Verify the model.
2. Make a complete and highly aggregate CLD of this simulation model.
3. Simulate the model over a period of 4 years. Make graphs of the evolution of the *susceptible population*, the *infections*, the *infected fraction*, and the *recovered population*.

What if not everyone in the Western World is infected?

It is likely that not everyone gets this flu, just like in case of the normal flu. That probably means that there is –apart from the *susceptible population*– also an *immune population*. Adapt the previous model.

Set the *susceptible population* in the Western World initially to 330.000.000 persons and the *immune population* to 270.000.000 persons. However, there is also a seasonal dynamic between both populations: the *susceptible population* grows towards the winter season, and the *immune population* grows towards the summer season.

The flow between these populations, the net *susceptible to immune population flow* is equal to: $(normal\ immune\ population - immune\ population)/susceptible\ to\ immune\ population\ delay\ time$, but cannot be greater than the $susceptible\ population/susceptible\ to\ immune\ population\ delay\ time$ if there is a net flow towards the immune population, and cannot be greater than the *immune population / susceptible to immune population delay time* if there is a net flow towards the susceptible population. Suppose that the *susceptible to immune population delay time* amounts to 1 month.

The *normal immune population* is equal to the product of the *total population* and the *normal immune population fraction*. This *normal immune population fraction* fluctuates between 30% in month 0, to 70% in month 6, to 30% in month 12, to 70% in month 18, and so on.

4. Extend the simulation model as described above.
5. Simulate the model over a period of 4 years. Make graphs of the evolution of the *susceptible population*, the *infections*, the *infected fraction*, and the *recovered population*. Compare these graphs with the previous ones: briefly describe the differences.

The Mexican flu as a pandemic

The flu epidemic in the Western World may be strongly influenced by the development of the flu in densely populated developing countries. Make therefore a similar submodel for a second region, namely the densely populated part of the third world[1]. There are some small differences:

Suppose that the average *contact rate* in this second region amounts to 100 close contacts per person per month. The *infection rate* is probably slightly higher, namely 15% infections per contact. The *susceptible population* of this region amounts initially to 2.000.000.000 persons, the *immune population* to 1.000.000.000 persons, and the *infected population* to 100 persons. [Scarcely populated regions are not modeled here because they are causally less important to the development and spreading of the flu.] The majority of these countries are located in the Southern hemisphere, and their populations generally have a lower immunity: the *normal immune population fraction* amounts therefore to 30% in month 0, 10% in month 6, 30% in month 12, 10% in month 18, and so on.

There is of course also contact between these regions (the Western World and the densely populated developing countries). Suppose that the *interregional contact rate* amounts to 1 close contacts per 10 persons per month. Add an additional term to the *infections* variables of both regions. In case of region 1, this additional term may look like:

$$+susceptible\ population\ region\ 1 * interregional\ contactrate * infectierate\ region\ 1 * infection\ fraction\ region\ 2$$

[1] Remark: The description in this subsection can be modeled even if you were unable to model the immune population.

6. Extend the simulation model as described above.
7. Simulate the model over a period of 4 years. Make graphs of the evolution of the *susceptible populations*, the *infections*, the *infected fractions*, and the *recovered populations* of both regions. Compare the graphs of the Western region with the previous ones: briefly describe the differences.
8. Validate the model: propose 2 validation tests (except sensitivity analysis), perform them, and briefly describe the results/conclusions.
9. Investigate the sensitivity of the model for small changes of the *contact rates*, the *infection rates*, the *recovery time*. Test for example a *contact rate* in region 2 of 200 close contacts per person per month. Describe briefly what you can conclude from these analyses in terms of the *infected fraction* of the Western World.
10. Suppose that a vaccine becomes available in month 9 and that 70% of the Western population gets vaccinated. What is the consequence in terms of the evolution of the *infected population* of the Western World?
11. Formulate (in one sentence) a policy recommendation concerning this flu variant for the Western World.

SIR, SEIR, SIRS or SEIRS?

A well-known professor notes that your model is basically a SIR model but needs to be a SEIRS model. SIR stands for susceptible-infected-recovered. SIR models relate to illnesses that produce permanent immunity and a typical cycle that involves susceptibles that are infected after which they recover. This does not mean that all individuals of the population must pass through these stages, some will not be infected and remain healthy, in other words, they will remain in state (S). Others will be immunized artificially by vaccination or another method and will pass directly to state (R) without having been infected.

SIRS stands for susceptible-infected-recovered-susceptible. It is similar to the previous model but applicable in cases where immunity is not permanent and the individual becomes susceptible again after some time. This applies to annual flu outbreaks in a sense that annual flu outbreaks are minor mutations of previous flu variants.

However, the fact that individual become susceptible again may be neglected when studying the effects of a potential pandemic shock of a new flu strand during the first wave. Later, when it becomes one of a set of annual flu variants, then it is indeed important to model the loss of immunity to this and other flu strands (see case 18.6).

The question remains whether your model should have been a SEIR model. The E stands for Exposed. Those who are exposed do not show any signs of illness during the incubation period, although they may be infected. The incubation time of flu strands is limited to 1 to 2 days.

- ⚡ Adapt your model: turn it into a SEIR model.
- ⚡ Test the effect of this incubation period on the ensemble of behaviors that can be generated with the model. Is inclusion of this stage really necessary for the type of dynamics that could be generated, that is, for a large ensemble or runs?
- ⚡ Is the SEIR formulation really needed for your policy recommendations?
- ⚡ So, what should have been modeled in the first place: SEIRS, SEIR, SIRS or SIR? Why?

14.6 Long Term Planning of New Towns

Introduction

The next few decades will be characterized by further urbanization. Part of it will –especially in Asia and Africa– be caused by so-called 'New Towns'. The concept of 'New Town' is used for a particular type of urban development: a more or less independent new town relatively distant from existing cities. New urban developments within existing (older) urban areas (New Town in Town) or large urban extensions to the edges of the major cities is generally referred to as urban renewal, not as New Towns. The New Town concept is not new. Worldwide, there are hundreds of new towns (Brasilia, Chicago, San Francisco, Milton Keynes, many Eastern European, Russian, South American, Chinese, Korean and French cities) and many new ones are under construction (especially in Asia and Africa). Although the number of inhabitants of these cities varies from less than 50000 to more than a million, and although they are very different in design and function, there are interesting dynamic parallels and the same 'mistakes' –in spite of good examples like Detroit– are being made over and over again. One of the SD classics –Urban Dynamics by Jay W. Forrester (1969)– shows that SD is an appropriate method to help to understand New Town structures and dynamics and to test policies to solve undesirable evolutions. Suppose that you are hired as an adviser-modeler by a few rising new towns to test policies to solve the 'root causes' of undesirable dynamics. Since you are following this SD course, you decide to make and subsequently use a SD model. Use the information below, which is based on a modified version of George Richardson's URBAN1 model (see link).

The population

The size of the *population* of a new town changes through *immigration*, *births*, *emigration*, and *deaths*. Suppose that the new town you are about to model already has 50000 inhabitants, and has a *birth rate* of 3%, and a *death rate* of 1.5%. And suppose that there is constant *emigration* with a *normal emigration rate* of 7% per year. *Immigration* could be modeled as the product of the current *population*, the *normal immigration rate*, the *job availability multiplier for immigration*, and the *housing availability multiplier for immigration*. This *housing availability multiplier for immigration* is a function of the *households to houses ratio*: suppose that if the *households to houses ratio* equals 1, the multiplier equals 1, that if the *households to houses ratio* equals 1.5, the multiplier equals 0.25, that if the *households to houses ratio* equals 2, the multiplier equals 0, that if the *households to houses ratio* equals 0, the multiplier equals 1.4, and that if the *households to houses ratio* equals 0.5, the multiplier equals 1.3. The number of *households* depends on the size of the *population* and the *average size of households*, in that part of the world still 4. Suppose that the *normal immigration rate* equals 10%.

Houses

The number of *houses*, initially equal to 14000, increases by means of *construction of houses* and decreases through *demolition of houses*. The average *demolition rate of houses* (without additional policies) equals 1.5% per year. The *construction of houses* could be modeled as a 3^{rd} order delay (delayed with 2 years) of the product of the *land availability multiplier for houses*, the *housing scarcity multiplier*, the number of *houses*, and the *construction rate of houses* of 7% per year. The *housing scarcity multiplier* is a function of the *households to houses ratio* connecting following points (0, 0.2), (0.5, 0.3), (1, 1), (1.5, 1.7), and (2, 2). The *land availability multiplier for houses* is a function of the *land fraction occupied*: for a *land fraction occupied* of 0% the multiplier equals 0.4, for a *land fraction occupied* of 25% the multiplier equals 1, for a *land fraction occupied* of 50% the multiplier equals 1.5, for a *land fraction occupied* of 75% the multiplier equals 1, and for a *land fraction occupied* of 100% the multiplier equals 0. The land fraction occupied corresponds to the sum of the land use of all businesses and the land use of all houses, divided by the *total area*. Suppose that the useful *total area* of the new town is 5000 hectare, that the amount of *land per house* is 0.05 hectare, and that the amount of *land per business* (i.e. for each business structure) is 0.1 hectare.

Businesses and labor force

The number of *businesses* (i.e. business structures), initially 1000 business, increases through *construction of business structures* and decreases through *demolition of business structures* with an average *demolition rate of business structures* of 2.5% per year.

Construction of business structures could be modeled as the product of the *land availability multiplier for business structures*, the *business labor force multiplier*, the number of *businesses*, and the *construction rate of business structures* of 7% per year.

This *land availability multiplier for business structures* is a function of the *land fraction occupied*: the multiplier is of course 0 for 100% of the land fraction occupied, it equals 1 for 0% of the land fraction occupied, and it equals 1.5 for 50% of the land fraction occupied. The *business labor force multiplier* is a function of the *labor force to jobs ratio* connecting (0, 0.2), (0.5, 0.3), (1, 1), (1.5, 1.7), and (2, 2). The aforementioned *job availability multiplier for immigration* is also a function of the *labor force to jobs ratio* connecting following points (0, 2), (0.5, 1.75), (1, 1), (1.5, 0.25), and (2, 0.1). This *labor force to jobs ratio* depends of course on (i) the size of the *labor force* which equals the product of the *population* and the *labor force to population ratio* of 35%, and of (ii) the number of *jobs* which equals the number of *businesses* times the *initial number of jobs per business structure* which amounts to 18 FTEs. Model following two key performance indicators too: the *unemployment ratio* and the *housing vacancy ratio*. Both are per definition between 0 and 100%.

1. Model and verify the model.
2. Simulate over a long time horizon of 200 years. Make graphs of the evolution of businesses, houses and population and of the effects thereof on the *unemployment ratio* and the *housing vacancy ratio*. What are the problems you can derive from these graphs?
3. Make a strongly aggregated CLD of this system model that could be used to explain the model behavior. Use the CLD to explain the link between model structure and behavior.
4. Too high a *housing vacancy ratio* leads to urban decay (of entire districts and towns), which in turn influences *immigration* and *emigration*. Hence, model a *slum multiplier for migration*: this multiplier is a function of the *housing vacancy ratio* and connects following points (0, 1), (0.2, 1), (0.4, 0.5), (0.6, 0.1), and (0.8, 0). Adapt the formulations of *emigration* and *immigration*.
5. Forrester's Urban Dynamics shows that additional demolition of empty bad quality housing in case of high housing vacancy ratios and rezoning could prevent urban decay to kick in or worsen. Thus add a variable *additional demolition rate* to demolish beyond normal demolishing above a 10% housing vacancy ratio. Let the *additional demolition rate* increase linearly from 0% per year for a 10% vacancy ratio to 5% per year for a 15% vacancy ratio, and linearly from 5% per year for a 15% vacancy ratio to 50% per year for a 100% housing vacancy ratio. Add this additional effect to the *demolition of houses* too.
6. Draw the effect on the two key performance indicators? Is the combination of these endogenous effects and this policy a solution for the problems encountered earlier? Explain.

7. Land and buildings are used more efficiently in case of land scarcity. Model therefore following endogenous relation: the *effect of land scarcity on intensity of use of business structures* being a WITH LOOKUP function with argument *land fraction occupied* and connecting following couples (0, 1), (0.5, 1), (0.75, 1.15), (1, 2). This variable has a multiplicative effect on the *jobs* variable. Add a switch (name it '*switch jobs*') that could be used to activate/deactivate this endogenous effect.

8. Plot the effects of all these extensions together on the two key performance indicators. Is this endogenous effect a solution for the initial problems? If not, briefly explain how the problems have changed.

9. Briefly validate the model. Name minimally 2 validation tests (with the exception of sensitivity analysis), perform them, describe and conclude briefly.

10. Perform two sensitivity analyses to find policies to solve the remaining problems. Describe them, perform them, describe the effects, and conclude.

Propose a set of policies to solve all identified problems. Model this set of policies, test whether the set solves the problems, and you show this in graphs for both key performance indicators.

14.7 Tolerance, Hate & Aggression

This case is an adaptation of the aggression model described by Bossel (2007c, Z509) (follow this link to the zip file containing all Zoo models). This model is 'an attempt to connect only vaguely known relationships in an assumed system structure'. In his model, Bossel (2007c, Z509) assumes that unfamiliarity is the root cause of hate between population subgroups with infrequent encounters with other subgroups. Use the adapted description below to make a base model.

Create four stock variables: *tolerance*, *unfamiliarity*, *hate* and a *restraint threshold*. Set the initial value of *tolerance* equal to 50%, of *unfamiliarity* to 10%, of *hate* to 10% and of the *restraint threshold* to 50%. Assume that *unfamiliarity* increases with *unfamiliar experiences*. The inflow of *unfamiliar experiences* could be modeled as the multiplication of the number of *encounters*, the *encounter intensity* of 500% (that is, compared to a normal encounter intensity of 100%), the *degree of unfamiliarity* between the groups of of 50%, their *intolerance*, (1 + *violence*), and (1 - *unfamiliarity/maximum unfamiliarity*), with a *maximum unfamiliarity* of 100%. Assume that *encounters* take place with an *encounter interval* of 2 months, starting in month 5, with a duration of 1 month, and ending in month 50. Model *intolerance* as the difference between *maximum tolerance* of 100% and *tolerance*. The feeling of *unfamiliarity* is gradually reduced by *accustoming*. *Accustoming* is proportional to *unfamiliarity* and *tolerance* and inversely proportional to the *adaptation time*.

Suppose that *tolerance* only increases through an *increase in tolerance through educational effort* and that this flow is equal to the 3^{rd} order smoothing of the product of the *education effort*, the level of *tolerance*, and *intolerance*, with a smoothing time of 1 month. Suppose that the *education effort* is stepped up from 0 to an *education activity* of 50% in month 15. *Tolerance* decreases through *tolerance erosion* equal to the level of *tolerance* over the *adaptation time* of 1 month, reinforced (i.e. multiplied) by the level of *hate* and (1 + *violence*).

Specify the *increase in the level of hate* such that it is the product of the *relative hate gap* and the level of *hate* divided by the *adaptation time*, and that it is reinforced (i.e. multiplied) by *unfamiliarity*, *intolerance*, (1 + *violence*) and *social problems*. The *relative hate gap* is the difference between the *maximum amount of hate* of 100%, and the actual level of *hate*, divided by the *maximum amount of hate*. The decrease in the level of hate is more pronounced for greater tolerance: specify the *decrease in the level of hate* therefore as the product of *hate* and *tolerance* divided by the *adaptation time* of 5 months. Assume that *social problems* all of a sudden jump from nothing to 400% at the beginning of month 5.

Violence could be defined as the product of *hate* and *violent action*. Suppose that *violent action* erupts, i.e. jumps from 0 to 1, if the level of *hate* exceeds the *restraint threshold*. The latter stock variable only increases through *restraint buildup* and decreases through *restraint loss*.

There is more restraint if government resolve, and thus government authority, is relatively high, if ethical scruples are high, and if media attention paid to violence is low. Suppose *restraint buildup* could be modeled as the product of the *maximum restraint*, the *restraint threshold*, and the *relative restraint gap*, divided by the *adaptation time*. The *relative restraint gap* equals the difference between the *maximum restraint* and the *restraint threshold*, divided by the *maximum restraint*, with the maximum restraint equal to the product of the *government authority*, (1 - *violence in the media* of some 40% of the maximum thinkable), plus *ethical scruples* of, say, 10%. Suppose that, initially, *government authority* is not exercised and jumps to a *government resolve* of 100% in month 10. Existing hate, social problems, and violence in the media on the other hand contribute to restraint loss and corresponding decline of restraint threshold: *restraint loss* could thus be modeled, for example, as the product of *hate*, *social problems*, *violence in the media*, and the *restraint threshold* divided by the *adaptation time*.

1. Make a model of the description. Verify it. Simulate it over a period of 50 months. Plot the behaviors of *violence*, *tolerance*, *hate*, and the *restraint threshold* for these settings. What happens?

2. Note that this model is the translation of an imprecise qualitative theory into an overly accurate quantitative model. Not one of few runs but sets of modes of behavior could therefore, at best, help to test whether the theory is plausible, and whether policies would be appropriate if the theory would be plausible. Model simulations cannot be used to prove the model and outcomes are correct, nor whether policies will indeed be appropriate. In the light of these limitations, validate the model: list at least two tests, describe how they are used for validation in this particular case, perform them. What could eb concluded? Why?

3. Develop four base case policy scenarios related to different levels of the *education effort*: to do so, step up the *education activity* from 0 to 0%, to 25%, to 75% and to 100% in month 15. Plot them. Determine the threshold that causes a bifurcation in behavior.

4. Perform as exhaustive a sensitivity analysis as possible to identify parameters, functions, assumptions the model is most sensitive to. Start with a manual analysis, but also perform an automated multi-variate sensitivity analysis (using Latin Hypercube sampling). Report the most interesting analyses. What could be concluded?

5. Draw a causal loop diagram for a very low and very high *education activity*. Explain the link between structure and behavior.

⚡ Perform uncertainty analyses to determine the required level of *educational activity* under uncertainty: specify the initial values ranges and uncertain parameter ranges as broadly as necessary (and if you can, vary other assumptions too), and test the effectiveness of different levels of *education activity* under uncertainty. Describe and visualize some of your explorations. What could be concluded now?

⚡ Draft an alternative theory –your own causal theory– about Tolerance, Hate & Aggression. Turn it into a SD simulation model. Test it. Use it to identify appropriate policies to fight hate and aggression. What do you conclude? What do you recommend?

14.8 Electrical Vehicle Transition & Lithium Scarcity

Introduction

Given climate change, expected long term energy security problems, and the current crisis in the automotive industry, electric vehicles (EVs) are more and more often said to be '*the* solution'[2]. For example:

- Obama wants 1 million EVs on the American roads by 2015;
- The Dutch electricity grid company Enexis pushes the concept of smart grids in which many EVs and old EV batteries (taken out of EVs after about 3 years and used for another 7 years in the grid) to balance/buffer intermittent electricity generation and variable electricity demand.

Unless a revolutionary technology breaks through, these ideas depend to a large extent upon the availability of the most important and constrained element of the most promising battery technology, that is, lithium.

The Dutch electricity grid company hires you to investigate the long-term consequences (e.g. until 2100) of the availability of lithium. Follow the indications below in order to develop a (simplistic) experimental SD model to investigate the influence of a large-scale transition from ICEs (i.e. vehicles with Internal Combustion Engines) to EVs on the lithium resources and availability (and vice versa). Model all time delays, unless indicated differently, as simple first-order delays.

Modeling EVs, Lithium, etc.

Currently, the ICT sector is a large consumer of lithium. Supposing that there are/will be no other customers for lithium than the ICT and EV sectors, the *total demand for lithium to be exploited* equals the sum of the *lithium needed for EV batteries* and the *annual ICT lithium demand*. Suppose that, at the start of the simulation time in 2009, the *annual ICT lithium demand* equaled 20 kton lithium per year and the *lithium needed for EV batteries* 0 kton lithium per year.

This *total demand for lithium to be exploited* drives *lithium exploitation*. Specialists estimate the current *unexploited lithium reserves* that could be exploited in the future to amount to 13000 kton lithium. It goes without saying that the maximum *lithium exploitation* is smaller or equal to the *unexploited lithium reserves*. Suppose, for reasons of simplicity, that there are no further production constraints and that *lithium exploitation* follows –in the absence of recycling– the *total demand for lithium to be exploited*. The *exploitation time* is a month.

Lithium exploitation is followed by *processing of lithium in products* which takes time and could be modeled with a stock variable. This stock is emptied by a *lithium products brought into use* flow with an average *processing and introduction time* of 1 year. Initially, the *processing of lithium in products* equals 22 kton lithium. After lithium products are brought into use, lithium is tied up as *lithium in products* during an *average lifetime of products containing lithium*. Initially the amount of *lithium in products* equals about 100 kton lithium. The *average lifetime of ICT products containing lithium* is 5 years. And, as already mentioned, the total *average lifetime of EV batteries* (first 3 years in the EVs and afterwards 7 years in the electricity grid) may amount to 10 years.

Suppose that after the *average lifetime of products containing lithium*, these products are either thrown away –leading to a *loss of non-recycled lithium*– or recycled –leading to a *recovery*

[2]Interestingly enough, EVs are also one of the oldest solutions: electric motors existed before internal combustion engines (ICE) became the dominant technology.

of lithium through recycling. The respective sizes of these flows depend on the *effective lithium recycling fraction*, initially equal to 20%. Recycled lithium is blocked as *lithium in recycling* during an *average recycling time* of a quarter before it flows as *lithium from recycling to reprocessing* to the *processing of lithium in products* stock.

1. Make a submodel corresponding to the description above.
2. Make a CLD corresponding to the description/model. How many *feedback loops* should the diagram contain?

Suppose that the *total European car fleet* currently consists of some 100 million ICE cars and only 1000 EVs. Model the *electrification of the European vehicle fleet* as:

$$intensive\ advertisement * \frac{conventional\ vehicles}{average\ lifetime\ conventional\ vehicles} * \frac{electric\ vehicles}{total\ European\ vehicle fleet}$$

Assume an *average lifetime of conventional vehicles* in Western Europe of 9 years[3]. The batteries can only be used inside EVs –due to loss of capacity– during an average of 3 years. The total number of *EV batteries needed* therefore corresponds more or less to the *electrification of the European vehicle fleet* plus the existing *electric vehicles* divided by the *average lifetime of EV batteries*. Suppose that the *intensive advertisement* corresponds –between 2009 and 2016– to 10 times the normal amount of advertisement. To calculate the amount of *lithium needed for EV batteries*, assume that 20 kg or $2 * 10^{-5}$ kton *lithium* are needed per EV battery, and that 1 battery is needed per vehicle.

Assume that the *annual ICT lithium demand* initially equals 20 kton lithium/year, and grows with a (severely underestimated) *growth rate of lithium demand of the ICT sector* of 1% per year.

3. Make a submodel of this description (without connecting it to the other submodel).
4. Connect both submodels. Given the level of aggregation you may use an *approximated fraction of lithium used in EV batteries over the total amount of lithium in use* instead of a precise fraction.
5. Simulate the model and make graphs of the *unexploited lithium reserves*, the *processing of lithium in products* and the *lithium in products*.
6. The model is highly aggregated and should in a later stage be refined. It is nonetheless useful in this stage to do some validation tests. List four validation tests (except sensitivity analysis and risk analysis) that would be useful in this stage, execute them, and briefly describe the results.
7. The model contains some very uncertain variables/assumptions. List 2 of them. Do they have a large impact on the behavior of the model? Explore and explain.
8. Perform a manual sensitivity analysis using a best case and a worst case scenario. Use following intervals into account: *initially unexploited lithium reserves*: 4000–20000 kton lithium; *effective recycling fraction of lithium*: 10–100%; *growth rate lithium demand ICT sector*: 0–25% per year. What could be concluded? Why?

Closing the Loop

[3]After 9 years, many vehicles are exported.

- Until now, the consequences of possible lithium shortages on the electrification of the vehicle fleet have not been taken into account in the model. Include structures such that the electrification of the European vehicle fleet also depends on the availability of lithium. Divide the available lithium –if lithium supply is a bottleneck– between the ICT-sector and the EV-sector in proportion to their respective demands. Does that have an influence on the large-scale transition to EVs?
- Extend the model to the rest of the world.

14.9 Cholera Epidemic in Zimbabwe

Introduction (background information)

The deterioration of the Zimbabwean sanitary and health infrastructures over the years prior to August 2008 resulted in a lack of safe drinking water and health services, especially in and around the cities, which resulted in turn in the 2008-2009 cholera outbreak. The Zimbabwean Ministry of Health and Child Welfare (MoHCW) and the WHO reported a total of almost 30000 cholera cases and almost 1600 cholera deaths between August 2008 and January 2009.

Cholera is an infectious disease caused by the ingestion of the Vibrio cholerae bacterium present in faecally contaminated water. Symptoms are severe diarrhoea and dehydration. The extremely short incubation period is about 1 day. However, cholera can be prevented (rather easily) by taking the necessary precautionary hygienic measures and/or a good sanitary infrastructure. In case of a fast and appropriate treatment, the mortality is low, about 1%. That percentage was much higher in Zimbabwe.

Several international aid organizations offered to provide the necessary medical and sanitary facilities, safe water, and programmes to train aid workers to deal with and prevent cholera. At first, Mugabe refused international aid, but by mid December 2008, he allowed international aid organizations to provide clean drinking water. By that time, half of the population was undernourished . . .

Susceptible, Infected, Recovered and Immune Populations

When individuals from the *susceptible population* become infected (*cholera infections*), they shift to the *recently infected population*. The number of *cholera infections* is the product of the *susceptible population* and the *indirect infection rate*. Those shifted to the *recently infected population* leave that stock after an *average incubation time* of only 1 day and flow:

- as *mildly infected* to the *mildly infected population* if they show mild or moderate symptoms, or if they are infected but do not show any symptoms at all (asymptomatic cases);
- as *heavily infected* to the *heavily infected population* in case of severe symptoms.

The fraction of the *recently infected population* getting only *mildly infected* depends on the *average health condition* of the average Zimbabwean. The fraction used in the base model equals 95%. In other words, only 5% of the *recently infected population* in the base model becomes very ill after an *average incubation time* of 1 day.

All sick persons belonging to the *mildly infected population* shift –after an *average duration of the illness* of 10 days– as *recovered from mild infection* towards the *recovered temporarily immune population*. The sick persons belonging to the *heavily infected population* either die (*cholera deaths*) or recover and become immune (*recovered from heavy infection*) after the same *average duration of* *the illness* of 10 days. The fraction of the *heavily infected population* dying or recovering depends on the *effect of the average state of health services on the fraction of cholera deaths*, and hence, on the *average state of health services*.

The values of the *effect of the average state of health services on the fraction of cholera deaths* and the *average state of health services* can be estimated based on WHO information: suppose that the *effect of the average state of health services on the fraction of cholera deaths* is 100% in case of an *average state of health services* of 0%, 50% in case of an *average state of health services* of 25%, 20% in case of an *average state of health services* of 50%, 5% in case of an *average state of health services* of 75%, and 0% in case of an *average state of health services* of 100%. The *average state of health services* in Zimbabwe was extremely low at the time of the outbreak (until international aid agencies were allowed to enter): assume that the *average state of health services* amounts to 15%.

After a first-order *average immunity period* of 6 years, Zimbabweans from the *recovered temporarily immune population* flow back to the *susceptible population*.

The number of Zimbabwean citizens belonging, at the start of the epidemic, to the *susceptible population* can be assumed to amount to 3000000, the *recently infected population* to 1000, the *mildly infected population* to 950, the *heavily infected population* to 50, and the *recovered temporarily immune population* to 10226000 (this corresponds to the remaining population: 13228000 - 3002000).

Indirect Infection

The *indirect rate of infection* equals the product of following three factors: the *smoothed fraction of contaminated water*, the *effect of prevention and sanitation on the indirect degree of infection*, and the *connectedness of aquifers*. The *connectedness of aquifers* is assumed to amount to 28% in the base model.

The input of the *effect of prevention and sanitation on the indirect degree of infection* is the maximum of two variables: the *level of prevention* and the *state of the sanitary infrastructure*. If the maximum of these two variables is 0% then the effect on the *indirect rate of infection* is assumed to amount to 100%, if it is 25% then the effect is assumed to amount to 90%, if it is 50% then the effect is assumed to amount to 50%, if it is 75% then the effect is assumed to amount to 10%, and if it is 100% then the effect is assumed to amount to 0%. The *level of prevention* and the *state of the sanitary infrastructure* lie between 0% and 100%. In Zimbabwe both were very low: in the base model, the initial *level of prevention* could be assumed to amount to 10% and the initial *state of the sanitary infrastructure* to 30%.

The *effect of the fraction of infected on the fraction of contaminated water* is a graph/lookup function: if the *fraction of infected* is 0% then the fraction of contaminated water is assumed to be 0%, if it is 12.5% then the fraction of contaminated water is assumed to be 50%, if it is 25% then the fraction of contaminated water is assumed to be 75%, if it is 50% then the fraction of contaminated water is assumed to be 90%, if it is 75% then the fraction of contaminated water is assumed to be 99%, and if it is 100% then the fraction of contaminated water is assumed to be 100%.

Suppose the *smoothed fraction of contaminated water* smoothes the (3^{rd} order) *effect of the fraction of infected on the fraction of contaminated water* with a delay of 14 days. Initially it equals 0.0004 (or 0.04%), initiating the epidemic.

And the *fraction of infected* equals of course the sum of the *recently infected population*, the *mildly infected population*, and the *heavily infected population*, divided by the entire population.

1. Make a SD simulation model of the Zimbabwean cholera epidemic as described above. Verify your model.
2. Simulate the model over the first 150 days of the cholera epidemic. Make graphs of the evolution of the *heavily infected population*, the number of *cumulative cholera deaths* and the *smoothed fraction of contaminated water*.

3. Validate the model. Propose 3 appropriate validation tests (except sensitivity analysis), apply these validation tests and describe your results/conclusions. Use for example the WHO information that about 30000 cholera infections and about 1600 cholera deaths were reported after about 100 days. [Hint: Create a new structure to keep track of the number of *cholera infections* since the outbreak of the epidemic.]

4. It should be clear that this cholera epidemic could carry on unless drastic action would be taken. Simulate the model over a period of 10 years. Make graphs of the cumulative cholera infections and cholera deaths. What could be concluded from this long-term simulation?

5. Make an (extremely) aggregated/simplified CLD of this model that can be used to explain the short term epidemic as well as potential long term consequences.

6. Investigate the sensitivity of the model for small changes of following variables: the *connectedness of the aquifers*, the *effect of the fraction of infected on the fraction of contaminated water*, the *level of prevention*, and the *average state of health services*. What could be concluded? Why?

7. Suppose that following measures are abruptly implemented 150 days after the outbreak of the cholera epidemic:

   - The *level of prevention* is changed abruptly from 10% to 70% (by means of water filters, decontamination pills,...).
   - The *average state of health services* is increased suddenly from 35% to 70% (by means of field/emergency hospitals and the arrival of international aid organizations and large numbers of qualified medical personnel).

   What are the consequences in terms of the number of *cumulative cholera deaths* and the *cholera infections*? Plot the graphs. Are these measures sufficient? What about the long term future?

14.10 Signalled Run on a Bank

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Disclaimer: The model underlying this exercise is a very simplistic and highly aggregated model. It cannot be used in its current form to advise real banks.

Introduction

The recent international credit crunch, which started as a sub-prime mortgage crisis in the United States, also caused serious problems for many European banks. One of the largest banks of the Benelux (Belgium, the Netherlands and Luxembourg), the Fortis Bank, almost went bankrupt. The governments of the three countries met in a great hurry in the weekend of 27-28 September 2008 to rescue the Fortis Bank. The reason for rescuing the bank at all cost is that the Fortis Bank is a system bank, which means that it has a crucial role in the financial systems and its collapse could lead to a collapse of the rest of the financial system.

Suppose that –in spite of the fact that you are not a financial specialist– you are asked by the three ministers of finance (probably because of your excellent SD modeling skills) to help them understand the issue at hand, assess potential scenarios, and help them design appropriate policies to prevent the Fortis Bank from going bankrupt. Several top-level financial/banking experts and government officials are able to provide you with some general, high-level information concerning the Fortis Bank.

Let's ignore what happened afterwards and what was disclosed months later, and let's assume you have 2 hours to build a model, use it to generate scenarios and test policies.

Deposits and Shares

The *stock market value* of the Fortis company can only increase by means of an inflow –the *stock market value increase*– and can only decrease by means of an outflow –the *stock market value loss*. Generally speaking, the *stock market value loss* equals the relative *perceived overvaluation* times the *stock market value* divided by the *market loss delay* of about 1 week. And the *stock market value increase* equals the *perceived market opportunity* times the *stock market value* divided by a *market increase delay* of about 4 weeks. Suppose that the *initial stock market value* of the Fortis Bank, 1 week before the critical week, amounted to €10.

The *perceived overvaluation* –in relative terms, thus expressed in percentages– is then nothing but the difference between the *stock market value* and the *estimated underlying value*, divided by the *stock market value*. One of the financial experts advices you to model the *perceived market opportunity* as: (100% - *instant market fear and uncertainty*) ∗ *perceived undervaluation*. The *perceived undervaluation* –in relative terms, thus expressed as a percentage– is then nothing but the difference between the *estimated underlying asset value* and the *stock market value*, divided by the *stock market value*.

Suppose that the *estimated underlying value* (per share) of the Fortis Bank amounted initially, 1 week before the catastrophic week, to €10.16. The *estimated underlying value* can increase by means of *underlying asset increase*s and can decrease by means of *underlying asset loss*es (e.g. in case of a run on the bank, loss of unsecured assets, et cetera). The *underlying asset increase* could be simplified as the *average profitability* on the underlying assets times the *estimated underlying asset value*. The *average profitability* of the assets amounts to 0.2% per week. The financial advisors agree that the *underlying asset loss* (which should always be ≥ 0) should best be modeled as:

$$\textit{estimated underlying value} * (\textit{external real value loss shock} + \\ \textit{liquid deposits and loans loss fraction} * \textit{fraction of asset loss to deposit loss})$$

Assume the *liquid deposits and loans loss fraction* equals the *average bank client's fear and uncertainty* divided by the *average stickiness of deposits and loans*. Assume at first that the *fraction of asset loss to deposit loss* is equal to 1. [The assumption behind this formulation is of course that when fear and uncertainty increase, average bank depositors start to empty their deposits and average lenders stop lending, which needs to be compensated from the bank's assets. In reality these compensating assets are liquid at first but afterwards more and more fixed (and more and more losses are incurred by liquidating them). However, just keep the *fraction of asset loss to deposit loss* constant here.]

The *external real value loss shock* should be used to model and simulate the asset shock as a percentage of the *estimated underlying value*. Suppose that this *external real value loss shock* amounted to 35% in this week time[4]. . . The exact *average stickiness of the assets* of the Fortis Bank is unknown: it could lie anywhere between 4 weeks and 52 weeks. Just take the average value of 28 weeks for a start. The *average bank client's fear and uncertainty* follows the *market fear and uncertainty*, but then smoothed. Model the *average bank client's fear and uncertainty* therefore as a 3^{rd} order delay of the *instant market fear and uncertainty* with an *uncertainty and fear delay* of 2 weeks. Initially, the *average bank client's fear and uncertainty* is equal to 0%. The *instant market fear and uncertainty* could be modeled as:

$$\textit{instant market fear and uncertainty} = \textit{degree of external climate of fear} * \\ \textit{stock market value loss} \,/\, (\textit{stock market value} \,/\, \textit{market loss delay} * \textit{stock market fear factor}).$$

The *instant market fear and uncertainty* should also remain between 0% (absence of uncertainty and fear) and 100% (complete uncertainty and fear). The *stock market fear factor* is assumed to be some 25%. This factor is used to put the loss into perspective – that is to say, relative to the share price: the 25% means that people freak out completely if the share price drops 25% of its

[4]Hint: you can model this for example by means of two step functions or a pulse function.

initial value during the *market loss delay* period of one week. Since the general climate is one of uncertainty and fear, the *degree of external climate of fear* could be assumed to be rather high, for example twice as high as before the crisis, thus 200%.

1. Make a SD simulation model following the description above.
2. Verify the model very briefly. Include the necessary formulas/code/structures that ensure that variables that cannot become negative indeed remain greater or equal to zero. Examples are: the *perceived overvaluation*, the *perceived undervaluation*, and the *underlying asset loss*. Why do these variables always need to be greater than 0?
3. Validate the model extremely briefly. Use at most 2 very simple tests. Do not perform any extensive tests or sensitivity analysis here. Name or briefly describe the tests used.
4. Simulate the model for a period of 52 weeks. Plot graphs for following variables: *stock market value*, *underlying asset loss*, *instant market fear and uncertainty*, and *smoothed market fear and uncertainty*.
5. Three variables are particularly uncertain, simply because they are unknown: the *stock market fear factor*, the *average stickiness of assets*, and the *degree of external climate of fear*. Test the sensitivity of your model (manually) to changes in these variables. Keep it simple! What can you conclude regarding the sensitivity of your model to these changes?
6. Sketch the dynamics of the *stock market value* and the *smoothed market fear and uncertainty* for the worst case and best case scenarios in just two graphs:
   (a) a *stock market fear factor* of 25%, an *average stickiness of assets* of only 4 weeks, and a *degree of external climate of fear* of 200%;
   (b) a *stock market fear factor* of 100%, an *average stickiness of assets* of only 52 weeks, and a *degree of external climate of fear* of 100%.
7. Does the value of the *fraction of asset loss to deposit loss* matter a lot? Check it out and describe your conclusion very briefly.
8. Draw an extremely aggregated/simple *causal loop diagram* of the system to help you communicate the main feedback effects responsible for the worst case system behavior.
9. Explain the link between structure & behavior briefly for the worst case scenario only.
10. Add a policy that prevents the bank from collapsing, no matter which of the scenarios actually materializes. Test the policy at least in case of the worst case scenario and sketch the resulting dynamics.
11. What are your recommendations to the ministers? Debrief.

⚡ The model described above is highly aggregated. Too highly aggregated. A better, less aggregated, version of this model, is discussed and used in (Pruyt 2009d). Turn your model, if you feel like it, into a less aggregated and more realistic model. Moreover, use the classified information that became available after the crisis to improve the model. After improving your model, simulate it, and analyze the differences. Does it lead to different recommendations?

14.11 Fighting HIC on the National Level

Introduction

Burglary is one of several High Impact Crimes – high impact because (i) it has a strong impact on victims, and (ii) it is one of the most frequent crimes. It seems to be a recurring and intractable complex phenomenon. Each 73 seconds there is an (attempted) burglary somewhere in the Netherlands, a small country with about 17 million inhabitants. Intervention, investigation, prosecution and punishment of perpetrators cost many millions to Dutch society. The Dutch police force totals 55,000 policemen. Although only part of the police force is allocated to burglaries, both to intervention (intervention on the spot during or just after a burglary) and to investigation (the whole process post-burglary process focused on finding offenders and stolen goods). In spite of all the measures taken and resources spent, burglary is on the rise. Burglary has become one of the highest priorities of the Dutch police. Suppose the Chairman of the Board of Police Commissioners asks you to develop a simulation model related to burglaries in the Netherlands, to simulate it over a time horizon of 120 months, and use the model to test the suitability of new policies. Use the information below to build your model.

Burglars

Burglaries are committed both by occasional burglars as well as by organized criminals: the *total number of burglaries* is thus the sum of the number of *burglaries by members of the OC* (OC stands for '**O**rganized **C**rime') and the number of *burglaries by occasional burglars*.

Start with the submodel related to *burglaries by occasional burglars*. The number of *burglaries by occasional burglars* is proportional to the *percentage occasional thieves among 'coincidental' passers*, and the *monthly percentage burglaries by occasional burglars in houses with opportunities for burglaries*. Suppose there are 7 million houses, that the *monthly percentage burglaries by occasional burglars in houses with opportunities for burglaries* equals 20 percent, and that the *percentage occasional thieves among coincidental passers* is 5 percent. The *percentage houses with opportunities for burglaries* is seasonal: model it as the *seasonality of burglaries* times (1 - *vigilance regarding burglaries*). The *percentage houses with opportunities for burglaries* is never smaller than 10%. Model the *seasonality of burglaries* such that its value oscillates annually between 25% and 75% with its annual peak at the end of January (darkness provides cover) and the annual low at the end of July (holiday season, even for burglars). Model the *vigilance regarding burglaries* as a 3^{rd} order delay of the *relative media attention with regard to burglaries* with an average delay time of 3 months and an initial value of 70%. The *relative media attention with regard to burglaries* could be modeled as a function of the *total number of burglaries* divided by the *acceptable number of burglaries*, connecting following couples (0,0), (2,0.2), (4,0.8), (6,1), (8,1), (12,1). Suppose that the *acceptable number of burglaries* amounts to about 4500 burglaries per month.

Now, model the burglaries by OC. The number of *burglaries by members of the OC* is determined by the *members of OC active in burglary in the Netherlands* and the average of 4 *burglaries per member of the OC per month*. The number of *members of OC active in burglary in the Netherlands*, starting from 2450 members in 2000, gradually changes through the *net increase of active members of OC in burglaries in the Netherlands*. The *net increase of active members of OC in burglaries in the Netherlands* may be modeled as the product of the *normal size of OC in burglaries in the Netherlands*, and the *chance of being caught for burglary in neighboring countries* divided by de *effective chance of being caught for burglary in the Netherlands*, minus the *members of OC active in burglary in the Netherlands*. Suppose that the *chance of being caught for burglary in neighboring countries* is about 20%, and the *normal size of OC in burglaries in the Netherlands* amounts to 2500 (mostly) men.

The Police

The *effective chance of being caught for burglary in the Netherlands* is a function of the *total available hours for investigating burglaries* divided by de *total man-hours required for burglaries investigation*: the *effective chance of being caught for burglary in the Netherlands* is equal to 0% if the fraction equals 0, the *effective chance of being caught for burglary in the Netherlands* is equal to 20% if the fraction equals 1, the *effective chance of being caught for burglary in the Netherlands* is equal to 30% if the fraction equals 2, the *effective chance of being caught for burglary in the Netherlands* is equal to 40% if the fraction equals 4, and the *effective chance of being caught for burglary in the Netherlands* is equal to 50% if the fraction equals 8.

The *total man-hours required for burglaries investigation* equals the number of *burglaries under investigation* times 40 *man-hours required for investigation of a burglaries under investigation per month*. Model the variable *burglaries under investigation* as the integral of the *opening of new burglaries investigations* minus the *closing of old burglaries investigations*, with an initial burglaries under investigation of 32725 cases. The *opening of new burglaries investigations* is equal to the *total number of burglaries*, and the *closing of old burglaries investigations* is equal to the number of *burglaries under investigation* divided by the *average time under investigation* of 2 months.

Intervention has absolute priority. The *total available hours for investigating burglaries* therefore equal the difference between the *total available man-hours for burglaries* and the *total man-hours required for intervention with regard to burglaries*. The *total man-hours required for intervention with regard to burglaries* equal of course the *total number of burglaries* times the *man-hours required for intervention per burglaries* of 2 man-hours per intervention. The *total available man-hours for burglaries* correspond to the number of *policemen assigned to burglaries* times 160 available *man-hours per policeman per month*. The number of *policemen assigned to burglaries* is equal to the integral of the *net formation of teams of policemen assigned to burglaries*, with an initial value of 8760 policemen. This *net formation of teams of policemen assigned to burglaries* is simply the difference between the *policemen required for burglaries* and the number of *policemen assigned to burglaries*, divided by the *reassignment time* of 1 month. Assume that policemen assigned to burglary teams only deal with burglaries interventions and burglaries investigations; the number of *policemen required for burglaries* then equals the sum of the *total man-hours required for intervention with regard to burglaries* and the *total man-hours required for burglaries investigation*, divided by the *man-hours per policeman per month*.

1. Create a SD simulation model based on this description, and verify the model.
2. Validate the model: name two suitable validation tests (different from sensitivity analysis – see question 4), perform them, and draw conclusions.
3. Simulate the model, save your results, and plot the model behavior of following variables: (1) the *total number of burglaries*, the *burglaries by members of the OC* and the *burglaries by occasional burglars*, and (2) the *effective chance of being caught for burglary in the Netherlands* and the number of *members of OC active in burglary in the Netherlands*.
4. Perform useful sensitivity analyses: test the sensitivity of the model and policy for two important assumptions or parameters. Conclude.
5. Make an extremely aggregated CLD of this model. And explain the relationship between structure and behavior of this model with this policy briefly on the basis of this CLD. Keep it as simple as possible. Very few chiefs of police have a SD background. . .
6. During your explanation to the previous question, the Chairman noted that your explanation is not entirely correct because in reality a maximum of 9000 agents is assigned to burglaries. How do you solve this on the spot, in other words, what is the fastest way possible to adapt the model to this criticism. Do it. Plot the effects on the *burglaries by members of the OC* and the *burglaries by occasional burglars*. Explain the difference.

7. Describe a set of possible policies which allows to substantially reduce the number of burglaries. Implement this set of policies in the model and test it. What are the consequences of this set of policies for the citizens and the police?

14.12 Overfishing of Bluefin Tuna

Introduction

Tuna experts fear that the Atlantic bluefin tuna may be nearly extinct in a few years time. According to environmental organizations, the collapse of the East-Atlantic bluefin tuna is imminent as a consequence of systematic overfishing and illegal catches in the Mediterranean. Hence, their call for a moratorium in the eastern part of the Atlantic Ocean and the Mediterranean.

The East-Atlantic bluefin tuna is a migratory predator that commutes between the Atlantic Ocean and the Mediterranean Sea. Almost the entire catch is exported to Japan for its thriving sushi and sashimi markets. The tuna population has been in sharp decline in recent years and many tuna experts considered the 2011 meeting of the 'International Commission for the Conservation of Atlantic Tunas', ICCAT[5] for short, as the last chance to remedy the situation...

In the early 1980s, drastic catch restrictions were agreed upon for the Western part of the Atlantic Ocean. But those drastic measures were too little too late. The population only stabilized in the nineties at only 20 percent of the 1975 level.

It is clear that action needs to be taken now to save the East-Atlantic bluefin tuna. That is why you are asked to make a SD simulation model concerning this threatened tuna species (from now simply called tuna).

Fish in the Sea

The *tuna biomass* increases through *growth of tuna biomass* and *delayed tuna recruitment*[6], and decreases through *natural tuna fish deaths* and *tuna fish catches*. Assume that the initial value of the *tuna biomass* amounts to the *1990 unfished tuna biomass*[7] of 100000 tonnes.

The *growth of tuna biomass* is equal to the *tuna biomass* times the *rate of tuna growth* of 'adult tuna fish' of 4% per year. The *delayed tuna recruitment* equals the *tuna biomass* multiplied by the *tuna recruitment rate* of 1% per year, but is delayed (exactly) 4 years[8].

Natural tuna fish deaths are estimated to amount to the *tuna biomass* multiplied by the *ratio of current biomass to unfished biomass* over the *normal tuna lifetime* of 20 years. The *ratio of current biomass to unfished biomass* is simply the *tuna biomass* divided by the *unfished tuna biomass*.

And *tuna fish catches* depend on the *tuna biomass* and the *tuna catch fraction*. The *tuna catch fraction* depends in turn on the *total number of tuna fishing boats* and *tuna boat efficiency* of 0.0004% per boat per year. [Assume for now that:] The *total number of tuna fishing boats* is composed of 15000 *official tuna fishing boats* [this constant will be turned into a variable in the next section] and 10000 *illegal tuna fishing boats*.

1. Make a first SD simulation model of this issue.

[5] The ICCAT is an intergovernmental fishery-organization responsible for the preservation of tuna and tuna-like in the Atlantic Ocean and bordering seas, like the Mediterranean.

[6] Recruitment means reaching a certain size or reproductive stage. In fishery speak, recruitment usually refers to the age a fish can be caught and counted in nets.

[7] The *unfished tuna biomass* is the estimated tuna biomass without any (previous or current) tuna fishing.

[8] Tuna is assumed to mature at four years of age in the Mediterranean. It is also assumed here that harvesting tuna under the age of 4 is not interesting from economic and ecological points of view.

2. Simulate the model. What happens with a fixed *total number of fishing boats* of 25000, 15000, and 5000? What would be the *total number of fishing boats* that would keep the tuna biomass in equilibrium at the current level? Plot the four results in terms of the *tuna biomass*.
3. Write this system as a balance equation (make sure to choose appropriate symbols and explain their meaning).

Fishery and Fleet Management

The International Commission for the Conservation of Atlantic Tunas (ICCAT) is an intergovernmental fishery organization responsible for the conservation of tuna and tuna-like species in the Atlantic Ocean and its adjacent seas, more specifically the Mediterranean. ICCAT fleet size regulations are among the most important measures for preventing the extinction of the bluefin tuna homing in the East Atlantic-Mediterranean. ICCAT's functioning and policy-making can be seen as a high-level policy loop. This high-level ICCAT-policy loop may be summarized as follows:

First, the *ratio of current biomass to unfished biomass* is estimated.

Their *latest perception of the tuna fishery status* is a non-linear function of the *ratio of current biomass to unfished biomass* connecting following couples: (0,-10), (0.25,-2), (0.5,0), (0.75,1.5), and (1,10). The *ICCAT perceived state of tuna fishery* is a smoothed function of the *latest perception of tuna fishery status* with a *time needed to change the tuna fishery perception* of 2 years, starting from the *initial ICCAT state of tuna fishery* in the year 1990 of 10 (which corresponds to 'excellent').

The *official number of tuna fishing boats*, initially 15000, increases (and decreases) by means of the *net increase of the official number of tuna fishing boats* equal to the *proposed change in tuna fishing boats* divided by the *time to implement the tuna boat policy* of about 2 years.

The *proposed change in tuna fishing boats* is directly proportional to the *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats* and to the *official number of tuna fishing boats*. Given past and expected ICCAT perceptions and decisions, you can assume that this *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats* amounts to -0.9 for *ICCAT's perceived state of tuna fishery* of -10, to -0.5 for *ICCAT's perceived state of tuna fishery* of -7.5, to -0.25 for *ICCAT's perceived state of tuna fishery* of -5, to -0.1 for *ICCAT's perceived state of tuna fishery* of -2.5, to 0 for *ICCAT's perceived state of tuna fishery* of 0, to 0.075 for *ICCAT's perceived state of tuna fishery* of 2.5, to 0.15 for *ICCAT's perceived state of tuna fishery* of 5, to 0.21 for *ICCAT's perceived state of tuna fishery* of 7.5, and to 0.25 for *ICCAT's perceived state of tuna fishery* of 10 or more.

4. Extend the simulation model with the information provided above. Simulate the model and make graphs of the *official number of tuna fishing boats* and *tuna biomass*.
5. Validate the model. List 2 validation tests (with the exception of sensitivity testing), perform them and describe the results/conclusions. Compare the structure of your model to the one in MCQ 13 on p196.
6. Test the sensitivity of the model (more specifically of the *official number of tuna fishing boats* and the *tuna biomass*) for changes in 3 parameters of your own choice (choose them well!) as well as the *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats*. Briefly describe the tests you performed, your results and conclusions.
7. What happens to the *tuna biomass* and *official number of tuna fishing boats* if the number of *illegal fishing boats* falls –due to strict controls and severe punishments– from 10000 down to 0 in 2010? Apply, rename the model, and plot and briefly describe the results. [Preserve this drastic reduction of the number of *illegal fishing boats* described in this what-if question in the remainder of the questions.]

