Towards understanding and supporting complex decision-making by using game concepts

A case study of the Dutch railway sector

Bekius, Femke

DOI
10.4233/uuid:4470eb1d-c71a-4de1-b11e-36d93a77ad78

Publication date
2019

Document Version
Final published version

Citation (APA)
Bekius, F. (2019). *Towards understanding and supporting complex decision-making by using game concepts: A case study of the Dutch railway sector*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:4470eb1d-c71a-4de1-b11e-36d93a77ad78

Towards Understanding and Supporting Complex Decision-Making by using Game Concepts

A Case Study of the Dutch Railway Sector

Towards Understanding and Supporting Complex Decision-Making by using Game Concepts

A Case Study of the Dutch Railway Sector

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. dr. ir. T.H.J.J. van der Hagen,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op donderdag 19 september 2019 om 12:30 uur

door

Femke Anne Bekius

Master of Science in Logica, Universiteit van Amsterdam
geboren te Amsterdam, Nederland.

Dit proefschrift is goedgekeurd door de promotoren.

Samenstelling promotiecommissie:

Rector Magnificus	voorzitter
Prof. mr. dr. J.A. de Bruijn	Technische Universiteit Delft, promotor
Prof. dr. ir. S.A. Meijer	KTH Royal Institute of Technology, promotor
Onafhankelijke leden:	
Prof. dr. ir. P.M. Herder	Technische Universiteit Delft
Prof. dr. J. Edelenbos	Erasmus Universiteit Rotterdam
Prof. dr. E.A.J.A. Rouwette	Radboud Universiteit Nijmegen
Prof. dr. E. Subrahmanian	Carnegie Mellon University, USA
Prof. dr. B.A. van de Walle	Technische Universiteit Delft, reservelid
Overige leden:	
Drs. H. Thomassen	Ministerie van Infrastructuur en Waterstaat

This research was funded by ProRail through the Railway Gaming Suite program.

Printed by: Ipskamp printing

Front & Back: Sticky Visuals

ISBN 978-94-028-1661-7

An electronic version of this dissertation is available at
http://repository.tudelft.nl/.

Acknowledgements

The process of writing a dissertation is never performed alone. Although only my name is on the cover there are a number of people behind this piece of work. In this section I want to thank the people who contributed to this dissertation in one way or another.

First and foremost, I want to thank my promotores Hans de Bruijn and Sebastiaan Meijer. You gave me the opportunity to start this PhD as a logician in an empirical and dynamic environment. Your guidance during these years was crucial. Not only to reach the point of obtaining a PhD, but by steering my development, both academically and personally, and I really enjoyed what I was doing. Hans, you were always critical on the structure and the line of reasoning. Many times your questions made me rethink the what and the why, which definitely improved my work. Sebas, by working together you made me grow towards an independent researcher. You said this from the beginning and I believe you have succeeded. But it is more than that, you also taught me to do what enthuses me and keep a balance between scientific contribution and practical impact.

I would like to thank my committee members Eswaran Subrahmanian, Etiënne Rouwette, Paulien Herder, and Jurian Edelenbos for taking the time to read the dissertation and take part in the defence ceremony. I am especially grateful to Hugo Thomassen, as part of the committee, but also as sparring partner during the project. You gave me the opportunity to learn about and gain insight in the complexity of the Dutch railway sector and you provided me with valuable feedback on the theoretical side and practical implications of my work.

I express my gratitude to ProRail, and in particular to my colleagues from the innovation department and the RailwayLAB, for supporting the project and adopting me as part of the team. Jelle van Luipen, you were always present to discuss my progress and brainstorm on how the work could fit within the organization. Marjan, Inge, Edith, Lisette, and many others, thanks for thinking along with me and giving your feedback at different stages of the process. I am looking forward to see whether (and where) the game concepts decision-tree finds its place within the organization. A special thanks goes to Peter Scheffel who gave me the opportunity to get insight in the crucial moments of politically sensitive decision-making processes. Moreover, you were always available for questions and provided me with valuable feedback.

Without the support in form of coffee/lunch/diner/drinks breaks and train rides (Utrecht-Delft) with my colleagues of OG (former POLG) and at KTH in Stockholm finishing this dissertation would have been impossible. In particular, I want to thank Elisabeth and Eva (my paranymphs), Fabio, Jop, Julia, Klara, Linda, Maria, Samaneh, Shannon, Sharlene, and Xander. Vinutha and Jayant, thanks for the diners in Stockholm and our inspiring discussions over Skype.