8. What happens if countries studiously refuse to scale down their tuna fishing fleets, in other words, if the *net increase of the official number of tuna fishing boats* does not become negative? Apply, rename the model, and draw and briefly describe the results.
9. Make an extremely aggregated *causal loop diagram* of the model to explain the main feedback loops. Use it to explain the link between structure and behavior.
10. ICCAT policy making is heavily criticized for its unsustainability. Devise 2 feasible policies to improve the sustainability of the current high-level ICCAT policy-loop. Describe them, implement them (rename your model), test them separately and (if possible) together, and briefly describe your conclusions: is this ICCAT+ policy more sustainable?

Fishery and Fleet Management in a Changing World?

- It is well known that the ecosystem capacity for Tuna keeps on deteriorating (pollution, overfishing of species predated on by tuna, etc) and that the efficiency of tuna boats keeps on increasing. Model both evolutions and test the appropriateness of the 'ICCAT policy' and the 'ICCAT+ policy' (the ICCAT policy plus the policies devised in the previous question) given these evolutions. Draw and describe your outcomes and conclusions.
- From an individual fishery perspective, it makes sense to catch the fattest (and consequently the oldest) fish. But the older age classes actually contribute more to reproduction... Adapt the model accordingly. What does this information mean for the effectiveness of the 'ICCAT policy' and your 'ICCAT+ policy'?

14.13 Production Management

Introduction

You are asked by a plant manager to help him solve one of his production problems. The problem is one of unbalanced production and major internal fluctuations. The manager thinks that these major internal fluctuations are caused by external fluctuations. However, the external fluctuations that are observed in the real world are really very small. Nevertheless, the manager would like to eliminate these extremely disruptive fluctuations as much as possible since they lead to lost sales and major internal frictions between two divisions (the 'assembly line division' and the 'component line division').

The company produces and sells a single type of final product. Selling to a stable B2B customer base, the *customer ordering rate* is very stable at about 10000 units per week. The final product actually consists of two identical components –produced on the 'component production line'– which are subsequently joined on the 'assembly line'.

The Assembly Line

The *customer ordering rate* is currently used as *internal ordering rate for the final product*. If the *inventory of finished final products* is big enough to satisfy the *internal ordering rate for the final product*, then the *deliveries of final product* equals the *internal ordering rate for the final product*, else it equals the maximum amount deliverable, in other words, the *inventory of finished final products* divided by the *delivery period of final products* of 1 week. (Note: try to avoid using an `if then else` function to model this flow variable).

Hence, *deliveries of final product* decrease the *inventory of finished final products*. The *inventory of finished final products* increases through the *assembly of final products*. The *assembly of final products* happens according to the *deliveries of components* (see below). Initially, the *inventory of finished final products* equals the *desired inventory of finished final products*.

The *internal ordering rate for the final product* not only partially pulls items from the *inventory of finished final products*, it also drives the adaptation of the production capacity of the assembly line. The *internal ordering rate for the final product* times the *desired inventory coverage of the final product* of 1.5 weeks determines the *desired inventory of finished final products*.

Initially, the *production capacity of the assembly line* equals the *internal ordering rate for the final product*. The *capacity change of the assembly line* is decided about automatically according to the following formula: *capacity change of the assembly line* = ((*desired inventory of finished final products* - *inventory of finished final products*) / *assembly time*) / *adaptation time of the assembly line*. The *adaptation time of the assembly line* amounts to 12 weeks, and the *assembly time* to 1 week.

The Component Line

The structure of the component line is almost identical to the assembly line. The *production capacity of the assembly line* times the *number of components per final product* –remember, the assembly of 1 final product requires 2 components– is currently used as '*full capacity internal component ordering rate*'.

If the *inventory of components* is big enough to satisfy the *full capacity internal component ordering rate*, then the *delivery of components* equals the *full capacity internal component ordering rate*, else it equals the maximum amount deliverable, in other words, the *inventory of components* divided by the *component delivery period* of 1 week. (Note: try to avoid `if then else` functions to model this outflow). The deliveries always need to be greater than or equal to zero.

Hence, *deliveries of components* decrease the *inventory of components*. The *inventory of components* increases through the *production of components*. The *production of components* –which cannot be negative either– follows the *production capacity of the component line*. Initially, the *inventory of components* equals the *desired component inventory*.

The *desired component inventory* not only partially pulls the component inventory, it also drives the adaptation of the production capacity of the component line. The *full capacity internal component ordering rate* times the *desired component inventory coverage* of 1.5 weeks determines the *desired component inventory*.

Initially, let the *production capacity of the component line* equal the *internal ordering rate of final products* times the *number of components per final product*. The *capacity change of the component production line* is decided about automatically according to the following formula: ((*desired component inventory* - *inventory of components*)/*component production time*)/*adaptation time of the component production capacity*. The *adaptation time of the component production capacity* amounts to 8 weeks, and the *component production time* to 1 week.

1. Make a SD simulation model of this issue.
2. Verify the model very briefly. Include formulas/code/structures that ensure that the *production of components* and the *assembly of final products* cannot become negative. Name 2 other variables that necessarily need to be greater than or equal to 0 and explain why. Do not 'protect' these variables. Instead, monitor them, and only protect them later on if really necessary.
3. Simulate the model over 4 years. Is your model in equilibrium?
4. Now suppose that the *customer order rate* amounts to 11000 in weeks 5 until 10 (week 10 not included). Hint: you may for example use two step functions to model this temporary increase. Rename your model, add this temporary increase, and simulate your model.

5. Plot graphs for following variables: the *inventory of finished final products*, the *production capacity of the assembly line*, the *inventory of components*, the *production capacity of the component line*.
6. Briefly validate the model. Compare your structure to the structure of the model in MCQ 6 on p192. Check whether everything works fine. If not, describe the problems. Only adapt your model if absolutely necessary, that is to say, if the policy you propose below (in (9)) does not allow to solve the problem.
7. Draw an extremely aggregate/simple CLD of the model to help you communicate (only) the main feedback effects responsible for the disruptive internal fluctuations.
8. What is the real cause of these extreme internal fluctuations? Is it really caused by small external disturbances? If not, what causes these extreme internal fluctuations? In other words, explain the link between structure and behavior.
9. Change your model such that small external disturbances do not lead to extreme internal fluctuations. Briefly explain the changes you made to the model. Explain the policy briefly in words the manager would understand. Test the policy and sketch the resulting dynamics of the *inventory of finished products* and *inventory of components*.

14.14 Redevelopment of Social Housing Districts

Introduction

Many residential districts in the Netherlands were –and still are– constructed in their entirety by (social) housing corporations. Many of these districts gradually deteriorated over time and currently need to be redeveloped. Different redevelopment options are chosen: some districts are (partly) demolished and rebuilt, some districts are entirely renovated, some districts are gradually privatized in order to bring about a healthy mix of (social) tenants and private home-owners (owning the home in which they reside) and to generate the necessary revenues to renovate the social housing fraction, et cetera. However, any of these option chosen leads to complex dynamic behavior over time that needs to be investigated before the choice is actually made: the future development of the districts in terms of the mix of inhabitants, the quality of the housing, et cetera, crucially depends on the redevelopment option chosen. SD could be used to investigate this dynamic complexity.

In this case, the gradual privatization option will be investigated for a hypothetical social housing district. The main goal is to investigate the dynamics of privatization on the district level.

Modeling the District Redevelopment

Suppose that initially there are 3000 single family apartments in the district, of which 2990 are still in the social housing renting market and 10 are already privatized. An apartment is privatized when the *social housing family* decide to leave. The *outflow of social housing families* is proportional to the *perceived quality of life by social housing families*. The precise values of this causal relationship are unknown: assume therefore at first that 100% of the remaining *social housing families* leave at a *perceived quality of life* (QoL) of 0%, that 45% leave at a perceived QoL of 25%, that 15% leave at a perceived QoL of 50%, that 5% leave at a perceived QoL of 75%, and that 0% leave at a perceived QoL of 100%.

You suspect that the *perceived quality of life by social housing families* depends on the average *quality of social housing apartments* and the social cohesion between the social housing families (take the *fraction of social housing families* as a proxy for the social cohesion between the social housing families). However, the relative importance of these two criteria is unknown. Given the fact that the district is a close-knit district of the 'common people', it could be assumed that the relative *importance of social cohesion* is twice the relative *importance of the quality of social housing apartments*.

The average *quality of social housing apartments* equals the *total quality of all social housing apartments* divided by the number of *social housing apartments* (which equals the number of social housing families). Initially, the *total quality of all social housing apartments* equals the product of the *initial average quality of the social housing apartments* and the number of *social apartments*. The *initial average quality of the social housing apartments* amounts to 70% of the average quality of newly built apartments. An annual *loss of quality of social housing apartments through ageing* decreases the *total quality of all social housing apartments*: this annual loss equals the *total quality of all social housing apartments* divided by the *lifetime of social housing apartments without refurbishing* of about 30 years.

The *total quality of all social housing apartments* increases through *refurbishment*. Suppose that 5% of the social housing apartments are fully refurbished each year, increasing the average quality of the apartments that are refurbished to 100% (i.e. the quality level of newly built apartments).

A flow *loss of total quality of social housing apartments at privatization* also decreases the *total quality of all social housing apartments* when social housing apartments are privatized.

1. Make a SD simulation model of this description and simulate it over a period of 50 years.
2. What is the general dynamics of the model? Make graphs of the number of *social housing apartments*, *quality of social housing apartments*, and privatization of social apartments.
3. Do the uncertain assumptions have a major influence on the behavior of the model? Test and explain.
4. When presenting the results to the Mayor and Aldermen, they jump on the long-term dynamics of the mix of social housing and private housing. They ask you to investigate whether a different refurbishing policy leads to a better social mix:
   (a) What happens if 10% of all social housing apartments are refurbished annually? Make graphs of the *quality of social housing apartments* and the number of *social housing apartments*. Is this policy effective?
   (b) What happens if all social housing apartments are (all together) renovated once every 10 years? Make graphs of the *quality of social housing apartments* and the number of *social housing apartments*. Is this policy effective?
5. What policy do you propose to obtain a healthy mix of social rent and private apartments?
6. Assume that the average *quality of social housing apartments* remains constant, which means that part of the model (related to the quality of social housing apartments) could be deleted. Draw an aggregated CLD of the remaining system that allows to explain the dynamics of the *fraction of social housing families* to laymen.
7. Briefly explain the link between structure and behavior.
8. Validate your model. Compare the structure and behavior to the model and behaviors displayed in MCQ 1 on p189. If your model is invalid, how would you extend it to increase its validity?

⚡ If you feel like it, you may want to extend this model with subscripts to add different types of people in the district. That was what the larger model presented in (Pruyt 2008a) was developed for in the first place. Using subscripts/arrays, and possibly distributions, one may indeed make SD models with agent-based characteristics.

14.15 Mineral/Metal Scarcity I

From Extraction and Processing to Production of Goods

Rare Earths Metals (REM) are often used in very small quantities in modern appliances or applications. Assume that the *REM in goods* initially amounted to 2000000 ton in the year 2010. *REM in goods* are lost after an *average lifetime in goods* of some 15 years (recycling of REM is (currently) not feasible). The *use of REM in the production of goods* depends on the *demand for REM* or the *available supply of REM* –initially equal to 250000 ton– if the *available supply of REM* is smaller than the *demand for REM*. The *available supply of REM* only increases through *processing of REM* which in turn follows the *real REM extraction*.

1. Make a SD model of this description.
2. Make a complete CLD and a strongly aggregated CLD of this partial simulation model.

Demand and Supply of REM

The *demand for REM* –initially equal to 100000 tons in the year 2000– increases in principle by means of an *increase of the demand for REM* and decreases through a *decrease of demand through price elasticity of demand* or through *substitution losses*.

The *increase of the demand for REM* is simply the product of the *economic growth rate* and the *demand for REM*. Suppose for reasons of simplicity that the *economic growth rate* was equal to 3% until the year 2009, that it fell to -10% in 2009, and that it jumped to 8% in 2010. Assume that the *economic growth rate* remains constant at 5% from 2011 on.

The *decrease of demand through price elasticity of demand* could be modeled as:

$$-price\ elasticity\ of\ demand * demand\ for\ REM * \frac{\frac{1}{relative\ price} - \frac{1}{relative\ price\ of\ the\ previous\ year}}{\frac{1}{relative\ price\ of\ the\ previous\ year}}$$

With the *relative price* equal to the product of the *average REM extraction costs*, the *scarcity price effect* and (1 + *normal profit margin*). Suppose that the *price elasticity of demand* is 10% and that the *normal profit margin* is 15%.

If the *relative price* is greater than the *relative price of the cheapest substitute* then the *substitution losses* increase to the product of the *demand for REM*, $\frac{1}{relative\ price}$, and the difference between the *relative price* and the *relative price of the cheapest substitute*. The *substitution losses* due to price substitution effects are in other words non-negative. Suppose that the *relative price of the cheapest substitute* is constant at 100 (in other words 100 times the normal price of REM).

Suppose also that the *scarcity price effect* amounts to 100 if the *supply demand ratio* is 0, 10 if the *supply demand ratio* is 0.55, 1 if the *supply demand ratio* is 1.1, 0.75 if the *supply demand ratio* is 2.2, 0.5 if the *supply demand ratio* is 11, and 0.2 if the *supply demand ratio* is 22. The *supply demand ratio* is equal to the *available supply of REM* divided by the *demand for REM*.

3. Extend the SD model following the description provided above.

Commissioning and Decommissioning of Extraction Capacity

Suppose that the mining industry is myopic and has limited foresight: the *desired extraction capacity* then equals the *demand for REM*. And the *newly planned extraction capacity* then equals the product of the *profitability of REM extraction* between 0 and 1 and the difference between the *desired extraction capacity* and the *installed extraction capacity*. Note: the value of the latter difference necessarily lies between 0 and the value of the *installed extraction capacity*.

Newly planned extraction capacity increases the *extraction capacity under construction* –initially equal to 60000 t/yr. The *extraction capacity under construction* decreases through *commissioning of extraction capacity* which delays the *newly planned extraction capacity* with a *precise construction time of extraction capacity* of exactly 8 years. The *commissioning of extraction capacity* initially equals the *extraction capacity under construction* divided by the *precise construction time of extraction capacity*.

The *commissioning of extraction capacity* leads of course to an increase of the *installed extraction capacity*, initially equal to 100000 t/yr. The *installed extraction capacity* decreases on the one hand through *decommissioning of extraction capacity* and on the other hand through *decommissioning of unprofitable extraction capacity*. Model the *decommissioning of unprofitable extraction capacity* as: *installed extraction capacity* * (-MIN(*profitability of REM extraction*,0)).

The *decommissioning of extraction capacity* then equals the *installed extraction capacity* divided by the *average lifetime of extraction capacity* minus the *decommissioning of unprofitable extraction capacity*. Note that the formula of the *decommissioning of extraction capacity* needs to be non-negative. Set the *average lifetime of extraction capacity* to 30 years.

The maximum REM extraction is equal to the *installed extraction capacity*. The *real REM extraction* normally equals the *installed extraction capacity*, unless the *scarcity price effect* is smaller than 1, then it equals the *installed extraction capacity* times the *scarcity price effect*.

Cumulation of the *real REM extraction* gives the *cumulatively extracted REM* –initially equal to 4000000 ton. The difference between the *cumulatively extracted REM* and the *initial cumulatively extracted amount* is needed to calculate the *average REM extraction costs*. To do so, use a function with the difference between the *cumulatively extracted REM* and the *initial cumulatively extracted amount* as argument that connects following couples: (0, 1), (2.000.000, 2), (4.000.000, 4), (6.000.000, 8), (8.000.000, 16), (10.000.000, 32), (12.000.000, 64), (14.000.000, 128), (16.000.000, 256), (18.000.000, 512).

Finally, the *profitability of REM extraction* is equal to the difference of the *relative price* and the *average REM extraction costs*, divided by the *average REM extraction costs*.

4. Extend the SD model with the description provided above. Test it.

5. Extend the model: model the '*intrinsic demand*' –in other words, the demand in the absence of *decrease of demand through price elasticity of demand* and *substitution losses*– and make an output indicator '*fraction produced of intrinsic demand*' that allows to visualize the *use of REM in the production of goods* in function of the *intrinsic demand* over time.

6. Simulate between 2000 and 2080. Draw the behavior of the output indicator, of the *demand for REM*, of the *installed extraction capacity*, the *scarcity price effect*, and the *relative price*.

7. What happens if the '*initial extraction capacity under construction*' is 0? Compare, draw and conclude.

8. What happens if –on top of the previous what-if– the 'economic growth rate' amounts to 3% from 2011 on? Compare, draw and conclude.

9. Perform a sensitivity analysis. For which parameters and functions is the model behaviorally sensitive? Plot (only) interesting outcomes.

10. Make an aggregated CLD and explain the link between structure and behavior.

14.16 Radicalization & Deradicalization

Introduction

A new international research institute dedicated to security and terrorism has recently been founded in The Hague. The institute asks you to make a generic, explorative SD simulation model related to radicalization and deradicalization that could at a later stage be used to study animal rights activism, climate terrorism, etc. From discussions with leading security experts, you learn that:

The Issue

Radicalization is often brought about by a (real or perceived) *underlying phenomenon*. Suppose for example that this *underlying phenomenon* initially equals 50 and increases (or decreases) through a *net-increase of the underlying phenomenon*. *Problem symptoms* become visible when/if the level of this *underlying phenomenon* increases above a *problematic phenomenon level* of, say, 60. These problem symptoms could be modeled simplistically as the difference between the *underlying phenomenon* and the *problematic phenomenon level*, divided by the *problematic phenomenon level*. *Problem symptoms* can (mathematically speaking) only be non-negative.

But even if there are no *problem symptoms* yet, there is –for *convinced citizens*– a *perceived magnitude of the problem*, equal to the *underlying phenomenon* divided by the *problematic phenomenon level*. The higher the *perceived magnitude of the problem* is, the higher the *frustration of convinced citizens* will be. Security experts suggest to model the *frustration of convinced citizens* as a percentage between 0% and 100%, equal to the product of the *frustration due to marginalization*, the *frustration due to inertia*, the *average degree of conviction of convinced citizens*, and the *perceived magnitude of the problem*.

Unconvinced citizens could become *convinced citizens* if they are persuaded by already *convinced citizens*. However, there are also *citizens that will never be convinced*. Suppose that the initial number of *convinced citizens* equals 1.000, the initial number of *unconvinced citizens* equals 12.999.000 and that the initial number of *citizens that cannot be convinced* equals 3.000.000 – on a total population of 16.000.000 citizens. The *convinced citizens* could for example be modeled as the product of the *contact rate of convinced citizens*, the *fraction of convinced citizens*, the *unconvinced citizens*, the *persuasiveness of non-radical actions*, and the *visibility of the problem* (see last paragraph), divided by the *strength of incompatible self-interest*. The *strength of incompatible self-interest* stands for how hard it is do something given the interests or habits that are incompatible or counter. The *fraction of convinced citizens* equals of course the number of *convinced citizens* divided by the sum of all citizens.

Suppose for a start that: if the *fraction of convinced citizens* is equal to 0 then the *frustration due to marginalization* equals 100%, if the fraction equals 0.025 then the *frustration due to marginalization* equals 50%, if the fraction equals 0.05 then the *frustration due to marginalization* equals 20%, if the fraction equals 0.075 then the *frustration due to marginalization* equals 5%, and that if the fraction is equal or greater than 0.1, the *frustration due to marginalization* equals 0%.

More *convinced citizens* implies that more societal change may be expected. Societal change may allow to stop the increase of, or may even decrease, the underlying phenomenon: assume that the *rate of decrease through societal change* equals the *fraction of convinced citizens* multiplied by the *maximum attainable rate of decrease through societal change* of, for example, 5% per year. This *rate of decrease through societal change* mitigates the *net increase of the underlying phenomenon.* This *net increase of the underlying phenomenon* equals the product of the *underlying phenomenon* with the difference between the *intrinsic rate of increase of the underlying phenomenon* and the *rate of decrease through societal change.* Suppose in this generic model that the *intrinsic rate of increase of the underlying phenomenon* is equal to 1% per year.

The difference between the *maximal attainable rate of decrease through societal change* and the *rate of decrease through societal change*, divided by the *maximum attainable rate of decrease through societal change* can be used as a proxy for the *frustration due to inertia* which frustrates the convinced citizens if they do not see sufficient change.

Suppose that the *contact rate of convinced citizens* equals the *normal contact rate of convinced citizens* of, say, 1000 (different and sufficiently close) contacts per person per year multiplied by (1 - *radical action level*); with the *radical action level* equal to the *average readiness to take action* multiplied by the *frustration of convinced citizens.*

The *non-radical action level* is the complement of the *radical action level*, in other words (100% - *frustration of convinced citizens*) ∗ *average readiness to take action.* The *non-radical action level* and the *normal persuasiveness* of 1 persons per 100 contacts determine the *persuasiveness of non-radical actions.* The *average readiness to take action* equals the *total readiness to take action of all convinced citizens* divided by the number of *convinced citizens.*

Suppose that the *total readiness to take action of all convinced citizens* initially equals the product of the number of *convinced citizens* and an *initial readiness to take action per convinced citizen* of, say, 80%. The *total readiness to take action of all convinced citizens* increases through adding *readiness to take action of newly convinced citizens*, equal to the flow of the *newly convinced citizens* multiplied by the *readiness to take action per newly convinced citizen* of, say, 50%. The *average persuasiveness of the convinced citizens* also equals the *total readiness to take action of all convinced citizens* divided by the number of *convinced citizens.*

Suppose, for now, that the *visibility of the problem* is equal to the *problem symptoms* times the *reinforcement of the visibility of the problem through radical and non-radical actions*, and that the *reinforcement of the visibility of the problem through radical and non-radical actions* is equal to (1 + *non-radical action level*) ∗ (1 + *radical action level* * *reinforcement of the visibility of the problem through radical actions*). Set the *reinforcement of the visibility of the problem through radical actions* equal to 10, and the *strength of incompatible self-interest* to 2.

1. Model this issue. Verify the model. Simulate the model over a time horizon of 100 years, starting in 1980.
2. Make graphs of the *convinced citizens* and the dynamic factors that directly influence the *newly convinced citizens.*
3. Validate the model: describe and perform 2 different validation tests (except sensitivity analysis – see the next question) and the conclusions of these tests. What would/should be the goal of validation in this explorative case?
4. Test the sensitivity of the model for changes in following parameters: the *initial readiness to take action per convinced citizen*, the *readiness to take action per newly convinced citizen*, the *strength of incompatible self-interest*, the *reinforcement of the visibility through radical actions*, the *normal contact rate of convinced citizens*, and the *normal persuasiveness.* Briefly describe your conclusions.
5. Make two interesting and consistent exploratory scenarios. Simulate the scenarios and save the outputs (graphs). What could be concluded from those exploratory scenarios?
6. Make a strongly aggregated CLD of this simulation model. And use the CLD to explain the link between structure and behavior.

7. Formulate policy advice –based on this modeling exercise– related to ***de***radicalization.
8. Give examples of 2 'soft variables' in this model. Why could they be called 'soft'?
9. This is of course a preliminary generic model, and the analysis is explorative at best. Give advice related to future refinements and extensions. How do you think those refinements and extensions would change the model behavior?

14.17 Fundamental Behaviors

Basic modes of behavior can be generated by a simple positive or a simple negative feedback loop. A first-order[9] linear positive feedback loop system gives either an exponential increase (see figure 14.1a) or decrease. A negative feedback loop without delays leads to goal seeking behavior towards a (desired or implicit) goal (see figure 14.1b). Slightly more complex modes of behavior arise from the combination of these loops and the occurrence of delays and non-linearities.

Figure 14.1c shows *S-shaped growth* which can be generated by a shift in dominance from a positive to a negative feedback loop. Figure 14.1d displays *oscillatory behavior* which can be generated by the combination of a negative feedback loop and a delay. Figure 14.1e shows a *growth with overshoot* behavior which could be generated by a positive feedback loop which shifts to a negative loop with a delay. Figure 14.1f shows *overshoot and collapse* which could be generated by a dominant positive loop which activates the erosion of the 'carrying capacity', and a shift to a negative loop which goal state depends on the eroding carrying capacity.

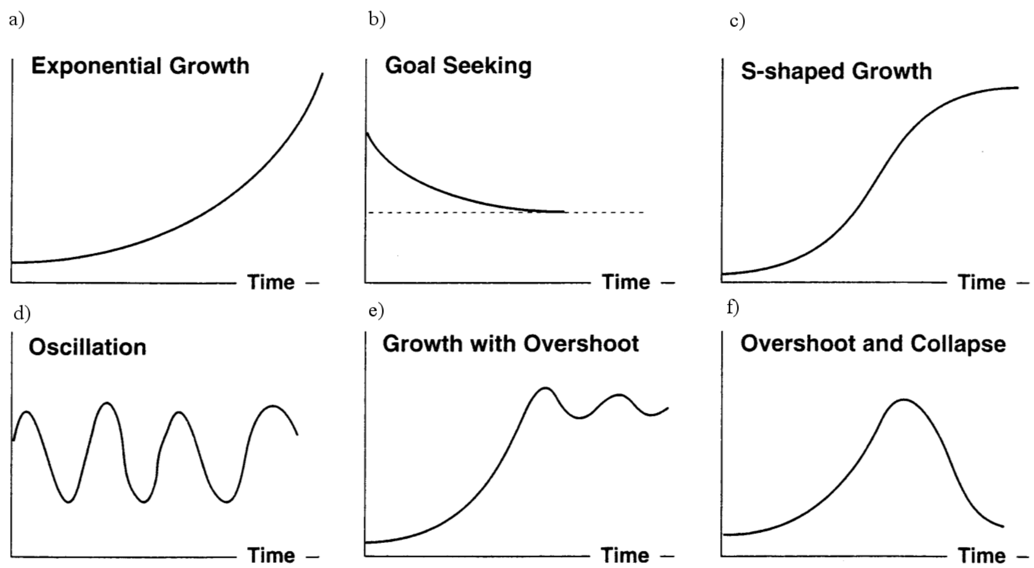

Figure 14.1: Modes of behaviours of simple dynamic systems as in (Sterman, 2000, p108)

[9]The order of a system or loop equals the number of independent stock variables it contains.

1. Knowing this, make for or each of the following behaviors the smallest possible model that could generate that particular type of behavior.
   (a) Exponential growth
   (b) Exponential decline
   (c) Balancing/converging/goal-seeking growth
   (d) Balancing/converging/goal-seeking decline or exponential decay
   (e) Oscillations
   (f) Damped oscillations
   (g) S-shaped growth
   (h) S-shaped decline
   (i) S-shaped growth with overshoot
   (j) Boom and bust or growth, overshoot and collapse
   (k) S-shaped growth with damped oscillations
   (l) Deterministic chaos
2. Develop at least one alternative structure that allows to generate each of the behaviors listed above.
3. Make a core model that allows to generate most of the behaviors listed above if the right loops are de/activated.

14.18 Additional Exercises in Online Repository

|⊕| Add. ex. 1
|⊕| Add. ex. 2
|⊕| Add. ex. 3
|⊕| Add. ex. 4
|⊕| Add. ex. 5
|⊕| Add. ex. 6
|⊕| Add. ex. 7
|⊕| Add. ex. 8
|⊕| Add. ex. 9
|⊕| Add. ex. 10
|⊕| Add. ex. 11
|⊕| Add. ex. 12
|⊕| Add. ex. 13
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|⊕| Add. ex. 19
|⊕| Add. ex. 20
|⊕| Add. ex. 21

Chapter 15

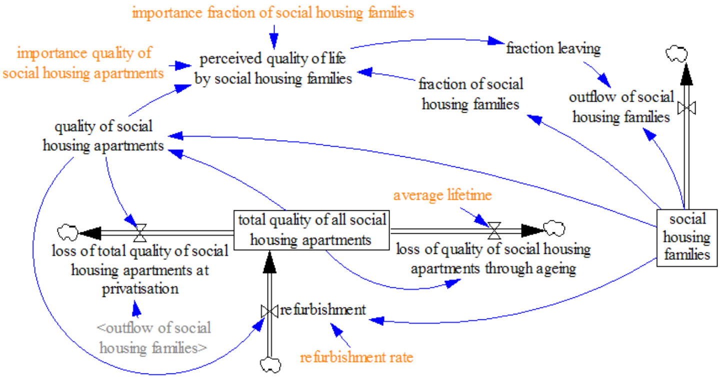
MCQs Part IV

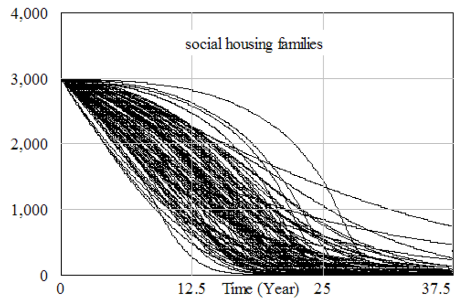
'Cessante causa cessat effectus.' Sallustius

Which of the following statements are right and which are wrong?

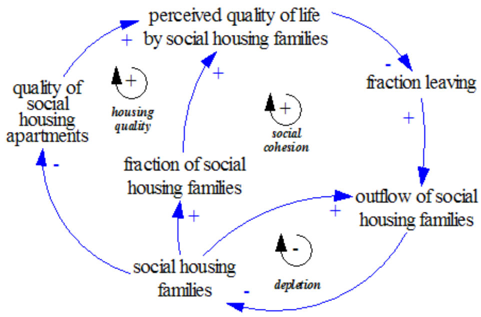
1. The result of a sensitivity analysis includes information on the response of the model to a large number of small changes to uncertain parameters.
2. The only real goal of sensitivity analysis is to find parameters with high leverage.
3. The most valid SD model is the one which produces better point predictions.
4. The choice of integration method and step size always needs to be checked.
5. Any SD model that accurately replicates historical data is always valid.
6. A system that is not sensitive to perturbations by exogenous variables, is in equilibrium.
7. A model that *is not* sensitive to small parameter changes is better than a model that *is* sensitive to small parameter changes.
8. SD models are almost always numerically sensitive to parameter changes, but that is not surprising and is not of much interest to system dynamicists.
9. One should also test the sensitivity of SD models to changes in equations of soft variables, table functions, structures and boundaries.
10. If a variable cannot be influenced by the decision-maker (that is, if it is not a policy lever), then behavior mode sensitivity to changes in that variable is desirable.
11. Sensitivity analysis could be used to study whether changes in parameters and structures lead to changes in modes of behavior and/or (relative) performance of policies.
12. SD validation is really all about checking whether SD models provide the right output behaviors for the right reasons.
13. Direct structure and structure-oriented behavior tests are used to find erroneous behavior.
14. If your software shows no errors regarding units, this means your dimensional analysis is completed and the model is good.
15. SD model testing should be designed to prove models are right, which makes falsification possible and, hence, adds to the credibility of models and modeler.

Multiple Choice Question 1

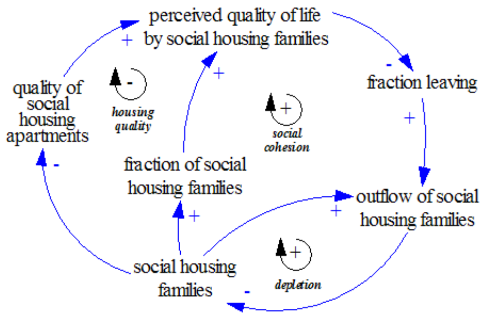




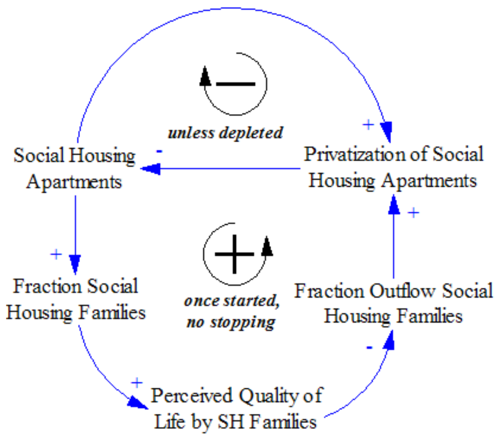
Consider the model about the exodus of a social housing district due to the social cohesion (exercise 14.14 on page 180) displayed above. Simulation of the SD model leads –even for very different values of the parameters in orange (see 100 very different runs in the graph)– to inverse S-shaped behavior of the original population. Which of the following aggregated CLDs is the best diagram to communicate the essential link between structure and behavior of this model?



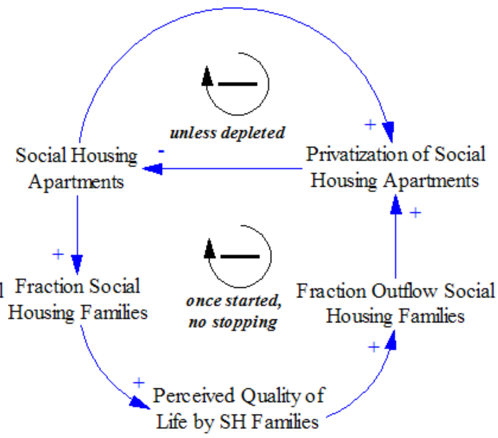
(a)



(b)



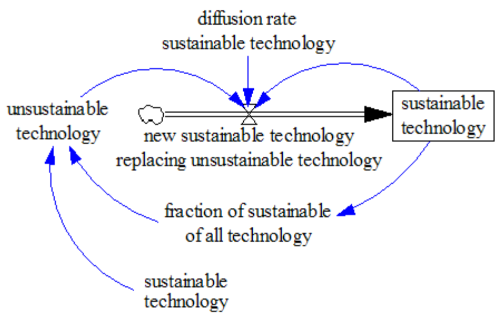
(c)



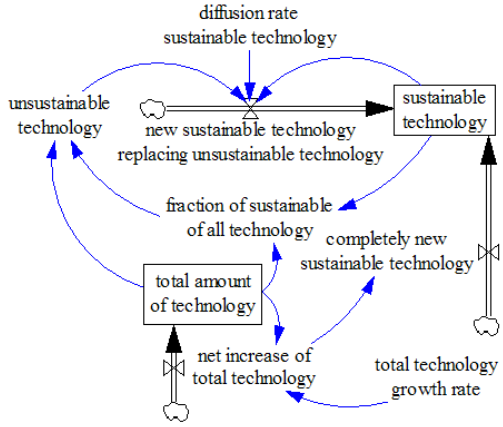
(d)

Multiple Choice Question 2

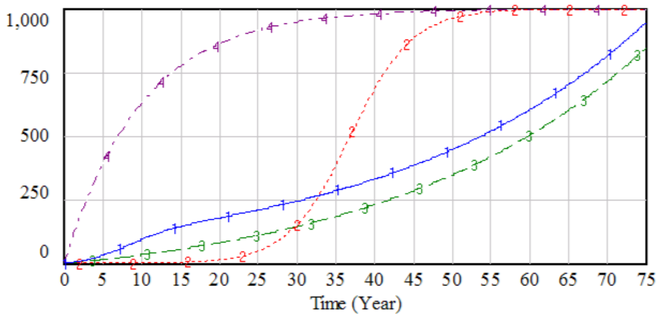
Given are two technology transition models. Suppose that all parameters and initial values > 0. Which of the following behaviors fit the variable '*sustainable technology*' of models (a) & (b)?



(a)



(b)



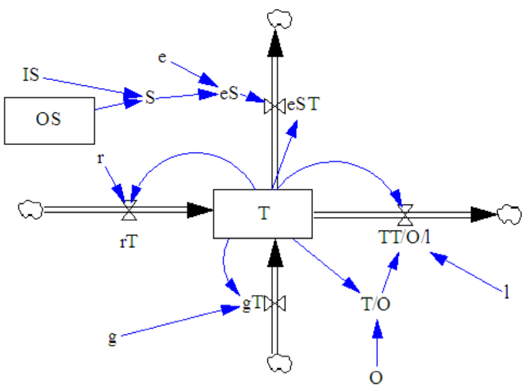
a. (1) fits model (a); (2) fits model (b).

b. (2) fits model (a); (1) fits model (b).

c. (3) fits model (a); (4) fits model (b).

d. (4) fits model (a); (3) fits model (b).

Multiple Choice Question 3



Consider the symbolic representation of a submodel of a larger bluefin tuna fisheries model. Which of the following equations could describe its behavior over time?

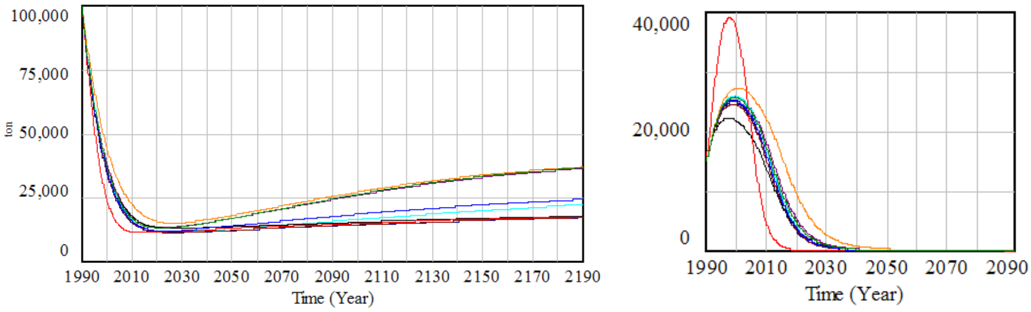
a. $\frac{\mathbf{dT}}{\mathbf{dt}} = \left(\mathbf{r} + \mathbf{g} - \mathbf{eS} - \frac{\mathbf{T}}{\mathbf{O}}/\mathbf{l}\right) * \mathbf{T}$

b. $\mathbf{dT} = \left(\mathbf{r} + \mathbf{g} - \mathbf{eS} - \frac{\mathbf{T}}{\mathbf{O}}/\mathbf{l}\right) * \mathbf{T}$

c. $\mathbf{T} = \left(\mathbf{r} + \mathbf{g} - \mathbf{eS} - \frac{\mathbf{T}}{\mathbf{O}}/\mathbf{l}\right) * \mathbf{T} * \mathbf{t}$

d. $\frac{-\mathbf{dT}}{\mathbf{dt}} = -\left(\mathbf{r} * \mathbf{g} + \mathbf{eS} - \frac{\mathbf{T}}{\mathbf{O}}/\mathbf{l}\right) * \mathbf{T}$

Multiple Choice Question 4



(a) tons of tuna (b) tuna ships

The trajectories in the graphs are obtained by testing the sensitivity of the *bluefin tuna* model with the existing policy to changes in parameters and uncertain functions. What could be concluded?

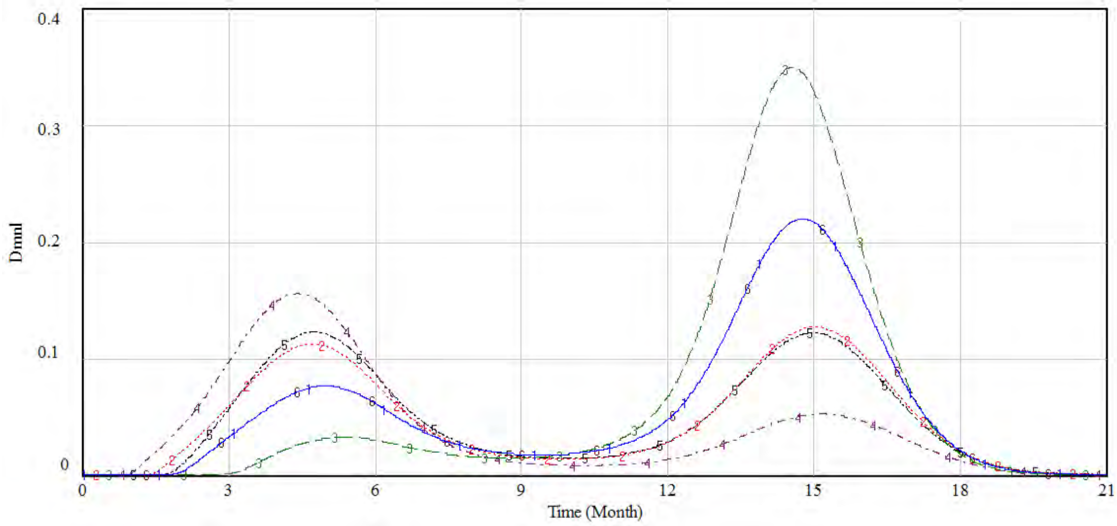
a. The model is both numerically sensitive and policy sensitive

b. The model is behavior mode sensitive, but not numerically sensitive

c. The model is numerically sensitive, but not behavior mode sensitive

d. The model is numerically sensitive, but not policy sensitive

Multiple Choice Question 5



Suppose that you are hired by the RIVM (the Dutch environmental agency) to model the epidemic outbreak of a new flu strand (actually just discovered). The RIVM estimates it will take about 6 to 9 months to develop and mass-produce a new vaccine. The simulation runs of the infected fraction give an indication of the sensitivity of the model to small changes in the variable *average contact rate*. Which of the following statements is *not* correct?

a. The rather different behaviors of the *infected fraction* for slightly different contact rates indicate that the contact rate may be exploited as a policy until a vaccine has been developed.

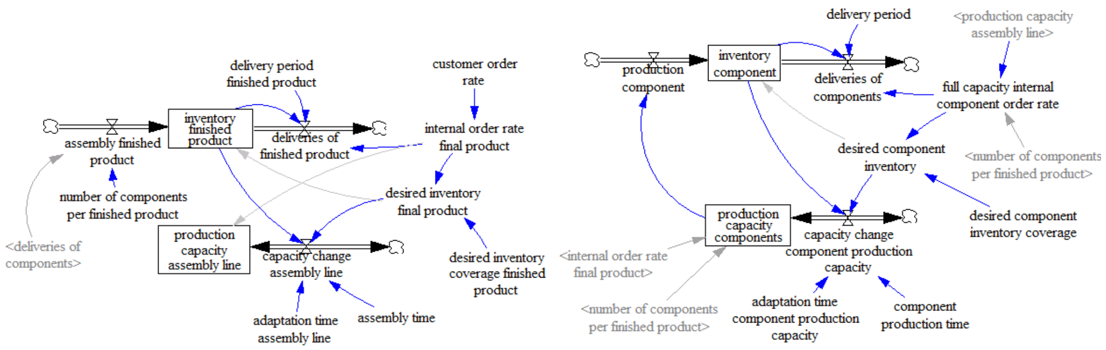
b. The model is numerically *and* policy sensitive to changes in the *average contact rate*.

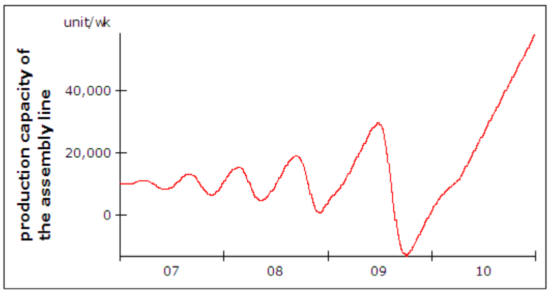
c. The model is not behavior mode sensitive to changes in the *average contact rate* because there are always two flu peaks and the epidemic is always over after 21 months.

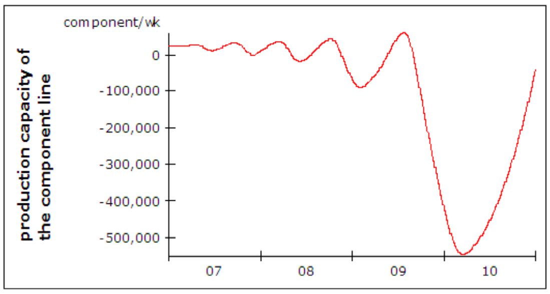
d. None of the statements above is correct.

Multiple Choice Question 6

Consider the simulation model below concerning a manufacturing company you may have made. Each final product assembled in the assembly line requires 2 components from the component line.







Simulation of this model generates the behavior displayed above. Which of the statements below concerning the model and the corresponding behavior is correct?

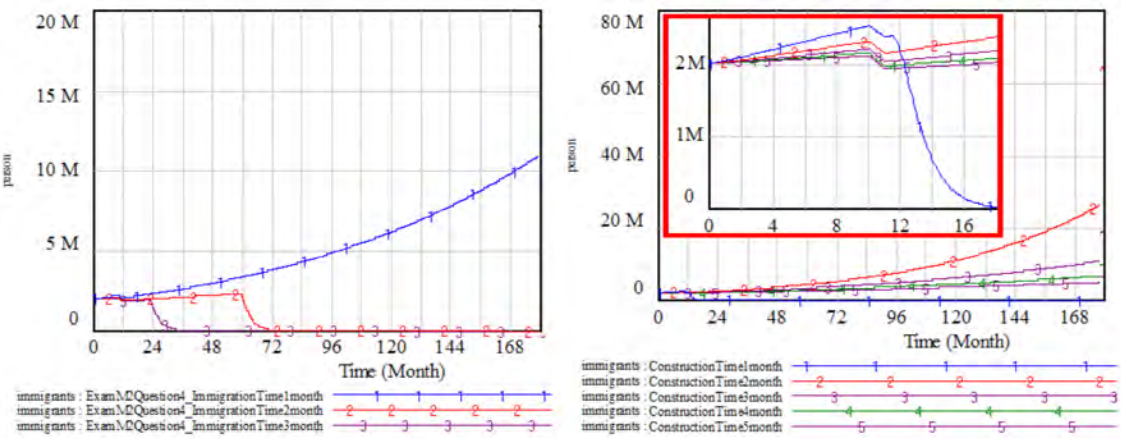
a. Although the structure and specification of the model are wrong, the behavior generated with it are plausible and realistic.

b. This behavior is impossible. It must be caused by a numeric integration error, i.e. an inadequate combination of integration method and time step.

c. The model was modeled in a non-protective manner in view of learning from it and designing policies to prevent undesirable (and impossible) dynamics from happening.

d. None of the statements above is correct

Multiple Choice Question 7



Small variations in two parameters –the '*immigration time*' (the time necessary to attract new immigrants) and the '*construction time*' (the time necessary to develop new real estate)– in a SD simulation model concerning the possible real estate bust in Dubai gives the graphs above. The (relatively small) shock in month 10 corresponds to the announcement of the suspension of payments by Dubai World. Both the '*immigration time*' and the '*construction time*' are to some extent policy variables. The number of 'immigrants' for immigration times of 1, 2, and 3 months are displayed in the left hand side graph. The number of 'immigrants' for construction times of 1, 2, 3, 4, and 5 months is displayed in the right hand side graph (note the detailed graph in the frame). The *immigration time* could be influenced by policy makers. What could be concluded from this sensitivity analysis?

a. For the changes above, the number of '*immigrants*' in the model is numerically sensitive, but not behaviorally nor policy sensitive.

b. For the changes above, the number of '*immigrants*' in the model is numerically and behaviorally sensitive, but not policy sensitive.

c. For the changes above, the number of '*immigrants*' in the model is numerically *and* behaviorally *and* policy sensitive.

d. None of the previous answers is correct.

Multiple Choice Question 8

Which of the following statements about validation is wrong?

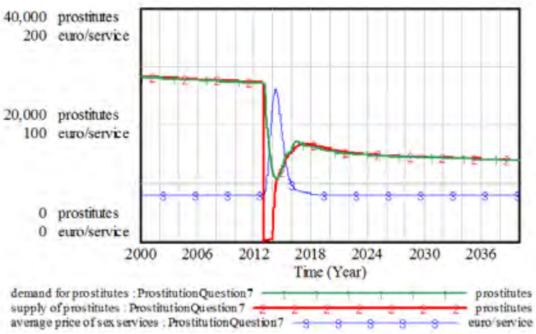
a. System Dynamics validation is about checking whether a System Dynamics model provides the right output behavior for the right reasons.

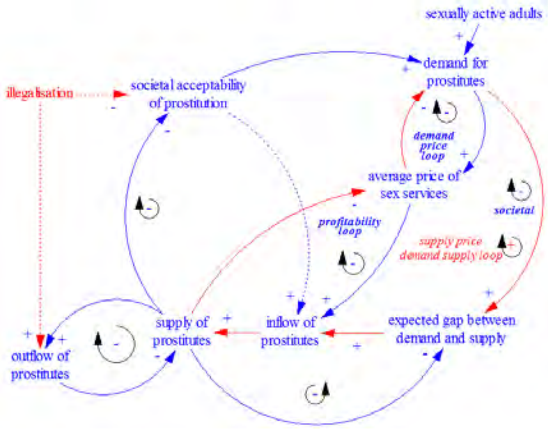
b. Direct structure tests are used to find erroneous structures, not erroneous behaviors. And structure-oriented behavior tests are used to find erroneous behaviors, not structures.

c. Sensitivity analysis could be used to study whether small changes in parameters and structures lead to changes in modes of behavior and/or policies.

d. A System Dynamics model that replicates historical data is not necessarily valid.

Multiple Choice Question 9

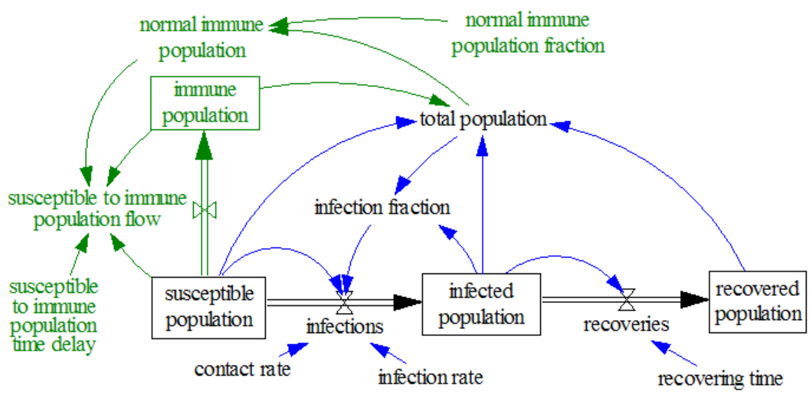




The graph displayed above shows the behavior of a model about the sudden illegalization of the supply of prostitution (Demand for prostitution (green), supply of prostitution (red), and the price (blue)). Which of the following statements regarding the formulation of this policy is correct? The stock of prostitutes can be emptied overnight in this model with:

a. a pulse function b. a pulse train function c. a step function d. a reset function

Multiple Choice Question 10



Consider the flu model comprising a seasonal form of immunity (the green part in the figure displayed above). The '*normal immune population fraction*' fluctuates over the course of the year. Suppose that you need to write an equation for the flow variable '*susceptible to immune population flow*'. Which of the following formulations is most appropriate for this SD simulation model?

a. IF THEN ELSE$\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay} < 0,\right.$
$MIN\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay}, \frac{susceptible\ population}{susceptible\ to\ immune\ population\ time\ delay}\right),$
$\left.MIN\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay}, \frac{immune\ population}{susceptible\ to\ immune\ population\ time\ delay}\right)\right)$

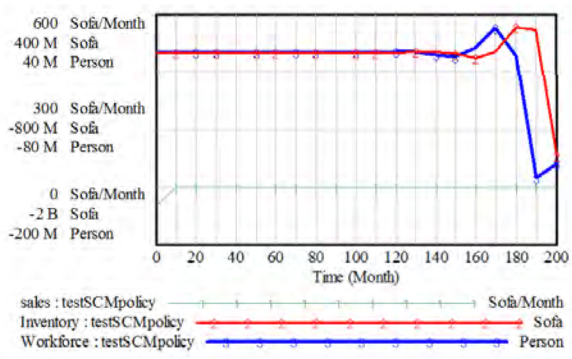
b. $MAX\left(MIN\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay},\right.\right.$
$\left.\left.\frac{susceptible\ population}{susceptible\ to\ immune\ population\ time\ delay}\right), \frac{-immune\ population}{susceptible\ to\ immune\ population\ time\ delay}\right)$

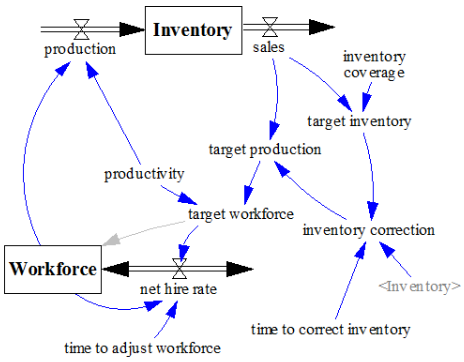
c. $MIN\left(MIN\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay}, \frac{susceptible\ population}{susceptible\ to\ immune\ population\ time\ delay}\right), \frac{-immune\ population}{susceptible\ to\ immune\ population\ time\ delay}\right)$

d. $MIN\left(MAX\left(\frac{normal\ immune\ population - immune\ population}{susceptible\ to\ immune\ population\ time\ delay}, \frac{susceptible\ population}{susceptible\ to\ immune\ population\ time\ delay}\right), \frac{-immune\ population}{susceptible\ to\ immune\ population\ time\ delay}\right)$

Multiple Choice Question 11

The runs displayed below were generated with the SD simulation model next to it: what is wrong?





a. The parameter values: such wrong behaviors are often caused by wrong parameter values.

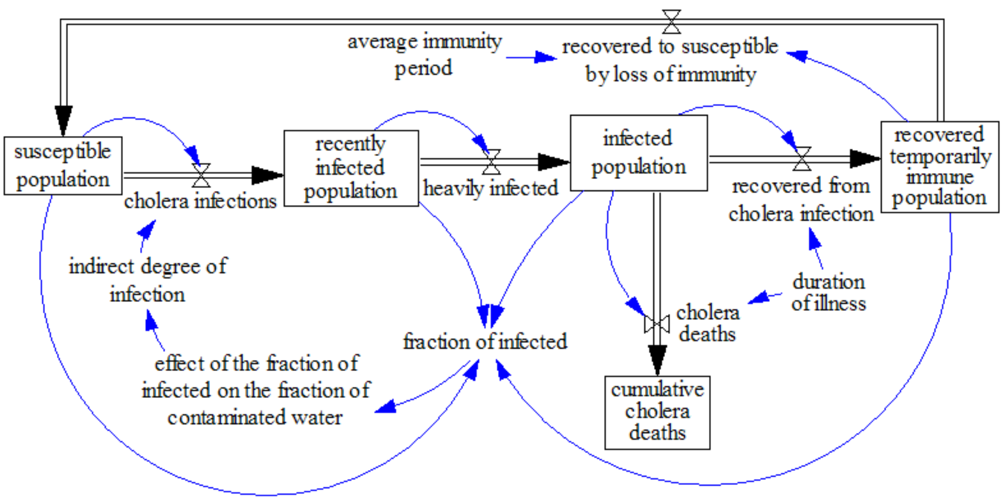
b. The model equations: the flows should have been specified as non-negative flows.

c. The combination of integration method and time step: this is a numeric integration error.

d. Nothing is wrong. If that is the model that generated this output, then it simply is the right model behavior.

Multiple Choice Question 12

Consider the (slightly aggregated and simplified) stock-flow diagram concerning the cholera epidemic in Zimbabwe (2008-2009) which you may have modeled and simulated (ex.14.9 on p169).

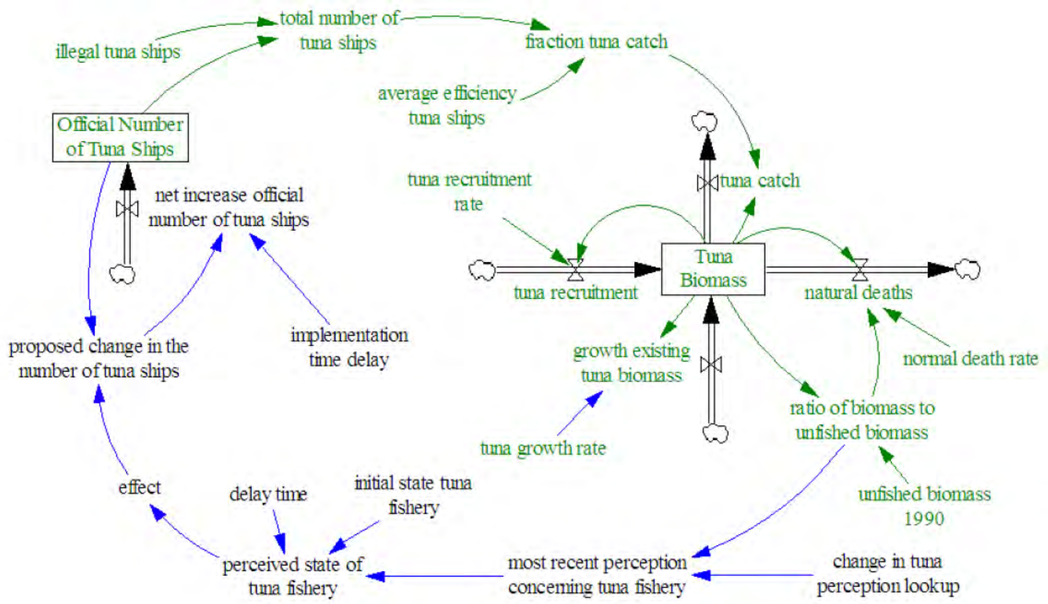


How many feedback loops do you need in an extremely aggregated CLD in order to respect the structure and the dynamics of the simulation model above?

a. 1 feedback loop b. 2 feedback loops c. 7 feedback loops d. None of the previous answers

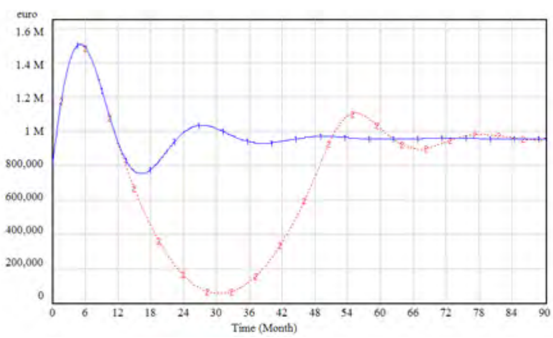
Multiple Choice Question 13

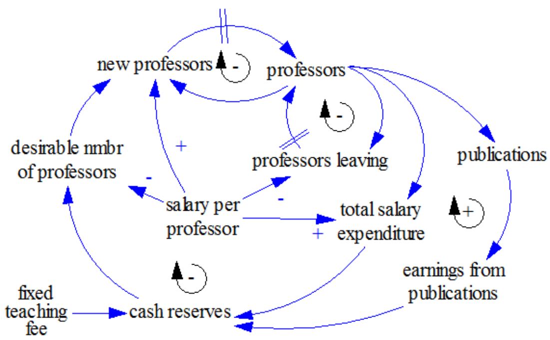
What is the minimum number of independent feedback loops in the following simulation model on overfishing of bluefin tuna?



a. 1 feedback loop b. 5 feedback loops c. 6 feedback loops d. 7 feedback loops

Multiple Choice Question 14





Suppose you are a professor at a faculty that depends on a fixed monthly teaching fee and a fixed amount of money earned per publication and has a policy to hire as many professors as possible as long as the (roll-over) cash reserves remain positive and stable. Your dean asks you to make a SD simulation model about the dynamics of a faculty to explore plausible futures of the system.

Your model, of which the incomplete CLD is displayed on the left, generates growth, overshoot, damped oscillations and, after a while, convergence to an equilibrium, both in terms of the number of professors (blue) and the cash reserves (red). The ambitious dean finds the limits to growth unacceptable and asks you to identify policy levers that will change the developmental path of the faculty in line with his expansionary desires. Based on this CLD (and possibly your experience with a simulation model like this), what would you advise the dean?

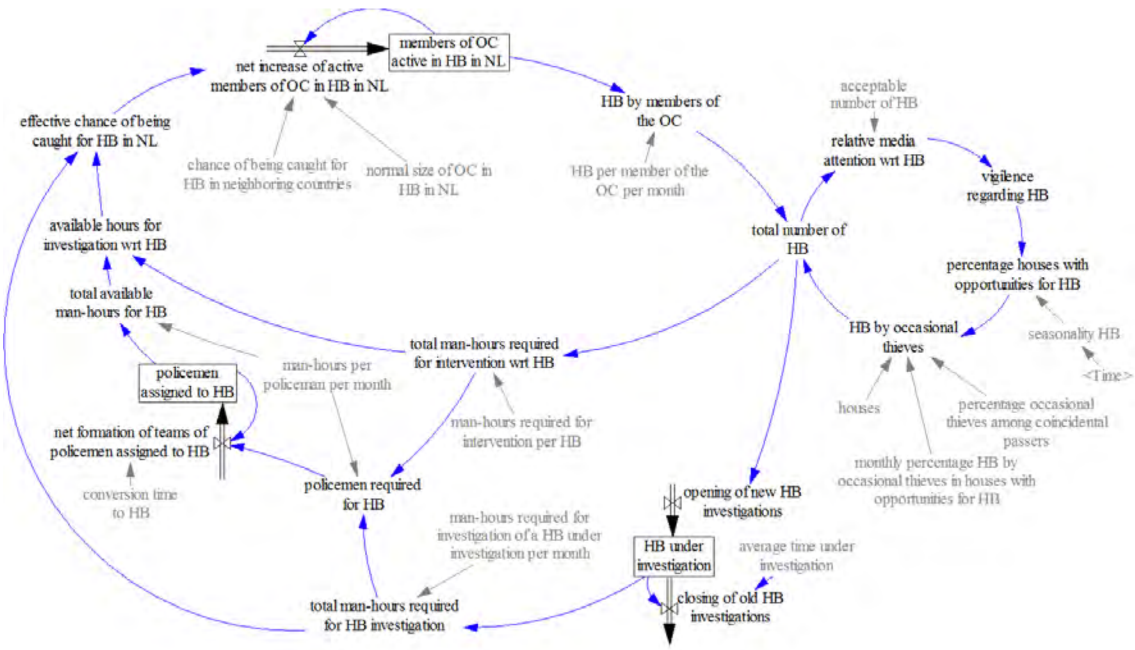
a. Reduce the average salary per professor!

b. Increase the average salary per professor!

c. Create the conditions for professors to publish more.

d. In the long term, nothing will help: this system will always converge to the same equilibrium.

Multiple Choice Question 15



What is wrong with the SD model about the police fight against burglaries (HB) displayed above?

a. One of the loop does not have at least one stock variable, hence, there are simultaneous equations.

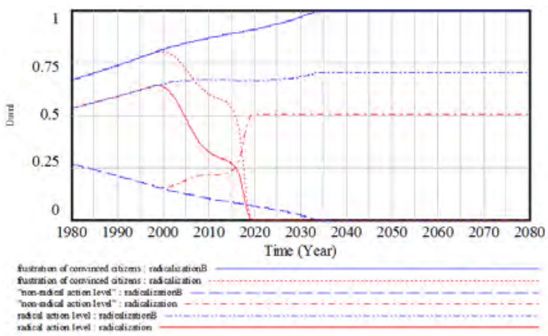
b. The police response seems to be reactive instead of proactive.

c. The simulation model is not endogenous enough: the seasonality of the percentage of houses with opportunities for burglary should have been modeled endogenously.

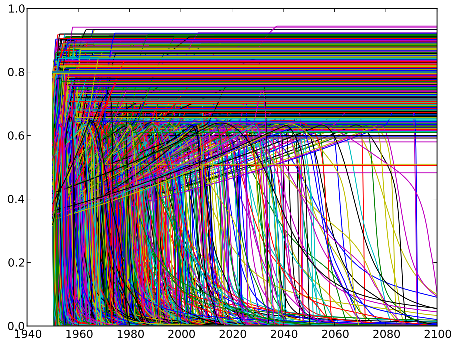
d. Nothing seems to be wrong with this simulation model nor with the situation it represents.

Multiple Choice Question 16

A quick sensitivity analysis on a model about de/radicalization generates only two types of behavior (see left figure below): either radicalization or deradicalization. A 'brute force' uncertainty analysis confirms this conclusion: this model only generates these two modes of behavior even with 10000 runs and enormous uncertainty bands. Further analysis shows that a particular set of counter-intuitive policies with regard to radicalization has –in contrast to other sets of policies– a robust influence on the modes of behavior: this appropriate set of proactive policies should allow to nip undesirable radicalization in the bud, that is to say, it does in the model. What do you conclude with regards to the sensitivity?



(a) deradicalization (red) versus radicalization (blue)



(b) radical action level (uncertainty analysis with 10000 runs)

a. Real-world de/radicalization is behaviorally –not policy– sensitive for these policies.

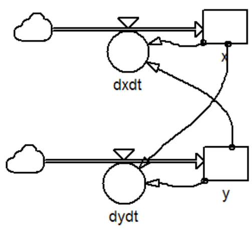
b. Real-world de/radicalization is behaviorally and policy sensitive for these policies.

c. This de/radicalization model is behaviorally –not policy– sensitive for these policies.

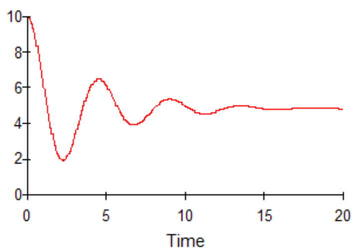
d. This de/radicalization model is behaviorally and policy sensitive for these policies.

Multiple Choice Question 17

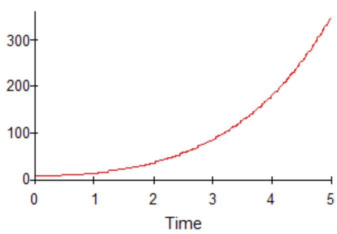
Which of the following graphs cannot be generated with the model on the right. (Note that equations and parameters are unknown and that it is not known whether X or Y are displayed in these graphs.)



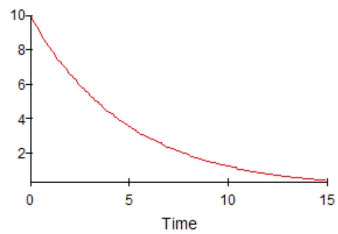
a. Only i b. Only ii c. Only iii d. Either none or all



(a) i

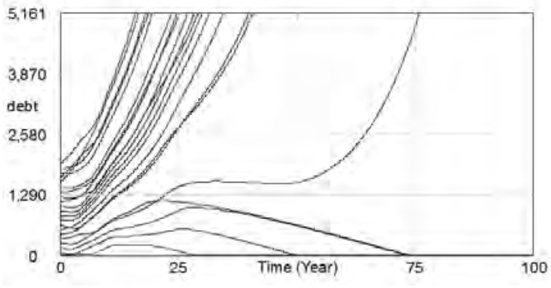


(b) ii

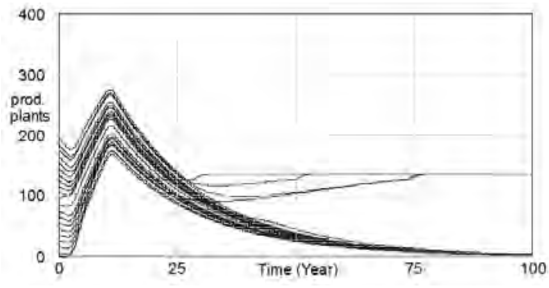


(c) iii

Multiple Choice Question 18

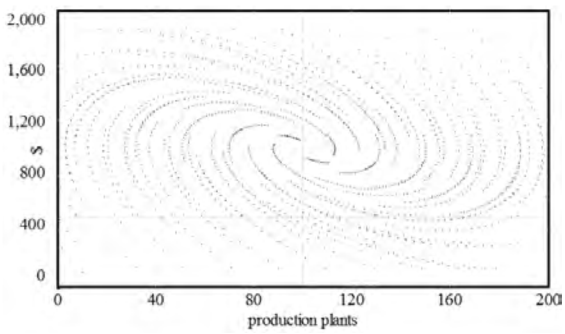


(d) Debt

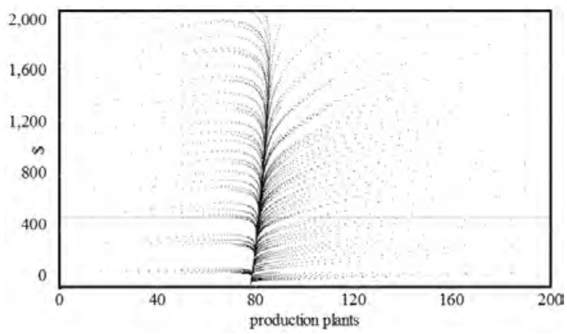


(e) Production Plants

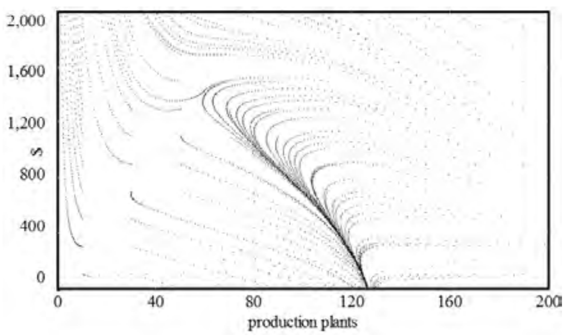
The graphs above display 20 simulations of the amount of debt over time and the number of production plants over time with the Debt Crisis model for variations of their initial conditions (initial production plants between 0 and 200, initial debt between 0 and 2000, latin hypercube sampling). Which of the following state space diagrams developed with the structure and models developed by Hartmut Bossel (2007a, Z115) corresponds to the above behaviors over time graphs?



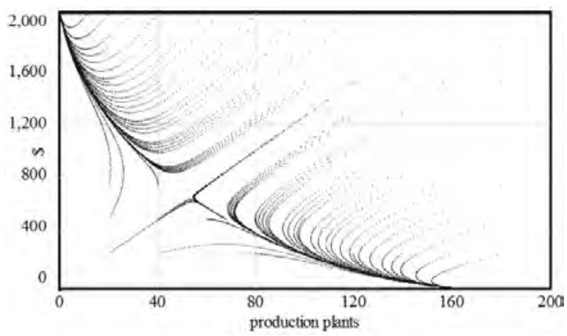
(a)



(b)



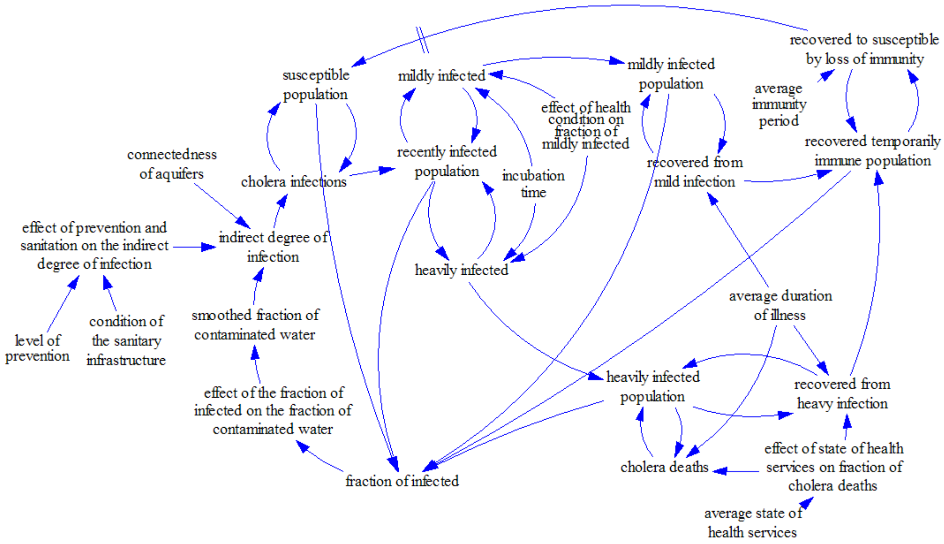
(c)



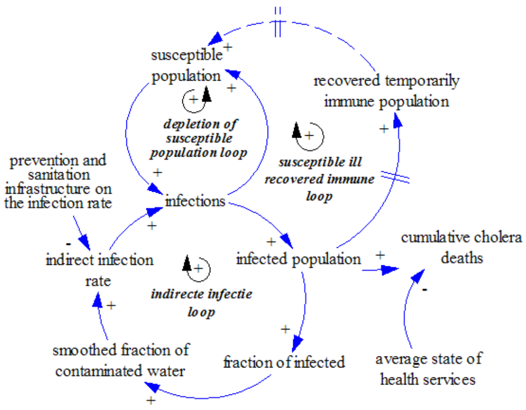
(d)

Multiple Choice Question 19

The unfinished and overly detailed CLD concerning the potential long term effects of cholera outbreaks displayed below is hardly communicable. Which of the aggregated CLDs corresponds best with the underlying simulation model and allows to communicate about potential short term as well as long term effects?

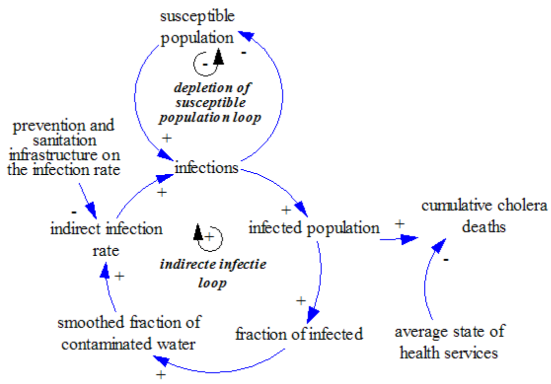


recovered to susceptible by loss of immunity
susceptible population
mildly infected
mildly infected population
average immunity period
effect of health condition on fraction of mildly infected
recovered temporarily immune population
connectedness of aquifers
recently infected population
recovered from mild infection
cholera infections
incubation time
effect of prevention and sanitation on the indirect degree of infection
indirect degree of infection
heavily infected
average duration of illness
smoothed fraction of contaminated water
level of prevention
condition of the sanitary infrastructure
heavily infected population
recovered from heavy infection
effect of the fraction of infected on the fraction of contaminated water
effect of state of health services on fraction of cholera deaths
cholera deaths
fraction of infected
average state of health services



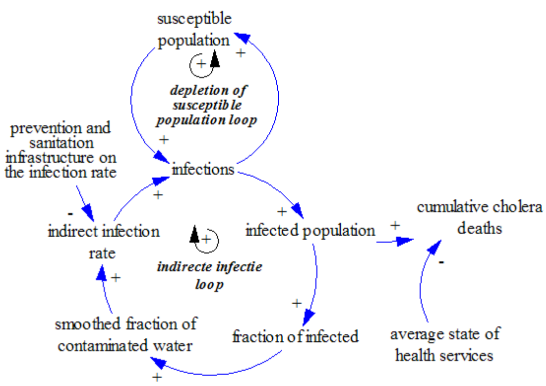
susceptible population
depletion of susceptible population loop
recovered temporarily immune population
susceptible ill recovered immune loop
prevention and sanitation infrastructure on the infection rate
infections
cumulative cholera deaths
indirect infection rate
indirecte infectie loop
infected population
smoothed fraction of contaminated water
fraction of infected
average state of health services

(a)



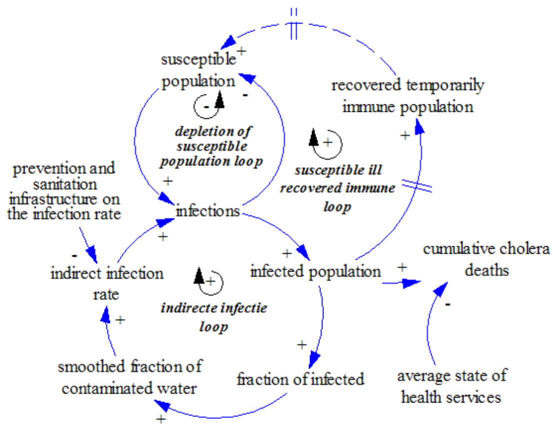
susceptible population
depletion of susceptible population loop
prevention and sanitation infrastructure on the infection rate
infections
indirect infection rate
indirecte infectie loop
infected population
cumulative cholera deaths
smoothed fraction of contaminated water
fraction of infected
average state of health services

(b)



susceptible population
depletion of susceptible population loop
prevention and sanitation infrastructure on the infection rate
infections
indirect infection rate
indirecte infectie loop
infected population
cumulative cholera deaths
smoothed fraction of contaminated water
fraction of infected
average state of health services

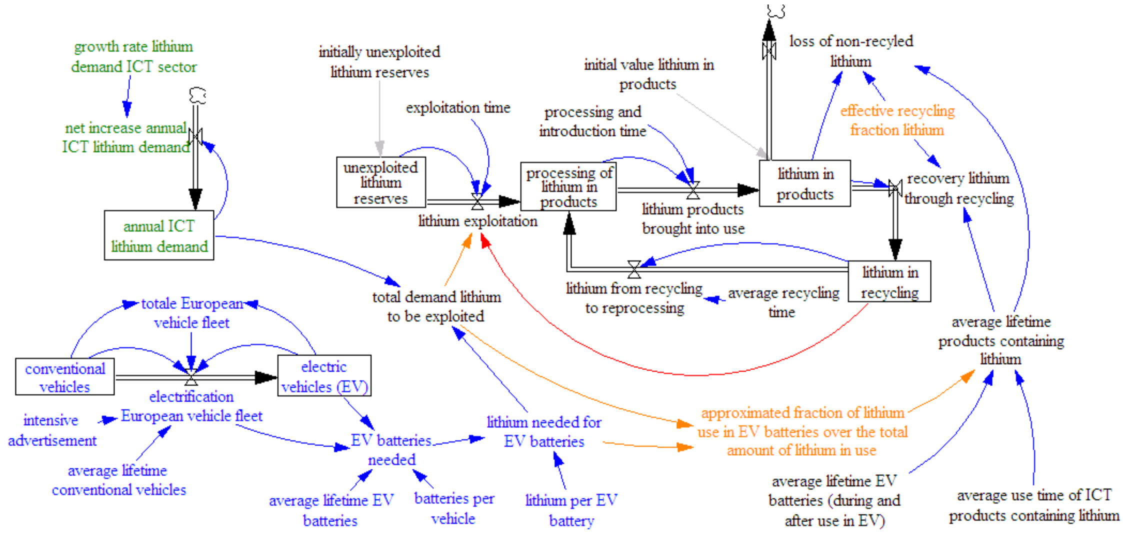
(c)



susceptible population
depletion of susceptible population loop
recovered temporarily immune population
susceptible ill recovered immune loop
prevention and sanitation infrastructure on the infection rate
infections
indirect infection rate
indirecte infectie loop
infected population
cumulative cholera deaths
smoothed fraction of contaminated water
fraction of infected
average state of health services

(d)

Multiple Choice Question 20



Which statement regarding the simulation model about the consequences of the growing demand for lithium from the ICT and electrical vehicles sectors fully displayed above is most correct?

a. The submodel in blue is an inherently limited diffusion structure. Due to these inherent limits, lithium will never be overexploited by electrical vehicle diffusion.

b. Although for a constant positive growth rate of lithium demand from the ICT sector, the submodel in green will first generate exponential growth of the annual ICT lithium demand, although, in the end, growth of the annual ICT lithium demand is likely to be constrained in this model by the limits to lithium exploitation.

c. Loop-wise this model is incomplete: important loops, such as the ones connecting lithium availability to the electrification of the vehicle fleet and growth of the lithium-based ICT sector, are missing.

d. Unexploited lithium reserves and resources should not be modeled as a limited non-renewable stock: the different reserves and resources should be modeled in detail.

Link to the answers to the 15 right/wrong questions & 20 multiple choice questions in this chapter.

Links to web based quizzes: | | | |

Chapter 16

Recap IV – Lessons to be Learned

'And the reason they were able to do that was that they've had more experiences or they have thought more about their experiences than other people. Unfortunately, that's too rare a commodity. A lot of people [...] haven't had very diverse experiences. So they don't have enough dots to connect, and they end up with very linear solutions without a broad perspective on the problem.' Steve Jobs in an interview with The Wired

Case-Based Lessons Part IV

14.1 The main lessons from the Managing a Faculty model are that:

- A fundamentally different behavior can be obtained by activating a loop beyond a critical limit;
- Flows may have to be protected from becoming negative with (soft)max functions if in reality they are strictly positive.

14.2 The main lessons from the Supply Chain Management model are that:

- Minor shocks may lead to (damped, constant and even reinforcing) oscillations in seemingly stable models;
- Increasing and decreasing delay times may lead to counterintuitive outcomes;
- Breaking or adding loops, for example to redirect information, may be at the basis of powerful policies.

$ 14.3 The main lessons from the Debt Crisis model are that:

- High indebtedness may lead to high interest payments relative to revenues, possibly autonomously increasing the indebtedness, causing developing countries to be caught in a debt trap;
- Phase plane plotting allows to assess the behavior starting from different initial conditions;
- The effectiveness of investments has a large effect on the behavior of the debt system: ineffective and unprofitable investments should be avoided.

14.4 The main lessons from the Miniworld model are that:

- Excessive aspirations with regard to future consumption and excessive growth accompanied by heavy pollution may lead to collapse and long-term depression;

- Moderate aspirations with regard to future consumption and 'sustainable' growth without excessive pollution may lead to high level convergence.

♥ 14.5 The main lessons from the Next Pandemic Shock model are that:

- Aggregate models are useful even for studying phenomena that diffuse on the individual level;
- A well-formulated MIN or MAX function may sometimes be a valid alternative formulation to an IF THEN ELSE function;
- Deep uncertainty necessitates adaptive closed-loop policies;
- Under deep uncertainty, policy robustness over a wide variety of assumptions should be tested.

14.6 The main lessons from the New Town Planning model are that:

- Inert phenomena require long-term vision and flexibility;
- Deteriorating lock-ins require drastic structural measures;
- Old low-quality housing may need to be sacrificed for new businesses.

14.7 The main lessons from the Tolerance Hate Aggression model are that:

- Threshold models often show bifurcating behavior;
- The hypothesis that long-term investment in education results in familiarity and tolerance is plausible.

♻ 14.8 The main lessons from the EVs and Lithium Scarcity model are that:

- Aggregated structures and approximate formulations may keep models small and almost as good as exact and accurate structures and formulations.
- Models often consist of canonical structures and can be constructed using building blocks or molecules.

♥ 14.9 The main lessons from the Cholera model are that:

- On paper and in simulation models, solutions may look surprisingly simple;
- After building and testing this model, it should be clear that more research and more detailed modeling related to the (influence of the) connectedness of aquifers is needed since the model is crucially dependent on aquifer related parameters, but also hugely sensitive to small changes in these parameters.

$ 14.10 The main lessons from the Signalled Bank Run model are that:

- Sticky assets, liquid liabilities, delays, perceptions, and market signals are a dangerous cocktail for a bank;
- Parties reacting to other parties' reactions may lead to a vicious cycles.

14.11 The main lessons from the Fighting HIC on the National Level model are that:

- Seasonality may be reinforced by reactive planning;
- Model-based proactive planning may be useful to avoid reinforcing seasonality.

14.12 The main lesson from the Bluefin Tuna model is that:

- Painful self-regulation in situations characterized by the tragedy of the commons archetype with long delay times are likely to be too little too late;

14.13 The main lesson from the Production Management model is that:

 - Overt modeling pays off: Flows should not be defined as non-negative if it helps to identify problematic behavior and policies can be designed which make non-negative flows impossible.

14.14 The main lessons from the District Redevelopment model are that:

 - Very strong pro-active policies may be required from the very start to stop undesirable positive feedback loops before it is too late.
 - Highly aggregated models may be useful to learn, but may be very difficult to communicate and understand by others.

14.15 The main lessons from the Mineral/Metal Scarcity I model are that:

 - The combination of loops, accumulations, and delays may lead to very non-linear dynamics;
 - One and the same model can generate very different types of behaviors.

14.16 The main lessons from the Radicalization & Deradicalization model are that:

 - Bifurcating lock-ins can be generated with diffusion structures in combination with non-linear effects;
 - Isolation and repression may be sources of radicalization based on an underlying phenomenon.

Link to the feedback video related to all STEP cases.

Part V

JUMP

Chapter 17

Using System Dynamics Models

'Models could be used to develop social visions far more internally consistent than those generated by mental models alone. They could point the way to critical, decisive experiments, and actively test social theories at far less cost than the costs of imposing those theories in ignorance and arrogance upon the whole society. They could be used to search for imprecise policies that are robust against uncertainties rather than precise policies that try to optimise something that is not understood. Perhaps most important, they could simply serve as communication devices in which different, partial, mental models of the social system could be expressed and integrated.' (Meadows and Robinson 1985, p429)

17.1 Model/Modeling Uses

There are many uses of SD models/modeling – to name a few:

- To surface assumptions and express/elicit/merge mental models (e.g. using Group Model Building);
- To communicate mental/formal models;
- To analyze & understand the link between structures & behaviors;
- To develop internally consistent social visions or scenarios;
- To test (social) theories;
- To generate/imagine plausible futures and explore uncertainties, risks and opportunities;
- To experiment in a 'virtual laboratory';
- To design policies that improve system behavior;
- To test the robustness of policies, i.e. their effectiveness under deep uncertainty;
- To train/teach/learn/experience (e.g. using flight simulators or multi-player games).

Below we will focus on one model use that is particularly important for policy analysts: to design policies that improve system behavior.

17.2 Policy Analysis, Policy Design, and Policy Testing

Policy Analysis and Policy Design

In this e-book we follow the intuitive/iterative/interactive approach of policy analysis, design and testing. Experienced modelers can often intuitively distill appropriate structural policies from the structure of a model, from playing with the model, and from performing sensitivity analyses. Following structural changes –in decreasing order of effectiveness– were already suggested:

1. adding/breaking/changing (information-based) feedback loops, decision routines, boundaries of systems and responsibilities,. . .
2. adding/breaking/changing (physical) stock-flow structures;
3. strengthening/weakening existing feedback loops and/or flow variables;
4. adding/eliminating delays/smoothing;
5. changing high leverage policy parameters, i.e. parameters that can be controlled by those involved and that have large effects for relatively small changes. The latter can be identified with sensitivity analysis (see chapter 13).

Mathematical and control engineering methods may also be useful[1]. For example, for a second order system of ordinary differential equation, one could calculate the eigenvalues of the system, i.e. the roots of the characteristic equation, and derive the behavior. If the eigenvalues/roots are real and both are negative, then the behavior is asymptotically stable. If the eigenvalues/roots are real and one or both are positive, then the behavior is unstable. If the eigenvalues/roots are complex and the real part is negative, then the behavior is asymptotically stable, e.g. damped oscillation. If the eigenvalues/roots are complex and the real part is 0, then the behavior is stable, e.g. oscillation with a constant amplitude. If the eigenvalues/roots are complex and the real part is positive, then the behavior is unstable, e.g. oscillation with increasing amplitude.

There are also more advanced analytical methods, statistical screening techniques, techniques to identify dominant loops and shifts in dominance, machine learning techniques, and advanced optimization techniques that can be extremely useful for policy design. These techniques are beyond the scope and level of this introductory case book. They will be dealt with in the follow-up book on ESDMA.

Policy Testing

After identifying high leverage interventions and building the corresponding policies into the model, one can test and compare policies. It is good practice to build in policies such that they can be switched on/off, and to use different run names for different policy runs so that the dynamics generated by these different policies can be compared. First test policies on runs that require improvement. If they are effective, then also test them on other runs. Are they effective across all plausible runs considered or do they deteriorate some of the runs that did not require improvement? If they are effective across all plausible runs, then they are said to be robust and one may consider implementing them as base policies, that is, from the start on and irrespective of the conditions of the system. Else, one may consider implementing them as adaptive policies, i.e. policies that are activated only when required by the evolution of the real system. Adaptive closed-loop policies are more powerful than closed-loop policies implemented as base policies (Hamarat et al. 2013). However, adaptive closed-loop policies are not easily designed, nor included in models, nor implemented in reality. This topic will be dealt with in the follow-up e-book too.

[1] See also the additional Math appendix. This appendix is ***not*** mandatory.

17.3 Interpretation

Most models contain many assumptions, aggregations, simplifications, uncertainties, roughly estimated parameters and initial values. Hence, a model instantiation (i.e. one combination of assumptions, aggregations, simplifications, uncertainties, roughly estimated parameters and initial values) will always differ from reality, and so will the behavior generated with the model, and the effects of policies. Hence, there is always a need for extensive sensitivity analysis, uncertainty analysis, and testing of policy robustness, i.e. testing whether policies are effective over the entire plausible uncertainty space and whether they work especially when they really need to work. SD, in combination with regret analysis, is very useful for testing whether policies and recommendations are robust.

Model outcomes also need to be interpreted. In SD, outcomes are never interpreted as point or trajectory predictions – they are mostly interpreted as plausible modes of behaviors. It is extremely important to keep that in mind when communicating model behaviors or recommendations based on SD modeling. And 'never say the model says' (Barabba 1994). Remember: models are but tools for thought.

SD modeling thus requires a lot of reflection beyond the model, the behavior patterns, and the capacity to improve behavior patterns. Since SD is a structural systems approach biased towards structural and consensual solutions, reflection beyond the model and the SD method is needed, especially towards nonstructural and non-consensual solutions. Reflection beyond the model is also necessary for other reasons: e.g. in spite of the fact that a model may show some side effects, it will only really do so if the corresponding subsystems, elements and causal effects are included in the model. Although setting broad boundaries and simulating over long time horizons helps to look at side effects and intertemporal effects, one should nevertheless reflect consciously about side effects and ethical implications, whether they are included in the model or not.

Additional (non-mandatory) chapter:

VII. Model Use

Ap. Math for SD

Chapter 18

Intermediate SD Cases

'Alius et idem.' Horatius

18.1 Policy Analysis, Design, Testing, and Advice

Revisit all exercises and cases you modeled so far: for each of them, (re)do the policy part (analysis, design, testing, and advice).

18.2 Unemployment

This case is based on the Unemployment model developed by Hartmut Bossel (2007c, Z511) (link to the zip file containing all Zoo models). The values in this model are relative values, e.g. all state variables are standardized to 100% or 1.

In this case, a small model is built about job losses in production and initial job additions, possibly followed by job losses, in services. The service sector corresponds –in this simplistic model– to the government sector, i.e. it is financed from tax revenues and/or increases of the debt position. Employment in the service sector thus corresponds to employment of civil servants. Employment in production corresponds to employment in industry and agriculture, that is, sectors that produce durable goods, nondurable goods, and services not provided for by civil servants.

Define *unemployment* as *potential labor force* minus *total employment*. *Total employment* consists, here, of *employment in production* and *employment in services*. The *unemployment rate* is the fraction of *unemployment* over the *potential labor force*.

Employment in production, initially equal to 100%, decreases (increases) through positive (negative) *net production jobs reductions*. The latter variable is proportional to the *employment in production*, the *net production jobs reduction rate* of 10% per year, and the *relative production surplus* limited to a maximum of 10%. That is, take the value of the *relative production surplus* if it is smaller than 10%, else take 10%.

The *relative production surplus* is the difference between the *product value* –which represents GDP– and the *demand value*, divided by the *demand value* of 100%. Model the *product value* as the *employment in production* times the *productivity* of employment in production. *Productivity* could be modeled as a stock variable, initially equal to 100%, which increases (decreases) logistically through *productivity increases*. In other words, the variable *productivity increase* could be modeled as the product of *productivity*, the *productivity increase rate* of 10%, and the difference between the *productivity limit* and the actual *productivity*, divided by a *productivity limit* of, say, 500%.

Employment in services, initially equal to 50%, increases (decreases) through positive (negative) *net service jobs additions*. Assume that *net service jobs additions* could be approximated by the product of the *relative gap in service demand fulfilment*, *financial buffer of the state*, *unemployment*, and a 5% *service jobs hiring rate*. The *relative gap in service demand fulfilment* is the difference between *service demand* and *employment in services*, divided by *service demand*. Assume service demand is equal to 100%. In other words, employment in sercives is initially 50% of what is demanded for.

The *financial buffer of the state*, initially equal to 100%, increases through *state cash inflows* and decreases through *state cash outflows*. Assume *state cash inflow* consists of *state debt increases* and *tax revenues on sales value*, which could be calculated as the *sales value* multiplied by the *sales tax ratio*. Calculate the *sales value* as the minimum of the *product value* and the *demand value*. And model the *sales tax ratio* as a function of the *financial buffer of the state* such that it is 60% for a *financial buffer* that is smaller or equal to 0, that it is 50% for a *financial buffer* of 40%, that it is 40% for a *financial buffer* of 80%, that it is 30% for a *financial buffer* of 120%, and that it is 20% for a *financial buffer* of 160% or more.

State debt, initially 0, increases over time through an inflow, the *state debt increase*, which is equal to $\frac{-financial\ buffer\ of\ the\ state}{Time\ Step}$ if the *financial buffer of the state* is smaller than 0, and is 0 otherwise. Assume *state cash outflow* is only used to pay for service *wages* which could be calculated as the product of a 25% *wage factor*, the *employment in services*, and the *wage index* which, here, is equal to *productivity*. In other words, employees are the beneficiaries of productivity increases.

And the *potential labor force* is equal to 1.5. In other words, the *potential labor force* is equal to total employment at time t_0.

1. Build the model, verify it, and simulate it. Plot the dynamics of the *employment in production*, *employment in services*, *financial buffer of the state*, *state debt*, and *productivity*.
2. Try to understand the model and its behavior. Make a highly aggregated CLD of the model. Use it to explain the link between structure and behavior and relate it to the real world.
3. Validate the model: List two useful validation tests for a simplistic illustrative model like the one developed in this case. Perform them, explain, and conclude.
4. What happens to the stock variables and the *unemployment rate* if *net service jobs additions* are not proportional to the *financial buffer of the state* but to the difference between the *financial buffer of the state* and *state debt*?
5. Perform univariate and multivariate sensitivity analyses. What could be concluded with regard to the sensitivity of the model to parameters and functions? What could be concluded with regard to potential policy leverage?
6. Perform similar analyses but now using state space diagrams (see exercise 10.10 on p130). What could be concluded?
7. Given the latter model: what would be most effective to counter the rise of the *unemployment rate*? Does that make sense in the real world?

- Which extensions and changes would make this model much more realistic? Add/change them.
- Revisit the policy question: what would be most effective to counter the rise of the *unemployment rate*?
- Most System Dynamicists do not like models with relative values if absolute values could be estimated or dimensionless variables if the real world elements can be expressed in meaningful units. Turn the model from a relative model into a more operational model: adapt it to a particular country, get rid of relative values and dimensionless units, and redo the analyses. What could be concluded?

18.3 Hospital Management

Introduction

Because of your SD expertise, you are hired by a specialized hospital to put a stop to the increase of the waiting list for the type of operation they are specialized in.

Broadly speaking, the system is as follows: People are listed on a waiting list before they are admitted to the hospital. People waiting for admission are called pre-operative patients or ***pre-ops***. Patients in the hospital are called operative patients in the hospital or ***ops***. As many people as possible are, after surgical intervention and discharge from the hospital, taken care of in aftercare (e.g. revalidation centers). However, post-operative patients (***post-ops***) are directly sent home if there are no vacant 'beds' in aftercare. About 98% of the patients who transit through aftercare, recover. The remaining 2% of the patients in aftercare, do not recover and are listed on the waiting list for re-admission to the hospital. Only 80% of all patients that are sent home directly, recover. The remaining 20% do not recover en are listed on the waiting list for re-admission to the hospital.

Modeling the hospital throughput

Through thorough investigation, you obtain the following additional information. Every week there are some 800 *newly referred pre-ops* that are first listed as *pre-ops on the waiting list before admission* before they are admitted –via *admission of pre-ops*– as *ops* to the hospital. The initial number of *pre-ops on the waiting list before admission* amounts to 2000 patients.

The *admission of pre-ops* is equal to the *capacity of the hospital* divided by the *average administrative processing time before admission* of one week minus the number of *ops* plus the *post-ops directed towards aftercare* plus the *post-ops sent home without aftercare*, unless the number of *pre-ops on the waiting list before admission* divided by the *average administrative processing time before admission* is smaller, then it equals the number of *pre-ops on the waiting list before admission* divided by the *average administrative processing time before admission*.

Hence, *ops* flow in through *admission of pre-ops* and flow out as *post-ops directed towards aftercare* **or** as *post-ops sent home without aftercare*. Initially, the number of *ops* equals the initial *capacity of the hospital* of 700 patients.

The surgical intervention is such that nobody dies, which makes that the total *number of discharged post-ops* is equal to the number of *ops* divided by the *average residence time in the hospital* of 1 week. As many patients as possible are referred to aftercare, but the *capacity of post-op aftercare* is limited to 1000 patients at a time. All others are simply sent home. The number of *post-ops sent home without aftercare* is thus equal to the total *number of discharged post-ops* minus the *post-ops directed towards aftercare*. Also make sure that the full capacity of aftercare is used if the inflow of post-ops is sufficiently high. The initial value of the *post-ops in aftercare* is equal to the *capacity of post-op aftercare*. [In case you'd need it: The *average administrative processing time of transfers towards aftercare* is 1 week.]

The *average residence time in aftercare* currently amounts to 3 weeks. The *fraction of recovered patients with aftercare* equals –as already mentioned– 98%, which feeds an outflow of *recovered post-ops with aftercare*. The others –the *non-recovered patients with aftercare referred back to the hospital*– flow back to the waiting list –after the same average residence time– as *pre-ops on the waiting list before admission*.

About the same counts for the *post-ops without aftercare* that are sent home for lack of beds in aftercare. At home, the *average recovery time without aftercare* amounts to 7 weeks. The *fraction of recovered patients without aftercare* is 80%. This causes an outflow of *recovered post-ops without aftercare*. The others –the *non-recovered patients without aftercare referred back to the hospital*– flow after the same average time back as *pre-ops on the waiting list before admission* to the waiting list. The initial number of *post-ops without aftercare* amounts to 300 patients.

1. Make an extremely simple CLD or an extremely simple SFD of the problem to sketch the underlying structure of the waiting list problem. Justify your choice.
2. Construct a SD simulation model. If you need delays in the model, then use simple first order delay constructions, anywhere in the model. Simulate the dynamics over 3 years.
3. Briefly verify and validate the model. Check whether the capacity is fully used if necessary. Is that the case?
4. Suppose now that there are two competing proposals (with the same costs) to solve the waiting list problem:
   - an *extension of the capacity of aftercare* with 500 beds which could be operational after 26 weeks;
   - an *extension of the capacity of the hospital* with 250 beds which could only be operational after 52 weeks.

   Sketch the behavior of both options over time. Which of these two measures is most suitable to reduce the waiting list?
5. Choosing the best extension, how large should the most appropriate extension be to eliminate the waiting list within 2 years?
6. Based on previous recommendations, the Board of Directors of the hospital has decided to go for the *capacity extension of the hospital* with 400 beds that will only be operational after one year. Simulate the dynamics of this option over exactly 3 years. Sketch the effect on the waiting list (*pre-ops on the waiting list before admission*).
7. The Board of Directors asks you to perform a number of additional analyses to take into account some of many uncertainties. The *referred pre-ops*, the *fraction of recovered patients with aftercare* and the *fraction of recovered patients without aftercare* are –according to the Board of Directors– particularly uncertain. List at least 3 other uncertain variables.
8. Manually and separately test the influence of following variables within the indicated uncertainty bounds:
   - *referred pre-ops* between 600 and 1000 patients per week
   - *fraction of recovered patients with aftercare* between 96% and 100%
   - *fraction of recovered patients without aftercare* between 70% and 90%

   Sketch the influence on the waiting list in 3 separate graphs.

9. Test –automatically and simultaneously– the uncertainty of these three variables between the uncertainty bounds indicated above. Use uniform distributions and assume the distributions are independent. Sketch the dynamics of at least 2 uncertainty bounds (e.g. 50% and 75%) for the waiting list. What is your conclusion: is this recommendation still acceptable considering these uncertainties?

18.4 Deer Population on the Kaibab Plateau

This case is a slightly adapted version of case 4.2 from Juan Martín García (2006), used here with Juan Martín García's permission. A short version of the Kaibab case is also available in (Goodman 1974, exercise 15) and an extended step-wise version is provided by Andrew Ford (2009) in chapter 21 of his brilliant book.

Introduction

'The Kaibab Plateau is a large, flat area of land located on the northern rim of the Grand Canyon. It has an area of about 1,000,000 acres. In 1907, President Theodore Roosevelt created the Grand Canyon National Game Preserve, which included the Kaibab Plateau. Deer hunting was prohibited. At the same time, a bounty was established to encourage the hunting of mountain lions and other natural deer predators. In 1910 nearly 500 mountain lions were trapped or shot. As a result of the extermination of the Kaibab mountain lions and other natural enemies of the deer, the deer population began to grow quite rapidly. The deer herd increased from about 5,000 in 1907 to nearly 50,000 in [1922].

As the deer population grew, Forest Service officials and other observers began to warn that the deer would exhaust the food supply on the plateau. During the winters of 1924 and 1925, nearly 60 percent of the deer population on the plateau died. The deer population on the Kaibab continued to decline over the following fifteen years, and it finally stabilized at about 10,000 in 1940.

Imagine you were an official of the National Forest Service in 1930, and you were interested in the fate of the deer population on the Kaibab Plateau. To examine some alternative approaches to the problem, you have decided to build a simulation model. Your main concern is the growth and rapid decline of the deer population observed over the period 1900 to 1930, and the future course of the population from 1930 to 1950. [. . . T]he problematic behavior (the reference mode) is the [dynamics of the] deer population.

Once you have developed an adequate model, you [may be able to] use it to examine some alternative ways of controlling the size of the deer population on the plateau.' (Martín García 2006, p59)

First Iteration

Make the simplest model possible. It should contain variables such as: *area*, *deer density* ($\sim$ 1/the amount of acres per deer), *deer population*, *net deer growth rate*, net deer *growth rate factor*, *deer predation rate*, *deer killed per predator*, *predator population*, and *deer killed per predator*. Assume the net *growth rate factor* of the deer population is 20%. First assume the model is in dynamic equilibrium. That is, if the *net growth rate* is 1000 deer, then the *deer predation rate* must also be 1000 deer. Assume the initial *predator population* amounted to 500 lions, and assume a density of 0.005 deer/acre.

Model the *deer killed per predator* with a table function with argument (*deer density/initial deer density*), units [deer/(year*lion)], and connecting following couples (0,0), (1,2), (2,4), (4,6), (5,6). That is, if the *deer density* is equal to 0, then the number of deer killed is 0, if the *deer density* is equal to the *initial deer density*, then each predator hunts 2 deer each year, and so on.

1. Draw a CLD and build a first iteration simulation model. What behavior do you expect?
2. Simulate the model. What behavior do you get? Does it correspond to the expected behavior? Is the model good enough to represent/explain/replicate the observed dynamics?
3. Is the simulated behavior sensitive to changes in constants and assumptions?

Second Iteration

This first model could be improved by turning the constant *growth rate factor* into another table function with argument (*food per deer/initial food per deer*) and values ((0,-0.6), (0.05,0), (0.1,0.2), (1,0.2)). The amount of *food* could at this point be assumed to remain constant at 100000 ton. Another variable that should be adapted is the *predator population* that should fall from 500 to 0 lions in 1910.

4. Draw a second CLD (extend the first CLD with the new variables) and expand the first iteration simulation model. What behavior do you expect?
5. Simulate the new model. What behavior do you get? What happens with the deer population in this version of the model? Does it correspond to the observed dynamics?
6. Is the simulated behavior sensitive to changes in constants and assumptions?
7. What structural assumptions need to be changed/added in order to obtain more realistic behavior?

Third Iteration

The assumption of a constant amount of *food* as in the previous model is a bit too simplistic and needs to be improved. A better way to deal with the amount of *food* would be to treat it as a stock variable with an initial value of 100000 ton, summing the *food generation rate* minus the *food consumption rate*. The *food consumption rate* then equals the *deer population* times the *food consumption per deer*. And the *food generation rate* could be modeled as the difference between the *food capacity* and *food*, divided by the *food regeneration time*. The *food capacity* could then be set to 100000 tonnes.

Two more table functions should be added too. First, the *food regeneration time* with argument (*food/food capacity*) and shape connecting following couples (0,40), (0.5,1.5), (1,1). This reflects the logic that the *food regeneration time* depends on the *food capacity* and the present amount of *food* (vegetation). Assume the *food regeneration time* is equal to 1 year if the amount of *food* equals the *food capacity*. A lower ratio will produce a higher *food regeneration time*. Another table function should be added for the *food consumption per deer*. Use as argument (*food/food capacity*) and values ((0,0),(0.2,0.4),(0.4,0.8),(1,1)). This means that *food consumption per deer* depends on the *food capacity* and present amount of *food*. If *food* equals *food capacity* then it is assumed that the *food consumption per deer* is equal to 1 ton. A lower ratio leads to a less *food consumption per deer*.

8. Draw the third CLD and expand the second iteration model. What behavior do you expect?
9. Simulate the model. What behavior do you get? Does it correspond sufficiently to the observed/expected behavior?
10. Is the simulated behavior very sensitive to changes in constants and structural assumptions?
11. What needs to be changed/added in order to obtain more realistic outcomes?

Using the Third Iteration Model

If this third model adequately captures the dynamics of the deer population on the Kaibab plateau, then use it to examine some alternative policies to control the size of the deer population on the plateau after 1930. If not, continue to extend the model until it does.

12. Test policies to control the deer population with predators (e.g. re-introduction and limited hunting of predators).
13. Test deer hunting policies, first static, then dynamic (incorporating feedback from the size of the deer population), first without delays and with perfect knowledge of the size of the herd, then with delays and imperfect information.
14. What is your policy recommendation?
15. Perform some policy tests:
    (a) Would the policy still work in case of real-world imperfections (e.g. poaching)?
    (b) Currently, the size of the deer population is not an explicit policy variable, it is simply the result of the policy being implemented. How about turning it into an explicit policy variable of, say, about 10000 deer?
    (c) Would the policy still work under random influences such as seasonal and random *weather* patterns?
    (d) Test refinements of the policy, such as specific sex and age policies (for example a Bucks-Only policy).
16. What about excluded variables? What about uncertainties? How robust are the policies?

⚠ Extend the model with an explicit predator submodel. Does that change the behavior and/or policy recommendations?

18.5 Prostitution and Human Trafficking

Introduction

For centuries, prostitution has been highly cyclic but also amazingly constant in many countries around the world. In the Netherlands, brothels were openly present in cities in the 17^{th} century. Between 1806 and 1911 Dutch brothels were regulated and registered. But in 1911, Christian campaigns lead to the illegalization of Dutch brothels. Some cities went even further by forbidding any form of prostitution (i.e. window prostitution and streetwalking). From the

1970s on, successive Dutch governments argued that repression does not eliminate prostitution. It disappear underground, which, in turn, makes it harder to control. The gradual change in mental models resulted in a range of policies across different cities, from tolerance to fierce prosecution. The ambiguous status of prostitution in the Netherlands was resolved on 1 October 2000 by the abolishment of the general Dutch brothel prohibition. From 2000 on, prostitutes of age and of their own free are allowed to work under strict conditions. Although the abolishment of the brothel prohibition act partly brought prostitution back to the upper world, it did not end the underlying human trafficking and organized crime. At the time of writing this case, some powerful politicians claimed that even in the legalized and regulated business more than half of the women work against their own will, are exploited, and do not use the rights reserved to them. Following these claims, the Dutch national government and several cities have again become more restrictive in relation to the prostitution sector in view of fighting the underlying human trafficking and organized crime. Some cities recently once more closed all bothels.

Suppose the Dutch government asks you to build and use an explorative SD model in order to investigate the possible consequences of new policies, measures, and actions. Closely follow the description below for constructing your model.

The Population

Suppose there is no sex tourism: the *demand for prostitutes* then emanates from the group of *sexually active adults*, initially equal to about 12 million. Suppose that this group –that is to say the group of *sexually active adults*– only increases through a flow *from minor to adult* and decreases through a an outflow *loss of sexual activity* after an average *sexual lifetime* of about 45 years. Model the flow variable *from minor to adult* for now as the number of *children* divided by the *age of consent* of 18 years. The number of *children*, initially equal to 4 million, only increases through *births*, equal to the number of *sexually active adults* times the *birth rate* of 17 children per 1000sexually active adults per year.

1. Model the above description.
2. Make a detailed CLD and a highly aggregated CLD of this model.

Demand for and supply of commercial sex services

The *demand for prostitutes* is the product of the male adult population (i.e. half the *sexually active adults*), the *normal percentage of Johns*[1], the *effect of societal acceptance on the percentage of Johns*, and the *price effect on the demand for prostitution*, divided by an average of 50 *clients per prostitute*. The *normal percentage of Johns* in the Netherlands amounts to 12% (in other words: 12% of Dutch men visit prostitutes). The *price effect on the demand for prostitution* is a function of the *average price of sex services* connecting following couples: (0, 4), (50, 1.5), (100, 1), (200, 0.5), (400, 0.2), (800, 0.1), and (1200, 0.1). In other words, the *price effect on the demand for prostitution* is equal to 1 if the *average price of sex services* is €100, et cetera. The *average price of sex services* could be modeled as a 3^{rd} order delay of 2 times the *naked costs per sex service* and times the *supply demand effect on the price of sex services*, with a delay time of a year, and an initial value equal to 2 times the *naked costs per sex service*. The average *naked costs per sex service* amount to €20.

The *supply demand effect on the price of sex services* is equal to 500% the normal value if the *supply demand ratio* equals 0, the *supply demand effect on the price of sex services* is equal to 300% if the *supply demand ratio* equals 0.05, the *supply demand effect on the price of sex services* is equal to 200% if the *supply demand ratio* equals 0.25, the *supply demand effect on the price of sex services* is equal to 100% if the *supply demand ratio* equals 1, the *supply demand effect on the*

[1]‘Johns’ are men that visit prostitutes.

price of sex services is equal to 60% if the *supply demand ratio* equals 2, and the *supply demand effect on the price of sex services* is equal to 50% if the *supply demand ratio* equals 3. The *supply demand ratio* is a measure of the *supply of prostitutes* relative to the *demand for prostitutes* – in other words, a measure of abundance of supply.

Suppose that the *effect of societal acceptance on the percentage of Johns* equals (0.5 + *societal acceptance of prostitution*/1.5), with the *societal acceptance of prostitution* equal to a 3^{rd} order delay of the function (1 - *supply of prostitutes*/100000), with an average delay time of 3 years. In other words, societal nuisance increases and societal acceptance decreases from 0 to 100000 prostitutes, and from 100000 prostitutes on, societal nuisance is so big that societal acceptance falls to 0. Model the *societal acceptance of prostitution* such that it is always between 0 and 1.

In the year 2000, there were 28254 prostitutes in the Netherlands –in other words, the *supply of prostitutes* was equal to 28254 prostitutes. The *supply of prostitutes* increases through *new Dutch prostitutes* as well as through *new foreign prostitutes*, and decreases through an unspecified *prostitution outflow*.

Suppose that the nonnegative flow of *new Dutch prostitutes* equals the product of half the flow *from underage to adult*, the *normal fraction of young Dutch adults willing to consider a job in prostitution*, the *profitability of prostitution*, and the *societal acceptance of prostitution*. Suppose that the *normal fraction of young Dutch adults willing to consider a job in prostitution* –that is, if the circumstances are favorable– equals 1 in 1000 youngsters.

The *prostitution outflow* is equal to the *supply of prostitutes* divided by an *average lifetime in prostitution* of 10 years. The *expected gap between demand and supply* then equals the sum of the *demand for prostitutes* and the *prostitution outflow* minus the *supply of prostitutes*. Model the nonnegative number of *new foreign prostitutes* as the product of the *expected gap between demand and supply* and the *profitability of prostitution*. Foreign prostitutes are likely to be 'supplied' by human traffickers. Assume the average '*delivery time*' in prostitution related human trafficking is on average about one year. And the *profitability of prostitution* is close to the difference between the *average price of sex services* and the *naked costs per sex service*, divided by the *naked costs per sex service*.

Total annual prostitution revenues are then the product of the *supply of prostitutes*, the average *visit frequency* per client, the number of *clients per prostitute*, and the *average price of sex services*. Suppose that clients have an average *visit frequency* of 24 times per year. That is, every two weeks except during the holidays which are often spent abroad.

3. Create a SD simulation model based on this description.
4. What does the equation of the *effect of societal acceptance on the percentage of Johns* mean?
5. Simulate the model from the year 2000 until the year 2040.
6. Change the flow variable *from minor to adult* such that majority is reached exactly 18 years after being born. Use an initial value equal to 222222 persons per year for this flow *from minor to adult*.
7. According to some politicians, the Netherlands should consider a ban on prostitution if the situation does not improve with the new prostitution law. Suppose the government asks you to simulate what would happen if the *supply of prostitution* is made completely illegal (not the demand as in Sweden) on 1 January of next year. To do so, add two variables: an outflow variable *reduction of supply through illegalization* in order to completely empty the *supply of prostitutes* early next year; and a variable '*influence of illegalization on the societal acceptance of prostitution* which equals 1 till the end of the year, after which it suddenly falls to, and stays, at 0.7. Multiply this last variable with the formula (1 - *supply of prostitutes* / 100000) in the *societal acceptance of prostitution*. Model this and verify the model.

8. Validate the model: list two different suitable validation tests (different from sensitivity analysis), perform them, and draw the necessary conclusions.

9. Simulate the model, save your results, and plot the model behavior of the following variables: (1) the *demand for prostitutes* and the *supply of prostitutes*, (2) the *average price of sex services*, and (3) *total annual prostitution revenues*.

10. Interpret the dynamics: What are the implications for organized crime, human trafficking, and victims of human trafficking?

11. Make a highly aggregate CLD of this model with this policy. Explain the link between structure and behavior of this model with this policy using the CLD.

12. Perform the necessary sensitivity analysis: test the sensitivity of the model and policy for two important assumptions or parameters. Conclude.

13. Suppose you advice against this policy: propose an effective policy to address the human trafficking and organized crime related to prostitution. Briefly describe your policy. Test its effects and robustness. Conclude.

18.6 Seasonal Flu

Introduction

Given your experience in building a SD model of the 2009 flu pandemic, you are invited by the European Centers of Disease Control to make a SD simulation model of seasonal Influenza A outbreaks in Europe (EU borders are non-existent for flu), which should help to increase the understanding of possible dynamics of seasonal flu and allow for virtual experimentation and policy testing.

Modeling Seasonal Flu

There are some 885 million Europeans. Depending on the time of the year (flu season or not), their condition and history, people are part of the *immune population*, the *susceptible population*, the *exposed population*, the *asymptomatic infected population*, the *symptomatic infected population*, or the *recovered population*. Suppose that initially 750 million Europeans are susceptible, 100000 Europeans are exposed, and 135 million Europeans are (temporarily) immune. Set the *asymptomatic infected population*, the *symptomatic infected population*, the *recovered population* and the *cumulative number of flu deaths* equal to zero at the start of the simulation.

People that are part of the *susceptible population* move to the *exposed population* through *infections*. The number of *infections* could be modeled by means of the product of the *susceptible population*, the *infected fraction*, the 5% *infection rate*, and the *contact rate*. Assume the *contact rate* is a function of the *infected fraction* such that it is equal to 500 persons per person per month if the *infected fraction* equals 0, that it is equal to 450 if the *infected fraction* equals 0.2, that it is equal to 300 if the *infected fraction* equals 0.5, that it is equal to 255 if the *infected fraction* equals 0.75, and that it is equal to 250 if the *infected fraction* equals 1.

Part of the exposed population is already contagious before flu symptoms show up and the contact rate of those who develop flu symptoms strongly reduces. The *infected fraction* could therefore be modeled as the sum of the *symptomatic infected population* multiplied by (1-*decrease in contact rate of the symptomatically infected*) and the *exposed population* multiplied by the *percentage symptomatic*, divided by (that is, the sum divided by) the *total population*. The *percentage* *symptomatic* is in the order of 66% for flu. And assume for now that the *decrease in contact rate of the symptomatically infected* amounts to 50%. This decrease in contact rate may seem small but is plausible given the facts that (*i*) every infected person on average only infects about 2 others, (*ii*) the flu virus survives for 2 days on door knobs and 17 days on bank notes, and (*iii*) the smallest droplet in the air or briefest hand-to-mouth or hand-to-eye contact may be sufficient to get infected. This also explains the very high (indirect) *contact rate* (see above).

Those who are exposed, either go through a *symptomatic development* phase to become part of the *symptomatic infected population*, or through a *asymptomatic development* phase to become part of the *asymptomatic infected population*. Model the *symptomatic development* as the *percentage symptomatic* times the *exposed population* divided by the *time before symptoms* develop. Symptoms develop after almost 2 days, or 0.06 months. Model the *asymptomatic development* as the complement of the *symptomatic development*.

Those who are infected with symptoms either die or recover. Model the flow of *flu deaths* as the *symptomatic infected population* times the case fatality ratio (*CFR*) of about 0.1%, divided by the average *duration of the illness* of 4.5 days or 0.18 month. Given these numbers, one should not be surprised by a few hundred thousand European flu deaths per flu episode. Only a small part of these deaths are reported as flu casualties. The '*symptomatic recovered*' flow is the complement of the *flu deaths* flow. The *asymptomatic infected population* does not die because of flu: they flow from the *asymptomatic infected population* to the *recovered population* via the '*asymptomatic recovered*', in spite of the fact that they do not show any flu symptoms. Model the *asymptomatic recovered* flow as a first order material delay of the *asymptomatic development* with the aforementioned *duration of the illness* as delay time.

Although the *recovered population* is immune for a particular flu variant after conquering it, it does not mean that the *recovered population* is immune against next year's flu variant: there are many flu strands and they permanently mutate (which is known as 'antigenic drift') into slightly different variants and/or recombine (which is referred to as 'reassortment') into radically new flu strands. The relentless mutation of, competition between, and high infectivity of flu strands results in annual flu outbreaks, mostly of somewhat different viruses and sometimes of radically different viruses. This actually means that each year the lion's share of the *recovered population* becomes susceptible again, be it to slightly different variants. Model the '*from recovered to susceptible through antigenic drift or reassortment*' flow between these two stocks as a 3^{rd} order delay of the *asymptomatic recovered* and *symptomatic recovered* flows, with a *recovered to susceptible delay* of 6 months.

But not everyone is susceptible to the next seasonal flu virus: people may be immune because of resistance to a closely related strand or because of the time of the year. The time of the year is rather important for European flu outbreaks since the virus survives better at lower temperatures and lower relative humidity –i.e. in winter– and vitamin D produced in human skin exposed to sunlight reinforces immunity to flu. Add therefore a flow variable '*from susceptible to immune and back*' between the *susceptible population* and the *immune population* stocks: the *susceptible population* increases towards the winter and the *immune population* increases towards the summer. The flow between these two subpopulations equals the difference between the *theoretic immune population* and the *immune population*, divided by the *immunity delay*. However, the value of this flow cannot be greater than the *susceptible population* divided by the *immunity delay* for a net flow from the susceptible to the immune population, and cannot be greater than the *immune population* divided by the *immunity delay* for a net flow from the immune to the *susceptible population*. Set the *immunity delay* equal to the time step. Model the *theoretic immune population* as the product of the *theoretic immune population fraction* and the *total population*. And model the *theoretic immune population fraction* as a sine function with a minimum of about 16% in the third week of January and a maximum of about 84% in the third week of July.

1. Make the model, verify it, choose appropriate settings.
2. Simulate the model over a period of 60 months and draw the behavior of following key performance indicators: (i) *susceptible population*, *immune population*, and *recovered popu-*

lation, (ii) *from susceptible to immune and back*, (iii) *cumulative number of flu deaths*, and (iv) *infections* and *infected fraction*.

3. Validate the model. List and use at least 2 different validation tests that are useful at this point in the modeling process. Conclude. Correct your model if necessary.

4. Investigate which parameters *and* functions the model is most sensitive to. Perform at least 4 different sensitivity analyses, explain what you did, and conclude.

5. Generate –based on the insights obtained in the previous question– three very different plausible scenarios (in terms of dynamics and consequences). Draw their dynamics (*infected fraction* and *cumulative number of flu deaths*). What are the differences in assumptions?

6. Draw an extremely aggregated CLD of this model that allows you to explain the link between structure and behavior of one of these scenarios (preferably for the most dramatic one).

7. Design (preferably based on your answers to the previous three questions) an intervention to substantially reduce the negative consequences of flu epidemics. Explain: what are the negative consequences you want to address? What is the intervention you propose? Model it, test it, and plot the effects.

8. Test this intervention under uncertainty. Explain what you do, plot the results, and conclude.

⚡ The formulation of this model mainly consists of 1^{st} order material delays. Change the 1^{st} order material delays into 3^{rd} order delays. Rename the model, save it, simulate it, test it, use it and conclude: does a different formulation of the delays result in different dynamics and conclusions?

18.7 Real Estate Boom and Bust

Introduction

At the end of the year 2010, Dubai announced that it overcame the crisis which started after Dubai World's announcement on 26 November 2009 that it had to delay repayment of its debt. However, at the time it seemed a bit premature to assume that all problems had been solved. Following the real estate bubble burst about a year earlier, the real estate market was still threatened by continued lack of occupancy (especially many buildings of poor quality in the desert). Let's therefore go back to November 2009 to make an exploratory SD model regarding the –then potential– real estate crisis in Dubai.

Real Estate Sector

The abbreviation of 'Real Estate Unit', i.e. REU, is used in the remainder of the text to refer to a single family house/ apartment or the space of a single person's office. Suppose that the *REU supply* initially, some 10 months before start of the crisis, consisted of 1.800.000 of these REUs. The *REU supply* decreases by means of *REU demolition* after an expected *average REU lifetime* of some 42 years (or 500 months).

The *REU supply* increases through *REU commissioning* of *REU under construction*. *REU commissioning* normally equals the number of *immigrants* divided by the product of the *REU construction time* and the number of *workers per REU under construction* of 25 persons per

REU. Note that *REU commissioning* can never be greater than the *REU under construction* over the *REU construction time* of 3 months. Set the initial value of *REU under construction* to the number of *immigrants* times the *REU construction time* divided by the *workers per REU under construction*.

REU under construction increases by means of *new REU plans approved*. New REU plans are approved in response to non-negative estimates of *expected REU shortage*s divided by the *average REU approval time* of 1 month as well as in response to investments the ruling Al Maktoum family is willing to make. Suppose that the Al Maktoum family is at any moment in time investing an *investment ratio of current REU supply* of 1% of the total *REU supply*. Suppose that the 'official' calculation of the *expected REU shortage* does not take into account demolition and therefore equals *REU demand* minus *REU supply* minus *REU under construction* plus *expected new REU due to immigration*.

1. Make a SD model of this description.
2. How do we call such stock-flow structures?
3. Make a complete CLD and a highly aggregated CLD of this (partial) simulation model.

Population: locals and immigrants

Suppose for the sake of simplicity that *locals* –initially 220.000– are not part of the workforce (at least not in the real estate construction business), that all *immigrants* –initially 2.000.000– are active on the labor market[2], and that all immigrants work in the real estate construction sector.

The number of *immigrants* increases through *workforce immigration*, and decreases through *workforce emigration* and through *integration*. *Workforce immigration* –which should be non-negative– can be modeled as the *relative attractiveness to immigrate* times the number of existing *immigrants* over the *average immigration time* of 1 month. Normal *workforce emigration* –which is also non-negative– can be modeled as the number of *immigrants* minus *labor demand*, divided by the *average emigration time* of 1 month. *Immigrants* can become *locals* if/when they integrate and find a self-sustaining job outside the REU business: this *integration* flow amounts to the *immigrant integration rate* of 0.1% of the *immigrants* per month.

Both *immigrants* and *locals* need REUs: their total *REU demand* is the product of the sum of these populations and the *REU demand per person*. Suppose that the *REU demand per person* increases linearly from 1 REU per person at the start of the simulation time to 2 REUs per person at the end of a time horizon of 120 months.

Linking population to real estate to population to . . .

Define *labor shortage* as *labor demand* relative to the number of *immigrants*. *Labor demand* is the product of the *REU under construction* and *workers per REU under construction*.

Suppose that the *average immigrant salary* amounts to the *normal immigrant salary* of 1000 dollar per person per month times the *labor shortage*. The *relative attractiveness to immigrate* is directly proportional to the v*average immigrant salary* divided by the *normal immigrant salary* and is inversely proportional to the *REU price* divided by 960. Dividing by 960 is motivated by the assumption that 75% of the housing cost is subsidized by companies or the Emirate, and a mortgage with a duration of 20 years can be obtained for the remaining amount.

The *REU price* is equal to the *normal REU cost* times the *REU shortage price effect* applied to the *REU shortage*. The *normal REU cost* amounts to $50.000 per REU (material costs) plus the product of the *average immigrant salary*, the *REU construction time*, and the number of

[2] In other words, immigrants come to Dubai without families or with inactive family members which are simply not entered into the workforce statistics and are therefore not counted as labor immigrants in your model.

workers per REU under construction. The *REU shortage price effect* consists of a curve connecting following couples (0,0.6), (10,4), (50,7.5), (100,10). *REU shortage* can be defined as *REU demand* over *REU supply*.

Expected new REU due to immigration equals the product of the *immigration multiplication factor* and the difference between the number of *immigrants* and the number of *immigrants in the previous period*. Set the *immigration multiplication factor* equal to 1.

4. Extend the simulation model with the information provided above. Verify the model briefly. Simulate the model and make graphs of the *immigrants*, the *REU supply*, the *REU shortage* and *labor shortage*.

5. Validate the model. List 2 validation tests (with the exception of uncertainty testing), perform them and briefly describe the results/conclusions.

6. Use the model to simulate the unfolding of the real estate bust after month 10:

   - Let the Al Maktoum family's *investment ratio of current REU* fall instantly from 1% to 0% at the beginning of month 10;
   - Add following non-negative term to the formula of *workforce emigration*: *exogenous emigration/average emigration time* that allows you to simulate an exogenous emigration of 200.000 immigrants in month 10.

   Simulate the model and make graphs of the *immigrants*, the *REU supply*, and a combined graph of the *REU shortage* and *labor shortage*. Are these changes enough to generate a real estate bust?

7. Keep the crisis settings from the previous question. Now, test the influence of uncertainty related to the *average immigration time* –test for instance *average immigration time*s of 1 month, 2 months, and 3 months– on the number of *immigrants*. Make a graph of the effects on *immigrants*. Do the same for uncertainty related to the *REU construction time* –test for instance *REU construction time*s of 1, 2, 3, and 4 months. Conclude.

8. Remove the crisis settings, and test the combined effect of different *average immigration time*s and *REU construction time*s on the number of *immigrants* without crisis settings. Briefly discuss your results and explain these effects and what causes them.

9. Make an extremely aggregated CLD of the model without crisis settings which allows you to explain the main feedback effects in case of an *average immigration time* that does *not* lead to a collapse. Use the CLD to briefly explain the link between system structure and behavior. In other words: why does the system not collapse? Now, make a new highly aggregated CLD or adapt the previous one (use a different color) to the case of an *average immigration time* of 1 month. Again, use the CLD to briefly explain the link between system structure and behavior.

10. Suppose that the ruling family still wants to turn Dubai into a regional metropole. The boom needs to be sustained in order to do so: what do you advice the ruling family to do –without spending/losing too much money– in order to sustain a continued boom?

⚡ This model is just a preliminary model. What would you add/change/... to improve the model and make it really useful for real-world policy analysis? Do do it.

18.8 DNO Asset Management

Introduction

In this case, one needs to build a highly aggregated electricity grid investment model for a medium-sized Distribution Network Operator (DNO), turn it into a serious game, and use it for gaming purposes. This model is based on an extended version of this model (regarding electricity and gas grids) that was developed for a Dutch DNO and used in a serious gaming and strategy development workshop.

Introduction

Although the electricity grid could be characterized simplistically in terms of km cable, there is more to it than just the grid length. What counts is the capacity where it is needed. Hence, the abbreviation of Electricity Grid Capacity, i.e. EGC, will be used here to refer to the capacity of the electricity distribution grid. The units are simply expressed in terms of units of EGC.

The *total available EGC* in a region consists of *regular EGC*, i.e. capacity younger than the *normal EGC replacement age* of 40 years, and *old EGC* that has not been decommissioned (yet). The *regular EGC*, with an initial regular EGC of 131508 units of EGC, increases through *commissioning of additional EGC*, *replacement of EGC at the end of its normal replacement age*, and *replacement of old EGC*, and decreases through *obsolescence of regular EGC without replacement* and *replacement of EGC at the end of its normal replacement age*.

Old EGC increases over time through *obsolescence of regular EGC without replacement* and decreases over time through *replacement of old EGC* and *decommissioning of old EGC*. Calculate the *initial old EGC* as the *initial EGC* of 142000 units of EGC minus the *initial regular EGC*. The *replacement of old EGC* is proportional to the amount of *old EGC* and the *percentage replacement of old EGC* of 0% per year. Assume that the *decommissioning of old EGC* is equal to 0: it is cheaper not to remove old EGC that has not been replaced as long as it does not cause harm.

Calculate the *replacement of EGC at the end of its normal replacement age* as the *total EGC at the end of its normal replacement age* times the *percentage EGC replacement after its normal replacement age* and the *obsolescence of regular EGC without replacement* as the *total EGC at the end of its normal replacement age* times (1 - *percentage EGC replacement after its normal replacement age*) with the *percentage EGC replacement after its normal replacement age* equal to 75%.

Model the *total EGC at the end of its normal replacement age* as the sum of the *EGC at the end of its normal replacement age* and a *historic time series of additionally commissioned EGC*. The amount of *EGC at the end of its normal replacement age* is equal to the *commissioning of additional EGC* delayed exactly with the *normal EGC replacement age* and initial value equal to 0. The *historic time series of additionally commissioned EGC* in the region is a function of (Time-40) with following couples: (1900,0), (1919,0), (1920,1), (1930,10), (1940,100), (1950,250), (1960,2000), (1969,4000), (1980,4000), (1990,2000), (2008,1000), (2008.9,1000), (2009,0), (2100,0).

The *commissioning of additional EGC*, which needs to be non-negative, amounts to the *additionally planned EGC* divided by the *average EGC planning and construction time* of 1 year. The *additionally planned EGC*, which initially amounted to 900 EGC, increases with *new planning of new EGC additions* and decreases with *commissioning of additional EGC*. In terms of a new investment strategy, it seems the DNO you are modeling for simply fills the gap, i.e. the *new planning of new EGC additions* equals the non-negative *expected EGC additions required*, which can be computed as the difference between *EGC needed* and *total available EGC*. Model the *EGC needed* as the product of the *initial EGC* and the *total relative EGC multiplier*. Assume for now that the *total relative EGC multiplier* remains 1 from 2010 till 2100. This time series variable will be used to insert scenarios regarding grid needs.

Finally, add four key performance indicators: the instant *EGC shortage* which is the non-negative difference between *EGC needed* and *total available EGC*, the *cumulative EGC shortage*, the instant *EGC excess* which is the non-negative difference between the *total available EGC* and the *EGC needed*, and the *cumulative EGC excess*.

1. Build, verify and validate the model, and simulate it from 2010 till 2050.
2. Make either a highly aggregated or detailed CLD of the model. Choose and justify your choice: what is in this case the best choice? Why?
3. Add EGC demand scenarios by means of the *total relative EGC multiplier*: include some very different plausible time series. Simulate these scenarios.
4. How does the model deal with unexpected shocks and with very different types of behaviors? Is the current policy built into the model appropriate for a deeply uncertain future?

- Extend the model with a financial module, knowing that *regular EGC investment costs* are in the order of €30000 per unit of EGC.
- Turn the model into a serious gaming simulator and use it for gaming purposes:
  - Change following constants and normal auxiliaries into gaming auxiliaries, i.e. change constant normal or auxiliary normal into auxiliary gaming for following variables: *new planning of new EGC additions*, *percentage EGC replacement after its normal replacement age*, *percentage replacement of old EGC*, *decommissioning of old EGC*.
  - Build an interface in your SD software or on www.forio.com.
  - Assume, and let others assume, the role of DNO asset manager by deciding on an asset management strategy and trying to implement it in the four demand scenarios defined above. What could be concluded? Why?
- Turn the model into a model that could be used for testing and experiencing investment strategies related to smartening energy grids.

18.9 Fighting HIC on the Regional Level

Introduction

After having made a model for the Dutch police about burglaries by occasional burglars and organized criminals, you are now asked to make a simulation model about home burglaries (from now on referred to as burglaries) and shop robberies (from now on referred to as robberies) with a time horizon of 10 years for a particular police precinct. Burglary and robbery are both 'High Impact Crimes'. Such models are needed since burglaries and robberies are substitutes: more/better preventive measures against robberies lead to more burglaries, and vice versa. Use the following information, obtained during interviews and background research, in your model.

The first iteration

In this precinct, burglaries and robberies are committed by locals, initially by some 200 *known offenders at liberty* and –so the police thinks– by some 750 *unknown offenders at liberty*. The average *number of offenses per known offender at liberty* amounts to 2.5 per year and the average *number of offenses per unknown offender* is assumed to amount to 1 per year. Burglaries are seasonal: the *number of seasonal robberies and burglaries* could be modeled as the *seasonality of these offenses* times the sum of the *number of offenses per known offender at liberty* times the number of *known offenders at liberty* and the *number of offenses per unknown offender* times the *unknown offenders at liberty*. Model the *seasonality of these offenses* such that the number of offenses reaches its peak at the end of the year and its low during the summer holidays, and that the peak is 50% higher than the average and the low 50% lower.

The number of *burglaries* could be calculated as the *relative attractiveness of burglary* times the *number of seasonal robberies and burglaries*. The *relative attractiveness of burglary* could be calculated as the *attractiveness of burglary* divided by the sum of the *attractiveness of burglary* and the *attractiveness of robbery*. The *attractiveness of burglary* is proportional to the *average gain per burglary* and inversely proportional to both the *chance of being caught after a burglary* and the relative *difficulty of a burglary*. The *average gain per burglary* is €600, the *chance of being caught after a burglary* is 8%, and the relative *difficulty of a burglary* is the norm for all High Impact Crimes, i.e. it equal to 100%. The number of effective *arrests after burglaries* equals the *chance of being caught after a burglary* times the number of *burglaries*.

Do the same for robberies[3]. Assume that the relative *difficulty of a robbery* is 10 times higher than the relative *difficulty of a burglary*, that the *average gain per robbery* is about €1200, and that the *chance of being caught after a robbery* is about 33%.

Model the *total number of arrests after burglaries and robberies* as a 3^{rd} order delay of the sum of *arrests after burglaries* and *arrests after robberies* with a delay time of a quarter of a year and an initial value of 100 offenses. The number of *known offenders* that is sent *to jail* then consists of the *total number of arrests after burglaries and robberies* times the *number of offenses per known offender at liberty* divided by the sum of the *number of offenses per known offender at liberty* and the *number of offenses per unknown offender*. The remainder of the arrests are arrests of unknown offenders. In other words, the non-negative number of *unknown offenders sent to jail* equals the difference between the *total number of arrests after burglaries and robberies* and the number of *known offenders sent to jail*. Initially, the number of *offenders in jail* is equal to 185. This stock only increases through the inflows of *unknown offenders sent to jail* and *known offenders sent to jail*, and only decreases through the outflows of *known offenders released from jail* and *those who stop after leaving jail*. Assume that 25% stops after leaving jail: model the number of *those who stop after leaving jail* as the product of the *percentage that stops after leaving jail* of 25% and the number of *offenders in jail*, divided by an *average time in jail* of 2 year. The flow of *known offenders released from jail* then equals the number of *offenders in jail* divided by the *average time in jail* minus the number of *those who stop after leaving jail*. Do not forget at this point, to adapt the equation of the stock variable *known offenders at liberty*. That is, *known offenders released from jail* become, after being released, *known offenders at liberty*. The number of *unknown offenders at liberty* is the integral of the *new offenders* minus the *unknown offenders sent to jail* over time. Model the number of *new offenders* as the number of *unknown offenders at liberty* times the *percentage increase of new offenders* of 2% per year. After all, petty crime is contagious. . .

1. Make a SD model based on the description above and verify it.
2. Simulate the model and plot the behavior of the following key performance indicators (KPIs): *burglaries*, *robberies*, and *total number of arrests after burglaries and robberies*.

[3] The number of *robberies* equals the *relative attractiveness of robbery* times the *number of seasonal robberies and burglaries*. The *relative attractiveness of robbery* could be modeled as the *attractiveness of robbery* divided by the sum of the *attractiveness of burglary* and the *attractiveness of robbery*. The *attractiveness of robbery* is proportional to the *average gain per robbery* and inversely proportional to both the *chance of being caught after a robbery* and the relative *difficulty of a robbery*. The *average gain per robbery* is €1200, the *chance of being caught after a robbery* is 33%, and the relative *difficulty of a robbery* is 10 times higher than that of a burglary. Suppose that the number of *arrests after robberies* equals the *chance of being caught after a robbery* times the number of *robberies*.

3. Draw a strongly aggregated CLD of this simulation model that allows you to explain the substitution effect between *burglaries* and *robberies*. Do that: use the CLD to explain the substitution effect.

Effectiveness of interventions in the first iteration model

The purpose of making the model is the assessment of the effectiveness of possible interventions:

4. Suppose additional time and effort will be spent to perform *additional arrests*, say 100 extra arrests in year 3. Draw the resulting behavior of the KPIs on your answer sheet.
5. Suppose now that the previous intervention is replaced by a 'person bound approach', also in year 3.

The 'person bound approach' (PBA) consists in several visits per month paid by police agents to *known offenders at liberty* so that they know they are being observed while other organizations help them build up normal lives. Model the PBA as follows: the number of *known offenders in PBA*, initially equal to 0, increases and decreases through the *net increase of known offenders in PBA* and only decreases through an outflow of *those who stop due to the PBA*. The *net increase of known offenders in PBA* could then be modeled as the difference between the *aimed number of known offenders in PBA* and the real number of *known offenders in PBA*, divided by the *PBA adaptation time* of 0.125 year. It should be clear that the *net increase of known offenders in PBA* cannot be applied to more known offenders from the *known offenders at liberty* than there are *known offenders at liberty*. Let the *aimed number of known offenders in PBA* be equal to 200 persons during the entire third year. Model the flow of *those who stop due to the PBA* as the number of *known offenders in PBA* times the *effectiveness of the PBA to quit* of 50%, divided by the *average time in PBA before quitting* of about three quarters of a year. Also assume that *known offenders in the PBA* do not commit offenses while being in the PBA. After all, they are and feel watched.

6. Plot the behavior of the 3 KPIs (*burglaries*, *robberies*, *total number of arrests after burglaries and robberies*). Is the PBA intervention effective and good enough? Explain.
7. Suppose both previous interventions are applied simultaneously. What behavior does your model generate now? Display or draw the behavior of the 3 KPIs. Do these measures reinforce each other? Which intervention is most effective: only the additional arrests, only the PBA, or both together? Why? What about the marginal effectiveness? Explain.

Second iteration with interventions

Although burglaries are seasonal, robberies are not. The formula of the number of *robberies* thus needs to be corrected for the *seasonality of these offenses*.

Suppose furthermore that only insufficiently protected (IP) homes are broken into, not sufficiently protected (SP) homes, and that only insufficiently protected (IP) stores are robbed, not sufficiently protected (SP) stores. The *fraction of IP homes* then equals the number of *insufficiently protected homes* divided by the sum of *insufficiently protected homes* and *sufficiently protected homes*. *Insufficiently protected homes*, initially 150,000 in this precinct, become *sufficiently protected homes*, initially also 150,000 in this precinct, through the installation of *protection against burglary*. Model the installation of *protection against burglary* as the number of *burglaries* times the *percentage installation of protection after a burglary* of about 50%. The installation of *protection against burglary* is thus reactive, not proactive. Now adapt the *attractiveness of* *burglary*: it is also proportional to the *fraction of IP homes*. That is, the more IP homes there are, the easier it is to commit burglaries.

Do the same for robberies assuming the number of *SP stores* initially amounts to 200, the number of *IP stores* initially amounts to 500, and the *percentage installation of protection after a robbery* is about 50%.

8. Extend the model.
9. What behavior does your model generate? Plot the behavior of all interventions (no intervention, only additional arrests, only PBA, both additional arrests and PBA) on the KPIs.
10. Compare the policies in the first and second version of the model. Can we speak of '*policy sensitivity*'? Explain.
11. Test the 'best' policy under uncertainty? Explain what you do & why. What is the result?

18.10 Innovation in Health Care

This case deals with the effects of new technologies on the average lifetime of human beings, especially the elderly (65+) in developed nations. This exercise is only available online since additional explanations about interacting with Excel and subscripts/arrays as well as additional Excel files are required, as well as software with subscript/array functionalities. Follow this link to the exercise and additional online materials if you have software with the necessary functionalities.

18.11 Carbon and Climate Change

This exercise is based on a modified version of the 'CO_2 dynamics of biosphere and atmosphere' System Zoo model developed by Hartmut Bossel (2007b, Z303) (follow this link to the zip file containing all Zoo models). Although it is not necessary to know much about the climate system to solve this exercise, it is assumed readers are familiar with climate change. If not, please read this background document on Climate Change and Energy Systems and/or solve ex.2.14 on p63.

Model the *fossil energy consumption*, starting at 0.1 GtC/Year in the year 1850, as the accumulation of the *net growth of fossil fuels consumption*. The *net growth of fossil fuels consumption* is proportional to the *fossil energy consumption* and the *growth rate*. Assume the *growth rate* equals the *average historical growth rate* times an indicator of the *scarcity of fossil fuels* equal to (1 - *exploitation factor*). Model the *exploitation factor* as the *cumulative fossil fuel consumption* divided by the *initial easily recoverable fossil fuel reserves* of 4000 GtC. Use a dummy flow variable named *fossil fuel consumption* equal to the *fossil energy consumption* to model the *cumulative fossil fuel consumption*, starting from an initial value of 10 GtC in 1850.

Fossil energy consumption is one of the main causes of *atmospheric carbon emissions*. Additional sources of *atmospheric carbon emissions* are *carbon emissions from fires*, *carbon emissions* *from deforestation*, *carbon emissions from animal respiration*, *carbon emissions from humus*, and *rock decomposition*. *Rock decomposition* amounts to about 0.5 GtC per year. But climate change is a stock problem instead of a flow problem: more important than annual *atmospheric carbon emissions* is the total amount of *carbon in the atmosphere* which, due to its long atmospheric lifetime, mixes homogenously. The stock of *carbon in the atmosphere*, which amounted approximately to 600 GtC in 1850, increases through *atmospheric carbon emissions*, decreases mainly through biospheric and hydrospheric *carbon uptake*. Model the *carbon uptake* therefore as the sum of the *net primary biomass production*, the *carbon uptake from afforestation*, and the *carbon uptake of oceans*. Suppose *carbon uptake of oceans* is a function of the amount of *carbon in the atmosphere* such that it increases linearly from 0 GtC/Year at 600 GtC in the atmosphere to 3 GtC/Year at 700 GtC in the atmosphere, and remains 3 GtC/Year at higher atmospheric carbon levels. The *ppm* CO_2 *in the atmosphere* is (approximately) equal to the *carbon in the atmosphere* divided by a *C per ppm factor* of 2.12 GtC per ppm.

Represent the biosphere by means of a stock of *carbon in living biomass*, of about 750 GtC in 1850. The stock of *carbon in living biomass* increases through *carbon uptake from afforestation* and *carbon absorption by primary biomass production*, and decreases through *carbon emissions from deforestation*, *carbon emissions from fires*, *carbon emissions from animal respiration* and from *annual carbon loss through plant litter*. *Carbon absorption by primary biomass production* is equal to the *net primary biomass production*, which could be modeled as the amount of *carbon in living biomass* times a *specific annual net primary biomass production* of 7.5% per year. Note however that 90.5% of *net primary biomass production* is lost –that is, lost as biomass– as *annual carbon loss through plant litter*. Simplistically model the *carbon emissions from animal respiration* as 6% of the *net primary biomass production* and *carbon emissions from fires* as 3.5% of *net primary biomass production*. Assume *carbon uptake from afforestation* rose linearly from 0 GtC per year in 1850 to 1 GtC per year in 1950 and afterwards. And model *carbon emissions from deforestation* as 60% of *deforestation*. Assume *deforestation* rose from 0 GtC per year in 1850 to 2 GtC per year in 1980, and will fall back to 1 GtC per year in 2100 and afterwards.

The amount of *carbon in humus*, which amounted to approximately 1600 GtC in 1850, increases through *carbon deposition in humus* and decreases through *carbon emissions from humus*. *Carbon deposition in humus* equals the *annual carbon loss through plant litter* plus 40% of *deforestation*. And *carbon emissions from humus* arise from *humus decomposition* and *soil oxidation*. Assume that *soil oxidation* rose from 0 GtC per year in 1850 to 1.5 GtC per year in 1980 and will fall back to 0 GtC per year in 2100 and will remain 0 GtC per year ever after. Model *humus decomposition* as the amount of *carbon in humus* divided by the *persistence time of carbon in humus* of about 30 years.

1. Build a SD model of this description. Verify the model.
2. Simulate it from 1850 until 2350. Plot graphs of the *fossil fuel consumption*, the CO_2 *increase*, the CO_2 *in the atmosphere*, and CO_2 *ppm*. Interpret these graphs: what do they show and what could be concluded if they would be real?
3. Compare these graphs to graphs about the same evolutions in the real world. Are the simulated evolutions more or less in line with the real evolutions? List one other validation test except sensitivity analysis. Perform the validation test and explain. Conclude. What is this simplistic model useful for? What could/should be improved?
4. This model is rather small, simplistic, and highly aggregated. Perform therefore an extensive sensitivity analysis and/or uncertainty analysis. What could be concluded?
5. What happens if:
   (a) The consumption of fossil fuels starts to decrease with 1% per year from 2014 on?
   (b) The *initial easily recoverable fossil fuel reserves* suddenly doubles in the year 2010 to 8000 GtC: suppose that shale gas and other unconventional fossil fuel reserves/resources become all of a sudden econimically recoverable?

(c) On top of the previous what-ifs, the *growth rate* increases to 5% per year from 2015 on.

6. What is the maximum atmospheric concentration in these cases. What could be concluded?

7. Use the model to design and test different policies that would keep the atmospheric concentration from doubling to pre-industrial values?

8. Extend the model with a submodel about the uptake by the oceans based on (Fiddaman 1997; Fiddaman 2002). Does the inclusion of this submodel change your (policy) conclusions?

18.12 Managing An Orchestrated Bank Run

Introduction

Disclaimer: The model underlying this exercise is a very simplistic and highly aggregated model. It does not capture important processes and events such as a 'haircut' we know –with hindsight– happened during the fall of the DSB Bank. Hence, this is just an educational case: the model made in this case cannot be used to advise real banks. All values in this exercise are fictitious.

Introduction

Many banks and financial institutions went bankrupt in 2009. The bankruptcy of a small Dutch bank, the Dirk Scheringa Bank or DSB Bank, is a very special case, because the bankruptcy was actually caused by an orchestrated bank run by angry clients following the call by Pieter Lakeman to empty their deposits.

Since you already modeled the fall of the Fortis Bank, you are asked by the Dutch central bank '*De Nederlandse Bank*' to model the fall of the DSB. Keep in mind that a crisis model is not the same as a complete bank model for going concern.

Modeling this Bank Run

Deposits being emptied are –from the point of view of a bank– *liquid deposits and loans lost*. These *liquid deposits and loans lost* drain the *liquid deposits and loans*, which initially amounted to €4,500,000,000.

Liquid assets lost are equal to the *liquid deposits and loans lost* because of the double accounting system. *Liquid assets lost* decrease the amount of *liquid assets*, which initially amounted to €1,150,000,000. Suppose that DSB had a *liquid asset liquid liability target* of 20%, which means that *fixed assets*, which initially amounted to €4,600,000,000, need to be liquidated and turned into *liquid assets* if less than 20% of *liquid deposits and loans* are covered by *liquid assets*. Suppose that the *liquidation time* is only 1 day, which means that there are enough interested parties to almost instantly sell assets to. However, in case of haste, there is a *liquidation premium* of 10% on emergency sales. In other words, only 90% of the fixed asset value is turned into liquid assets in emergency sales, and 10% of the fixed asset value is lost as *liquidation losses*. Keep in mind when you model the *liquidation* flow that the model you make is a crisis model and not a complete 'going-concern' banking model: there should at most be a net flow from *fixed assets* to *liquid assets*, but not the other way around. Apart from the *liquid deposits and loans*, DSB also had *fixed deposits and loans* worth €1,000,000,000 which remained constant during the crisis because *fixed deposits and loans* cannot be emptied by depositors or lenders before their due date.

In a normal bank run, the amount of *liquid deposits and loans lost* equals the *liquid fraction running away* times the *liquid deposits and loans* divided by the *withdrawal time*. However, two factors amplified the 'running away effect' in the case of DSB: clients were angry because of unacceptable sales practices and the mediatized unwillingness of the bank to compensate the victims of these practices, and people understood the hindrance of a bank failure[4] after having witnessed several bankruptcies in the banking world. Multiply the previous right hand side of the equation therefore with following two factors: (1+*hindrance of bank failures*) and (1+*anger*). Suppose that the *hindrance of bank failures* amounts to 0.5.

Since the DSB bank run was triggered by a call for a bank run, you have to add an additional term to take this orchestrated action into account, for example: *Orchestrated liquid fraction running away* times *liquid deposits and loans* divided by a *withdrawal time* of 1 day. Note that the maximum amount of *liquid deposits and loans lost* equals the amount of *liquid deposits and loans* divided by the *withdrawal time*.

Suppose that the *liquid fraction running away* amounts to 0% if the *perceived likelihood of a bank failure* is 0%, that it amounts to 0% if the *perceived likelihood of a bank failure* is 25%, that it amounts to 1% if the *perceived likelihood of a bank failure* is 50%, that it amounts to 10% if the *perceived likelihood of a bank failure* is 75%, and that it amounts to 50% if the *perceived likelihood of a bank failure* is 100%.

Model the *perceived likelihood of a bank failure* as (100% - *credibility of the denials*) times the maximum of either the *perceived likelihood of a liquidity failure* or the *perceived likelihood of a solvency failure*.

Suppose that the *perceived likelihood of a liquidity failure* amounts to 100% if the *liquid asset liquid liability ratio* equals -1, that it amounts to 100% if the ratio equals 0, that it amounts to 80% if the ratio equals 0.1, that it amounts to 40% if the ratio equals 0.2, that it amounts to 10% if the ratio equals 0.3, that it amounts to 1% if the ratio equals 0.4, that it amounts to 0% if the ratio equals 0.5, and that it amounts to 0% if the ratio equals 1.

Suppose that the *perceived likelihood of a solvency failure* amounts to 100% if the *total asset total liability ratio* equals 0, that it amounts to 100% if the ratio equals 0.8, that it amounts to 90% if the ratio equals 0.9, that it amounts to 50% if the ratio equals 1, that it amounts to 10% if the ratio equals 1.1, that it amounts to 0% if the ratio equals 1.2, and that it amounts to 0% if the ratio equals 2.

The *liquid asset liquid liability ratio* is of course equal to the amount of *liquid assets* over the amount of *liquid deposits and loans*. And the *total asset total liability ratio* is equal to the sum of the *fixed assets* and the *liquid assets* over the sum of the *liquid deposits and loans* and the *fixed deposits and loans*.
Suppose the central bank issues a *bank failure declaration* (forcing a bank into bankruptcy) if the *liquid asset liquid liability ratio* falls below 0.05 or the *total asset total liability ratio* falls below 0.9.

1. Make a SD simulation model of this issue. Verify the model.
2. Simulate the model first of all over a time horizon of about 60 days without any anger or 'organized' bank run. In other words, set *anger* equal to 0, *Orchestrated liquid fraction running away away* equal 0%, and the *credibility of the denials* equal to 90%. Plot the *liquid deposits and loans lost* and the *perceived likelihood of a bank failure*.
3. Now, adapt the model to simulate a bank run following Pieter Lakeman's call for an orchestrated bank run. Suppose for example that the *Orchestrated liquid fraction running away* jumps to 5% on day 2 and falls down to 0% on day 4 and that the *credibility of the denials* falls from 90% to 10% from day 2 on. Suppose also that on top of these changes the variable *anger* amounts to 0.5 and the *liquidation premium* to 25%.

[4] Even without losing money (in case of depositor guarantees), depositors have to wait for months to get their money back.

   (a) Simulate the model over a time horizon of 60 days. Plot the *liquid deposits and loans lost* and the *perceived likelihood of a bank failure*.
   (b) Explain the behaviors obtained, especially if you obtain strange behaviors.
   (c) Briefly describe whether and what the bank could do to prevent this bank run (do not model it here).

4. Simulate a bad case scenario, again over a time horizon of 60 days, in which *anger* is 1, *hindrance of bank failures* is 1, and the *liquidation premium* is 25%.
   (a) Plot the *liquid deposits and loans lost* and the *perceived likelihood of a bank failure*.
   (b) Briefly describe the differences with the previous behavior?
   (c) Briefly describe whether and what the bank could do to prevent this bank run (do not model it here).
5. Validate the model extremely briefly. Use maximum 2 different validation tests. List the tests used and briefly describe the conclusions of these tests.
6. Draw a CLD of the system to help you communicate the main feedback effects responsible for the bank run after the call.
7. Explain the link between structure & behavior (e.g. for the 'bad case' scenario).
8. Add a simple closed loop policy that prevents the bank from collapsing. Describe the policy briefly. Test the policy at least in case of the 'bad case' scenario and plot the resulting dynamics.
9. How do we call variables like *hindrance of bank failures* and *anger*?

18.13 Activism, Extremism and Terrorism

Introduction

After having modeled a generic model about radicalisation and deradicalisation, you are asked to make a more detailed model focused on phenomemon based activism and extremism. Take the example of animal rights activism and extremism.

Citizens, Activists, and Extremists

Just as in the more generic model (case 14.16 on page 184), you can simplify the population submodel by assuming that the population remains constant (no migration, no births and no deaths). Suppose that there were 16 million citizens in the country in 1980, of which about 3 million *citizens that cannot be convinced*, 12900000 initially *unconvinced citizens*, about 100000 initially normal *convinced citizens*, and no *activists* nor *extremists*. *Unconvinced citizens* become *convinced citizens* through '*persuasion*'. *Convinced citizens* could possibly become –still law-abiding– *activists* through *activation*. Some *activists* start to operate after some time outside of the legal framework and thus become *extremists*. The latter process may be called *extremization*.

The *persuasion* variable could be modeled as the product of the *contact rate of convinced with unconvinced* citizens, the *fraction of all convinced citizens*, the *unconvinced citizens* that are not (yet) convinced but possibly could be, the *persuasion rate* of 1%, and the *reinforced visibility of animal distress* divided by an *average transition time* of 10 years. Note that the *persuasion* flow cannot be greater than the number of *unconvinced citizens* divided by an *average transition time*. Set the *contact rate of convinced with unconvinced* citizens equal to the *frustration of all convinced citizens* times the *normal contact rate of convinced* of 1000 contacts per convinced citizen per year.

Simplify the *activation* and *extremization* flows: assume the *activation* flow is equal to the difference between the *potential number of activists* and the number of *activists*, divided by the *average transition time*, and that the *extremization* flow is equal to the difference between the *potential number of extremists* and the number of *extremists*, divided by the *average transition time*.

The *potential number of activists* is determined by the product of the *potential fraction of activists* of 5%, the number of *convinced citizens*, and the *frustration of all convinced citizens*. And model the *potential number of extremists* as the product of the *potential fraction of extremists* of 5%, the number of *activists*, the *frustration of all convinced citizens*, and the *frustration through marginalization*.

Human Distress

The *frustration of all convinced citizens* –always between 0% and 100%– could be modeled as the product of the *perceived animal distress* and the sum of the *frustration through marginalization* and the *frustration through inertia*.

The *frustration through marginalization* is a function of the *fraction of all convinced citizens* connecting following couples: (0, 1), (0.025, 0.50), (0.10, 0.20), (0.25, 0.04), (0.5, 0), (1, 0). The *fraction of all convinced citizens* is of course equal to the sum of convinced citizens, activists, and extremists, divided by the total population.

Model the *frustration through inertia* as the difference between the *maximum attainable rate of decrease through societal change* of 5% and the *rate of decrease through societal change*, divided by the *maximum attainable rate of decrease through societal change*, but then delayed with exactly one year (because statistics are always delayed and news papers report statistics after publication).

This *rate of decrease through societal change* is equal to the *fraction of all convinced citizens* times the *maximum attainable rate of decrease through societal change*.

Animal distress and Visibility

Perceived animal distress could be modeled as the real *animal distress* divided by the *societal acceptance threshold with regard to animal distress*, but then smoothed (3^{rd} order over a year). Suppose that the *societal acceptance threshold with regard to animal distress* changes over time from 100 in 1980, to 80 in 2000, to 40 in 2020, to 20 in 2040, to 12 in 2060, and to 10 in 2080.

Real *animal distress* –in 1980 equal to the reference value 100– increases (or decreases) through the *net increase of animal distress* – which could be modeled as the product of *animal distress* and the difference between the *exogenous rate of increase of animal distress* and the *rate of decrease through societal change*. The *exogenous rate of increase of animal distress* amounts to -0.1%, in other words, animal distress decreases exogenously.

Model the *visible animal distress* as the difference between *animal distress* and the *societal acceptance threshold with regard to animal distress*, divided by the *societal acceptance threshold with regard to animal distress*. The *visible animal distress* should always be non-negative. The *visible animal distress* multiplied by the *radical action level* results in the *reinforced visibility of animal distress*. The *radical action level* is equal to the number of *extremists* times the *frustration of all convinced citizens* times the *fraction of all convinced citizens*.

1. Make a model of the description above. Verify it. Then simulate the model over a time horizon of 100 years, starting in 1980.
2. Make a graph of the *convinced citizens*, *activists*, *extremists*, and a graph of the *persuasion* rate and the *frustration of all convinced citizens*.

3. Validate the model: name, briefly describe and perform 2 different validation tests (except sensitivity testing – see following question) for a model like this and briefly conclude.

4. Test the sensitivity of the model for parameters and table functions. Briefly describe the tests performed and the major insights obtained.

5. Make different consistent and interesting (thus behaviorally different) scenarios starting from your conclusions in the previous question. Simulate these scenarios and draw graphs for two scenarios of the *convinced citizens*, *activists*, *extremists*, and the *persuasion* rate and the *frustration of all convinced citizens*.

6. Make a highly aggregated CLD of this model that could be used to explain the link between structure and behavior of one of the scenarios. Use this CLD to explain that behavior.

7. Formulate policy advice –based on this exercise– with regard to animal right activism.

8. This model is of course but a first simple model, and the analysis is explorative at most. Provide advice with regard to future extensions and refinements of the model.

18.14 Project Management

Introduction

Project planning is a successful SD application field. Let us therefore make a SD project models to see how and why System Dynamics could be useful for project planning and 'project litigation'(using SD models before or in court to show the causes of project delays, cost overruns, and hence, who is responsible and should bear the costs).

Suppose that you are appointed project manager in a large company specializing in project management and project implementation. Your main tasks consist of planning and managing relatively large projects. Because of your background in SD, you decide to make a SD model to help you plan and manage your projects. Use the information below, which is based on a modified version of George Richardson's Project models, available here.

Project Management I

A typical project consists *initially* of 1200 *project tasks* to be completed. A typical project model thus starts with a stock of 1200 *remaining project tasks*. During the project, *project tasks that are properly completed* become part of the *properly completed project tasks*. At the start of a project, the number of *properly completed project tasks* is 0. The *project tasks that are properly completed* is equal to the *progress* made during the project. *Progress* made during the project is equal to the *gross productivity of project personnel* times the size of the *workforce* assigned to the project. The *gross productivity of project personnel* depends on the number of *remaining project tasks*: with a project of, say, 1200 tasks to be completed, the *gross productivity of project personnel* is maximal –that is to say 100%– from 1200 remaining tasks until there are some 100 remaining tasks, after which the *gross productivity of project personnel* decreases to 95% at 75 remaining tasks, 85% at 50 remaining tasks, to 20% at 0 remaining tasks. The last mile is the hardest.

When you become project manager, it is not common practice to hire *testing personnel* (see below), only *project personnel*. Suppose that the number of *project personnel* at the start of the project is equal to the size of the *workforce*, equal to 2 (the project manager –you– and the Assistant Project Manager –your secretary). However, much more manpower is needed to complete projects. The *workforce* of your company internally assigned to a particular project increases and decreases through *net hiring of personnel* equal to the difference between the *desired workforce* and the *workforce*, divided by the *time to adapt the workforce*. Suppose that according to the project workforce policy of your company, the *desired workforce* equals the *perceived effort remaining* divided by the *perceived time remaining*.

Model the *perceived time remaining* as: '-Time' plus a first order information delay with argument *Time + perceived effort remaining/desired workforce*, with a delay *time to adjust the project schedule*, and with as initial value the *initially remaining project time*. Make sure that the *perceived time remaining* is larger than a quarter of a month: experience shows that such projects always have a time overrun of at least a week. Since the company you work for mainly implements projects of the same kind, permanent staff is mainly moved between projects which makes that the *time to adapt the workforce* is relatively short – about a month.

The *initially remaining project time* of such projects typically amounts to 40 months, and the *time to adjust the project schedule* to 1 month. The *perceived effort remaining* equals the *remaining project tasks* divided by the *perceived productivity*. Avoid dividing by zero. The *perceived productivity* corresponds to the *perceived cumulative progress* over the *cumulative effort delivered*. The *perceived cumulative progress* could in this first version of the model be assumed to be equal to the amount of *properly completed project tasks*. Suppose that –in spite of the saying 'a good beginning is half the task'– the *cumulative effort delivered* initially only amounts to 0.1%. The *cumulative effort delivered* increases by means of the *additional effort delivered* by the workforce, which therefore simply equals the *workforce*.

In order to ensure that the model simulates exactly as long as needed, you can represent the system variable *Final Time* as a shadow variable and change its argument into 'IF THEN ELSE(*perceived fraction completed* < 0.999, 200, *Time*). But before doing so, you need to set the *perceived fraction completed* to the *perceived cumulative progress* divided by the *initial number of project tasks*.

1. Make a SD simulation model based on the description above, and verify the model.
2. Use Months as Units for Time. Simulate the model and display the behavior: do you get almost linearly increasing behavior (actually S-shaped behavior) until completion in 41 months and half a week? If not verify your model.

Project Management II

Despite the timely completion of your project, the client appears to be very unhappy about the quality. After some inquiries you find out that that all former project clients are rather dissatisfied: either the quality is perceived to be poor, or there were enormous time and/or budget overruns. According to your client the quality of the completed project is not half of what he expected. From your own investigation it appears that only about half of the tasks are executed properly, and, perhaps even worse, severely defective tasks are not detected and are therefore not properly addressed. After reporting this to the Vice President Projects, you are instructed to use your SD skills to get to the bottom of it, more precisely to improve the Vice President's and your understanding of this largely invisible problem and to experiment in your virtual world (the model) in order to prevent future problems in the real world. You decide to add undiscovered rework to the model you made before (in Project Management I) and to test some strategies.

Start by adding a stock variable *undiscovered rework* to the model. Two flows connect this new stock to the stock of *remaining project tasks*: the *poor completion of project tasks* flow and the *detection of undiscovered rework* flow, i.e. inappropriately completed work. The *detection of undiscovered rework* depends on the number of *testing personnel* times the average *productivity of testing*.

Poor completion of project tasks goes hand in hand with *progress* proportional to (1- *fraction of properly completed*).The *project tasks that are properly completed* variable from the previous model version therefore needs to be updated to the *progress* times the *fraction properly completed* of about 50%. The *perceived cumulative progress* variable from the previous model version needs to be updated too: this variable now sums the *properly completed project tasks* and the *undiscovered rework*.

The *productivity of testing* equals the *fraction of undiscovered rework* times the *maximum productivity of testing* of 2 tasks per person per month. The *fraction undiscovered rework* is of course equal to *undiscovered rework* divided by *perceived cumulative progress*. Ensure that the denominator in the previous equation cannot be equal to zero.

Model the *reported fraction of detection of undiscovered rework* as the 3^{rd} order information delay of the *detection of undiscovered rework* over the sum of *project tasks that are properly completed* and *detection of undiscovered rework*, with a delay time of 1 month.

The amount of the *testing personnel* is equal to the *fraction of personnel for testing* multiplied by the total *workforce* assigned to the project. Model the *fraction of personnel for testing* (in view of adding later on an endogenous testing strategy) as an endogenous function of a model variable going through the following couples (0,0.1), (0.2,0.15), (0.4,0.3), (0.6,0.6), (0.8,0.75), and (1,0.8). As for now use a constant, more specifically 0.5, as argument of this function: which results in an assignment to testing of 45% of the workforce assigned to the project. Since testing personnel is selected from the total workforce, assigning personnel to testing of completed project tasks influences the number of employees assigned to project tasks. Update the variable *project personnel* accordingly.

A first key performance indicator (KPI) is of course the *Final Time* of the project. Add a second KPI to monitor the *average quality of completed project tasks*: this KPI could be defined as the *properly completed project tasks* divided by the sum of *properly completed project tasks* and *undiscovered rework*. Ensure the denominator cannot become zero.

3. Expand the SD model based on the description above and verify it.
4. Validate the model: list to appropriate validation tests (sensitivity analysis excluded), perform them, and conclude.
5. Simulate the model, save your results, and plot: (1) the *perceived cumulative progress* including the end of the projects; (2) the *average quality of completed project tasks* and the *cumulative effort delivered*; (3) and the *workforce*, *project personnel* and *testing personnel*. Draw in dotted lines or in pencil for the sake of comparison with the behavior of the first model on the corresponding indicators.
6. Interpret these graphs: what are the consequences of the testing on the quality and final time of such a project?
7. Make the variable *fraction of personnel for testing* truly endogenous, i.e. replace the constant by a model variable that is or could also be observed in the real world such that the variable becomes part of one or multiple feedback loops. Which input variable do you use? Why? Draw the consequences of your endogenous testing strategy (preferably in another color on the previous graph) for (1) the *perceived cumulative progress* including the end of the projects; (2) the *average quality of completed project tasks* and the *cumulative effort delivered*; (3) and the *workforce*, *project personnel* and *testing personnel*. What does it mean for such projects: Is this strategy an improvement?
8. Draw a strongly aggregated CLD of this model including your endogenous strategy.
9. Perform a sensitivity analysis in view of improving planning and managing such projects. Test the sensitivity of the model with your endogenous strategy for changes in following assumptions: the *gross productivity of project personnel* and the *fraction of personnel for testing*. Do it, briefly explain what you did, and conclude.
10. Managing extreme fluctuations in staff is always difficult. So it would be better to use a strategy that leads to less extreme workforce fluctuations. Propose a strategy for doing so, model it, and test it. What could be concluded?

18.15 Mineral/Metal Scarcity II

Introduction

Rare earth metals are necessary in ever bigger quantities for all sorts of innovative –mostly 'green'– technologies such as hybrid cars, flat screens, solar cells, led lamps, mobile phones, et cetera. But these metals are, as the name suggests, rare. Moreover, some countries such as China, which already have quasi-monopolies on the extraction of particular Rare Earths, are said to have constrained the export of these Rare Earths. These natural and artificial constraints may lead to temporary or/and structural scarcity, which in turn may hinder the transition of our society towards a more sustainable one...

Make a SD model about the dynamics of the extraction and scarcity of a particular –non-specified– rare metal, 'metal X', based on the following description, and simulate it from the year 2000 to 2050.

Extraction, Use and Recycling

Unextracted *reserves of metal X*, initially equal to 10000t, decrease through *extraction* with an extraction time of one year. *Extraction* increases the *supply of metal X*, initially equal to the *initial demand for metal X* from 400t per year, and *production of metal-X-containing products* decreases the *supply of metal X* stock after an average *production time of metal-X-containing products* of a year. That increases the *quantity of metal X in use*, initially equal to 3000t.

After an *average lifetime of metal X in use* of 10 years, part of this *quantity of metal X in use* is recycled and the rest is lost. This division depends on the *recycling fraction of metal X*. Initially, there is no metal X in recycling. The annual *recycling time of metal X* is one year and generates a *supply of recycled metal X* flow which increases the *supply of metal X* stock, and determines in turn –together with the *expected price driven demand for metal X*– the *desired extraction of metal X*. Desired extraction drives the *extraction*.

1. Make a preliminary SD simulation model of this issue. Use, if necessary, first-order delay structures.
2. Make a detailed CLD of the preliminary model. How many feedback loops are there?

Intrinsic demand, price driven demand, recycling demand, etc.

Suppose that the *expected intrinsic demand for metal X*, initially equal to 400t (see above), increases annually with an *expected percentage increase of the intrinsic demand for metal X* of 3% per year. Model the *expected price driven demand for metal X* as a first-order delay of a year –with as initial value the *expected initial demand for metal X*– of the following fraction:

$$\frac{expected\ intrinsic\ demand\ for\ metal X}{relative\ price\ metal\ X}.$$

The *supply shortage price effect* is a table function with as argument the *expected price driven demand for metal X* divided by the *production metal X containing products*. The *desired recycling of metal X* equals this *expected price driven demand for metal X* multiplied by the relative attractiveness of recycling versus extraction[5] plus the difference between the *desired extraction of metal X* and the real *extraction of metal X*.

[5] This relative attractiveness could be modeled as: $\frac{\frac{1}{relative\ recyclingcost\ of\ metal\ X}}{\frac{1}{relative\ exploitationcost\ of\ metal\ X}+\frac{1}{relative\ recyclingcost\ metal\ X}}$.

The *recycling fraction of metal X* is equal to the *fraction available of desired recycling of metal X* times the *desired recycling of metal X* divided by the *maximum recyclable quantity metal X*. The latter fraction is necessarily limited to a maximum of 100%. The *maximum recyclable quantity of metal X* equals the *quantity of metal X in use* which becomes available at the end of the *average lifetime of metal X in use* of 10 years. Suppose that the *fraction available of desired recycling of metal X* increases as follows: 10% in 2000, 50% in 2010, 80% in 2020, 89% in 2030, 90% in 2040 at which it stabilizes. The effective *fraction recycled supply of total supply* equals the *supply of recycled metal X* divided by the sum of the *extraction of metal X* and the *supply of recycled metal X*.

Suppose that the ***relative*** *recycling cost of metal X* decreases from 10 (i.e. 10 times the normal extraction cost) in 2000, to 2 in 2010, to 1 in 2020, to 0.9 in 2030 at which it stabilizes, and that the *relative exploitation cost of metal X* is a function of the *fraction of metal X reserves remaining* with values (0, 100), (0.05, 2.5), (0.1, 1.25), (0.15, 1.1), (0.2, 1), (0.25, 1). In other words, at a fraction of 5% the relative cost is 2.5 times as high as with a fraction of 20% or more. The *average cost of metal X* is then the weighted average of the *relative recycling cost of metal X* and the *relative exploitation cost of metal X*, proportional to the *fraction of recycled supply of total supply of metal X*. The *fraction of metal X reserves remaining* is of course equal to the *reserves of metal X* divided by the *initial reserves of metal X*.

Suppose now that the market functions such that the *relative price of metal X* equals the *relative cost of metal X* times the '*supply shortage price effect*'. Suppose that this *price effect* is a function of the demand/supply fraction, or here, of the *expected price driven demand for metal X* divided by the *production metal X containing products*, with values (0, 0.1), (1, 1), (1.5, 2), (2, 10), (5, 100). In other words, a demand/supply fraction of 5 leads to a price which is 100 times higher than usual.

Also make sure that there is not more extraction than there are non-extracted resources. And add a key performance indicator to monitor the *fraction metal X delivered of intrinsic demanded*, i.e. the *supply of metal X* divided by the *expected intrinsic demand for metal X*.

3. Extend the simulation model with the information above. Verify the model. Simulate the model and make graphs of the *expected price driven demand for metal X*, the *relative price of metal X*, the *reserves of metal X*, and the output indicator *fraction supplied of intrinsic demand for metal X*.
4. Validate the model. List 2 validation tests, perform them and describe the results (briefly).
5. Test the sensitivity of the *fraction delivered of intrinsic demand for metal X* and the *reserves of metal X* for (small) changes in following functions and parameters: the *supply shortage price effect*, the *initial reserves of metal X*, and the *fraction available of desired recycling of metal X*. Describe briefly the tests you performed, your results, and conclusions.
6. Make an extremely aggregated CLD of the model which allows you to explain the main feedback loop effects. And use the CLD to explain the link between structure and behavior (more specifically of the key performance indicator).

Strategic and speculative reserves

Some argue that strategic and speculative reserves may help. Others argue that strategic and speculative reserves add to the problem, especially if strategic and speculative reserves strategies are not countercyclic or if these strategic and speculative reserves are being built by states that already have a quasi-monopoly on the exploitation.

⚡ Extend the model with a submodel dealing with strategic reserves (for national use, which means they are not available on the world market). Simulate the model and plot the difference in behavior.

⚠ Extend the model with a submodel dealing with speculative reserves (temporarily unavailable on the market to be sold later for a higher price on the market). Simulate the model and sketch the difference in behavior. Is building strategic and speculative reserves a good idea?

18.16 Energy Transition Management

Introduction

And although many conceptual transition models exist, there is a need for useful simulation models to simulate plausible transition dynamics. The Ministry of Economic Affairs therefore asks you to make a series of SD models concerning the long-term dynamics of the electricity generation, from the year 2010 until the year 2100. The dynamics of the installed generation capacity is important for the transition because electric power plants have a long lifetime of some 30 to 40 years.

'Grey' development

Suppose, at first, that there is just one 'regime technology' –technology T1– which is a rather polluting non-renewable technology. The *installed capacity of T1*, initially equal to 15000MW, increases through *commissioning of capacity T1* and decreases through *decommissioning of capacity T1*. Newly *planned capacity T1* –initially equal to 700MW– needs to be built before it can be commissioned: the *capacity under construction T1* initially amounts to 700MW and the *average construction time of T1* is equal to 1 year. The newly *planned capacity T1* is non-negative and equals the *desired fraction of new capacity T1* of the total *new capacity to be installed*. Suppose for the sake of simplicity that the *new capacity to be installed* is equal to the difference between the *expected capacity required* (of all types – although currently it is assumed that only one type exists) and the *total installed capacity* (idem). The *desired fraction of new capacity T1* amounts of course to 100% since there is only this technology T1 in this subsection. Hence, the *total installed capacity* consists only of *installed capacity* of technology *T1*. Assume that the *planning period* for planning *new capacity to be installed* amounts to one year. Suppose that the *expected capacity required* increases from 15700MW in the year 2010 to 45000MW in the year 2100.

1. Make a SD simulation model of the description above.
2. Make a detailed CLD and a highly aggregated CLD of this model.

Learning effects

Even old technologies like technology T1 keep on descending their learning curves, which makes that the marginal investment costs keep on decreasing further –although slower than in case of newer technologies. Learning curves can be written mathematically as:

$$C_t = C_{t-1}\Big(\frac{X_t}{X_{t-1}}\Big)^e$$

C_t stands for the investment cost per MW at time t, X_t for the cumulative historic capacity (in other words, all ever constructed capacity of that technology), and e for the learning curve parameter.

This learning curve can be included –somewhat artificially– into a SD model: add a stock variable *marginal cost of new capacity T1* with an initial value equal to €1.000.000 per MW. This stock variable has an outflow variable *marginal cost of new capacity T1 of the previous year* equal to the stock variable, and an inflow variable *marginal cost of capacity T1* equal to the *marginal cost of new capacity T1 of the previous year* multiplied by

$$\left(\frac{cumulative\ ever\ installed\ capacity\ T1}{cumulative\ ever\ installed\ capacity\ previous\ year\ T1}\right)^{-learningcurve\ parameter\ T1}$$

The *learning curve parameter T1* equals $-log_2(progressratioT1)$. Suppose that the *progress ratio* of technology T1 is 90%, which means that each doubling of the *cumulatively ever installed capacity* leads to a cost reduction of 10%. This *cumulatively ever installed capacity T1* equals the sum of the *installed capacity of T1* and the *cumulatively decommissioned capacity T1* of 10.000.000 MW. The value of the latter stock variable increases through the corresponding flow variable *decommissioned capacity T1* through which the *installed capacity* of this technology is decommissioned after an average *lifetime* of 30 years.

3. Add the learning curve construction to the simulation model. Verify the model briefly.
4. Simulate the model and make a graph of the *marginal cost of new capacity T1*.

Development with a sustainable alternative

Add an alternative 'sustainable' technology (T2) to the model. Almost the same structure as used above can be used for that purpose. The main differences relate to the initial values: *initial capacity T2* = 3MW; *initial capacity under construction T2* = 1MW; *initial cumulative decommissioned capacity T2* = 10MW; *progress ratio T2* = 0.8; en *initial marginal cost new capacity T2* = €8.000.000 per MW.

Not to be copied, but requiring adaptations, are common and/or interface variables such as the *total installed capacity*, the *new capacity to be installed*, and the *expected capacity required*.

Suppose furthermore that the *desired fraction of new capacity T1* now becomes (100% - *desired fraction new capacity T2*). This fraction –like similar fractions– lies between 0 and 1. Set the *desired fraction of new capacity T2* equal to:

$$\frac{1/marginal\ cost\ new\ capacity\ T2}{1/marginal\ cost\ new\ capacity\ T1 + 1/marginal\ cost\ new\ capacity\ T2}.$$

Finally add an important output indicator: the *sustainable fraction of the total installed capacity*.

5. Extend the simulation model.
6. Simulate it. Make graphs of the *marginal cost of the new capacities of T1* and *T2* and a graph of the *sustainable fraction of the total installed capacity*. From which year on is more than half of the installed capacity 'sustainable'?
7. Explain how this structure generates this behavior.
8. Test the sensitivity of the model for changes in the learning curve parameters. Explain what could be concluded from these sensitivity tests.
9. A continued linear demand growth such as described above is rather unrealistic. Suppose that the demand for generation capacity develops as follows: 15700MW in 2010, 22000MW in 2020, 19500MW in 2030, 25000MW in 2040, 27000MW in 2050, 34000MW in 2060, 30000MW in 2070, 40000MW in 2080, 46000MW in 2090, and 45000MW in 2100. Does the *sustainable fraction of the total installed capacity* change much? And the *newly planned capacities*? Explain using the graphs.

With more sustainable alternatives and uncertainty

Now it is up to you to investigate whether the overall outcomes change if there are several sustainable technologies instead of just one. . .

- Suppose that there are two sustainable technologies, 'T2' and 'T3' instead of just 'T2'. Suppose –in order to make a decent comparison with the dynamics of the previous version of the model– that both sustainable technologies have identical characteristics and each only 1.5MW installed capacity and 0.5MW capacity under construction. Model and simulate this new system. Are there major differences in terms of the *sustainable fraction of the total installed capacity*?
- Suppose that there is a difference between the two sustainable technologies: one of them has a *progress ratio* of 0.75 and the other of 0.85. What can be concluded now concerning the *sustainable fraction of the total installed capacity*?
- Now add some more uncertainty – alternatives may seem promising now, but may not live up to the expectations. Analyze the investment decision under uncertainty: what investment strategy do you recommend concentration or spreading?

18.17 Fighting HIC across Multiple Districts

Introduction

Since you already developed a generic SD model with regard to burglaries in the Netherlands and a SD model with regard to the 'waterbed effect' between burglaries and robberies in a particular police precinct, you are now asked to make a SD simulation model with regard to the burglary 'waterbed effect' between different districts. Alter all, 'waterbed effects' between burglaries (and robberies) in different districts are known to exist too. Use the following information to build your model. First model district 1 and burglaries in district 1. Use –as in the text below– the label 'district 1' for all district-specific variables, but not for non-district-specific variables, and don't use shadow variables (in order to make copy-pasting much easier in the second part).

First district 1

District 1 consists of *protected houses in district 1* –initially equal to the *total number of houses in district 1* of 5000 houses times the *initial fraction of protected houses in district 1* which amounts to 3%– and *unprotected houses in district 1* –initially equal to the rest of the houses in that district. Suppose for the sake of simplicity that the total number of houses in this and other districts in this region will remain constant over the next 10 years. Set the *percentage CSSL in district 1* (CSSL stands for Certificate Safe and Secure Living – 'Keurmerk Veilig Wonen' in Dutch) for the sake of simplicity equal to the number of well-*protected houses in district 1* divided by the *total number of houses in district 1* times 100 (to express it as a percentage instead of a fraction).

Unprotected houses in district 1 become protected houses through investments in the *installation of security systems in district 1*. These investments in security systems and measures in district 1 consist on the one hand of an autonomous component (not influenced by recent burglaries) and of a burglary dependent component on the other hand. Set the *installation of security systems in district 1* therefore equal to the product of *unprotected houses in district 1*, the *average* *autonomous security investment ratio* of 1%, and the *relative purchasing power and loot in district 1* of 100% (i.e. this is an average district in terms of spending power) plus the 3^{rd} order delay of the product of the *burglaries in houses in district 1*, the *burglary awareness in district 1*, and the *relative purchasing power and loot in district 1*, with a delay time of $1/8^{th}$ of a year.

The *burglary awareness in district 1* could be modeled as the *effect of recent burglaries on burglary awareness* with as argument the *fraction of houses with a recent burglary in district 1*. Suppose someone estimated the *effect of recent burglaries op the burglary awareness* to be 20% for 0% of the houses broken into per year, 25% for 1% of the houses broken into per year, 50% for 3% of the houses broken into per year, 75% for 6% of the houses broken into per year, 100% for 12% of the houses broken into per year, 200% for 24% of the houses broken into per year, and 10000% for 100% of the houses broken into per year. The *fraction of houses with a recent burglary in district 1* equals the *number of recent burglaries in district 1* divided by the *total number of houses in district 1*. The *number of recent burglaries in district 1* is in fact the collective memory of recent burglaries and could be modeled as the first order delay of *burglaries in houses in district 1* with an '*average memory*' of 2 years, and an initial value of 175. The number of *burglaries in houses in district 1* could be approximated by the product of the *average chance of burglary in the region* of 3% of the houses per year, the *relative burglary attractiveness of a house in district 1*, the *total number of houses in district 1*, and the *seasonality of burglaries*. Model the *seasonality of burglaries* continuously such that it is 50% higher than average at the beginning of January, and 50% lower than average at the beginning of July.

The *relative burglary attractiveness of a house in district 1* is equal to the *burglary attractiveness of a house in district 1* divided by the *average burglary attractiveness in the region*. Set the *average burglary attractiveness in the region* for the moment equal to the weighted average: $(burglary\ attractiveness\ of\ a\ house\ in\ district\ 1 * total\ number\ of\ houses\ in\ district\ 1 + total\ number\ of\ houses\ in\ all\ other\ districts * burglary\ attractiveness\ of\ houses\ in\ all\ other\ districts)/(total\ number\ of\ houses\ in\ district\ 1 + total\ number\ of\ houses\ in\ all\ other\ districts)$, with about 200000 *houses in all other districts* of the region and an average *burglary attractiveness of houses in all districts* of 10.

The *burglary attractiveness of a house in district 1* is directly proportional to the *relative purchasing power and loot in district 1*, with the *fraction of houses with opportunities for burglary in district 1* and with the *familiarity of criminals with district 1* of –in case of 'normal' district 1– 100%, and inversely proportional to the *chance of arrest of a burglary in district 1*. The *fraction of houses with opportunities for burglary in district 1* corresponds to the number of *houses with opportunities for burglary in district 1* over the total *number of houses in district 1*. And the *chance of arrest of a burglary in district 1* corresponds to a first order material delay of the product of the *normal chance of being caught for burglary* of 8% and (0.5 + *burglary awareness in district 1*), with a delay time of $1/8^{th}$ of a year.

The number of *houses with opportunities for burglary in district 1* is equal to the sum of the *unprotected houses in district 1* and the share of behaviorally ill-protected protected houses, i.e. the number of *protected houses in district 1* times the *behavior induced burglary prone fraction of protected houses in district 1*. Set the *behavior induced burglary prone fraction of protected houses in district 1* equal to $(1 - normal\ burglary\ preventive\ behavior) * (1 - burglary\ awareness\ in\ district\ 1)$, knowing that this fraction should always be between 0 and 1. Assume the *normal burglary preventive behavior* of the average Dutch family with a protected house is about 50%.

Protected houses become unprotected houses after a while through *obsolescence of security systems in district 1*. Assume obsolescence follows a first order delay of the other flow, i.e. the *installation of security systems in district 1* (see infra), with an *obsolescence time of security systems* of 10 year.

1. Build a model based on the description above.

. . . then district 2. . .

Add a second district. Advanced users may want to add subscripts/arrays. For Vensim, follow the procedure below to quickly add a second district if the names of your variables were well chosen and shadow variables were not used (i.e. exactly as suggested above).

- Use the shadow variable tool <var> to change all variables and parameters that are not specific for a district and that do not end in 'district 1' into shadow variables.
- Select all variables (Ctrl+A), copy all selected variables (Ctrl+C), paste all copied variables (Ctrl+V), choose the option 'Replicate' and add a 'Suffix': **2**, click on OK, and drag the copied variables to a pristine area. All variables –with the exception of shadow variables– are now copied and added as new global variables with suffix 'district 12'. You do not need to change 'district 12' to 'district 2'.
- Shadow variables were copied without adding new global variables. Select the shadow variable *average burglary attractiveness in the region*, turn it into a normal variable with the Model Variable button (next to the Shadow variable button). Change the formula of the *average burglary attractiveness in the region*, i.e. add district 2 to the formula.
- Adapt the values of the following district specific parameters and initials for district 2:
  - *initial fraction of protected houses in district 2* = 6%
  - *total number of houses in district 2* = 1000
  - *relative purchasing power and loot in district 2* = 200%
  - *familiarity of criminals with district 2* = 25%
  - the initial value of *number of recent burglaries in district 2* = 20

2. Follow the procedure outlined above. Save your model as 'model2'. And verify the model.
3. Simulate the model and draw the behavior of following indicators in three graphs: (i) the *percentage CSSL in district 1* and the *percentage CSSL in district 2*, (ii) the *fraction of houses with a recent burglary in district 1* and the *fraction of houses with a recent burglary in district 2*, and (iii) the *fraction of houses with opportunities for burglary in district 1* and the *fraction of houses with opportunities for burglary in district 2*
4. Interpret and compare the basecase dynamics of the normal spending power districts and the above-normal spending power districts. What are the relatively fewer burglaries in district 2 caused by?
5. Validate the model.
6. Draw a highly aggregated CLD of this model that allows you to explain the waterbed-effect between districts. And do that: explain the waterbed-effect using your CLD.

. . . to test the effectiveness of interventions

This model is meant to be a submodel of a larger model (see case 22.5). But before merging this submodel with other models on page 298), it may be interesting to identify highly effective interventions using this submodel.

7. Perform a minimum of 2 sensitivity analyses in view of identifying effective interventions. Explain what you do and conclude.

8. Design (preferably based on your answer to the previous question) a policy that significantly reduces the number of burglaries in a single district from the middle of the first simulation year on. Model the intervention, test it, draw the resulting dynamics of the burglaries in *both* districts. Interpret and explain the effects.

9. Design (preferably based on your answer to the previous two questions) an intervention that significantly reduces the number of burglaries from the middle of the first simulation year on in *both* districts. Model the intervention, test it, draw the resulting dynamics of the burglaries in *both* districts. Explain.

10. Is the *seasonality of burglaries* important for your recommendation based upon this sub-model? Test, conclude, and explain what you did.

⚡ Test the effectiveness of this policy under deep uncertainty? Interpret and explain.

18.18 Antibiotic Resistance

Antibiotic resistance is a major public health risk. Major causes are excessive prescription, excessive over-the-counter use, and excessive use of antibiotics in the livestock industry. Antibiotic resistance is also studied with SD. Homer et al. (2000) published for example a paper in the System Dynamics Review about resistance to beta-lactam antibiotics focused on pneumococcal infections. Beta-lactams –named after the β-lactam ring in their molecular structure– are a broad class of antibiotics including penicillin derivatives (penams), cephalosporins (cephems), monobactams, and carbapenems. In this case, one needs to build the model developed and used by Homer et al. (2000) in order to replicate their analyses.

To Do

1. Download the artible by Homer et al. (2000) and read it (link to the SDR article).

2. Either replicate their model based on the mathematical equations in the paper or based on the case description below. Both approaches should lead to the same model. The names of the variables in the original model are used below.

Bug Population

Suppose bugs can either be highly resistant (HR), or intermediately resistant (IR), or susceptible (S). Model the *HR bugs* as the integral of *net proliferation of HR bugs*. Express the units of *HR bugs* in 'percent of niche'. The initial value of the *HR bugs* variable is the product of the *total bugs initial* and the *initial percentage of HR bugs* divided by 100. The *total bugs initial* of this type is 70 percent of the niche. And the *initial percentage of HR bugs* is 0 percent. In other words, initially there are no HR bugs. *Net proliferation of HR bugs* with units 'percent of niche per year', is the sum of two effects: *IR to HR mutation* and the proliferation of highly resistant bugs, i.e. *HR bugs* times the *HR bug net proliferation rate*. Homer et al. (2000) calculate the *HR bug net proliferation rate* as the multiplicative effect of the *bug elimination rate* and (*HR proliferation ratio*-1). The dimension is 'fraction per year'. And they calculate *IR to HR mutation* as the amount of *IR bugs* times the *IR to HR mutation rate* of 0.25% per year.

The intermediately resistant bugs submodel is similar to the highly resistant bugs submodel. Model the *IR bugs* as the integral of *net proliferation of IR bugs* with as initial value the product of the *total bugs initial* and the *initial percentage of IR bugs* of 1.5 percent divided by 100. *Net proliferation of IR bugs* is equal to the sum of *S to IR mutation* and net proliferation of IR bugs, i.e. *IR bugs* times the *IR bug net proliferation rate*, with the *IR bug net proliferation rate* equal to the product of the *bug elimination rate* and (*IR proliferation ratio*-1). Homer et al. (2000) calculate *S to IR mutation* as the amount of *S bugs* times the *S to IR mutation rate* of 0.05% per year.

The susceptible bugs (S bugs) submodel could then be modeled as rest category. Model the stock of *S bugs* as the integral of *net proliferation of S bugs*, with units 'percent of niche' and initial value the *total bugs initial* minus the *IR bugs* minus the *HR bugs*. *Net proliferation of S bugs* is equal to the amount of *S bugs* times the *S bug net proliferation rate*, but does not include a mutation term. And the *S bug net proliferation rate* can be calculated as the *bug elimination rate* times (*S proliferation ratio*-1).

Proliferation

The model will be simulated in years although much happens on a daily time scale. The *bug elimination rate* then becomes 365/*bug elimination days*, with bugs being eliminated on average after 36 days.

In this model, the *HR proliferation ratio* is calculated as the product of the *maximum HR proliferation ratio* of 1.151, the *effect of niche saturation*, the *effect of AB on HR proliferation*, the *effect of distribution on resist proliferation*, and the *effect of distribution on HR proliferation*. The *effect of distribution on HR proliferation* is a function of the *HR pct of bugs* connecting the couples: (0,1), (5,1), (10,1), (15,0.96), (20,0.92), (25,0.88), (30,0.85), (35,0.82), (40,0.8), (45,0.78), and (50,0.76). The *HR pct of bugs* is equal to *HR bugs* divided by *total bugs* * 100. The *effect of niche saturation* is a function of *total bugs* going through the couples: (0,1), (10,0.997), (20,0.992), (30,0.986), (40,0.977), (50,0.963), (60,0.941), (70,0.901), (80,0.821), (90,0.625), and (100,0). This table function corresponds to $Y = (1 - e^{(-3*(100-X)/100)})/(1 - e^{-3})$. Model the *effect of AB on HR proliferation* as:

$$(1 - Inhibition\ of\ HR\ proliferation\ at\ 200\ Rxs\ per\ 1000)^{(AB\ Rxs\ per\ 1000\ popn/200)}$$

with an *inhibition of HR proliferation at 200 Rxs per 1000* of 0.004. Model *AB Rxs per 1000 popn* as a LOOKUP BACKWARD(AB Rxs per 1000 popn series, Time) with following *AB Rxs per 1000 popn series*: (1980,211.9), (1985,212.1), (1988,238), (1989,264.4), (1990,257.3), (1991,233.7), (1992,302.7), (1993,227.4), (1994,216.4), (1995,230.3), (1996,200.8), (1997,168.5), (1998,160.1), (1999,190), (2000,190), and (2001,190). The LOOKUP BACKWARD function allows one to control the interpolation mode of a lookup table so that the previous y value is held between x values instead of interpolated. And model the *effect of distribution on resist proliferation* as a function of the *resistant pct of bugs* connecting the couples: (0,1), (10,1), (20,1), (30,1), (40,1), (50,0.98), (60,0.96), (70,0.94), (80,0.92), (90,0.9), (100,0.88).

The *IR proliferation ratio* is the product of the *maximum IR proliferation ratio* of 1.159, the *effect of niche saturation*, the *effect of AB on IR proliferation*, and the *effect of distribution on resist proliferation*. Calculate the *effect of AB on IR proliferation* as:

$$(1 - inhibition\ of\ IR\ proliferation\ at\ 200\ Rxs\ per\ 1000)^{(AB\ Rxs\ per\ 1000\ popn/200)}$$

And the *S proliferation ratio* is the product of the *maximum S proliferation ratio* of 1.23, the *effect of niche saturation*, and the *effect of AB on S proliferation*. Calculate the *effect of AB on S proliferation* as:

$$(1 - inhibition\ of\ S\ proliferation\ at\ 200\ Rxs\ per\ 1000)^{(AB\ Rxs\ per\ 1000\ popn/200)}$$

Set the *inhibition of IR proliferation at 200 Rxs per 1000* equal to 0.03 and the *inhibition of S proliferation at 200 Rxs per 1000* to 0.09.

Historic Data

This subsection contains the historic data used by Homer et al. (2000). To include it in the model, first add a variable *Year* which is *Time - TIME STEP*.

Include following information regarding the situation in the USA: The *HR pct of resistant bugs USA* is 100 * *HR pct of bugs USA/Resistant pct of bugs USA* and is zero if dividing by zero. Model the *resistant pct of bugs USA* as: LOOKUP BACKWARD(*Resistant pct of bugs USA series*, *Year*) with following *resistant pct of bugs USA series*: (1979, 1.8), (1980, 1.5), (1981, 5.8), (1982, 4), (1983, 5), (1984, 1.8), (1985, 4), (1986, 5.3), (1987, 3), (1992, 6.5), (1993, 13.8), (1994, 14.5), (1995, 23.6), (1997, 25), (1998, 27). Model the *HR pct of bugs USA* as: LOOKUP BACKWARD(*HR pct of bugs USA series*, *Year*) with following *HR pct of bugs USA series*: (1979, 0), (1980, 0), (1981, 0), (1982, 0), (1983, 0), (1984, 0), (1985, 0), (1986, 0), (1987, 0), (1992, 1.3), (1993, 3), (1994, 3.5), (1995, 9.5), (1998, 13).

Include following information regarding the situation in Spain: *HR pct of resistant bugs Spain* is 100 * *HR pct of bugs Spain/resistant pct of bugs Spain* and is zero if dividing by zero. The *resistant pct of bugs Spain* is a LOOKUP BACKWARD(*resistant pct of bugs Spain series*, *Year*) with following *resistant pct of bugs Spain series*: (1979, 6), (1980, 15.8), (1981, 12.7), (1982, 7.5), (1983, 22.6), (1984, 24.4), (1985, 20.7), (1986, 26.8), (1987, 31.5), (1988, 36.7), (1989, 44.3), (1990, 39), (1991, 36), (1992, 35), (1993, 40), (1994, 40), (1995, 44), (1996, 42). Model the *HR pct of bugs Spain* as: LOOKUP BACKWARD(*HR pct of bugs Spain series*, *Year*) with following *HR pct of bugs Spain series*: (1979, 0), (1980, 1), (1981, 0), (1982, 0), (1983, 0), (1984, 5), (1985, 9.6), (1986, 15.8), (1987, 14.2), (1988, 12.8), (1989, 15.4).

And include following information regarding the situation in Hungary and South Africa: *Resistant pct of bugs Hungary* is a LOOKUP BACKWARD(*resistant pct of bugs Hungary series*, *Year*) with following *resistant pct of bugs Hungary series*: (1975, 21), (1976, 30), (1977, 25), (1978, 33), (1979, 37), (1980, 45), (1981, 51), (1982, 38), (1983, 33), (1984, 28), (1985, 46), (1986, 48), (1987, 47), (1988, 42), (1989, 51), and (1990, 46). *Resistant pct of bugs SAfrica* is a LOOKUP BACKWARD(*resistant pct of bugs SAfrica series*, *Year*) with following *resistant pct of bugs SAfrica series*: (1979, 4.9), (1980, 5.3), (1981, 7.2), (1982, 5.6), (1983, 8.5), (1984, 5.7), (1985, 10.6), (1986, 14.1), (1987, 10.1), (1988, 7.9), (1989, 16.3), (1990, 14.1).

Key Performance Indicators

Finally add following key performance indicators. The *S pct of bugs* is equal to 100 * *S bugs/total bugs*. The *IR pct of bugs* is equal to 100 * *IR bugs/total bugs*. The *HR pct of resistant bugs* is equal to 100 * *HR pct of bugs/resistant pct of bugs*, but is zero if dividing by zero. The *resistant pct of bugs* is the sum of the *IR pct of bugs* and the *HR pct of bugs*. And *total bugs* is the sum of *S bugs*, *IR bugs* and *HR bugs*.

Questions

3. Verify the model using the description (if you used the equations) or equations from the paper (if you based your model on the case description).

4. Then use the model to replicate the study described in the paper. Simulate the model from 1979–2030 with Euler and a time step of 0.0625. Are you able to fully replicate this study and the results? If not, make additional assumptions.

5. Update the model and data with more recent information. Is the model still useful? Do the conclusions change in the light of more recent information? What are your main conclusions? What would your advise be based on this study?

⚡ Extend the model to multi-resistance to mulltiple classes of antibiotics.

18.19 Globalization & Liberalization

This case is based on the Globalization model originally developed by Hartmut Bossel (2007c, Z608) (follow this link to the zip file containing all Zoo models). In this case, 2 countries are modeled. The countries are structurally similar but differ in key values. First, country I is modeled. Adding the suffix *cI* to all country I variables will make copy-pasting country II much easier. That is, copy-paste (replicate with suffix I) will automatically relabel all country II variables to variables with suffix *cII*. Then trade barriers between the countries are suddenly lifted at globalization, at time = 10. Values in this model are relative values, e.g. all state variables are standardized to 1.

Country I

In country I, *production capacity cI*, initially equal to 100%, is increased through *investments cI* and decreased through *depreciation cI*. Suppose the latter variable is equal to a 5% *depreciation rate cI* times the *production capacity cI*. Model the *investments cI* as the product of a 10% *investment rate cI*, the *production capacity cI*, and the *investment function cI*, if and only if the *surplus cI* is negative, else as equal to 0. Assume the *investment function cI* is equal to 2 before globalization and to an *investment factor cI* afterwards. Set the *investment factor cI* to 2 too.

The *surplus cI* is defined as the *supply cI* minus the *demand for products from cI*. Assume all production capacity is used at the full 100%, i.e. *supply cI* is equal to the *production capacity cI* times a 100% *production rate cI*. The *demand for products from cI* is the sum of the domestic demand which is the *percentage purchased by cI from cI* times the *market volume cI* of 100% and the foreign demand which is the *market volume* ***cII*** of 100% times (1 - *percentage purchased by* ***cII*** *from* ***cII***). Suppose the *percentage purchased by cI from cI* is a function of the *price ratio of domestic versus imported products in cI*, i.e. *price of cI products in cI / price of cII products in cI*, such that the *percentage purchased by cI from cI* is 1 if the price ratio is 0, the *percentage purchased by cI from cI* is 1 if the price ratio is 0.5, the *percentage purchased by cI from cI* is 0.5 if the price ratio is 1, the *percentage purchased by cI from cI* is 0 if the price ratio is 1.5, the *percentage purchased by cI from cI* is 0 if the price ratio is 2, and the *percentage purchased by cI from cI* is 0 if the price ratio is 5.

Suppose the market in country I is so competitive that the *product price cI* equals the *product costs* times (1 + the *tax rate* of 20%). The *product costs cI* are the sum of the *resource costs cI* of 100% and the *production costs cI* which, in turn, are equal to the *standards of cI* times the *standard factor cI* of 100%. Model the *standards of cI* with a stock variable, initially equal to 1, which increases through *progress cI* and decreases through *deterioration cI*. *Deterioration cI* is proportional to the *standards of cI* with a *deterioration rate cI* of 5% per year. *Progress cI* could be modeled as the product of *standards of cI*, *investment in progress cI*, and (1 - *product price cI/reference price cI*), with a *reference price cI* of 5. Suppose *investment in progress cI* is equal to the amount of *investments cI* times a *progress function cI*. Model the *progress function cI* such that it is 2 until month 10 and equal to the *progress factor cI* thereafter. Set the *progress factor cI* for the moment to 2.

The *price of cII products in cI* is equal to the *product price* ***cII*** times (1 - *subsidy* ***cII*** + *customs duties raised by cI*). Assume the *subsidy cI* falls from 75% to 0% and the *customs duties raised by cI* from 50% to 0% at globalization.

> 1. Model country I.

Country II

2. Model country II: Copy-paste (replicate) the previous submodel with suffix I. That will automatically relabel all country II variables to variables with suffix cII. And make the following changes.

Assume that country II never had export subsidies, i.e. *subsidy cII* is zero, nor imposed customs duties. And assume that the initial *standards of cII* and *production capacity cII* were equal to 0.1. Mirroring the situation in country I, *demand for products from cII* is equal to the *percentage purchased by cII from cII* times the *market volume cII* plus *market volume **cI*** times (1 - *purchase decision **cI***). Similarly, the *price of cI products in cII* is equal to *product price **cI*** times (1 - *subsidy **cI*** + *customs duties raised by cII*). Suppose the *progress function cII* rises at globalization from 1 to 2 and the *investment function cII* from 0.2 to 2.

3. Verify and validate the model. Explain what you do and why.
4. Simulate the model over a period of 50 years. Plot the effects on *production capacity* and *standards* for both countries.
5. At time 10, trade is liberalized. What happens subsequently in both countries. Explain.
6. Make a CLD of the model. Use it to explain the link between structure and behavior.
7. Perform sensitivity analyses, both manual and automated: explain what you do and why. Conclude.
8. Perform uncertainty analyses, both manual and automated: explain what you do and why. Conclude.
9. Link the state space diagram from Bossel (2007a, Z115) to this model, rename it, and analyze the effects of different initial conditions of country I. What could be concluded based on your model-based analysis about the effects of dis/similar initial conditions between countries that plan to liberalize their trade relations?

⚡ Solve questions 2-5 from (Bossel 2007c, Z608 p136-137).

18.20 Higher Education Stimuli

Introduction

A mass demonstration was organized on 21 January 2011 –a few days after the SD exam– in order to demonstrate against proposed legislation to fine 'slow students' and universities with slow students. My TU Delft students –who are bright but also slow according to the definition of 'slow students'– were asked to model the potential consequences for our faculty based on the description below.

The BSc Student

First, model the inflow of BSc students. There is an *annual BSc inflow* in the BSc studies at the *BSc inflow moment*. Suppose for reasons of simplicity that there is 1 inflow moment per year. Use a PULSE TRAIN(start, width, tbetween, end) with a *width* equal to the *time step*: model the normal *annual BSc inflow* as the *normal evolution of the new BSc inflow* divided by the *time step* times the *BSc inflow moment*. Suppose that the *normal evolution of the new BSc inflow* gradually increased from 20 new BSc students when the faculty was founded in 1990 to 90 new BSc students in 1995 to 120 new BSc students in 2000 to 130 new BSc students in 2008 to 200 new BSc students in 2010 and to 250 BSc students in 2014 and that it is believed to stabilize at 250 until the year 2030. The *real inflow of BSc students* is then the product of the *annual BSc inflow* and the *quality* (the lower the quality, the lower the real inflow will be). For now, set the *quality* equal to 100%.

The real inflow of BSc students is added to the group of *BSc students*. The group of *BSc students* decreases through the *outflow BSc students* when/if students obtain their BSc or as *BSc quitters*. Model the outflow of *BSc quitters* simplistically (but not entirely correctly) as the *fraction of BSc quitters* times the *BSc outflow after the fixed and additional study time*. Suppose that 30% of the students quits the first year, 10% the second year, and 5% the third year. The *fraction of BSc quitters* –always between 0 and 1– is then the sum of these fractions divided by the *quality* (the lower the quality of the studies, the more quitters). Those who do not drop, obtain their BSc diploma, eventually. The *outflow of BSc students* then equals the *BSc outflow after fixed and additional study time* multiplied by the complement of the *fraction of BSc quitters*. Model the *BSc outflow after fixed and additional study time* as the first order delay of the '*BSc outflow without additional study time*' with a total delay time equal to the product of the *minimum BSc study time* of 3 years and the *additional annual BSc study time* of (on average) 50% divided by the *quality*. And model the variable '*BSc outflow without additional study time*' as the delay of the *inflow of BSc students* with a fixed *minimum BSc study time* of exactly 3 years.

1. Make a SD model of the description above.
2. Make a complete CLD and a strongly aggregated CLD of this partial simulation model.

The MSc Student

Now, model the throughput of MSc students: almost the same applies to MSc students as to BSc students. Following details are different: The *real inflow of MSc students* equals the *quality* of the education times the sum of the *annual MSc inflow of new MSc students* (not flowing semi-automatically from the BSc studies) and the product of the *outflow of BSc students* and the *fraction of* BSc students that flow semi-automatically from the *BSc to the MSc* program. The *evolution of the new MSc inflow* was 0 students per year until 2007, started with 2 students per year in 2008, rose to 5 students per year in 2010, and is assumed to grow to 15 students per year in 2015 and 20 in 2020 after which it is assumed to remain constant. The *fraction of* students that flow semi-automatically from the *BSc to the MSc* program was about 100% before the year 2008 – suppose that it fell to 80% of the students in 2008 and afterwards. The *minimum MSc study time* is equal to 2 years. And the *fraction of MSc quitters* –always between 0 and 1– is lower too: 10% in the first year and 10% in the second year. In summary: the structure of the MSc students submodel is the same as the BSc students submodel – a hand full of new MSc students is absorbed by a larger –but decreasing– group of students flowing semi-automatically from the BSc to the MSc program.

3. Extend the SD model with the description above.

The Faculty

The *quality* is a function of the *professor hours per student*: if the number of *professor hours per student* is 0 hours per student per year then the *quality* is 10%, if it is 50 hours per student per year then the *quality* is 60%, if it is 100 hours per student per year then the *quality* is 90%, if it is 150 hours per student per year or more then the *quality* is 100%.

Model the *professor hours per student* as a 3^{rd} order delay with one year of the product of 1000 hours per professor and the number of *professors* divided by the *total number of students*. Make sure in the previous formula that the denominator cannot become 0.

Model the number of *professors* –initially 5 in 1990– and the increase and decrease of the number of *professors* in a rather simplistic way: suppose that *net hiring of professors* equals the difference between the *maximum number of professors* and the number of *professors*, divided by the average net *hiring time*. The *hiring time* (and firing time) for professors is rather long – on average 2 years from the moment a new professor is needed. The *maximum number of professors* then equals the *amount of money available for education* divided by the *average professor salary* of €100000 per professor per year.

The *amount of money available for education* –initially 0– increases through the *inflow of money available for education* and decreases through the *outflow of money available for education*. Without a fine for slow students, the *outflow of money available for education* approximately amounts to the number of *professors* times the *average professor salary*.

The *fraction of slow students* seems to be –at least partly– a function of the *quality* of the education: if the *quality* is 0% then the *fraction of slow students* is 90%, if the *quality* is 25% then the fraction is equal to 85%, if the *quality* is 50% then the fraction is equal to 66%, if the *quality* is 75% then the fraction is equal to 40%, and if the *quality* is equal to 100% then the fraction is equal to 25%.

The *inflow of money available for education* equals the *subsidy per new BSc student* times the *inflow of BSc students* plus the *subsidy per BSc graduate* times the *outflow BSc students* plus the *subsidy per new MSc student* times the *inflow of MSc students* plus the *subsidy per MSc graduate* times the *outflow of MSc students* plus the *annual lump sum and other subsidies*. The *subsidy per new BSc student* amounts to €15000, the *subsidy per BSc graduate* €5000, the *subsidy per new MSc student* €5000, and the *subsidy per MSc graduate* €5000. Suppose that the *annual lump sum and other subsidies for educational purposes* amount to an additional €1 million per year.

4. Extend the SD model based on the description above.
5. Simulate the model without fines for slow students from the year 1990 until the year 2030. Make graphs of following variables: *BSc students* and *MSc students*, *outflow of BSc students* and *outflow of MSc students*, *professors*, and the *amount of money available for education*. Is the faculty healthy without the proposed system of fines?

And now with fines for slow students...

But what does the proposed system of fines for slow students mean for the faculty? Model the system of fines as follows. With the system of fines, the *outflow of money available for education* changes into the *fraction of slow students* times the *total number of students* times the *fine per slow student* plus the number of *professors* times the *average professor salary*. Expect (at least) a one year delay before implementation due to opposition and demonstrations, you can assume that fines for slow students will only be introduced from 2012 on. According to government plans, the *fine per slow student* would amount to €3000 per year. This is of course only part of the picture: increased tuition fees to be paid by slow students are not taken into account here.

6. Extend the SD model with the description provided above.
7. Simulate the model *with* the system of fines. Make graphs of following variables: *BSc students* and *MSc students*, *outflow of BSc students* and *outflow of MSc students*, *professors*, and the *amount of money available for education*. Is the faculty healthy with the proposed system of fines?

8. What if the number of new students increases to 300 BSc students per year and to 60 new MSc students per year in 2020?
9. Your model is used by your university and national student council to fight these plans. The cabinet is furious: they claim your model is totally wrong because the *outflow of money available for education* still needs to be divided by a factor 2.5 (the average number of study years of BSc and MSc). Is that correct? Do the conclusions change?
10. After the previous proposed correction has been made, the cabinet now argues that the LOOKUP function of the *fraction of slow students* needs to be adapted too – the cabinet assumes after all that students will study faster in the new system. Change the lookup, discuss the new function and the consequences of this change for the faculty.

⚡ It should be clear that this model requires further adaptation: how could you make it more realistic? Describe what and how, do it, and describe possible changes in results.

From Fining to Lending

The Dutch government first turned the slow students fine forced upon universities into a lump sum cut in their subsidies. And during the first year of imposing an individual fine on slow students, the system was abolished... This resulted in big losses, both financial and human: measures had already been implemented, systems had been changed, students had dropped out, et cetera. The fine system was then turned into a social lending system. Nowadays, Dutch students can borrow money to finance their studies.

⚡ If you feel like it, model the new system. What could be concluded?

⚡ An even bigger challenge would be to model and simulate the catastrophic political process... From this process, much can be learned about *how not to* change a system but nevertheless stay in power.

18.21 Financial Turmoil on the Housing Market

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Introduction

The Dutch housing market has been in crisis for a while and will most likely remain in crisis for several years to come: average real estate prices have decreased a lot since 2008; the largest mortgage lenders changed the ease with which mortgages could be obtained from mid-2011 on; new housing construction in 2012 is only a fraction of new housing construction in previous years and of what would be required for the longer term future; fewer new construction projects have been initiated; and new mortgage related regulation and fiscal policies further depress the housing market, even though some mitigating actions were agreed upon by the Dutch cabinet and opposition. Homeowners and potential homeowners that may want/need to buy/sell a house in the coming years want to foresee the evolution of housing prices in the coming years. Policymakers want to foresee how the existing shortage on the housing market may evolve in the medium to long term. Suppose that the Ministry of Housing asks you therefore to develop a SD model that would allow them to foresee the evolution of the Dutch housing market and to assess policies related to it.

Iteration I

Assume for the sake of simplicity that the Dutch housing market only consists of houses for sale (no apartments; no renting market and no social housing market). Houses are either *new* (younger than 15 years old) or *old* (15 years or older). The supply of *new houses*, equal to 1500000 in the year 1985, increases through *completion of brand new houses* and decreases through *aging of houses* after which they are added to the *old houses*. The supply of *old houses*, initially 3665000 houses in 1985, decreases through *demolishing of old houses*.

The *completion of brand new houses* could be approximated by dividing the *houses in planning and under construction* by the *planning and construction time*. The number of *houses in planning and under construction* increases only through the *inflow into planning and construction* and decreases only through the *completion of brand new houses*. Suppose that the *initial amount of houses in planning and under construction* in 1985 was 175000. Suppose that the *planning and construction time* is a function of the number of *houses in planning and under construction* divided by the *initial amount of houses in planning and under construction*: the *planning and construction time* equals 1 year if this ratio is equal to 1, equals 1.5 years if the ratio is equal to 2, equals 2.5 years if the ratio is equal to 5, equals 3.25 years if the ratio is equal to 9, equals 4.5 years if the ratio is equal to 20, and it equals 0.75 years if the ratio is close to 0.

The *inflow into planning and construction* could be modeled as the '*housing gap*' multiplied by the *profitability multiplier* and divided by the *delayed direct effect of uncertainty*. Suppose in this first iteration that the *profitability multiplier* is 1. Model the *delayed direct effect of uncertainty* as a 3^{rd} order delay of *uncertainty* with a delay time of 1 year. Assume the *uncertainty* on the housing market was normal, i.e. 100%, from 1985 until mid 2007, after which uncertainty suddenly doubled. The uncertainty most likely remains twice as high until the end of 2013, and could be assumed to decrease linearly from double to normal between the end of 2013 and the beginning of 2015 – remaining normal ever after, or so one would hope.

The non-negative *housing gap* is equal to the *estimated number of households* times the number of *houses per household* minus the *expected total housing supply*. The *estimated number of households* amounted to 5,430,000 in 1985, to 5978000 in 1990, to 6798000 in 2000, to 7397000 in 2010, to 7470000 in 2011, and is assumed to amount to 8500000 in 2050, and to 9000000 in 2085. Assume that households do not have more than one house: i.e. the number of *houses per household* is 1. The *expected total housing supply* is the sum of *new houses*, *houses in planning and under construction*, and *old houses*, minus the houses expected to be demolished over the course of the year.

The *aging of houses* follows the *completion of brand new houses* with a delay time equal to the *life expectancy as new houses* of exactly 15 years. Model the *demolishing of old houses* as the number of *old houses* over the *average life expectancy of old houses* of about 60 years multiplied with a *demolishing multiplier of old houses*. Suppose the latter multiplier could be modeled as the 3^{rd} order delay of 1/*housing scarcity ratio* with a delay time of 1 year. The *housing scarcity ratio* is directly proportional to the *estimated number of households* and inversely proportional to the *expected total housing supply*.

1. Model the description above.
2. Simulate the behavior from the year 1985 until the year 2085.
3. Draw a an extremely aggregated CLD which could be used to explain the general dynamics of the *housing gap*. Explain the general dynamics of the housing gap using, and referring to, this extremely aggregated CLD.

Iteration II

Suppose that the *profitability multiplier* is a function of the *profitability of construction of new housing* in such a way that this multiplier equals 0 if the *profitability of construction of new* *housing* is equal to -100%, that it equals 0.01 if the profitability is equal to -50%, that it equals 0.02 if the profitability is equal to -20%, that it equals 0.2 if the profitability is equal to -10%, that it equals 0.8 if the profitability is equal to 0, that it equals 1 if the profitability is equal to 10%, that it equals 1.1 if the profitability is equal to 20%, that it equals 1.2 if the profitability is equal to 50%, and that it equals 1.25 if the profitability is equal to 100%.

The *profitability of construction of new housing* could be formulated simplistically as:

$$\frac{(1 + acceptable\ \%\ additional\ cost\ for\ living\ in\ a\ new\ house) * average\ house\ price - construction\ cost\ new\ house}{construction\ cost\ new\ house} \tag{18.1}$$

with an *acceptable % additional cost for living in a new house* of 5%. The *average construction cost of a new house* equals the *initial average construction cost of a new house* of €95000 per house times the *cumulative inflation since 1985*. The *cumulative inflation since 1985* could be calculated as the integral of:

$$inflation\ rate * cumulative\ \ inflation\ \ since\ \ 1985 * MAX((1 - (uncertainty - 1)), 0) \tag{18.2}$$

with an initial value equal to 1. Assume for the sake of simplicity that the *inflation rate* was, is, and will be 2% per year. The *average house price* corresponds –given the simplification that every household has at most 1 house– to the delayed product of the *average spending limit for buying one house per household* and the *housing scarcity ratio*, with an average delay of one year. The *average spending limit for buying one house per household* equals the *average salary per household* times $(1 + salary\ loan\ multiplier)$. Suppose that the *average salary per household* is the product of the *initial average salary per working person* of €27,000 per year, the *cumulative inflation since 1985*, and the *expected work force* divided by the *estimated number of households*. Add following time series: suppose that the *expected work force* amounted to 5.75 million in 1985, to 7.5 million in 2012, to 8 million in 2020, to 7.6 million in 2040, to 7.3 million in 2050, and to 6 million in 2085. The *salary loan multiplier* used to calculate the average mortgage lending capacity of an average household is then:

$$\frac{normal\ salary\ loan\ multiplier * (1 - loan\ risk)}{delayed\ direct\ effect\ of\ uncertainty} \tag{18.3}$$

The *normal salary loan multiplier* increased linearly between 1985 and the end of 2011 from 3 to 6, but fell back (given the stricter rules for banks and mortgage transactions, and the gradual decline of the mortgage interest relief) between 2011 and 2013 to 4, and could be expected to slowly fall back to 3.5 by 2050 and stay there ever after. Suppose finally that the *loan risk*, i.e. the risk of non repayment of loans, could be approximated by a 3^{rd} order delay of $MAX(0, uncertainty-1)/6$ with an average delay time of 2 years.

4. Model the above description. Verify and simulate the model. Compare the dynamics of the *average house price* and the '*housing gap*' of the first and the second iteration model.
5. Validate the second iteration model: list 2 good validation test for this phase in the modeling process, execute them, and describe the results.
6. Some inputs, exogenous future evolutions (time series) and endogenous relations are rather uncertain. Test the sensitivity of the most important indicators (*average house price* and *housing gap*) for changes in at least 1 uncertain parameter and 1 uncertain time series or endogenous relation. Explain briefly (what? why? how? result?).
7. Simulate –on top of the *base case* scenario– two very different scenarios with respect to the *average house price* and/or the *housing gap*. What is the narrative of the three scenarios? Plot their dynamics for the two key performance indicators.
8. What is undesirable about these plausible futures? Design a policy to turn undesirable dynamics into desirable dynamics. Describe briefly, test in your model, draw and compare the undesirable and desirable dynamics.

9. EITHER: Test this policy under uncertainty: do, briefly describe, and conclude. OR: Write a short model-based recommendation concerning the real estate market: what do you advise to the government, and/or to current homeowners, and/or to future homeowners?

18.22 Collapse of Civilizations

This case is to a very large extent based on case 4.3 from Martín García (2006) (with permission from Juan Martín García). The introduction is almost entirely the same and the model upon which the remainder of the case is based is the same as Juan Martín García's model.

Introduction

One of the great mysteries of human history has been the sudden collapse –around 800 AD– of one of the main centers of Mayan civilization in Central America at a time when it was apparently peaking in terms of culture, architecture and population. No one knows exactly why this society of several million people collapsed, but new research shows a gradually tightening squeeze between population and environment that may have been crucial to the fall. Tropical environments are notoriously fragile.

Research suggests that the population increased –just before the collapse– to about 200 to 500 persons per square kilometer. This population density required advanced agriculture or/and large-scale trade. Within two to four Mayan generations, the population density dropped to less than 20 persons per square kilometer (i.e. the same as 2000 years earlier). Furthermore, after the collapse, whole areas remained almost uninhabited for some thousand years. Some of the environmental changes appear to have been as long-lasting as the loss of population. Lakes that were apparently centers of settlement in the Maya era have not yet entirely recovered in terms of productivity.

Scientists[6] of Florida State University and the University of Chicago estimate that there was an exponential growth in Mayan population during at least 1700 years in the tropical lowlands of what is now Guatemala such that the population doubled every 408 years. This trend may have caught the Maya in a strange trap. Their numbers grew at a steadily increasing pace, but, for many centuries, the growth was too slow for any single generation to see what was happening. Over the centuries, the increasing pressure on the environment may have become impossible to sustain. Yet the squeeze could have been imperceptible until the final population explosion, just before the collapse.

New estimates for the southern lowlands are based largely on a detailed survey of traces of residential structures that were built, occupied and abandoned over the centuries. The studies focuss on the region of two adjacent lakes (Lake Yaxha and Lake Sacnab) in the Peten lake district of northern Guatemala. The area was inhabited as early as 3000 years ago and the first agricultural settlements appeared there about 1000 BC. The land was largely deforested by 250 AD. Gradually-intensified agriculture and increasing settlements seem to have caused severe cumulative damage to an originally verdant environment. Essential nutrients washed away in the lakes, diminishing the fertility of agricultural land. Increases in phosphorus in the lakes from agriculture and human wastes seem to have aggravated the environmental damage.

[6] Dr. Don S. Rice, assistant professor of archaeology at the University of Chicago and adjunct assistant curator of archaeology at the university museum, Dr. Edward S. Deevey, leader of the research team and graduate research curator of paleoecology at the Florida State Museum, H.H. Vaughan, Mark Brenner and M.S. Flannery of the University of Florida and Prudence M.Rice, assistant curator of archaeology and assistant professor at Florida University.

1. Draw the essence of this hypothesis (in simple form) in a CLD. Identify and name the loops. Analyze the CLD. Are firm conclusions possible from a purely qualitative study?
2. Build a SD model to simulate the collapse of the Maya civilization. Base your simulation model on the CLD above and include following assumptions in the model.

- The *consumed food per person* was about 400 kg per person per year.
- The Mayans deforested the area they needed to close the *gap* (in kg) between the *food produced* and the *demand for food*, given the *fertility of the agricultural land* (kg/km^2) and the *intensity* of the agriculture. Following function could be used[7]:

  Deforestation = MIN(*gap* / MAX(*fertility of Lands*, 1), *forest*/4) / Intensity ; Units: km^2/year.
- Only 5% (the '*emigration ratio*') of those that theoretically were left without food[8] actually emigrated. The others stayed because of redistribution of the existing food.
- the stock variable *fertility of agricultural land* was initially 5000000 kg/(km^2*year). With the initial value of 5000000 kg/km^2, 40000000 kg *food* could be produced with an initial 8 km^2 of *agricultural land*. This is equal to the initial food demanded for a *Population* of 100000 persons with a *consumed food per person* equal to 400 kg per year. However, this initial *fertility of agricultural land* is reduced with a flow variable '*fertility Losses*'.
- The *forest* area has an initial value of 5000 km^2 and could decrease by means of *deforestation*.
- Define the food *Gap* as *demand of food* - *food produced*.
- The *intensity* initially equals 1. The variable could be used to regulate the speed of *deforestation* and the speed of *fertility losses*. If *intensity* = 1, then all the forest needed is deforested every year.
- Use a Net *natural population increase* flow of the *population* that leads to a growth of the population from initially 100000 in 1000 BC to 2000000 inhabitants in the year 800 AD, or in other words, that leads to a doubling of the *population* every 408 years.
- Model the '*fertility losses*' as:

  fertility of land * MIN(2,(*agricultural land*/*forest*)^x)/*intensity*; in [kg/(km^2*year)/year].

  This means that the *fertility losses* are proportional to the existing *fertility of agricultural land*, and to the fraction of *agricultural land* and *Forests* with an (almost) quadratic relation. Calculate the exponent x that leads to a collapse in the year 800.

3. Calculate missing exponent(s) and/or flow(s).
4. Simulate a 2000 year evolution starting in 1000 BD.
5. What happens to the population? Make a graph of the resulting population dynamics. Does it correspond to the observed behavior?
6. What needs to be changed in or added to the model in order to obtain more realistic outcomes?

[7]The MAX function is used to prevent errors if dividing by 0. The MIN function is used to temper the model response.

[8]Hint: the *gap* of food divided by the *consumed food per person* gives the equivalent number of people without food.

7. Is the simulated behavior very sensitive to changes in constants and structural assumptions?
8. Extend the model to simulate (dynamic) policies that could have prevented a catastrophic collapse of the population.
9. Which currently existing systems are very similar to the one studied here? What would be your intuitive policy recommendations concerning these systems?

- Read chapter 5 'The Maya Collapses' in the book 'Collapse: How Societies Choose to Fail or Succeed' by Jared Diamond (2005). Extend the model to capture the story of the Maya collapse according to Diamond (2005).
- Choose another ancient society that failed from (Diamond 2005), model it and simulate its dynamics under uncertainty. Design and test policies to prevent it from collapsing/failing.

18.23 Additional Cases in Online Repository

|⊕| Add. ex. 1
|⊕| Add. ex. 2
|⊕| Add. ex. 3
|⊕| Add. ex. 4
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Chapter 19

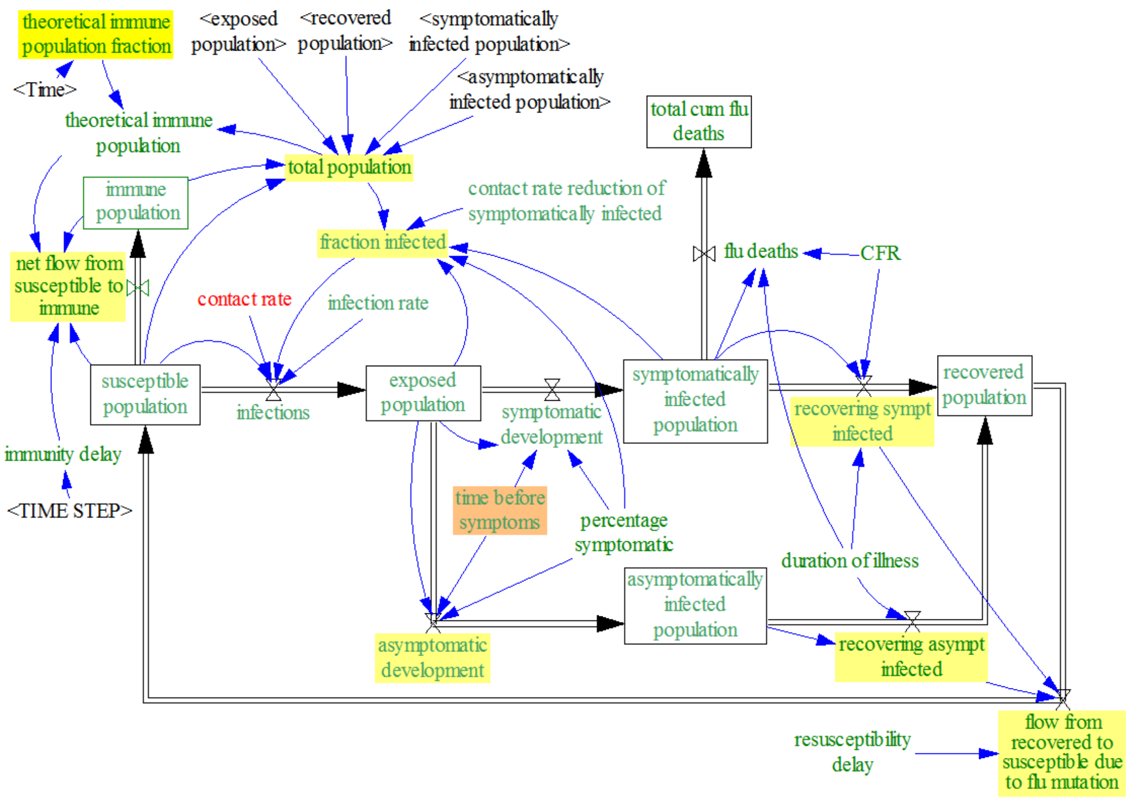
MCQs Part V

'We are all passengers on an aircraft we must not only fly but redesign in flight.' (Sterman 1994, p292)

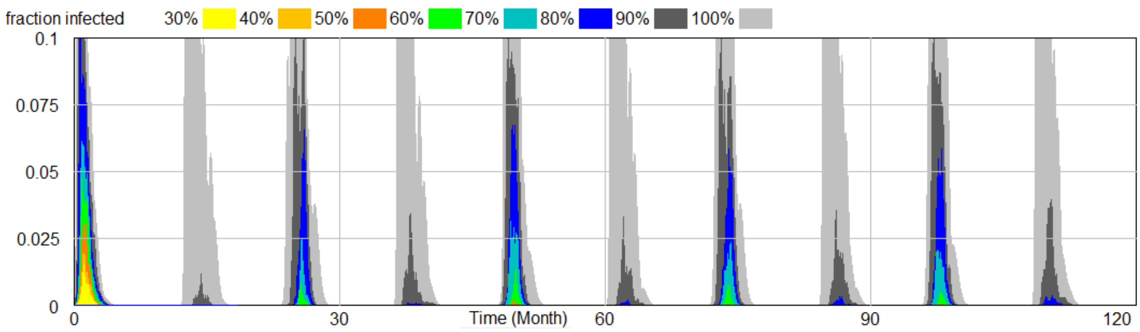
Which of the following statements are right and which are wrong?

1. A graph function cannot be changed as part of a policy.
2. Changing the feedback structure of a model can be used to change model behavior and test solution strategies.
3. To make SD models scientific, actors need to be modeled as rational agents.
4. '[Models] should be used to search for precise policies that are optimal for the most likely forecast of the future.' (Meadows and Robinson 1985, p429)
5. 'I am suggesting that we do indeed know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase.' (Forrester 1971, p126)
6. If a SD model produces an output which almost exactly fits the historical data of the last 50 years, it is certainly safe to use that model to predict the outputs 20 years from today.
7. Models are hardly useful since reflection beyond models is always needed.
8. The desired level of aggregation of a model depends on the goal or function of the model.
9. A system that is not sensitive to perturbations by an exogenous variable, is not necessarily in equilibrium.
10. A model that *is not* sensitive to small parameter changes is better than a model that *is* sensitive to small parameter changes.
11. If a variable cannot be influenced by the decision-maker (that is, if it is not a policy lever), then behavior mode sensitivity to changes in that variable is desirable.
12. Using the Euler integration method with a time-step (dt) of 0.25 time units, the value of x at time $t = 0.5$ will be equal to 82.30 for $\frac{dx}{dt} = \frac{20-x}{2}$ with $x(0) = 100$.
13. General-understanding modeling tends to be more process-oriented than product oriented.
14. If the true underlying structure is not, or cannot be, known, then models are plausible at best.
15. In complex systems, adaptive closed loop policies are generally speaking more effective than policies that are not embedded in a feedback loop.

Multiple Choice Question 1



Consider the seasonal flu model above. The sensitivity graph below was generated with this model, large uncertainty intervals, and Latin Hypercube sampling (200 runs). What could be concluded?



a. There is a a reasonable chance that (mutations of) this flu variant will first compete every second year for dominance among seasonal flu strains, and after a while, every year.

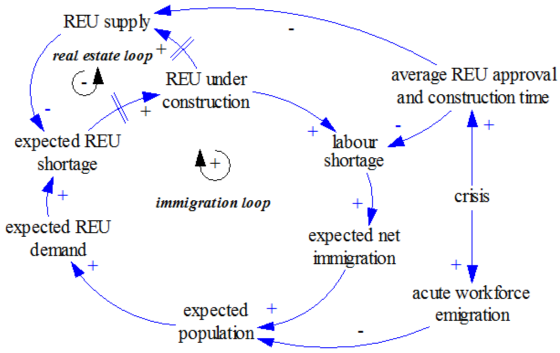
b. Nothing.

c. This flu variant will return every year with 100% confidence, and every second year with some 90% confidence.

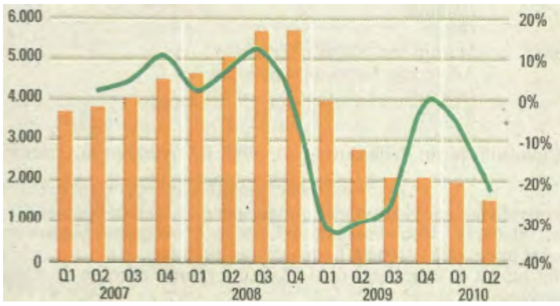
d. The infected fraction is higher in the first year, since there are flu deaths but no births in this model. Conclusion: the model is wrong and cannot be used for studying seasonal flu.

Multiple Choice Question 2

Following the suspension of payments by Dubai World, Dubai's real estate boom abruptly ended and turned into a bust. A sudden exodus of (often highly paid) migrant workers occurred and the delivery time of construction drastically increased (after which many construction projects turned into ghost projects). Both the residential real estate market and the office market (see graph on the right hand side) were affected. Suppose your colleagues made a SD simulation model of the collapse of the real estate market. One of them also made the CLD on the left, which is supposed to be a simplified representation of the simulation model, in view of better understanding the link between structure and behavior and to communicate this understanding to others. Assuming that the simulation model generates very similar behavior to the graph displayed below, which of the following statements is then least correct?



(a) CLD of the RE crisis



(b) Orange/left scale: avg rental price per m^2; Green/right scale: % change wrt previous quarter. Source: NRC 161010 / CB Richard Ellis

a. The positive immigration loop is the endogenous mechanism driving the boom – this mechanism is active when the shortage on the real estate market is more difficult to solve than the scarcity on the labor market: Continued immigration is the engine of the real estate boom.

b. The positive immigration loop is the endogenous driving mechanism behind the bust – this mechanism is active when the shortage on the real estate market is easier and faster to solve than the shortage on the labor market.

c. After the crisis loop is activated, there is a shift in the dominance from the immigration loop towards the real estate loop, turning the real estate loop into the endogenous mechanism driving the bust.

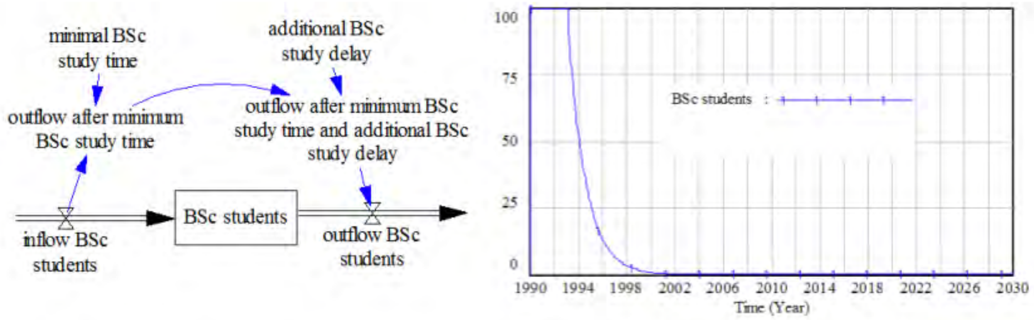
d. After the sudden crisis, the immigration loop remains dominant but turns from an exponential increase into an exponential decrease, from time to time partly damped by the real estate loop.

Multiple Choice Question 3

The real cause of the current economic depression is –according to Nobel Prize winner Paul Krugman (2012, p45-46)– systemic: '[I]f too many players in the economy find themselves in debt trouble at the same time, their collective efforts to get out of that trouble are self-defeating. If millions of troubled homeowners try to sell their houses to pay off their mortgages – or, for that matter, if their homes are seized by creditors, who then try to sell the foreclosed properties – the result is plunging home prices, which puts even more homeowners underwater and leads to even more forced sales. [...] And if things get bad enough, the economy as a whole can suffer from deflation – falling prices across the board – which means that the purchasing power of the dollar rises, and hence that the real burden of debt rises even if the dollar value of debts is falling. [...The latter] is the main explanation of the depression we're in right now.' Which of the following archetypes corresponds best to this situation?

a. Eroding goals b. Escalation c. Tragedy of the commons d. None of these archetypes

Multiple Choice Question 4



On average, students spend a long time studying in Delft: Not only are engineering studies offered in Delft difficult, student life is great and extra-curricular activities are considered to be important. Suppose you make the following SD model (top left) to study the throughput of BSc students. Your test run consists of a batch of 100 students that started their studies in 1990. The right hand side graph shows the development of this test batch for the stock variable *BSc students*. Which of the following statements is *not* correct?

a. The *outflow after minimum BSc study time* is a DELAY FIXED (Vensim) or a DELAYPPL (Powersim) with argument *inflow BSc students*, with delay time *minimum BSc study time*, and initial value equal to 0.

b. The *outflow after minimum BSc study time and additional BSc study delay* is equal to a first order material delay with as argument the *outflow after minimum BSc study time* with an *additional BSc study delay*, and an initial value = 0.

c. The *outflow BSc students* is equal to the *outflow after minimum BSc study time and additional BSc study delay*.

d. None of the above: all statements are correct or two or more statements are wrong.

Multiple Choice Question 5

After performing a sensitivity analysis, it seems like your model is numerically sensitive *and* behavior mode sensitive, but not policy sensitive. What could be concluded?

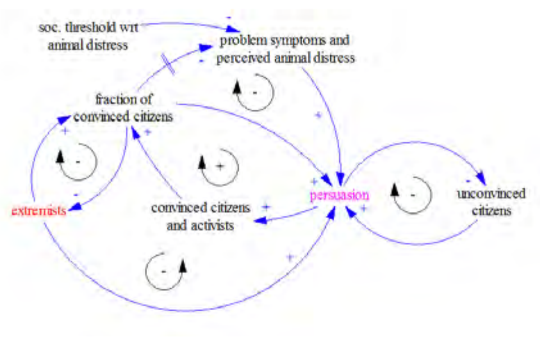
a. The lack of policy sensitivity is actually a good sign.

b. The model is not useful, especially because of the numeric sensitivity.

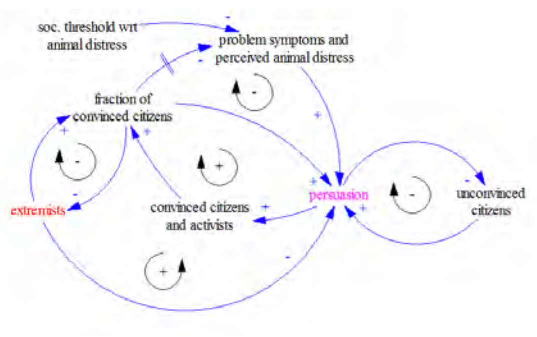
c. The numeric sensitivity and behavior pattern sensitivity lead to opposite conclusions related to the appropriateness of the policy.

d. Numeric sensitivity and behavior pattern sensitivity almost always occur. The lack of policy sensitivity is troubling.

Multiple Choice Question 6



(a)



(b)

Which simulation models represented by CLD (a) and CLD (b) displayed above are most likely to lead to radicalization and/or deradicalization?

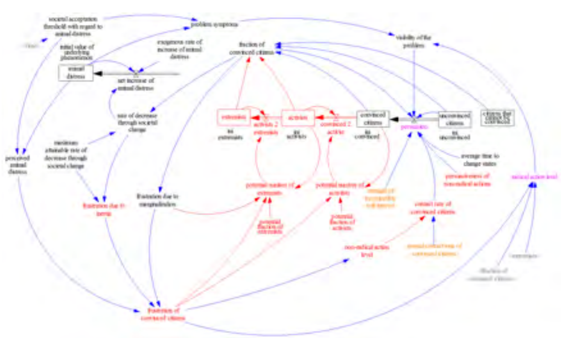
a. (a) to radicalization & (b) to deradicalization

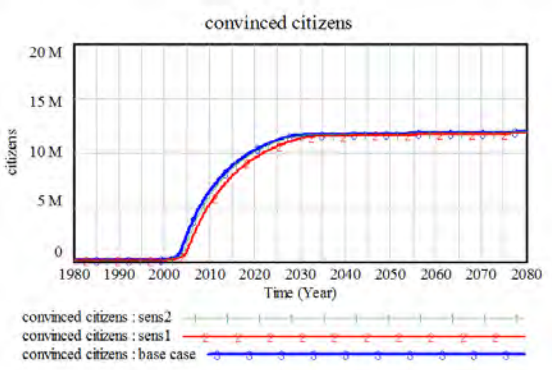
b. (a) to radicalization & (b) to radicalization

c. (a) to deradicalization & (b) to radicalization

d. One cannot possibly argue one of the previous answers is correct.

Multiple Choice Question 7





The model of a radicalization case (18.13) described in this e-book is displayed below. A sensitivity analyses performed with this model are displayed on the right hand side. What could be concluded?

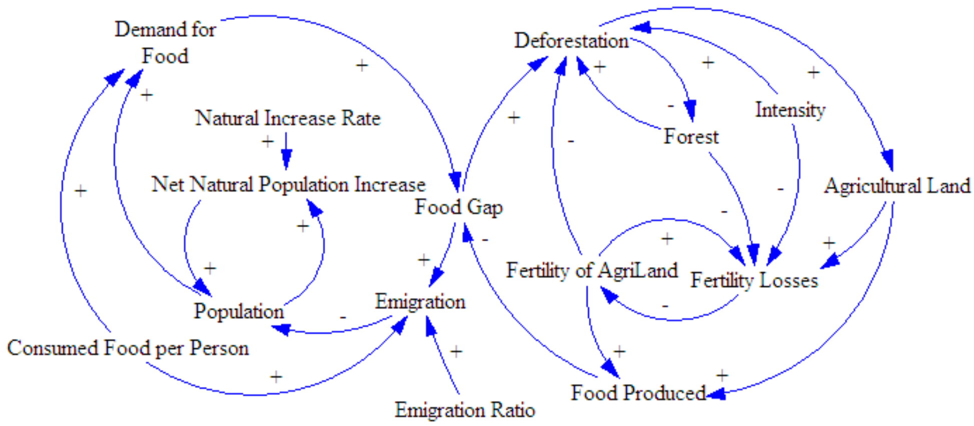
a. The variable *convinced citizens* is not uncertain.

b. The behavior of the *convinced citizens* is a little bit numerically sensitive for the two sensitivity analyses displayed above.

c. The model is good because it is robust.

d. The model is bad because it is too robust.

Multiple Choice Question 8



What is the most plausible behavior for a simulation model summarized by the above CLD?

a. Continued exponential population growth due to the positive population loop.

b. Boom and bust due to limits to growth of food production.

c. Logistic growth due to foresight on the part of the population

d. Constant population and agricultural proceeds.

Multiple Choice Question 9

Which of the following requirements is needed *least* for choosing SD as a modeling method?

a. The real-world system is truly continuous.

b. The system behavior is dynamic and largely depends on past states (i.e. is endogenous).

c. Assumptions about causes, feedback effects, and underlying structures can be formulated.

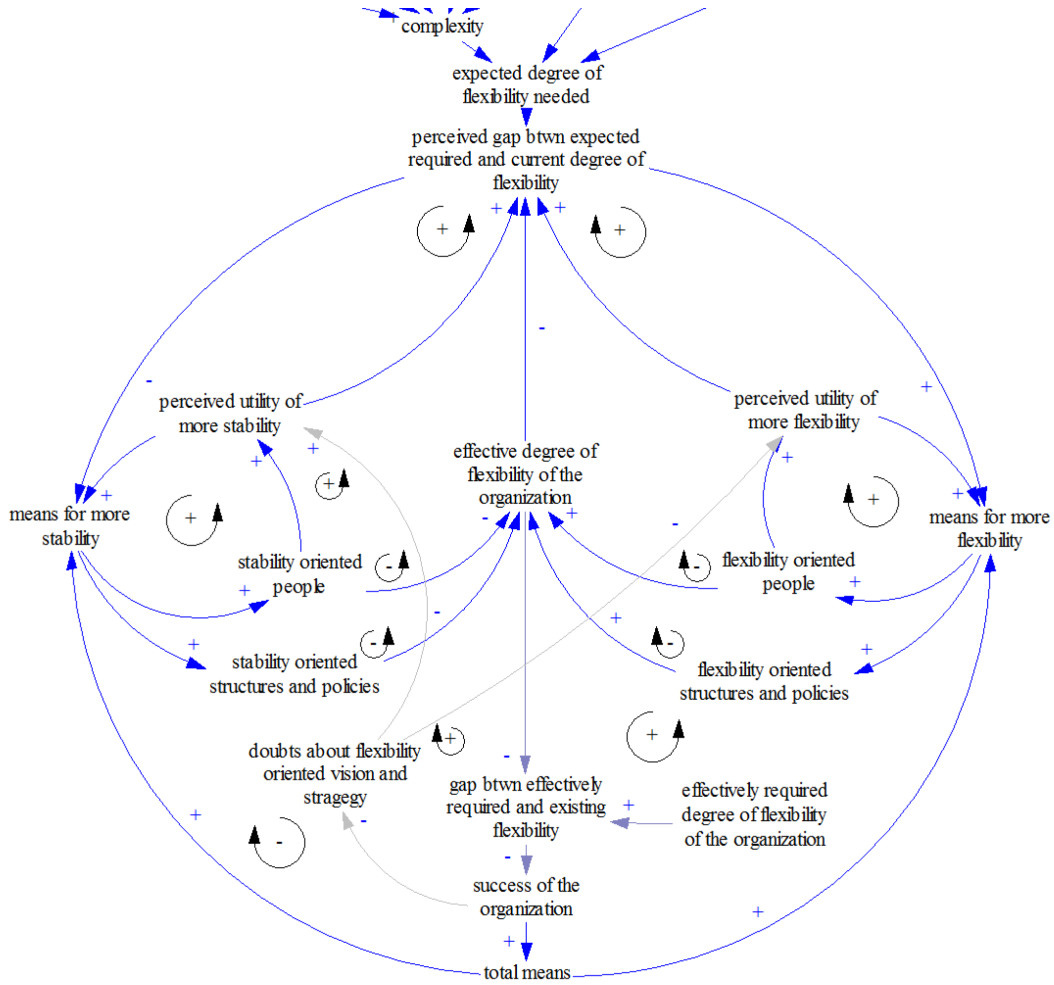
d. It's all about the 'big picture' (broad system boundaries, long time horizon,...).

Multiple Choice Question 10

In densely populated urban areas (such as New York, Mexico City, or Istanbul), the real estate demand (i.e. demand for apartments, offices, houses, etc.) is on the one hand highly sensitive to prices. Once there is a decline in the property prices (which happens when the real estate supply is higher than the real estate demand), demand rises rapidly. The construction sector, on the other hand, initiates new projects based on new demand for properties. When there is an increase in demand, new projects are initiated immediately. Construction projects are completed with relatively long delays of about 2-3 years. What kind of dynamics would you expect to see in property prices if many construction companies operate in these urban regions and they are not aware of the construction projects initiated by others?

a. Continued increase b. Continued decrease c. Some form of oscillations d. Boom & bust

Multiple Choice Question 11



Which of the following partial stories is not consistent with the CLD related to the choice between investing in more flexibility or in more stability in an organization (casse 22.4)?

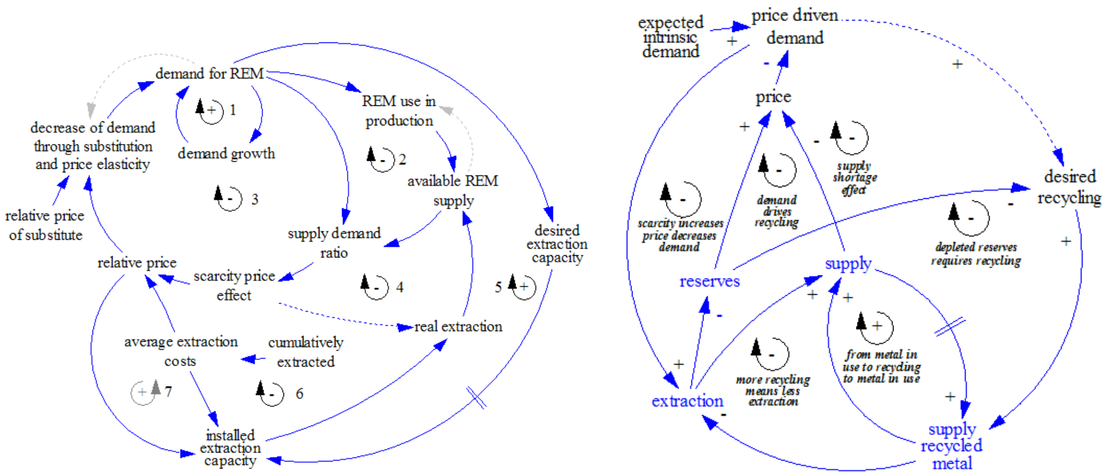
a. Ever more complexity (caused by several –mostly external– evolutions) leads to a continued increase in the expected degree of flexibility needed, and to a widening of the perceived gap between the expected required degree and the real degree of organizational flexibility.

b. A perceived widening of the gap between the expected required degree of flexibility and the current degree of flexibility of the organization leads to relatively more investments in flexibility (flexibility-oriented people, structures and policies) than in investments in stability, reducing the effective degree of flexibility of the organization and hence increasing the gap.

c. In an environment that requires flexibility, flexibility-oriented people are able to activate reinforcing feedback loops, possibly resulting in excessive investments in flexibility and underinvestments in stability. But if the effective degree of flexibility of the organization is not in line with the effectively required degree of flexibility of the organization, then the organization is likely to become less successful, leading to fewer total means available.

d. If the right people start doubting the (excessively) flexibility-oriented vision and structure of the organization, and succeed in questioning the perceived utility of more flexibility and less stability, then the vision and strategy may become relatively more stability-oriented.

Multiple Choice Question 12



Both CLDs displayed above relate to mineral and metal scarcity problems. What is the least important difference between them?

a. The left one is about scarcity-induced substitution and the right one about scarcity-induced recycling.

b. The left one consists of 7 feedback loops and the right one consists of 6 feedback loops.

c. Price formation in the model on the left is a function of relative supply and demand, whereas price formation in the model on the right is a function of the reserves and demand.

d. Demand growth is endogenous in the left one and exogenous in the right one.

Multiple Choice Question 13

Which of the following statements concerning MAX and MIN functions is *not* correct?

a. A MAX function can be used to keep auxiliary variables from adopting negative values.

b. -MIN(-. . . ,0) can be used to keep auxiliary variables from adopting positive values.

c. MIN(MAX(. . . ,. . .),. . .) constructions can be used to keep auxiliary variables *within* a specified interval (in other words: between a lower bound and an upper bound).

d. MIN(MAX(. . . ,. . .),. . .) constructions can be used to keep auxiliaries *out* of an interval.

Multiple Choice Question 14

Which of the following statements is *not* correct?

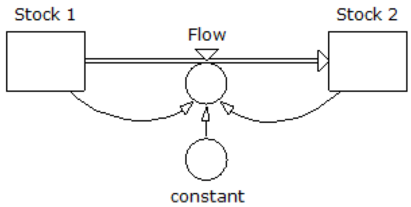
a. The behavior of information and material delays of corresponding order differs only for variable delay times.

b. A pipeline delay or delay fixed is in fact a material delay of infinite order.

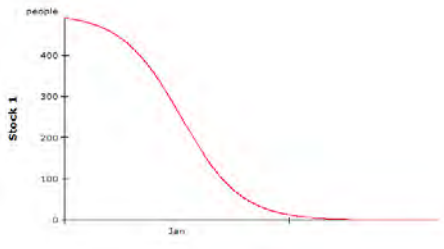
c. Each feedback loop needs to contain at least one stock variable or one delay variable.

d. Higher order delays are always more realistic than lower order delays.

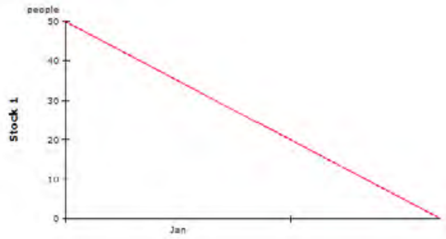
Multiple Choice Question 15



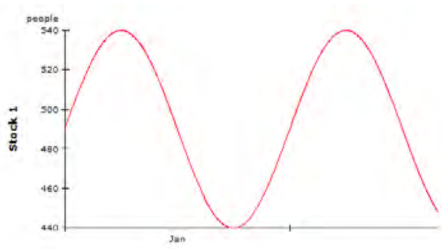
Consider the simple model above, with *Flow* = *Constant* x *Stock*1 x *Stock*2 and *Constant* > 0. Assume that *Constant* has a very small value compared to the values of *Stock* 1 and *Stock* 2. Which of the following outputs regarding *Stock* 1 could be obtained from this system?



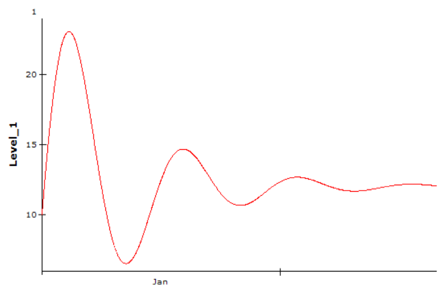
(a)



(b)



(c)



(d)

Multiple Choice Question 16

Which of the following statements is *not* correct?

a. Each stock variable needs to be embedded in at least one feedback loop.

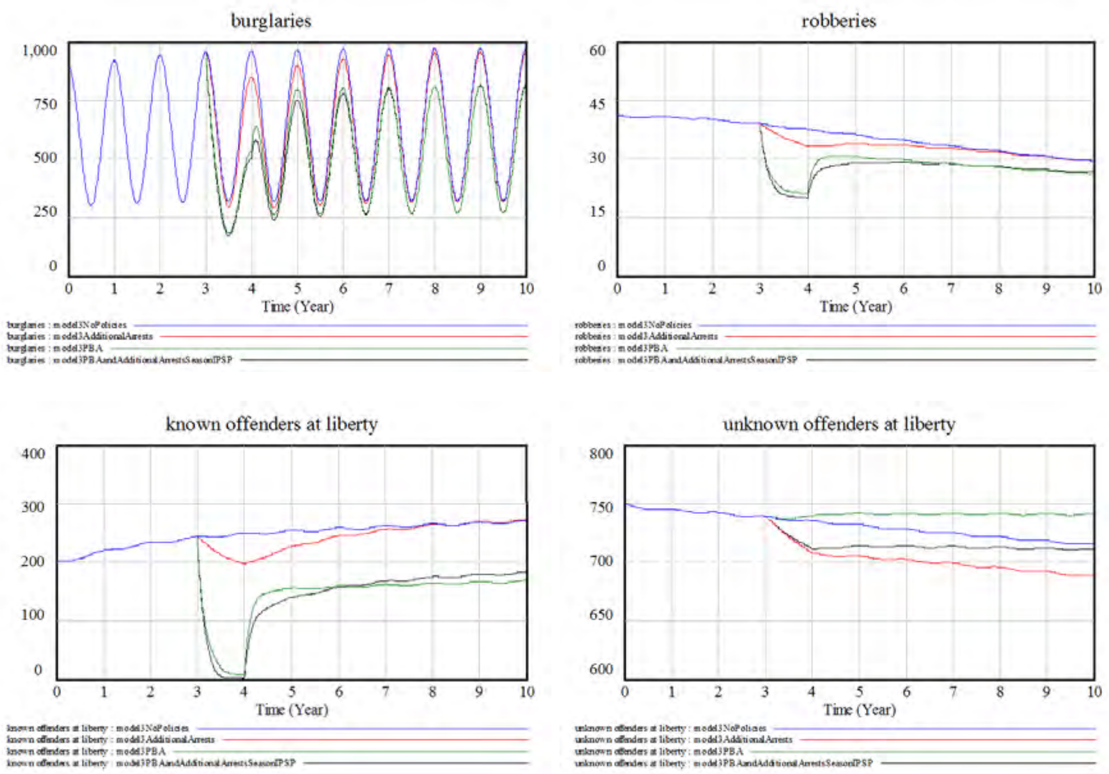
b. Dominant positive feedback loops generate reinforcing effects for all variables in them.

c. Variables in a loop are both cause and effect of changes in the values of variables in the loop.

d. Systems of two coupled negative feedback loops do not necessarily generate convergence.

Multiple Choice Question 17

The graphs displayed below were generated with a regional police model for fighting burglaries and robberies. The blue trajectories were generated without any policies. The red trajectories result from 100 additional arrests in the fourth year (from year 3 to 4). The green trajectories result from the implementation of the Person-Bound Approach (PBA), i.e. the police keeping a eye on a criminal and social services focusing on building up an alternative crimeless life, with a capacity of 100 criminals in the PBA program in the fourth year (between year 3 and 4). And the black trajectory is the combination of 100 additional effective arrests *and* a PBA program with a capacity of 100 criminals, both in the fourth year. If locking away 100 arrested criminals and applying the 100 person PBA program are more or less as expensive –both are expensive– what would you, based only on these graphs, advise the the chiefs of police?



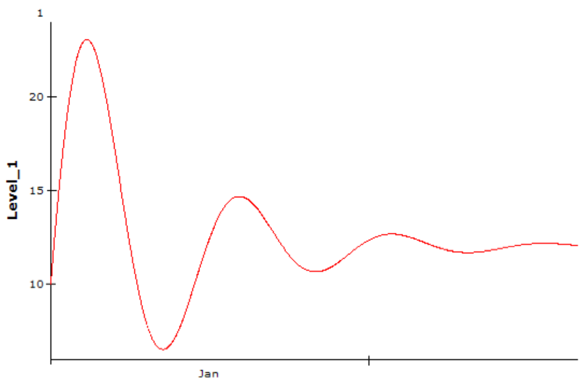
a. The 100 additional arrests policy is effective in reducing the number of known offenders at liberty and most effective in reducing the (estimated) number of unknown offenders at liberty and should therefore be implemented. This will result in more offenders in jail –more than in case of the combined policy and much more than in case of the PBA. Hence, the 100 additional arrests policy should be implemented, not the combined one.

b. The PBA is much more effective than the 100 additional arrests policy. Hence, the PBA should be implemented. Performing 100 effective arrests on top of the PBA only adds marginally to the effectiveness of the fight against robberies and burglaries. Hence, the 100 additional arrests policy should not be implemented.

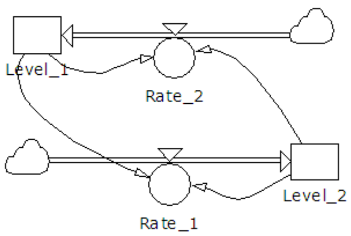
c. The PBA is much more effective than the 100 additional arrests policy. Hence, the PBA should be implemented. Although performing 100 effective arrests on top of the PBA only adds marginally to the effectiveness of the fight against robberies and burglaries, it may help to identify unknown offenders at liberty who may then be arrested and/or may enter the PBA.

d. None of the previous pieces of advice should be given.

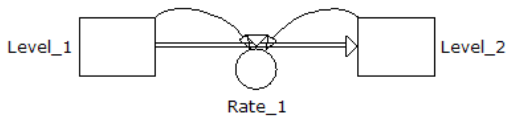
Multiple Choice Question 18



Which of the following model structures may allow to generate the output displayed above?



(a)



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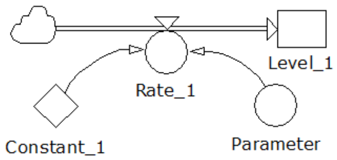

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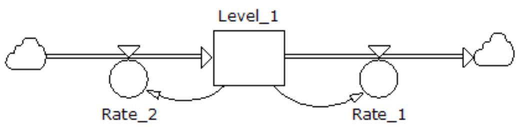
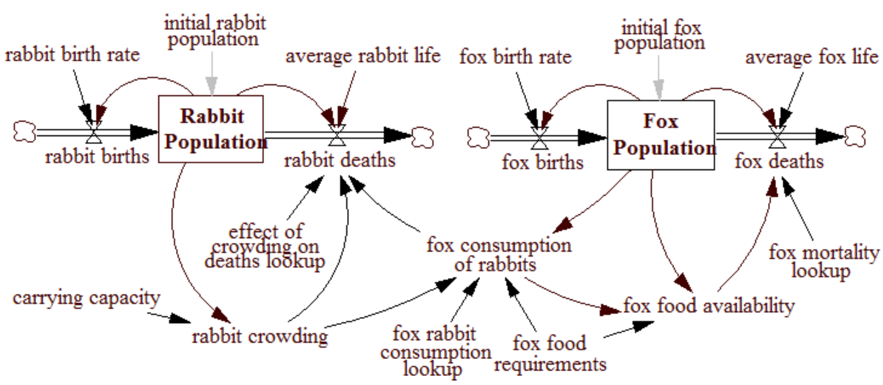
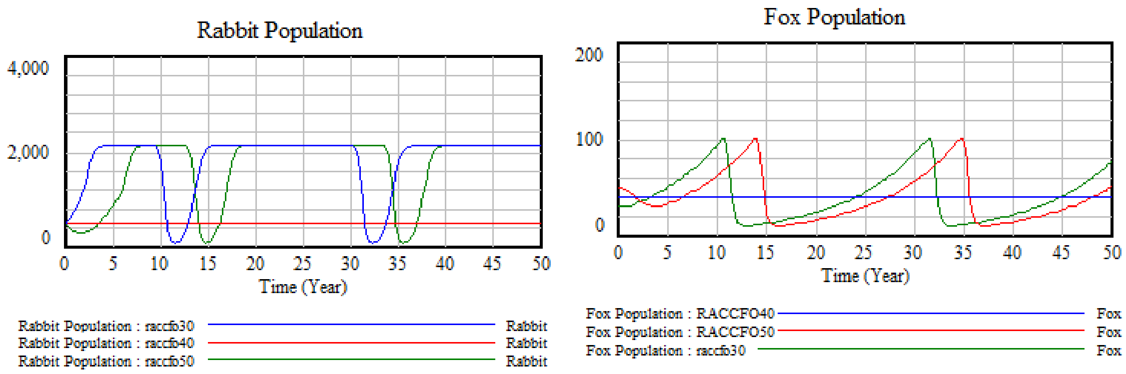


(d)

Multiple Choice Question 19





Given is the predator-prey simulation model displayed above. This model is one of the example models that ships with Vensim. Looking at the SFD and the corresponding behavior, what could be said about the properties of this model?

a. Unless one of these populations is killed off exogenously, they will oscillate around a center (here at 40 foxes and 500 rabbits).

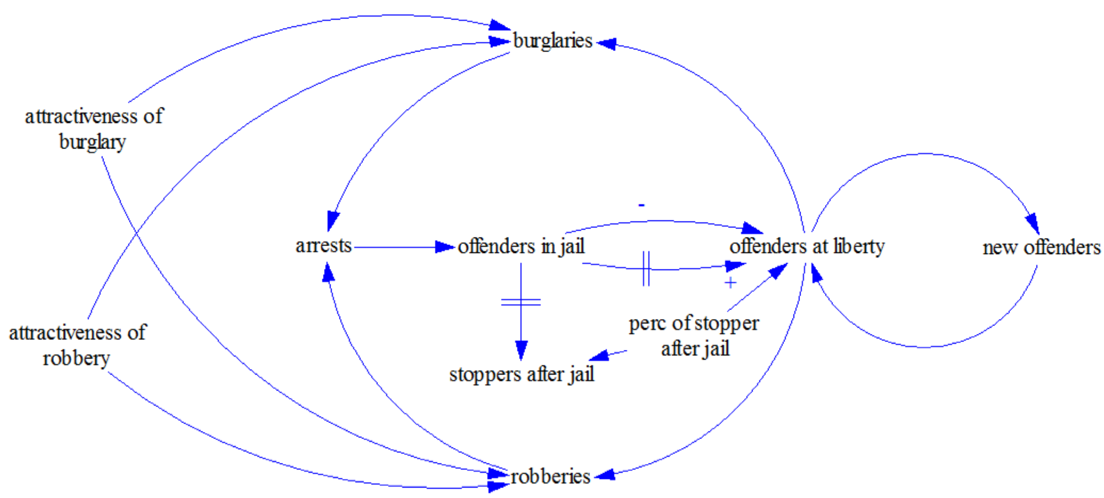
b. One saddle point at the origin prevents these populations to be killed off endogenously and another saddle point at 100 foxes and 2000 rabbits prevents these populations to rise above these limits.

c. The system has two interacting fixed points: a sink at 40 foxes and 500 rabbits and a source at 0 foxes and 0 rabbits.

d. None of statements above is correct.

Multiple Choice Question 20

Consider the aggregated CLD about the 'water bed effect' between burglaries and robberies and the effects of jailing displayed below. Which of the following statements is correct?



a. There are 5 feedback loops: 3 ⊕ and 2 ⊖.

b. There are 3 feedback loops: 2 (+) and 1 (−).

c. There are X+2 feedback loops because the two delays count for one loop each.

d. This aggregated CLD is wrong, and so is the number of loops, since many offenders at liberty never get caught. Hence, at least one more loop needs to be added.

Link to the answers to the 15 right/wrong questions & 20 multiple choice questions in this chapter.

Links to web based quizzes: | | | |

Chapter 20

Recap V – Lessons to be Learned

'[M]odelers can see themselves as responsible not to parochial, short-term interests, but to all humankind. They can see themselves as simplifiers, clarifiers, and fellow-explorers. They can listen more than they talk, ask the questions people really want asked, draw forth visions, designs, and experiments. They can be comfortable with the fact that they have glands, hearts, values, beliefs, moral stands, and blind spots. They can be willing to be wrong, vulnerable, caring, and idealistic. They can hold the highest intellectual standards of scientific hypothesis-formation and disproof, along with the highest human standards of integrity, compassion, and truthfulness. We can imagine what kind of system of modeling such a self-image might bring forth. It would be a transformation.' (Meadows and Robinson 1985, p433)

Case-Based Lessons from Part V

18.1 The main lessons from the Policies exercise are that:

- Policy testing almost always involves additional modeling and testing;
- Closed-loop policies are mostly better than open-loop policies;
- Sensitivity and uncertainty analysis allow to identify potential leverage points.

$ 18.2 The main lessons from the Unemployment model are that:

- This model first generates increasing employment in (government) services as long as expenditure is under control;
- It also generates increasing unemployment in production due to productivity increases without increasing demand.

18.3 The main lesson from the Hospital Management model is that:

- 'A stock-maintaining balancing feedback loop must have its goal set appropriately to compensate for draining or inflowing processes that affect that stock. Otherwise, the feedback process will fall short of or exceed the target for the stock' (Meadows 2009).

18.4 The main lesson from the Kaibab Plateau model is that:

- Killing off one species may seriously destabilize the entire ecosystem for years/decades.

18.5 The main lessons from the Prostitution & Human Trafficking model are that:

- Instantly emptying a stock variable with a PULSE requires division by the time step;
- Illegalization is actually beneficial to criminals.

18.6 The main lessons from the Seasonal Flu model are that:

- SIRS and SEIRS models often generate multi-annual dynamics;
- Strong outbreaks are followed by minor outbreaks;
- Outbreaks of new flu strands are much stronger than those in subsequent years.

18.7 The main lessons from the Real estate boom and bust model are that:

- A small difference in relative strength between feedback loops may lead to large differences in behavior (boom versus bust);
- A shock or temporary external pressure on a system may turn a boom into a bust;
- Sensitivity analysis is extremely useful for detecting tipping points between very different modes of behavior.

18.8 The main lessons from the DNO Asset Management model are that:

- It is relatively straightforward to turn SD models into flight simulators and/or serious games;
- Reactive strategies are focused on the past, not the future.

18.9 The main lessons from the Fighting HIC on the Regional Level model are that:

- There are waterbed effects between different types of High Impact Crime;
- Hence, their joint root causes need to be addressed first and foremost.

18.10 The main lessons from the Innovation in Health Care model are that:

- Technologies are very likely to further increase the average lifetime of the elderly in the developed world;
- Subscripted aging chains with representative micro-dynamics for slices of distributions per cohort allows for agent-based dynamics in SD models.

18.11 The main lessons from the Quantitative Climate Change model are that:

- Climate change is a stock problem although many regard it, and design policies for it, as if it were a flow problem (focus on emissions);
- Climate change is regulated by strongly delayed processes: today's emissions will influence the climate for centuries.

$ 18.12 The main lessons from the Orchestrated Bank Run model are that:

- Instant bank runs and 'bleeding' bank runs are both problematic;
- Instant bank runs require automated mechanisms to be in place;
- In bleeding bank runs, one may have more time, but immediate and strong action is nevertheless required.

18.13 The main lessons from the Radicalization II model are that:

- Groups characterized by different degrees of radicalization need to be included;
- Alternative simulation models can be made about one and the same phenomenon.

18.14 The main lessons from the Project Management model are that:

- Modeling the hidden side of processes helps to improve their visible side;
- Adaptive proactive human resource management and planning may be needed and could be simulated.

18.15 The main lessons from the Rare minerals/metals II model are that:

- In case of long-term scarcity of key materials, recycling will in the end start up endogenously, although likely too late;
- In the absense of recycling, potentially valuable scrap needs to be conveniently stored for future recycling or 'mining'.

18.16 The main lessons from the Energy Transition towards Sustainability model are that:

- Learning curves can easily be included in SD models;
- Renewables compete against capital intensive technologies with a head start of several decades, which, from a learning curve point of view, is very difficult;
- Investments are flows with associated costs, while installed capacities are stocks that generate revenue and profits.

18.17 The main lessons from the Fighting HIC across Multiple Districts model are that:

- There are partial waterbed effects between different regions;
- The root cause of crime needs to be addressed instead of more region specific action.

18.18 The main lessons from the Antibiotic Resistance model are that:

- Models allow to assess thresholds and tipping points;
- Timing of policies is of extreme importance, even for reversible problems;
- Replicating SD studies, even well documented ones, is very insightful, but not easy.

$ 18.19 The main lessons from the Globalization model are that:

- After liberalization, production capacities and standards will converge over time;
- Sudden institutional changes may lead to decade-long restructuring processes;
- During restructuring processes, prices may change considerably, and thus, have a strong signaling effect.

18.20 The main lessons from the Higher Education Stimuli model are that:

- SD models can deal with batches;
- Changes in incentive structures may have very (un)desirable long-term effects.

18.21 The main lessons from the Financial Turmoil on the Housing Market model are that:

- Uncertainty leads to semi-automated actions by the banking system may not be in the interest of the banking system or the interest of the public;
- Financial markets have very strong influences on housing markets;
- Banks and financial markets need more system thinkers.

18.22 The main lessons from the Collapse of Civilizations model are that:

- Many civilizations collapsed due to their own pressures and unsustainability;
- Overshooting population and associated resource pressures tend to cause intensifying social and political tensions which can all of a sudden cause outbreaks of wars.

Link to the feedback video related to all JUMP cases.

Part VI

FLY

Chapter 21

How to Fly

21.1 Pitfalls & Challenges for Novice SD Practitioners

Following modeling mistakes are very common for novice SD practitioners:

- Models are too big and/or too difficult/complicated: more time should have been spent conceptualizing and choosing a better level of aggregation.
- The modeling process is not iterative enough: Start small and build out. From time to time, start all over again from scratch. Plan enough iterations – at least three serious ones.
- Not enough time is budgeted: Be aware that modeling takes effort and time. Do not expect the first version of your model to be correct. Conceptualization takes time but could save even more time. Taking your time to build a good model saves a lot of time debugging and testing/rebuilding/testing/... and starting over again.
- Too much time is spent on modeling and not enough time spent on using the model in a modeling process, e.g. for policy analysis and policy testing. Remember that, in the end, models are tools for thought. Policy-makers are interested in brilliant thoughts, not in detailed models and complex analyses.
- Insufficient time and attention is paid to exploring alternative boundaries/formulations/..., exploring the consequences of alternative formulations, and reflect beyond the model(s).
- Too much confidence/trust is attached to, and hard conclusions are drawn from, one among many plausible models. After all, multiple models can mostly be specified about the same issue. Models consist of many assumptions or micro-hypotheses that, together, constitute a macro-hypothesis about the system and plausible behavior. If the true underlying structure is not, or cannot be, known, then plausible models are all we can make. But given the fact that we could generate different dynamics and learn different lessons from different plausible models, it is often useful to develop and use different plausible models about the same issue.
- Models are insufficiently tested and/or models are not really useful for the purpose at hand. Spend a lot of time testing your models. And ask System Dynamicists that are particularly good at model testing to test your models. Remember: all models are wrong, but some models are simply wronger than other models. Try to avoid the latter. Always try to make useful models: to do so, model in view of the purpose.
- Models are often idealistic/unrealistic. Try to avoid making and using SD models with unrealistic assumptions or 'without people in the model'. Add incentives, delays, traditions,

typical (suboptimal) behaviors, and boundedly rational decision routines. Distinguish between desired conditions and actual conditions, and between real conditions and perceived conditions. Decisions are made on the basis of perceived conditions, and can only be based on available information. This means that variables for which the value is not available (or measurable) in reality should not be used in decision making routines in the model.

- Insufficient time spent on documenting the process and justifying the choices made in the modeling, analysis and policy design process.

21.2 From Here On...

So far you only learned basic skills to build SD models and use them to perform basic analyses. I strongly advise anyone who got to this point to:

- Read at least one of the following books: (Sterman 2000) and/or (Ford 2009). And those interested in more SD cases, are strongly advised to continue with Hartmut Bossel's case books (Bossel 2007a; Bossel 2007b; Bossel 2007a).
- Enrol in a SD project course under supervision of an experienced System Dynamicist. So far you acquired basic modeling skills, but not the necessary process skills, nor the experience it takes to apply SD for real. Then, take advanced SD courses.
- Make models about any important dynamically complex issue you come across.
- Attend SD conferences and gatherings, and especially the workshops at the end of the ISDC.
- Start reading SD books, the System Dynamics Review, and other SD articles. See section 21.3 and 21.4 for a few suggested entries in the SD field and for each of the nine themes.

21.3 Introductory Reading & Additional SD Resources

Highly recommended learning resources include (but are not limited to):

- Excellent introductory SD books mixing explanations with exercises and cases, including recent ones such as (Ford 1999; Sterman 2000; Richmond 1992; Morecroft 2007; Warren 2002; Ford 2009; Meadows 2009), older ones such as (Forrester 1968; Richardson and Pugh 1981) and SD books in other languages (Aracil 1977; Boersma et al. 1995), as well as introductions to SD without exercises and cases such as (Randers 1980a).
- The System Zoo books by Hartmut Bossel (Bossel 2007d; Bossel 2007a; Bossel 2007b; Bossel 2007c) which contain many SD models (follow this link to the zip file that contains all ZOO models), ranging from models with regard to physics and engineering (Bossel 2007a), over models with regard to climate, ecosystems, and resources (Bossel 2007b), to models with regard to economy, society, and development. Other SD exercises and case books, including (Goodman 1974; Martín García 2006), and the series of Road Maps developed by the System Dynamics in Education Project (self-study guides bringing together important papers, books, and modeling exercises) and all the materials available through MIT's open courseware.
- K12 education materials at the Creative Learning Exchange, SD Games, and SD play book.
- Study books introducing SD among other computational methods (Shiflet and Shiflet 2006) or to support domain studies such as studies in sustainable development (de Vries 2012).
- Articles in journals such as the System Dynamics Review or Systems Research and Behavioral Science, as well as many articles in other scientific journals, articles in Proceedings of the International Conference of the System Dynamics Society, and notes, articles and theses in the MIT SD collection.

- Online simulators at Forio and at Insightmaker.
- Other e-books including Money and Macroeconomic Dynamics by Kaoru Yamaguchi, a forthcoming interactive Systems Thinking book by Scott Fortmann-Roe and Gene Bellinger.
- Excellent classic SD reads such as (Randers 1980a; Meadows et al. 1982; Meadows and Robinson 1985) and (Forrester 1961; Forrester 1969; Forrester 1971).

21.4 Further Reading per Theme

There are also many excellent papers in the SD field, both in scientific journals and in the annual proceedings of the International Conference of the System Dynamics Society. A few books, papers, and special issues related to each of the nine themes are listed below. They are just the tip of the iceberg, hopefully providing enough of an entry into the SD literature related to each of these themes.

|♥| Health Policy, Epidemiology & Drugs:

- (Homer 2012; Paich et al. 2009)
- (Thompson and Duintjer Tebbens 2007; Morrison et al. 2009; Homer et al. 2000)
- SDR special issue on Health and Health Care Dynamics. 15(3), 1999

|| Environmental & Ecosystems Management:

- (Forrester 1971; Fiddaman 1997; Ford 2009)
- (Moxnes 2000; Fiddaman 2002; Faust et al. 2004; BenDor and Metcalf 2006; Dudley 2008)
- SDR special issue on Environmental and Resource Systems. 20(2), 2004
- SDR special issue on Sustainable Development. 14(2-3), 1998
- SDR special issue on The Life of Dana Meadows. 18(2), 2002

|♻| Resource Dynamics & Energy Transitions:

- (Meadows et al. 1972; Bunn and Larsen 1997)
- (Ford 1990; Wils 1998; Dudley 2004)
- SDR special issue Environmental and Resource Systems. 20(2):89–198, 2004
- SDR special issue on Sustainable Development. 14(2/3), 1998
- SDR special issue on The Life of Dana Meadows. 18(2):101-310, 2002

|| Safety, Security & Risk:

- : (Wils et al. 1998; Cooke 2003; Cooke and Rohleder 2006; Anderson 2011)
- : SDR special issue on Terrorism, etc. (forthcoming)
- : Bibliography of the Special Interest Group on Conflict, Defense & Security

|| Policing & Public Order:

- (Weaver and Richardson 2006; Hovmand et al. 2009; Carter and Moizer 2011)

|| Housing Policy & Urban Planning:

- (Forrester 1969)
- (Eskinasi et al. 2009; Alfeld 1995)
- SDR special issue on System Dynamics and Transportation. 26(3), 2010

|| Education & Innovation:

- (Milling 1996; Abdul-Hamid and Madnick 1991; Georgantzas and Katsamakas 2008) and (Andersen 1990)
- SDR special issue on Education 9(2), 1993
- SDR special issue on Information Systems Research with SD. 24(3), 2008

|$| Economics & Finance:

- (Yamaguchi 2013)
- (Radzicki 1990; Saeed 1998)

|| Management & Organization:

- (Forrester 1961; Sterman 2000; Warren 2002)
- (Gary et al. 2008; Weil 2007)
- SDR virtual issue on Project Management
- SDR special issue on the Dynamics of Supply Chains and Networks. 21(3), 2005
- SDR special issue on ST and SD in Small-Medium Enterprises. 18(3), 2002
- SDR special issue on Consulting and Practice. 17(3), 2001

Chapter 22

First, Simulate Some Flights

'This sort of learning-by-doing, or what is called applied learning, represents the future of education. Instead of a teacher standing in front of a class teaching the multiplication tables, they ask students to solve a problem. Perhaps the students are also given some clues about how to solve the problem. Then the kids team up and use all the tools at their disposal [. . .] to solve the problem through collaborative and independent research. Where real learning comes into play, however, is when those same students apply what they learn in some way – perhaps in a project or via an illustration. More magic happens when those students present the evidence of that application to their teachers and fellow students.' Heather Hiles LinkedIn 13 March 2013

22.1 Food or Energy

Introduction

Dramatically risen fuel prices, expected future fuel shortages, increasing environmental consciousness and climate change awareness, pressures for energy independence, technological innovations, and a favorable political floor have drawn worldwide attention and investments to renewable energy sources over the last decade.

Bioenergy is renewable energy produced from biomass (from living organisms of biological origin). Bioenergy derived from biological feedstocks[1] can be used –through direct combustion or gasification– for heating and electricity generation, and –through conversion to biofuels– for automotive propulsion. Bioenergy consumption multiplied in recent years, and currently provides some 11-14% of the world primary energy consumption. There is however a significant difference in percentage of the primary energy mix, growth rate, type, and use between developing countries –where traditional bioenergy (mostly firewood) remains the main energy source– and industrialized countries –where a rapidly growing biofuel sector drives the booming cultivation of (dedicated) bioenergy crops. Bioenergy might also provide a substantial source of alternative energy in the future.

Proponents of bioenergy, and more specifically of biofuels, argue that the large-scale development of bioenergy could be part of the solution for diversifying energy sources, enhancing security of energy supply, and meeting environmental and rural development objectives. In the light of the current world food crisis, proponents of biofuels argue that biofuels are responsible for only a mi-

[1] Biological feedstocks include wheat, corn, and other grains, wood and wood waste, straw, crop harvest residues, sugarcane, sugar beets, rapeseed, sunflower, soybeans, algae, vegetal and animal waste.

nor share (some 3%) of current food price rises[2]. US Agriculture Secretary Ed Schafer was quoted saying: 'We recognise that biofuels have an impact, but the real issue is about energy, increased consumption and weather-related issues in grain producing countries' (BBC News 2008a).

Opponents of biofuels on the other hand argue that they are to a large extent –some 30% (BBC News 2008b) or more[3]– responsible for current food price rises. Hence, opponents argue that biofuels threaten (agricultural) food security, diverting land from food production to energy production (BBC News 2008a). They point out that this leads to serious negative impacts on the poor in urban areas, poor nations, international trade flows, and possibly to negative impacts on small-holders and poor in rural areas. Biofuel opponents also point out potential environmental dangers, such as deforestation, destruction of natural ecosystems, mono-culture expansion, agricultural intensification, excessive use of fertilizers and pesticides.

This divide between proponents and opponents of biofuels has not been resolved at the world summit dedicated to the world food crisis, held in Rome in June 2008[4], and agreements on (limitations of) biofuel production have not been reached. Decisions are on the other hand made in several countries to stop or to freeze current and future biofuel projects. Jean Ziegler, Special UN Rapporteur for the Right to Food, has also called for a 5-year moratorium on biofuel production using current methods (FAO 2008c).

However, that might be undesirable too. Bioenergy might namely also revitalize the agriculture sector, generate more income for farmers and the agricultural sector as a whole, attract more agricultural investments, and hence, foster rural development and alleviate poverty. It might also improve (rural) access to sustainable energy (FAO 2008a), both in the short and the long run: first generation biofuels –which compete directly with food crops for the same arable land, and hence, increase the cost of food production– are often argued to be an intermediate step, necessary for a successful transition towards second generation biofuels –which do not compete directly for the same arable land and do not affect food crop prices to the same extent.

The controversy and framing of the policy issue as 'Food against Bioenergy' is highly undesirable and counter-productive. The dynamics of food and biofuel production –and hence of food and fuel security– are complex, interlinked, and need to be studied as a whole. The interactional effects between, and joint dynamics of, agricultural food and bioenergy production need to be studied in order to design appropriate policies and make good decisions –reconciling present and future, food and energy security, and economic, social, and environmental dimensions. The food/bioenergy issue is therefore actually about sustainable development. And the policy/ethical tradeoff between short-term food security and long-term energy security might not really be a tradeoff: both food and energy security are needed, and they might even reinforce one another on the system level if managed properly. But to manage complex issues properly, a thorough understanding of the issues is necessary. Since the mental assessment of the dynamics over time of complex issues is almost impossible for unassisted human beings[5], there is also a need for appropriate tools, e.g. simulation models, to help generate this understanding.

A World Food/Bioenergy Model

You are therefore asked by the FAO make an exploratory model related to the world food bioenergy controversy. Your world food/bioenergy model should allow to generate insights into the possible impact of bioenergy crop cultivation on food crop cultivation, food prices, food shortages, and hence, the world food crisis.

[2]The cereal/food import bill of developing countries increased some 10 % in 2005/2006, 33-37% in 2006/2007, was forecast to rise by 56% in 2007/2008 (FAO 2008d, p30), to ease from their recent record peaks, but to average, over the next 10 years, well above their mean levels of the past decade (OECD-FAO 2008).

[3]According to an unpublished Word Bank report leaked to The Guardian (Chakrabortty 2008), food prices are estimated to have risen by 140% between 2002 and February 2008, biofuels are estimated to have been responsible for an increase of 75%, and higher energy and fertilizer prices for an increase of only 15%.

[4]See `http://www.fao.org/foodclimate/hlc-home/en/`

[5]Successful mental simulations related to the energy/food issue, probably supported by models, can nevertheless be found, among else in (Müller et al. 2007; FAO 2008b).

Focus on bioenergy crops –instead of bioenergy from waste or forestry– because they have the greatest interaction effect with food production, are currently already feasible, are argued by proponents to be a prerequisite for the development of second generation biofuel technologies, and are assumed by the European Environmental Agency (2006, p8) to provide the largest potential in the long-term. The purpose of your simple SD model should be to generate insights.

Conceptualization

Many of the concerns and aspects discussed in the previous subsection could actually be brought together in a systems model. The world model outlined in the current section is a highly-aggregate and simple SD model. The goal of the model is not to prove one or the other position in the food/bioenergy debate. It should however be useful for integrating several causal effects –assumed to be important by different parties– in the same system model, and to generate and analyze the impact of different (sets of) assumptions on the modes of behavior of the system model. Likely modes of behavior of different opinions (e.g. proponents and opponents), modeled as different sets of (structural and parameter) assumptions, should be explored too.

1. Model the population dynamics of –and between– 'rich' (overnourished) and 'poor' (undernourished), their respective crop demands (reflecting their lifestyles), and the dynamics of the crop supply to satisfy their demands endogenously. Let the industrialization-related enrichment and lifestyle changes, and per capita biofuel demand increases exogenously drive the model. Model the desired food buffer, additional investments in crop yield and crop land, and distributional inefficiencies also exogenously. Do not include following structures in the simple version of your model:
   - a link between (bio)fuel demand and crop prices;
   - environmental/ecological aspects such as deforestation, impact on natural ecosystems, mono-culture expansion, agricultural intensification, use of fertilizers and pesticides;
   - other resources and local conditions (soil types, availability of arable land, water, and labor);
   - and import and export between regions and countries.
2. Why would you use SD modeling for this job? Convince the FAO.
3. Make a CLD. What can you conclude from this Causal loop diagram (without simulation)?

Specification

Include a population view/sector to the simulation model. Include a population structure of 'rich' (read: overnourished) and 'poor' (read: undernourished) populations and the constitutive parts of their respective 'crop demands'. The total per capita *crop demand of the rich* is much higher than the per capita *crop demand of the poor*. The *total crop demand* equals the *desired percentage buffered*, times the sum of the *crop demand of the rich* and the *crop demand of the poor*. In this simplistic version of the model, the *total crop demand over crop supply* is a proxy for the fraction of market price over production cost, or in other words, the *extra economic profitability*, which –in this version of the model– equals the *expected extra economic profitability*. If this proxy is greater than unity, it gives rise to a pauperisation flow '*rich to poor*'. If this proxy is smaller than unity, it leads to an enrichment flow '*poor to rich*'. The enrichment flow *poor to rich* is also driven exogenously by a flow of *poor to rich through industrial development*.

An *instant crop shortage* occurs in this model if the *instant crop demand rich and poor* is greater than the *crop supply* times the *distributional inefficiency*. This *instant crop shortage*

Table 22.1: Constants & parameters assumptions of the reference run of the world biomass model

CONSTANTS & PARAMETERS	BASE CASE	BOUNDS	EXPLANATION / SOURCE
adaptation time poor to rich [yr]	5.5	1–10	= assumption
adaptation time rich to poor [yr]	5.5	1–10	= assumption
average birth rate poor [10^{-3} p/(p.yr)]	26	20–32	= assumption
average birth rate rich [10^{-3} p/(p.yr)]	20.3	19–21	world average '07 ±10% (CIA 2007)
average crop storage time [yr]	5	2–8	= assumption
average lifetime poor [yr]	45	40–50	= assumption
average lifetime rich [yr]	75	70–80	= assumption
conversion yield bioenergy [l/kg]	0.35	0.35–1	
conversion yield meat [kgmeat/kg]	0.15	0.02→0.28	bovine→poultry (IMAGE-team 2001)
crop demand per capita poor [kg/person/yr]	155.5	124–186.5	assumption: 50% of rich ±20%
crop demand per capita rich [kg/person/yr]	311	248–373	assumption: (681-55.5/0.15) ±20%
crop land expansion time [yr]	10	2–18	= assumption
crop land reduction time [yr]	2	1–3	= assumption
crop yield adaptation time [yr]	10	5–15	= assumption
desired percentage buffered [dmnl]	0.1	0.05–0.15	= assumed value policy variable
distributional inefficiency [dmnl]	0.05	0–0.1	= assumed value policy variable
distributional ineff. of crop buffer [dmnl]	0.25	0–0.5	= assumed value policy variable
fract.add. crop land thr.ex.inv. [dmnl]	0		= assumed value policy variable
fract.add.crop yield incr.thr.ex.inv. [dmnl]	0		= assumed value policy variable
initial crop land [Gha] (if not as variable)	1.38	1.54	(FAO 2008e, d) (Müller 2007)
initial crop yield [kg/ha/yr]	3000	2500–3500	(Gilland 2002, p59)
initial population [10^9 person]	6	5.9–6.1	
initial fraction poor [dmnl] (undernourished)	0.135	0.15–0.12	800 10^6 in 2000 (FAO 2004)
initial fraction rich [dmnl]	0.86	0.85–0.88	idem
max.pot. crop area [Gha] (if not as var)	4.4	3.52–5.28	(Müller 2007) ±20%
maximum potential crop yield [kg/ha/yr]	5000	4400–6600	= assumption ±20%
meat demand per cap. rich [kgmeat/p/yr]	55.5	41–70	by '50 (Millennium Ecosystem Ass.)
starvation fraction of famished	0.2	0.1–0.3	= assumption
fraction rich above poverty threshold	0.2	0.1–0.3	= assumption

could then be buffered (*crop shortage buffered*) with a certain degree of inefficiency (*distributional inefficiency of the crop buffer*), which results in the *crop shortage after use of the buffer*. The *number of food shortage deaths* then equals the *crop shortage after use buffer* divided by the *crop demand per capita of the poor population* times the *starvation fraction of the famished*, that is, if this number is smaller than the *poor population*.

Add a crop buffer which increases in case of surpluses, and decreases to buffer shortages and because of decay after an *average crop storage time*. Also add structures to take the size of the crop land and the average crop yield into account:

- *crop land* is extended or abandoned depending on whether the *expected extra economic profitability* is greater than or smaller than unity,
- the *average crop yield* is extended if the *expected extra economic profitability* is greater than unity, and
- the *crop supply*, which can be randomized in order to simulate natural variability of harvests.

Simulation and Analysis

4. Make a simulation model from the above description.
5. Make and simulate a base case simulation run. Use the data in table 22.1 for your base case simulation run and use the data in Table 22.2 for the base case simulation of the lookup/graph variables.

Table 22.2: Lookups of the reference run of the world biomass model

LOOKUPS VARIABLES	VALUES BASE CASE
poor to rich thr. industrial development	(2000,0),(2100,0)
fraction second generation biomass	(2000,0),(2010,0.01),(2030.28,0.2),(2050,0.5),(2075,0.8),(2100,0.9)
fossil fuel supply [10^{12} l/yr]	(2000,4.4),(2005,4.9),(2008,5.2),(2013,6.2),(2025,6.2),(2100,6.2)
fuel demand per capita rich [l/(person.yr)]	(2000,848),(2008,970),(2100,970)
fraction vegetarians of rich population	(2000,0.1),(2100,0.2)
mandatory percentage biofuel	(2000,0),(2010,0.01),(2100,0.2)

6. Make following 5 scenarios starting from the values displayed in tables 22.1 and 22.2. Compare them on several key variables. What could be concluded from this scenario analysis?

- Make and simulate a scenario **S00** in which crops are not, and will not, be cultivated for biofuel production: *crop demand for bioenergy* = 0, at all times. It is therefore implicitly assumed that fossil fuel supply (or other alternatives besides liquid biofuels) will be sufficient to accommodate the liquid fuel demand over the 21^{st} century. This scenario S00 is the *no-biofuels base case* scenario.

- Make and simulate a scenario **S01** which equals scenario S00 with the exception that bioenergy crops *are* cultivated for biofuel production. This scenario is the *biofuels base case* scenario. Make sure that the fraction of first generation bioenergy crops decreases in this scenario following an inverse S-function, equal to 1-*fraction second generation biomass* (see table 22.2).

- Make and simulate a scenario **S02** which equals scenario S01 with the exception that the *fossil fuel supply* decreases linearly from 6.2 10^{12} l/year in the year 2025 to 1 10^{12} l/year at the end of the century. Use following values in your lookup/graph *fossil fuel supply* function: (2000, 4.4 10^{12}), (2005, 4.9 10^{12}), (2008, 5.2 10^{12}), (2013, 6.2 10^{12}), (2025, 6.2 10^{12}), (2100, 1 10^{12}).

- Make and simulate a scenario **S03** which equals scenario S02 with the exception that the *fraction of vegetarians of the rich population* linearly increases to 90% and the *fuel demand per capita of the rich* linearly decreases after 2008 to 500 l/person/year by the end of the century[6]. The cause of these actions is not what matters here: they might emanate autonomously from the rich population, might be caused by high energy and food prices, or might be steered by policies.

- Make and simulate a scenario **S04** which equals scenario S03 except that the *fraction of additional crop yield increase through exogenous investments* amounts to 10% instead of 0%, that the *distributional inefficiency* is 0%, and that the *distributional inefficiency of the crop buffer* is 0% (both rather utopian). These changes are in fact policies.

7. Test the sensitivity of the model to changes in parameters and constants –one at a time– always starting from S02 scenario. There are two important reasons for starting from scenario S02, namely: (i) that the combination of bioenergy crop cultivation and decreasing (relatively cheap) *fossil fuel supplies* is a very likely one; and (ii) that the goal of this analysis is the discovery of parameters and constants that enable turning the highly undesirable mode of behavior and effects of scenario S02 into acceptable ones. Your sensitivity analysis should therefore focus on behavioral sensitivity. Test the influence of following uncertain

[6] *fraction vegetarians of rich population*: ((2000, 0.1), (2100, 0.9)); and *fuel demand per capita of the rich*: ((2000, 848), (2008, 970), (2100, 500)).

parameters and constants: the *adaptation time rich to poor* (which is a proxy for the time it takes before the 20% poorest slice of the *rich population* falls into poverty), the *fraction rich above poverty threshold*; the *poor to rich through industrial development*, the *maximum potential crop yield*, the *maximum potential crop area*, the *maximum potential crop area*, the *maximum potential crop area*, the *desired percentage buffered*, the *conversion yield of bioenergy*, the *crop storage time*, the *average birth rate of the rich*, the *average birth rate of the poor*, the *average lifetime of the rich*, the *average lifetime of the poor*, and the *adaptation time of poor to rich*.

8. Use your model as a virtual laboratory to assess the dynamics of scenarios and experiment with policies before their real-world realisation/implementation. Test what happens if first generation biofuels break through, but second generation biofuels do not take over. Start for this what-if analysis from scenario S01. Simulate scenarios in line with the ones developed above.
   - Make and simulate a scenario S11 which equals scenario S01, except that the lookup variable *fraction second generation biomass* is at any time 10 times lower than in S01.
   - Make and simulate a scenario S12 which equals scenario S11, except that the lookup variable *fossil fuel supply* decreases linearly from 6.2 10^{12} l/year in 2025 to 1 10^{12} l/year in 2100.
   - Make and simulate a scenario S13 which equals scenario S12, except that the *fraction of vegetarians of the rich population* increases to 90% by 2100 and the *fuel demand per capita of the rich* decreases to 500 l/person/year in 2100.
   - Make and simulate a scenario S14 which equals scenario S13, except that the *fraction of additional crop yield increase through exogenous investments* amounts to 0.1, and that the *distributional inefficiency* and *distributional inefficiency of the crop buffer* are eliminated.
9. Display the simulation results in a graph. What could be concluded from this analysis?

22.2 Cod or Not?

The Issue

The cod population off the coast of Nova Scotia in Eastern Canada, south of New Foundland, is recovering from previous overfishing (Frank et al. 2011). The dramatic collapse of this cod population is the perfect example of the dangers of overfishing, and more generally, of the *problem of the commons* archetype. After a fortunate period of uncontrolled fishing, the stock of large predatory fish such as cod, haddock, pollock and hake near Nova Scotia almost completely collapsed within three years round 1990. Fishing was banned in 1993, but recovery of predatory fish populations did not occur. However, it appeared that smaller prey fish cod hunts for like herring, capelin and sandeel, greatly increased in number. These smaller prey fish live on zooplankton (tiny floating animals) and it was assumed that they also ate larvae of the –now rare– predators. Ecologists call this phenomenon predator-prey reversal. Some feared that the restoration of the ecological situation would be blocked forever.

But the disappearance of large predatory fish lead to a trophic cascade. The numbers of prey fish increased, resulting in a reduction of zooplankton, which in turn led to an increase in phytoplankton (algae). The prey fish have been the victims of their own gluttony, there is shortage of zooplankton, and their populations decrease since 1999. Consequently, more cod larvae survive and gradually encounter more zooplankton, their primary food. This damped oscillation could be captured by SD models. The cod and haddock populations have been on the rise since 2005.

1. Make a SD model of this ecosystem based on the description above. Elicit and justify specific modeling choices (esp. the uncertain ones). Verify, validate, and simulate the model.
2. Extend the model using additional resources such as (Frank et al. 2011) (see link).
3. Whether the old situation will return remains to be seen. In the transition period, new (exotic) species may also take over part of the ecosystem. Or jellyfish. And then there is climate change... Extend your model in view of studying plausible consequences of exotic species invasion, jellyfish take-over, and climate change.
4. Look at the comment related to the article by Frank et al. (2011) posted on the web site of Nature. Model this perspective too. Use both models for policy testing. What are your conclusions?

22.3 Wind Force 12

Introduction

In this case, the 2002 bottom-up spreadsheet assessment of the *Wind Force 12* report of the European Wind Energy Association and Greenpeace (2002) (see Blackboard for the full report) is replicated and turned into a simple top-down system dynamics model. Then some typical spreadsheet errors of the *Wind Force 12* report are detected and corrected using a stock/flow replication model. The obtained model could then be used to simulate different policies, to test the sensitivity of parameters and structural hypotheses, before extending the model to make it more dynamic.

Wind Force 12

The report assesses the feasible fraction of world wind power in the total power mix. Figures 22.1, 22.2, 22.3 contain the basic logic and data from table 4-1, appendix table 1 and appendix table 3 of the *Wind Force 12* report.

1. Replicate the model and data in MS Excel.
2. Test the sensitivity of the Excel model. Is the model sensitive to specific assumptions?
3. Assess different policies using the Excel model.
4. Make a SFD in your SD software to replicate the logic and data of the *Wind Force 12* report (see figures 22.1, 22.2, 22.3) when using the Euler integration scheme with a time step of one year.

One way to replicate the model is displayed in figure 22.4. Note the three similar stock-flow structures (co-flows) to keep track of three related stock variables: *total capacity of wind turbines*, *total number of installed wind turbines* and *total energy generated by wind capacity*.

The variable *percentage growth new capacity of wind turbines* is the exogenous driver of the growth of the stock variable *new wind turbine capacity capacity* –which represents the capacity

Table 4-1 : 12% wind-powered electricity worldwide by 2020

Year	Average annual growth rate	Annual new capacity	Cumulative capacity by end of year	Annual wind electricity production	World electricity demand	Wind power penetration of global electricity
ratio		MW	MW	TWh	%	TWh
2001		6,800	24,900	54.5	15,578	0.35
2002		8,500	33,400	73.1	16,014	0.46
2003		10,625	44,025	96.4	16,463	0.59
2004	25%	13,281	57,306	125.5	16,924	0.74
2005		**16,602**	**73,908**	**161.9**	**17,397**	**0.93**
2006		20,752	94,660	207.3	17,885	1.16
2007		25,940	120,600	264.1	18,385	1.44
2008		31,128	151,728	332.3	18,900	1.76
2009		37,354	189,081	414.1	19,429	2.13
2010	20%	**44,824**	**233,905**	**512.3**	**19,973**	**2.56**
2011		53,789	287,694	705.7	20,493	3.44
2012		64,547	352,241	864.0	21,025	4.11
2013		74,229	426,470	1,046.0	21,572	4.85
2014	15%	85,363	511,833	1,255.4	22,133	5.67
2015		**98,168**	**610,001**	**1,496.2**	**22,708**	**6.59**
2016		107,985	717,986	1,761.1	23,299	7.56
2017		118,783	836,769	2,052.4	23,905	8.59
2018	10%	130,661	967,430	2,372.9	24,526	9.68
2019		143,727	1,111,157	2,725.4	25,164	10.83
2020		**150,000**	**1,261,157**	**3,093.4**	**25,818**	**11.98**
2030	0%	150,000	2,571,277	6,306.8	31,318	20.14
2040		150,000	3,044,025	7,999.7	36,346	22.01

Figure 22.1: Table 4.1 from the Wind Force 12 Report

of the wind turbine construction industry– and therefore of the whole replication model. In the report, this wind turbine construction capacity increases from 2002 on with 25%, from 2008 on with 20%, from 2013 on with 15%, and from 2016 on with 10%, in 2020 with 4,36% and from 2021 on with 0% which means that the modeled industry does not shrink. The *new wind turbine capacity capacity* will be commissioned every year through the flow variable *new capacity of wind turbines* in the installed capacity structure in figure 22.4. This commissioned capacity will be decommissioned after exactly 20 years (*lifetime wind capacity*) as in the Wind Force report.

The bottommost structure in figure 22.4 counts the number of installed wind turbines. The *new number of wind turbines* consists of the *new capacity of wind turbines* divided by the average *wind turbine size* at the moment of commissioning. The sum of the *total number of installed wind turbines* and the *cumulative decommissioned number of installed wind turbines* is the *cumulative historical number* of wind turbines. The variables *cumulative historical number*, *cumulative historical number t-1* of the previous year and the *experience curve parameter* determine the production cost per kW of a new wind turbine according to the following experience curve formula used in the report:

$$C_t = C_{t-1}\Big(\frac{X_t}{X_{t-1}}\Big)^e \tag{22.1}$$

Where C_t stands for the production cost of a wind turbine per kW at moment t and X_t for the *cumulative historical number* of wind turbines ever built, and e for the *experience curve parameter* which is equal to $-log_2$`(progress ratio)`.

The *initial cost* of new capacity in the report and the model is 879 €/kW in 2001. The stock variable *cost new capacity (t+1)* performs of course the technical function of memory.

5. Make a causal loop diagram of the model.

Growth rate	Year	Cumulative MW	Annual MW	Annual avg WTG (MW)	Cumulative No. of units (%)	Capacity factor	Production TWh	Progress ratio	Replacement MW	Units
	2001	24,900	6,800		56,000	25%	54.5			
	2002	33,400	8,500	1.0	64,500	25%	73.1			
	2003	44,025	10,625	1.0	75,125	25%	96.4			
	2004	57,306	13,281	1.2	86,193	25%	125.5			
25%	2005	73,908	16,602	1.2	100,027	25%	161.9			
	2006	94,660	20,752	1.2	117,321	25%	207.3	0.85		
	2007	120,600	25,940	1.3	137,274	25%	264.1			
	2008	151,728	31,128	1.3	161,219	25%	332.3			
	2009	189,081	37,354	1.4	187,900	25%	414.1			
20%	2010	233,905	44,824	1.4	219,917	25%	512.3			
	2011	287,694	53,789	1.4	258,338	28%	705.7			
	2012	352,241	64,547	1.5	301,369	28%	864.0			
	2013	426,470	74,229	1.5	350,855	28%	1,046.0			
15%	2014	511,833	85,363	1.5	407,764	28%	1,255.4			
	2015	610,001	98,168	1.5	473,209	28%	1,496.2			
	2016	717,986	107,985	1.5	545,199	28%	1,761.1			
	2017	836,769	118,783	1.5	624,388	28%	2,052.4			
10%	2018	967,430	130,661	1.5	711,495	28%	2,372.9	0.90		
	2019	1,111,157	143,727	1.5	807,313	28%	2,725.4			
	2020	1,261,157	150,000	1.5	907,313	28%	3,093.4			
	2021	1,411,157	150,000	1.5	1,007,313	28%	3,461.3			
	2022	1,561,157	150,000	1.5	1,107,313	28%	3,829.2			
	2023	1,711,157	150,000	1.5	1,207,313	28%	4,197.1			
	2024	1,847,876	150,000	1.5	1,307,159	28%	4,532.5		13,281	11,068
0%	2025	1,981,274	150,000	1.5	1,406,993	28%	4,859.7		16,602	13,835
	2026	2,110,522	150,000	1.5	1,506,816	28%	5,176.7		20,752	17,293
	2027	2,234,583	150,000	1.5	1,606,627	28%	5,481.0		25,940	19,954
	2028	2,353,455	150,000	1.5	1,706,434	28%	5,772.6		31,128	23,945
	2029	2,466,101	150,000	1.5	1,806,236	28%	6,048.9		37,354	26,681
	2030	2,571,277	150,000	1.5	1,906,032	28%	6,306.8		44,824	32,017
0%	2031	2,667,488	150,000	2.0	1,980,824	28%	6,542.8		53,789	38,421
	2032	2,752,941	150,000	2.0	2,055,609	28%	6,752.4		64,547	43,031
	2033	2,828,712	150,000	2.0	2,130,398	28%	6,938.3		74,229	49,486
	2034	2,893,349	150,000	2.0	2,205,188	28%	7,096.8	1.00	85,363	56,909
	2035	2,945,181	150,000	2.0	2,279,981	30%	7,739.9		98,168	65,445
0%	2036	2,987,197	150,000	2.0	2,354,783	30%	7,850.4		107,985	71,990
	2037	3,018,414	150,000	2.0	2,429,593	30%	7,932.4		118,783	79,189
	2038	3,037,752	150,000	2.0	2,504,409	30%	7,983.2		130,661	87,107
	2039	3,044,025	150,000	2.0	2,579,231	30%	7,999.7		143,727	95,818
	2040	3,044,025	150,000	2.0	2,654,066	30%	7,999.7		150,000	100,000
0%	2041	3,044,025	150,000	2.0	2,728,917	30%	7,999.7		150,000	100,000
	2042	3,044,025	150,000	2.0	2,803,781	30%	7,999.7		150,000	100,000
	2043	3,044,025	150,000	2.0	2,878,657	30%	7,999.7		150,000	100,000

Figure 22.2: Appendix table 1 from the Wind Force 12 Report. Annual avg. WTG (MW) stands for the average Wind Turbine Size.

Cost (DKK/kWh) = a * (X/X0)^-b

USD 1 = 1.1494
USD 1 = kr 8.30

Progress ratio	Year	Cumulative MW	Cumulative no. of units	USD cent/kWh	Electricity EURO cent/kWh	Capacity USD/kW	Capacity Euro/kW	Electricity DKK/kWh	Capacity DKK/kW
	2001	24,900	56,000	3.61	4.15	765	879	0.300	6,350
	2002	33,400	64,500	3.50	4.02	740	851	0.290	kr 6,143
	2003	44,025	75,125	3.37	3.88	714	821	0.280	kr 5,927
a = 0.300	2004	57,306	86,193	3.27	3.75	691	795	0.271	kr 5,739
X0 = 56,000	2005	73,908	100,027	3.15	3.63	668	768	0.262	kr 5,542
b = 0.2345	2006	94,660	117,321	3.04	3.49	643	739	0.252	kr 5,339
85%	2007	120,600	137,274	2.93	3.37	620	713	0.243	kr 5,146
	2008	151,728	161,219	2.82	3.24	597	686	0.234	kr 4,955
	2009	189,081	187,900	2.72	3.13	576	662	0.226	kr 4,781
	2010	233,905	219,917	2.62	3.01	555	638	0.218	kr 4,607
	2011	287,694	258,338	2.56	2.94	542	623	0.212	kr 4,496
	2012	352,241	301,369	2.50	2.87	529	608	0.207	kr 4,391
	2013	426,470	350,855	2.44	2.81	517	594	0.203	kr 4,291
	2014	511,833	407,764	2.39	2.74	505	581	0.198	kr 4,193
	2015	610,001	473,209	2.33	2.68	494	568	0.194	kr 4,099
a = 0.218	2016	717,986	545,199	2.28	2.62	483	556	0.190	kr 4,012
X0 = 219,917	2017	836,769	624,388	2.24	2.57	473	544	0.186	kr 3,930
90%	2018	967,430	711,495	2.19	2.52	464	533	0.182	kr 3,852
b = 0.1525	2019	1,111,157	807,313	2.15	2.47	455	523	0.179	kr 3,779
	2020	1,261,157	907,313	2.11	2.43	447	514	0.175	kr 3,712
	2021	1,411,157	1,007,313	2.08	2.39	440	506	0.173	kr 3,653
	2022	1,561,157	1,107,313	2.05	2.36	434	499	0.170	kr 3,601
	2023	1,711,157	1,207,313	2.02	2.33	428	492	0.168	kr 3,554
	2024	1,847,876	1,307,159	2.00	2.30	423	486	0.166	kr 3,511
	2025	1,981,274	1,406,993	1.98	2.27	418	481	0.164	kr 3,472
	2026	2,110,522	1,506,816	1.98	2.27	418	481	0.164	kr 3,472
	2027	2,234,583	1,606,627	1.98	2.27	418	481	0.164	kr 3,471
	2028	2,353,455	1,706,434	1.98	2.27	418	481	0.164	kr 3,471
	2029	2,466,101	1,806,236	1.98	2.27	418	481	0.164	kr 3,471
	2030	2,571,277	1,906,032	1.98	2.27	418	481	0.164	kr 3,471
	2031	2,667,488	1,980,824	1.98	2.27	418	481	0.164	kr 3,471
a = 0.164	2032	2,752,941	2,055,609	1.98	2.27	418	481	0.164	kr 3,471
X0 =	2033	2,828,712	2,130,398	1.98	2.27	418	481	0.164	kr 3,471
1,406,993	2034	2,893,349	2,205,188	1.98	2.27	418	481	0.164	kr 3,471
100%	2035	2,945,181	2,279,981	1.98	2.27	418	481	0.164	kr 3,471
b = 0.001	2036	2,987,197	2,354,783	1.98	2.27	418	481	0.164	kr 3,471
	2037	3,018,414	2,429,593	1.98	2.27	418	481	0.164	kr 3,471
	2038	3,037,752	2,504,409	1.98	2.27	418	481	0.164	kr 3,471
	2039	3,044,025	2,579,231	1.98	2.27	418	481	0.164	kr 3,471
	2040	3,044,025	2,654,066	1.98	2.27	418	481	0.164	kr 3,470
	2041	3,044,025	2,728,917	1.98	2.27	418	481	0.164	kr 3,470
	2042	3,044,025	2,803,781	1.98	2.27	418	481	0.164	kr 3,470
	2043	3,044,025	2,878,657	1.98	2.27	418	481	0.164	kr 3,470

Figure 22.3: Appendix table 3 from the Wind Force 12 Report

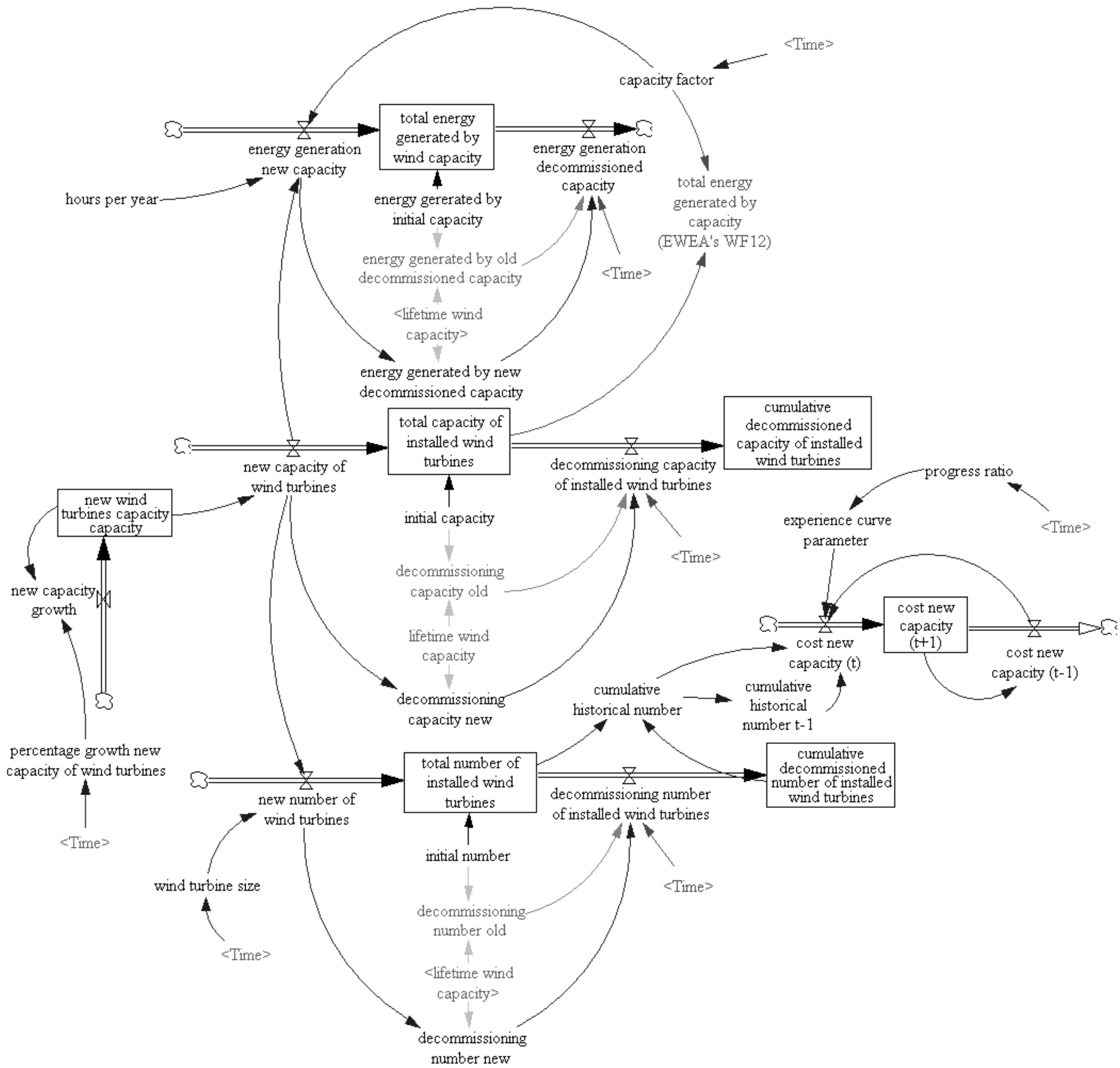


Figure 22.4: A possible stock/flow diagram of part of the Wind Force 12 report.

6. Analyze the stock-flow diagram, the causal loop diagram, the data and the simulation results. Is this model a dynamic model?

7. After analysis of the data, the simulation results, the Excel model and the SD model, it should become clear that the original Wind Force model contains some errors –or structures that could be improved– that are easily discovered when modeling in terms of stocks and flows. Which errors have you discovered? Improve the model / correct the errors.

- A first improvement: In the *Wind Force 12* report, only the newly added wind turbines from 2004 on are decommissioned. In the report, decommissioning of capacity starts only in 2024, which means that the initial capacity and the capacity commissioned before 2004 are not decommissioned (after a *lifetime wind capacity* of 20 years). All other things being equal (thus not corrected for other errors), this comes down to 75125 wind turbines with a total nominal power of 44025MW generating 96,41TWh per year assuming a capacity factor of 25% (before 2011), or 107,98TWh per year assuming a capacity factor of 28% (2011-2034), or 115,69TWh per year assuming a capacity factor of 30% (from 2035 on) (see also table 22.3). For comparison, the total Belgian electricity demand in 2003 was 85,50TWh.

  In order to project the long-term world wind power, these 44025MW need to be decommissioned (before 2024). Thus, a decommissioning scheme needs to be added in order to project the outputs more accurately. Improve the model by adding the necessary structures to simulate a decommissioning of capacity installed before 2004 on top of the decommissioning of newly installed capacity from 2004 on. Model for example a (simplistic) linear decommissioning of 1245MW per year until 2020[7], of 6800MW in 2021 (commissioned in 2001), of 8500MW in 2022 (commissioned in 2002) and of 10625MW in 2023 (commissioned in 2003) was modeled. Generate the improved output and compare it to the original output.

- A second improvement: relates to the sudden *capacity factor* change for all installed wind turbines: in 2011 the capacity factor[8] increases all of a sudden from 25% to 28% for the *total capacity of installed wind turbines*, and not only for those that are being commissioned at that moment, but also for all those that have already been installed before, all around the world. In 2035 the *capacity factor* increases again all of a sudden from 28% to 30% for all these wind turbines which results in a rather marked and unrealistic discontinuity in terms of *total energy generated by capacity* (compare the red line in the left-hand side graph of figure 22.5 to the blue line). This second error is replicated in figure 22.4 by the variable *total energy generated by capacity (EWEA's WF12)*.

  Structurally, it would be better to assume that all wind turbines commissioned from 2011 on have a theoretical *capacity factor* of 28%, and all wind turbines commissioned from 2035 on have a theoretical *capacity factor* of 30%. That would result in a less pronounced adjustment (the blue line in the left-hand side graph of figure 22.5). The stock variable *total energy generated by wind capacity* allows for more correct calculations[9]. Here, the flow variable *energy generation new capacity* consists of the multiplication of the *new capacity of wind turbines*, the *number of hours per year* (8760h) and the expected *capacity factor* at the time of installation. This amount of energy generated per year is then stored in the stock variable *total energy generated by capacity* during a *lifetime wind capacity* of 20 years. Thus, the stock variable *total energy generated by capacity* represents the total energy generated per year taking into account the installed capacity of wind turbines at that moment and the capacity factor at the time of their commissioning.

  Model both structures in your own model and compare the outcomes with figure 22.5 and table 22.3. All else being equal (thus not correcting the decommissioning of initial capacity)

[7] $\frac{1}{lifetimewindcapacity}$ or $\frac{1}{20}^{th}$ of the initial capacity of 24900MW

[8] The capacity factor is the fraction of the year the wind turbine would have to generate at nominal (maximum) power to generate the electricity generated intermittently on average during the year.

[9] A gradual shift would even be better, because more in line with reality.

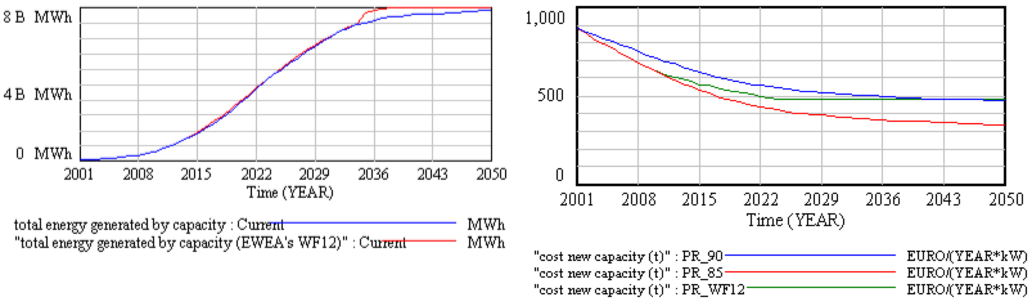


Figure 22.5: **Left-hand side:** *Total energy generated by capacity* as in the *Wind Force 12* report (red curve) and as calculated in the corrected model (blue curve). **Right-hand side:** The impact on the *cost of new capacity (t)*[€/kW] of the changing *progress ratio* of the *Wind Force 12* report compared to two constant *progress ratios* of 85% and 90%.

the difference amounts to about 76TWh in 2020, and to 413TWh in 2040. Combined with the previous improvement (the decommissioning of initial capacity), the simulated difference grows to 128TWh in 2020, to 164TWh in 2025, to 624TWh in 2035 and 510TWh in 2040.

Table 22.3: The difference between the *total energy generated by capacity* as in the *Wind Force 12* report and as calculated in the corrected model [TWh]

Year	2010	2020	2025	2030	2035	2040
Only correcting the decommissioning of initial capacity	25	58	108	108	115	116
Only correcting the *capacity factor*	0	76	68	25	398	413
Correcting the *capacity factor* **and** the decommissioning of initial capacity	25	128	164	122	624	510

- A third improvement: Quite particular –not so much erroneous– is the experience curve driven by the *cumulative historical **number*** of wind turbines instead of the cumulative historical **capacity**, which means among else that the development of larger sized –instead of more smaller sized– turbines slows learning. The *progress ratio* used by the EWEA augments abruptly from 85% in the period 2001-2010 to 90% in the period 2011-2025 and jumps to 100% from 2026 on (see the right hand side graph in figure 22.5 for the resulting *cost new capacity (t)* as compared to constant *progress ratios* of 90% and 85%). Referring to equation 22.1 (on page 286), a *progress ratio* of 85% expresses that when the cumulative output X_t doubles, the production cost C_t decreases with the learning rate of (1-85%) or 15%. The *progress ratio* of 100% from 2026 on means that learning leading to production cost decreases will have stopped completely. In the limit, this would also have happened with a constant *progress ratio*.

  One could wonder why the increasing *progress ratio* has been chosen, while experience curves with constant *progress ratios* also become constant in the limit. This results from the fact that the percentage decrease in costs only happens when doubling the cumulative capacity installed or produced or the number of wind turbines installed or produced or the quantity of electricity generated. The right-hand side of figure 22.5 shows the effect of the EWEA evolution of the *progress ratio*, and that of a *progress ratio* of 85% and one of 90%. The explanation provided for by the EWEA are the expected benefits of series production, and the utilization of the full potential of future design optimizations. But if the full benefits of series production are still to be reaped, how could the progress ratio go up instead of down? And why should costs stop decreasing after 2029?

Table 22.4: The decreasing number of jobs per MW (*jobyear per MW lookup*).

1998	2005	2010	2015	2020
22	14.7	12.2	10.9	9.8

Model therefore a single *progress ratio*. Using a single *progress ratio* has two advantages: (i) the single *progress ratio* could easily be subjected to sensitivity analysis, and (ii) it could easily be changed to project different technological development paths or changes in technological development. Is the model sensitive to changes of the *progress ratio*? Why?

- A fourth improvement –at least from a system dynamics perspective– would involve replacing the exact *lifetime wind capacity* of 20 years by an **average** *lifetime wind capacity* of 20 years. Adapt the model. Do the results change significantly? Why?

8. Now, add calculation modules for the electricity generation costs, jobs created and CO_2 emissions avoided. Three small modules could indeed be added to the model to calculate the costs per kWh of the wind turbine electricity generated, the (direct and indirect) jobs created by the wind turbine industry and the CO_2 emissions avoided by the generation of wind power instead of electricity generated with other technologies. In this model, these calculation modules will not lead to dynamic changes in the rest of the model. In an extended model, these modules –those on the CO_2 emissions avoided and the price per kWh– could feed back to the main model.

- Costs of wind electricity generated: Make sure that the currently installed as well as the newly commissioned *total cost new capacity installed* will be decommissioned –just as in the former similar structures– after the (average) *lifetime wind capacity* of 20 years.

  Assume that the *operational and maintenance costs* amount annually to 3% of the *total cost capacity installed*, that the interest costs amounts to the *interest rate* of 10% times the *total cost capacity installed*, and the *write-off costs capacity installed* equal the fraction of *total cost capacity installed* over the (average) *lifetime wind capacity*[10].

  The *cost wind turbine electricity generated* in [€/MWh] is then calculated as the *annual total cost wind capacity* divided by the *total energy generated by wind capacity.*

- Number of jobs created: Several job variables could be calculated, because the *Wind Force 12* report lacks precise information concerning these jobs which makes that the data cannot be replicated. Develop several structures to assess the number of jobs created, based on the information that '17 man-years are created for every MW of wind energy manufactured and 5 job-years for the installation of every MW. With the average price per kW of installed wind power at $1000 in 1998, these employment figures can then be related to monetary value, showing that 22 job-years (17+5) are created by every $1 million in sales' (European Wind Energy Association and Greenpeace 2002, p36). Table 22.4 could be used for this purpose. The different outcomes could either be used to calculate an interval or be validated against real-world data in order to select the most appropriate structure. Nevertheless it should be kept in mind that all these relationships are nothing but extrapolations of a historical numerical relationship.

- The amount of CO_2 emissions avoided: The quantity of CO_2 emissions avoided depends on the CO_2 emissions of the electricity generation mix it is substituting for. The *Wind Force 12* report assumes a mix with a constant average value of $600tCO_2/GWh$ to 2020. But the higher the wind energy percentage in the total mix, ceteris paribus, the lower the emissions

[10] annual total cost wind capacity = total cost capacity installed * (interest rate + operational and maintenance cost rate) + write-off costs capacity installed

per GWh of the mix, the new wind turbines are substituting for. Therefore, it seems to be better to take the specific emissions of the substituted generation mix into account.

Improve this assumption with the following information/assumptions from the World Energy Outlook 2000 (International Energy Agency 2001, p356), the *Wind Force 12* report and from (Voorspools et al. 1999). Coal technologies emit directly and indirectly between 751-962tCO_2/GWh, gas technologies between 400-428tCO_2/GWh, oil technologies 726tCO_2/GWh, nuclear technologies 7tCO_2/GWh, wind turbines between 9-28tCO_2/GWh, hydro between 8 and 15tCO_2/GWh and biomass between 55-540tCO_2/GWh[11] (see table 22.5). Table 22.5 also lists the assumed shares of the different technologies at different moments in the world electricity supply taken from the World Energy Outlook 2000 (International Energy Agency 2001, p356) to calculate the mix and its specific emissions.

Table 22.5: Assumptions in the system dynamics model concerning CO_2-emissions and generation by other technologies.

Technology	CO_2-emissions per GWh [tCO_2/GWh]	basecase spec. CO_2 [tCO/GWh]	generation in 2001 [TWh]	generation in 2010 [TWh]	generation in 2020 [TWh]
gas	400-428	400	5992	4698	7745
coal	751-962	800	1331	7467	9763
oil	726	726	2940	1442	1498
nuclear	7	7	2471	2647	2369
hydro	8-15	8	2804	3341	3904
biomass	55-540	100	268	395	603

The sum of the *specific CO_2 emissions* of the different technologies multiplied by the electricity generated with these technologies, gives the annual *total CO_2 emissions*. The *world electricity supply* is simply the sum of the *electricity generation* with the different technologies. The *total CO_2 emissions* divided by the *total CO_2 emissions* gives the sought-after *specific CO_2 emissions world* of the *generation mix*. Subtracting the *specific CO_2 emissions wind* from the latter variable, gives the variable *net specific CO_2 emissions avoided*. Multiplying this variable by the *total energy generated by wind capacity* gives the flow variable *annual CO_2 emissions avoided* and the stock variable *cumulative CO_2 emissions avoided* from 2001 on.

Compare the outcomes of this flow-stock structure to the outcomes of a calculation with a fixed *tCO_2 avoided per GWh if constant mix* of 600t/GWh times the electricity generated as in the model, and to the data from the *Wind Force 12* report (*annual CO_2 emissions avoided WF12* and *cumulative CO_2 emissions avoided WF12*). Do the outcomes of the improved model –in terms of CO_2 avoided– differ strongly from the conclusions of the report?

9. Design different policies to boost world wind power. Use the model to test these different policies.
10. Use the model to test the sensitivity of parameters and structural hypotheses.
11. Turn this rather static model into a more dynamic model. What adaptations do you propose? Are the more dynamic models more sensitive to parameters and structural hypotheses? Why? Are the policy recommendations different?
12. A model and model results should also be reassessed / updated regularly. It is interesting in that sense to compare the projections with the new model(s) with the new projections of the

[11] The generation of the item *Other Renewables* from the WEO2000 (International Energy Agency 2001, p356) is assumed to be generated completely by *biomass*. Thus, biomass is probably overrated. Apply therefore the specific emission of 100tCO_2/GWh.

updated Wind Force 12 report (Global Wind Energy Council and Greenpeace International 2005, June) (GWEC).

According to this updated study:

- The total MW installed in 2020 will reach 1254GW.
- The wind power generated in the year 2020 will amount to 3054TWh.
- This results by 2020 in annual CO_2 emissions avoided of 1,832 $GtCO_2$/y according to the GWEC (1,585 $GtCO_2$/y as calculated in the initial Wind Force 12 report), or to a cumulative CO_2 reduction until 2020 of 10,771 $GtCO_2$ according to the GWEC (8,214 $GtCO_2$ as calculated statically by the initial Wind Force 12 report).
- The total annual investment in wind power reaches €80 billion in 2020, which is related to the marginal investment costs in 2020 of €512/kW.
- This partly leads to an electricity generation cost in 2020 of €24,5/MWh according to the GWEC. However, these costs are only partial since interest costs, maintenance costs, et cetera, are not included.
- And the number of total job-years reaches 2,3 million.

Compare your results with the revised data of the GWEC. Adapt your model if necessary.

A last remark concerns the use of spreadsheets for system dynamics modeling. Spreadsheets could be used to model system dynamics models. But spreadsheets implicitly hide many structural assumptions which are rendered explicit with graphical system dynamics packages. There are however graphical add-ins (such as Expose) that improve system dynamics modeling by means of spreadsheets.

22.4 Strategic Management & Leadership

Introduction

Although the word 'leadership' could be defined in terms of the behavior of a leader, it could also be defined –referring to aspects of inter-personal relations, social influence processes, relationship between leader and team, environmental factors surrounding teams, relationships between teams, and perceptions of organizational climates– at the organizational/collective level. In this ever more complex, interconnected, and uncertain world, genuine organizational leadership is needed more than ever. And although significant future changes in leadership requirements could be expected, the literature on leadership and most leaders largely ignore dynamic complexity and deep uncertainty. Only a gradual continuation of recent trends or a future characterized by ever faster change, ever more (required) flexibility, and ever more scarcity (especially in terms of highly qualified human resources) are considered by leadership gurus. Plausible consequences of dynamic complexities and deep uncertainty are largely ignored and robustness of strategies for dealing with many different futures is hardly ever considered.

Here, organizational leadership over time, i.e. building future organizational leadership capabilities, is focused on. In this case, you need to build a SD-based leadership flight simulator tailor-made for serious gaming workshops with CEOs and senior HR managers to pull them out of their predictive modes, to allow them to experience different futures, and to help them broaden their perspectives on the uncertain(ty of the) future and the consequences for the future of strategic (HR) management. The model to be built here is a leadership model, in spite of the fact that it does not contain variables that refer explicitly to leadership, since it is centered around three important decisions related to leadership and building organizational leadership capabilities: vision, workforce (composition and size), and (institutional) policies and (work) structures.

Capital-Based Competitive Advantage

This case is based on an extension of the concept of capital for competitive advantage. In today's environment, the traditional focus on *economic capital* (i.e. financial and tangible assets) is no longer sufficient to ensure competitive advantage. Today, *human capital* defined as employees' knowledge, experiences, skills and expertise, and flexibility, innovation and speed-to-market are equally crucial for sustained organizational performance (Luthans et al. 2004). Harter et al. (2002), among others, revealed that when the human capital in an organization is engaged and aligned with the corporate strategy, the performance of the organization increases. This finding is in line with the resource-based theory of the firm (Barney 1991). On top of investing in economic and human capital, organizations should also invest in social capital. Social capital refers to trust, relationships, and contact networks (Luthans et al. 2004).

But, investing in economic, human and social capital alone may in the medium term future not be sufficient: Luthans et al. (2004) argue psychological capital or PsyCap needs to be invested in too. Where traditional *economic capital* relates to what you have, *human capital* relates what you know/can do, and *social capital* relates to whom you know, *positive psychological capital* relates to self-esteem, optimism, resilience, hope, self-awareness, et cetera – in other words: to who you are.

From this perspective, *positive psychological capital* equips organizations for dealing with complex uncertain futures. PsyCap could be invested in by attracting and investing in authentic leaders. Authentic leaders are leaders 'who are deeply aware of how they think and behave and are perceived by others as being aware of their own and others' values/moral perspectives, knowledge, and strengths; aware of the context in which they operate; and who are confident, hopeful, optimistic, resilient, and of high moral character' (Avolio et al. 2004). Authentic leaders have high PsyCaps. On the organizational level, authentic leadership could then be defined as 'a process that draws from both positive psychological capacities and a highly developed organizational context, which results in both greater self-awareness and self-regulated positive behaviors on the part of leaders and associates, fostering positive self-development' (Luthans and Avolio 2003).

Capital-Based Model of the Firm

Assume, for the sake of simplicity, that economic capital consists of manufacturing plants and machines, that human capital consists of both *lowly skilled employees* and *highly skilled employees*, that social capital consists of highly educated people with networking skills and extended networks, i.e. the *social networkers*, and that positive psychological capital consists of *authentic employees*. Add explicit stock-flow structures for lowly skilled personnel, highly skilled personnel, social networkers, and authentic leaders.

Assume that social networkers are highly skilled employees with actively developed networking skills and networks, who are allowed to spend part of their time on networking activities. If insufficient resources are made available to support their networking activities, they are likely to leave the organization or stay but lose their networks and skills, thus turning from social networkers into highly skilled personnel. Assume that authentic employees are highly skilled, almost natural social networking talents, with an intrinsic motivation, and authentic ethos and ethic. Attrition rates of authentic employees are much lower than those of other social networkers. However, authentic leaders are so scarce and intrinsically motivated that it takes a lot of time and resources to find, interest, and hire them. Social networkers may –over time or through good coaching– become authentic leaders, but authentic leaders –by the fact that their motivation, ethic and ethos are intrinsic– do not fall back. All categories can be hired and fired.

Hence, except for the lowly skilled, there is some form of mobility between these groups: part of the highly skilled employees (could) become social networkers, but social networkers fall back to 'just' highly skilled personnel if insufficient recurrent resources (money and time) are invested in their networking skills and networks, and only social networkers (could) possibly become authentic personnel. Once authentic, always authentic. And these different groups are characterized by different degrees of scarcity and attrition rates.

To capture the main human resource decisions for these four groups of employees, add the following six decision variables for future budget allocations (it takes more than a year for decisions to take effect, and in some cases they may not even lead to the desired results):

- total planned personnel expenditures for next year,
- fraction of next year's personnel expenditures spent on lowly skilled personnel,
- fraction of next year's personnel expenditures spent on highly skilled personnel,
- fraction of next year's personnel expenditures spent on social networkers,
- fraction of next year's personnel expenditures spent on authentic leaders, and
- total planned networking expenditures (which are necessary to breed and keep social networkers, else they leave or regress into highly skilled personnel).

The degree of transformational culture of the organization corresponds to the sum of the fraction of authentic personnel and the fraction of social networkers. The degree of transactional culture of the organization corresponds to the fraction of lowly skilled and highly skilled people.

Decisions also need to be made about *investments in organizational and structural stability* and *investments in organizational and structural flexibility*, and about the *authenticity and flexibility orientedness of vision and strategy* (i.e. the vision).

Model the '*transformational structure score*' as the minimum of the *transformational culture* score, the *transformational structure score*, and the *authenticity and flexibility orientedness of vision and strategy*. And model the '*transactional organization score*' as the minimum of the *transactional culture* score, the *transactional structure score* and the complement of the *authenticity and flexibility orientedness of vision and strategy*. In other words, the weakest link (i.e. vision, personnel, or policies and structures) determines the strength of the chain (leadership and outcomes of the strategy).

But vision, composition of personnel, and policies and structures also need to match the environment – driven by the exogenous lookup variable *ideal degree of flexibility and authenticity*. This environmental and organizational fit determines the revenues earned per employee. And the total available financial buffer accumulates revenues minus costs minus taxes over time. Add the following decision variables too:

- authenticity and flexibility orientedness of vision and strategy (0 = 100% stability-oriented; 1 = 100% flexibility-oriented),
- (planned) investments in organizational and structural stability, and
- (planned) investments in organizational and structural flexibility.

Challenges

1. Build a relatively simple model that captures all of the above. Although the underlying model should be simple, it should also be good enough for the flight simulator that will be built on top to simulate different 'leadership strategies' such as:
   - transactional leadership: a vision focused on transactions and stability, HR focused on lowly and highly skilled personnel, and implementation of stability oriented policies and structures;

- transformational leadership: a vision focused on authenticity and flexibility, HR focused on networking and authentic personnel, and implementation of flexibility oriented policies and structures;
- ambidextrous leadership: a vision focused on flexibility *and* stability (efficiency), HR focused on a delicate balance of all types of employees, and implementation of both types of policies and structures;
- robust leadership: a contingent vision, HR focused on hiring at least a sufficient number of employees of different types (especially of those types that are difficult to hire) that would be minimally required for an ensemble of futures, and sufficient investments in both types of structures and policies;
- contingent leadership: a contingent vision, HR focused on hiring and firing according to the evolution of the environment of the particular future, and reactive investments in the type of structures and policies required by the environment of that particular future;
- transitional leadership: gradually shifting from one leadership strategy to the other;
- inconsistent leadership: any inconsistent combination of vision, HR decisions, and policies and structures.

2. Make an interface that looks like a flight simulator dashboard with four dynamic Figures –one related to all expenditures, one to personnel, one to financial bottom line and buffer, and one to environmental indicators and drivers– and nine sliders for the decision variables. In these four views, players see the evolutions of key external and internal indicators from the start of the simulation until the year before the one they have to make their decisions about (e.g. in 2025 information is available from 2010 until 2024).

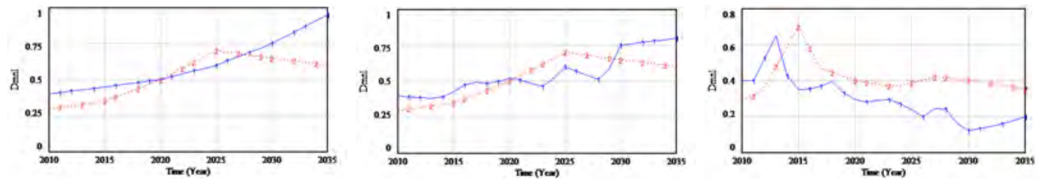
3. Make sure that consistency of vision, HR decisions, policies and (work) structures, and to a lesser degree consistency of these with external evolutions are required to score well. Inconsistency should be punished, possibly with a delay. Add external evolutions related to workforce flexibility, degree of globalization, environmental flexibility, average company size, and degree of governmental interventionism. Not all of these evolutions need to influence the rest of the model. Also add two exogenous drivers that drive most of these external evolutions: the *ideal degree of flexibility and authenticity* and *workforce flexibility*. Add three sets of time series as in Figure 22.6 that are the basis of the following three scenarios:

   - Scenario S1 consists of an increasing workforce flexibility especially between 2015-2025 followed by slowly decreasing workforce flexibility, continued globalization, rather stable environmental flexibility, decreasing average company size, and exponentially decreasing governmental interventionism.
   - Scenario S2 consists of similar evolutions of the same indicators as in scenario S1 except for somewhat less gradual and slightly more cyclic evolution of the globalization, the environmental flexibility, and the governmental interventionism.
   - Scenario S3 consists of more pronounced changes at the beginning followed by gradual developments.

   Although the past evolutions of these scenario variables should be visible to the gaming participants, not all of these indicators have to influence the underlying simulation model. Drive most of the changes in these scenarios by two time series: the *ideal degree of flexibility and authenticity* and *workforce flexibility* (see Figure 22.6). The latter two should also influence the rest of the model.

4. Test the model, scenarios, and interface.

5. Then, use it for serious gaming purposes.



(a) Underlying drivers S1 (b) Underlying drivers S2 (c) Underlying drivers S3

Figure 22.6: Underlying drivers of three scenarios: ideal degree of flexibility and authenticity (–1– blue) and workforce flexibility (–2– red)

6. What could be concluded?
7. Make a CLD of the system that could be used to explain the choice between investing in flexibility and investing in stability.

22.5 Evidence-Based Fight against HIC across Districts

Introduction

The goals of this case are to merge all previous cases related to High Impact Crime fighting –case 14.11 on p.174, case 18.9 on p.225, and case 18.17 on p.241– into a single model, extend it with different types of criminals, their motives, and the judicial chain, to subscript the new model for three base teams and 20 districts, and to link the model to an Excel sheet with real data of these 20 districts.

1. Open the models of case 14.11 'fighting HIC on the national level', of case 18.9 'fighting HIC on the regional level', and of case 18.17 'fighting HIC across multiple districts'. Merge these three case models into a model with as many local details as possible;
2. Open the background reading related to different types of criminals and their motives, and to the judicial chain. Extend the judicial chain submodel with an integrated submodel regarding criminals in/out of the judicial chain;
3. Subscripts for 20 districts for each of 3 base teams, i.e. 60 districts in total, and extend the police capacity submodel;
4. Link the model to the Excel file with data of the 20 districts and 3 base teams;
5. Study the random properties of the data in the Excel sheet. Add randomizers or random randomizers to replicate the randomness of the data in simulated counterparts of processes with random processes;
6. Test the model.
7. Use it for advice under uncertainty to the chief of police: what needs to be done across these districts to effectively fight High Impact Crime?

22.6 Heroin

The Issue

Europe is currently (first half of 2007) flooded by cheap heroin. The European heroin price dropped from about €50/gram to €30/gram (and even €10/gram in some cities). The cause seems to be the increased poppy cultivation (+50% last year) in Afghanistan which has a share of almost 90% of the world poppy production. Poppy cultivation has become a quick and steady source of incomes / means to survive in the strife-torn country, especially for the rebels (VRT News, 11 July 2007).

The United Nations have estimated that over 13 million Afghans are involved in the drug trade, with more than 2.3 million Afghans involved in opium cultivation. Alternative livelihood programmes have given little or no incentive to switch to legal crops for farmers for whom opium is the only source of income. In a UN report, crop eradication was found to be at the root instability in many regions of Afghanistan. Opium licensing could provide Afghanistan with the stability and the income it needs to stand on its own two feet and could be crucial for Afghanistan's reconstruction and its future.

In January 2006, the European Parliament called the existing counter-narcotics strategies 'seriously flawed'[12], highlighting its concern for increasing heroin use in Afghanistan which could also lead to an HIV/AIDS epidemic in the region, and pinned *opium licensing* as hope for the Afghan drug crisis. In the resolution, the European Parliament called on decision-makers to consider opium licensing for the production of medicines as an option for tackling the massive drug crisis in Afghanistan.

On Friday January 27 2006, the Daily Times published following opinion article by Emma Bonino (member of the European Parliament) explaining the EP position:

> ***Poppy power***
> An increase in production of 'medical' opium would address its lack of availability worldwide. It would also provide Afghan peasants, who have been growing poppy despite forced eradication of the plant and incentives to change crops, with an option that is regulated by law and that, in time, could have an impact on the heroin trade.
>
> This month, the European Parliament adopted a resolution on Afghanistan that could pave the way for a new and more open-minded approach to counter-narcotics strategies worldwide. In fact, the resolution calls on the participants at a conference of donors, to take place in London at the end of January, 'to take into consideration the proposal of licensed production of opium for medical purposes, as already granted to a number of countries.'
>
> This proposal was originally made by the Senlis Council, an independent organization based in Paris, during a workshop in Kabul last September. The text introduced by the European Liberal Democrats, with the support of virtually all political groups in the European Parliament, is revolutionary, not only because it goes against conventional thinking, but also because it raises the issue above the stagnant reality of the 'war on drugs'. In Afghanistan, that so-called war has essentially been based on eradication campaigns and alternative livelihood projects, which have achieved only scant results. The European Parliament's new stance may, I hope, mark the beginning of a radical policy shift by all actors involved in rebuilding Afghanistan.

[12] Counter-narcotics strategies in Afghanistan have so far been limited to crop eradication and alternative livelihood programmes, but these tactics have barely dented the amount of opium produced, which went down a mere 2% in 2005, but increase by some 50% in 2006.

According to the United Nations Office on Drugs and Crime, despite Orchestrated efforts at eradication and crop substitution, Afghanistan produced 87 percent of the world's opium in 2005 –roughly 4.1 tonnes– generating $2.7 billion of illegal revenue, which amounts to roughly 52 percent of the country's GDP. The 2005 Afghanistan Opium Survey, released last November, estimates that the total value of this opium, once turned into heroin and distributed around the world, could reach more than $40 billion.

Moreover, in recent years, factories and laboratories for processing opium into heroin have been sprouting in Afghanistan, producing 420 tonnes of heroin last year alone. The increase in domestic heroin production has provided a massive boost to the local retail market, giving rise to concerns about HIV/AIDS spreading in a country with poor infrastructure and nonexistent health services.

In addition, the itineraries used by the export convoys are no longer limited to the infamous 'golden route' through Pakistan and Iran, but have multiplied, employing exit points in former Soviet Republics such as Tajikistan, Uzbekistan, and Turkmenistan. This is promoting further instability in already volatile political contexts.

International counter-narcotics policy is currently driven by pressure for rapid and visible results. But eradication and alternative livelihood projects mainly affect the lowest end of the value-added chain, the farmers, with no real impact on those higher up, such as large landowners and local traffickers, not to mention the extremely powerful drug lords and the international cartels and mafias. Most landless farmers find it difficult to switch to different crops, being caught up as they are in the illegal opium-denominated market, which forces them to live at the mercy of the drug traffickers, who provide them with access to credit and market outlets.

The result of this was laid out in a report by the European Union's Election Observation Mission that I presented in Kabul last December: Afghanistan risks becoming a 'rentier' state with easy access to resources that lubricate corruption throughout its entire political system, finance illegal armed groups, and fuel regional destabilization. Illicit Afghan networks, replicating well-known methods that organized crime has applied successfully for decades in other parts of the world, are mobile and resourceful, and can plug into a range of legal economic activities to sustain themselves.

This might lead Afghanistan into a situation of no return: becoming a narco-state that drifts away from any form of rule of law and disengages itself from the fragile social contract with its own citizens that it has started to establish. As New York University's Barnett Rubin, an expert on Afghan society, has put it: 'Afghanistan cannot be stabilized while the most dynamic sector of its economy is illegal, nor if more than half of its economy is destroyed.'

So what should be done?

Because of the serious threat that the illegal drug economy poses to stability and democracy in Afghanistan, we must start thinking in terms of regulated poppy growing for medical purposes, in particular for painkillers, with the active participation of donor countries and the UN itself. Indeed, the UN estimates that just six countries prescribe 78 percent of the total legal production of opiates, implying shortages of opium-based painkillers in many of the UN's 185 other member states. Hence the potential legal demand is huge.

Moreover, the UN also estimates that there are 45 million people living with HIV/AIDS in countries where health systems are either absent or very poor, and that over the next 20 years there will be some 10 million new cases of cancer in the developing world. These estimates, together with poor countries' additional needs when natural catastrophes strike, imply that the potential legal demand for medicinal opiates is even higher.

Governments, international organizations and individuals that participate in the London conference must not dismiss the call made by the European Parliament, for it offers a far more workable strategy to promote Afghanistan's future than the current counter-narcotics policies permit. T-PS

Legally grown poppies could thus at the same time help to solve the chronic worldwide / European painkiller shortage. Currently, many European countries are chronically short of strong painkillers such as diamorphine. Diamorphine –also known as heroin– is used to relieve pain after operations and for the terminally ill. Poppies contain morphine which has to be chemically modified to produce diamorphine.

On Tuesday 23 January 2007, Adam Brimelow –BBC health correspondent– reported on the issue on the BBC News:

Afghan poppies 'could help NHS'

Doctors want Afghan poppy fields to be used for the NHS. Leading doctors say Afghanistan's opium-poppy harvest should be used to tackle an NHS shortage of diamorphine. The British Medical Association says using the poppy fields in this way, rather than destroying them, would help Afghans and NHS patients. Diamorphine, also known as heroin, is used to relieve pain after operations and for the terminally ill. But the UK and Afghan governments reject using the poppy fields to address the UK's diamorphine shortage.

However, UK doctors say the diamorphine shortage is getting worse, leaving them reliant on less effective, more expensive alternatives. Dr Jonathan Fielden, a consultant in anaesthesia and intensive care medicine in Reading, said: "Unfortunately over the last year in particular, the availability of diamorphine has dramatically reduced. It's not clear why this is, but it has got to the stage where it is almost impossible in some hospitals to get hold of this drug for use outside very specific circumstances. This is a great shame because it is such a good drug."

Barriers

The BMA has proposed a radical solution –harnessing the Afghan opium-poppy crop to produce diamorphine for the NHS. It says this would benefit patients while providing much-needed income for Afghan farmers.

Dr Vivienne Nathanson, head of science and ethics at the BMA, said it was time for a new approach. "If we actually were harvesting this drug from Afghanistan rather than destroying it, we'd be benefiting the population of Afghanistan as well as helping patients and not putting people at risk. There must be ways of harvesting it and making sure that the harvest safely reaches the drug industry which would then refine it into diamorphine. It should be possible, and really government and the international groups that are in Afghanistan should be looking at this and saying how can we convert it from being an illicit crop to a legal crop that is medicinally useful."

The Department of Health acknowledges there's been a shortage of diamorphine, but it says the situation is improving. A spokeswoman said: "We have been in discussion with other possible entrants to the market, but there are barriers to be overcome. One of the problems is that diamorphine injection has to be freeze-dried. This is a specialised process and there is limited production capacity both in the UK and elsewhere in the world."

'Direct benefits'

The Afghan authorities –backed by the UK government– reject the idea of local licensing to produce poppies for medicines. They are stepping up their programme of poppy crop eradication, and prosecution of drug-traffickers.

However Emmanuel Reinert, executive director of the international think-tank The Senlis Council says destroying poppy crops will only encourage people to support the Taleban. "The licensing system should be established at the village level, and the morphine should be produced at the village level. Therefore the mark-up will benefit directly to the villagers and the farmers and all the families. And it would be easy to export from the village to Kabul and then to the rest of the world, tablets from Afghanistan."

Other charities working in Afghanistan, including Christian Aid, are sceptical. They say the best solution is to provide long-term support such as irrigation projects to help

> farmers produce other crops.
> Dr Fielden accepted that persuading the international community to try the idea would not be easy[:] "The biggest difficulty will be changing the views of those countries, particularly the US, where this drug is banned. That will take a great cultural change to let them realise that a very cheap drug, easily produced, beneficial to patients, can be brought back in and used, rather than being seen as a drug of abuse."

See also on BBC News:

- Afghan drug crop to flood Europe 23 November 2006
- Afghanistan 'to spray poppy crop' 07 November 2006
- NHS painkiller shortage warning 23 December 2004

1. Make a causal loop diagram of the Afghan drug crisis.
2. What are the real issues?
3. Make a simple simulation model of the Afghan drug crisis.
4. Is the proposed licensing strategy an effective solution?
5. Could it solve the European painkiller shortage?
6. A lot has changed since early 2007: look for more recent information too! Then update your study. What would you advise the EU to do?

22.7 SD Project Cases

Add. case 1	Add. case 8	Add. case 15
Add. case 2	Add. case 9	Add. case 16
Add. case 3	Add. case 10	Add. case 17
Add. case 4	Add. case 11	Add. case 18
Add. case 5	Add. case 12	Add. case 19
Add. case 6	Add. case 13	Add. case 20
Add. case 7	Add. case 14	Add. case 21

Archive

'Every man knows that in his work he does best and accomplishes most when he has attained a proficiency that enables him to work intuitively. That is, there are things which we come to know so well that we do not know how we know them.' Albert Einstein

OLD LECTURES (Note: In the new set-up of the course, lectures have been replaced by Q&A sessions. In other words, you don't need these lectures: Watching them simply costs time.)

SD101 E-book	Lecture 3 fall 2012	Lecture 6 fall 2012
Lecture 1 fall 2012	Lecture 4 fall 2012	Lecture 7 fall 2012
Lecture 2 fall 2012	Lecture 5 fall 2012	Closing words (e-book)

SELECTION OF PRACTICE/OLD EXAMS (some are password protected)

2013 January: Seasonal Flu	2010 October: Boom and Bust in Dubai
2013 January: Drama on Housing Market	2010 January: Mineral/Metal Scarcity II
2012 November: Burglaries III	2010 April: Bluefin Tuna
2012 April: New Towns (based on GPR)	2009 October: 2009 Flu Pandemic
2011 November: De/Radicalization II	More practice/old exams
2010 October: De/Radicalization I	RAR folder with many exams in Dutch

ADDITIONAL ONLINE CHAPTERS (password protected – you don't need these old chapters!)

I. Systems and Models	V. Model Formulation
II. Hard and Soft Systems	VI. Model Testing
III. Intro to System Dynamics	VII. Model Use
IV. Model Conceptualization	Ap. Math for SD + bibliography

ONLINE REPOSITORIES OF CASE DESCRIPTIONS

|| Level 1 case descriptions (italics + MCQs)
|| Print. level 2 descriptions (teachers only)
|| Level 3 case descriptions (wo italics/MCQs)
|| Level 4 case descriptions (story+question)
|| Case descriptions in other languages

REPOSITORIES OF CASE DESCRIPTIONS & CHAPTERS FOR OTHER SOFTWARE

|| Case descr. for diff. software packages
|| Chapters for different software packages

ONLINE REPOSITORIES OF OTHER RESOURCES

|| Tutorials
|?| Recorded Q&A Sessions
|| Online MCQs Banks
|| Answers MCQs E-Book
|| MCQ Tests (for TUD students only)
|| Printable E-Book Chapters
|| Weekly videos
|| Instruction videos (hints)
|| Feedback videos
|| Feedback documents

ONLINE REPOSITORIES OF VIDEOS PER WEEK/DAY OF THE LEARNING PATH

|| Videos week 1
|| Videos week 2
|| Videos week 3
|| Videos week 4
|| Videos week 5
|| Videos week 6-10

ONLINE NEWS, INFO RELATED TO EXERCISE & CASES, ERRATA, INFO & CONTACT

|| News
|| Info and Contact
|| Exercises and cases
|| Errata (per version)

REPOSITORIES OF NEW/RECENT EXAMS FOR OTHER PROFESSORS ONLY

|| Recent/new exams in English
|| Recent/new exams in Dutch

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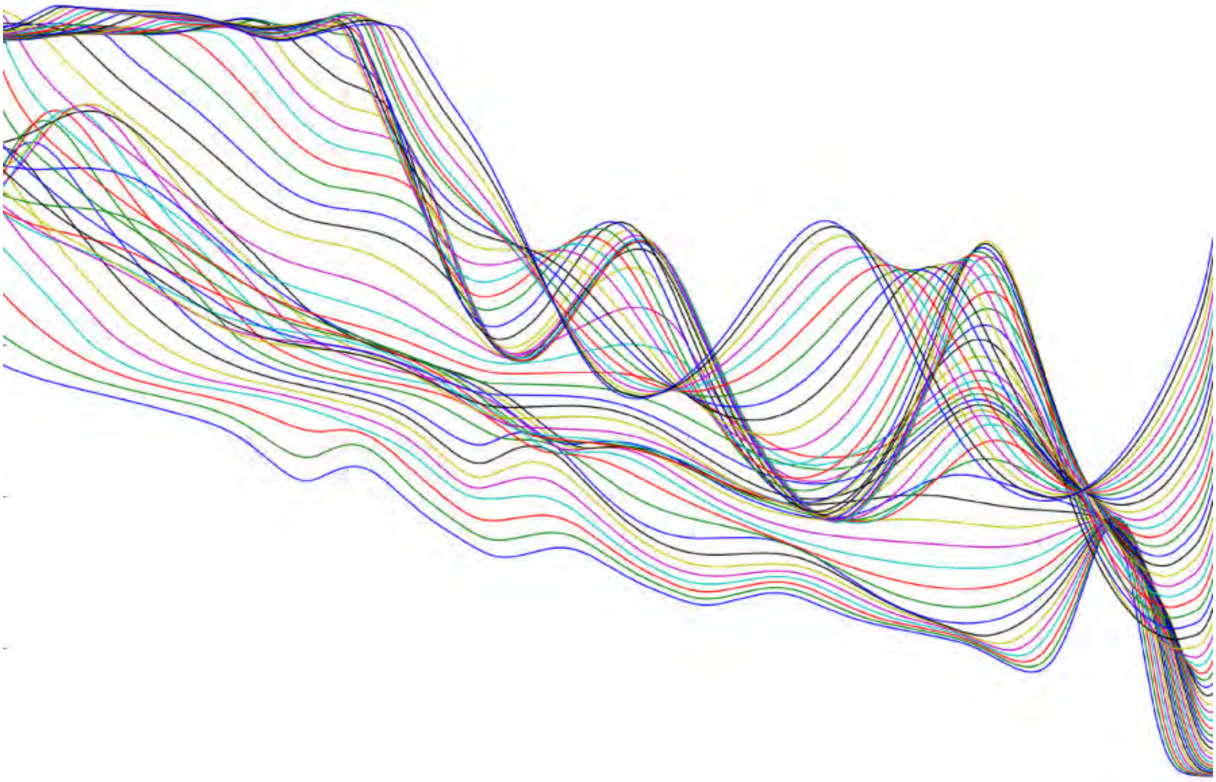
Epilogue

Flexible E-Book for Blended Learning with Online Materials

Although this e-book is first and foremost an electronic case book, it is much more than just a set of case descriptions: it is the backbone of an online blended-learning approach. It consists of 6 concise theory chapters, short theory videos, 6 chapters with about 90 modeling exercises and cases, many demo and feedback videos, feedback sheets for each case, 5 overall chapters with feedback, 5 chapters with multiple choice questions (with graphs or figures), hundreds of online multiple choice questions, links to on-site lectures, past exams, models, online simulators, 126 slots for new exercises and cases, and additional materials for lecturers (slides, exams, new cases). The fully hyperlinked e-version allows students (or anybody else for that matter) to learn –in a relatively short time– how to build SD models of dynamically complex issues, simulate and analyze them, and use them to design adaptive policies and test their robustness.



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