Bill, you were a great PhD-project partner. Particularly, I enjoyed our discussions on how to connect our research, which resulted in a nice and interdisciplinary collaboration.

On the formal part of the thesis I am very grateful for the collaboration with Helle Hansen. I really hope to continue our work in the future. Apart from the work, I highly appreciate the more personal talks we had.

I am very thankful for having been a supervisor of three excellent master students: Jorien, Laura and Vincent. You let me experience the role of supervisor, were open for new ways of supervision and collaboration, and we enjoyed doing interdisciplinary research. Additionally, you made a valuable contribution to this dissertation.

My dearest logician friends, Aybüke and Sebastian, I owe you quite some proofreading time. Wherever you are, you always feel close by. You were so understanding the last month that I felt less alone in writing the final part. Thanks a lot for this and let's celebrate when you happen to be in Amsterdam.

Aino, Annike, Anouk, Babette, Ellen, Jolien, Loes, Merel, Nienke, and Sacha you are present in my life for longer and shorter periods. In one way or another you are there and whenever I needed it one of you would say that I was doing a good job. Thanks for this.

I want to thank my parents Doeke and Dieteke for always being there for me and showing your enthusiasm whatever choice I made. Also, you taught me to do what I like the most and go for it which I believe I am doing now.

At the time of starting the PhD I met Wouter. I am very happy that you became a maatje, partner, husband, and father of Wisse. I do not know how to thank you for your unlimited support and belief in me. Maybe we just do another swimrun?

My final words are for Wisse, although you are not able to read this thesis yet, you made a huge contribution by just being there and getting me out of the working mode every now and then, for example, by asking 'Mama werken? Waarom?'.

Femke Bekius
19th of August 2019

Contents

1

INTRODUCTION

INFRASTRUCTURE systems are essential for our society. They provide us with energy, supply drinking water, and make transportation and communication possible (Herder and Verwater-Lukszo, 2006, Weijnen and Bouwmans, 2006). Infrastructure systems are essential not only because of the physical components they consist of, such as railway tracks or energy cables, but primarily because they are able to connect societal needs and economic activities, leading to participation in society and the creation of public values (Idenburg and Weijnen, 2018).

Infrastructure systems are complex networks that consist of various systems that are *interdependent*. Their interdependencies do not only exist within infrastructure systems, but also between infrastructure systems (Weijnen and Bouwmans, 2006). In addition, the complexity of infrastructure systems arises from the interdependencies between *technical* systems (Sage and Cuppan, 2001), as well as from interdependencies between *social* systems, related to the actors and their institutional rules. The fact that multiple actors with different incentives, perspectives, and responsibilities towards the system exist, shows another level of complexity (De Bruijn and Herder, 2009).

This complexity relates to the concept of *agency* (Sen, 1985), which includes the capability of an actor to act, as well as the responsibility of actors towards the system (Ballet et al., 2007). This responsibility means “who owns what” and gives actors *power* to make decisions on the system (Alkire, 2008, Epstein, 2013). Given the interdependencies within and between infrastructure systems, such responsibilities are often diffuse and not always clear. As a result, decision-making in, and on, such systems is complex (Idenburg and Weijnen, 2018).

Adding to this complexity, the *path dependency* of decision plays a major role (Teisman and Klijn, 2008). Infrastructure investments on which we decide today have an impact on the society of future generations, and decisions of the past influence our society as it is today (Weijnen and Bouwmans, 2006). This path dependency of decisions explains why taking an optimal decision seems to be important. However, the diffuse responsibilities and thus different perspectives cause that each actor has its own view on the optimal decision, and therefore it is difficult, or even impossible, to select a decision that is optimal for everyone.

In this thesis, we focus on the Dutch railway sector as an infrastructure system. The railway network in the Netherlands is a dense and occupied network used by a large number of travellers each day (Meijer, 2012a).[1] The sector is currently facing several system challenges, such as the increase in frequency of the number of trains per hour due to the expected passenger growth, and the introduction of a new safety system for the entire network (Veeneman, 2016). In this thesis, we use the concept of Complex Adaptive System (CAS) for the Dutch railway sector. This concept is chosen since it describes actors at multiple levels who are interdependent and show emergent behavior (Holland, 1995).

We intend to improve our understanding of decision-making on this system by combining *game concepts* that originate from different fields - ranging from game theory to public administration. Game concepts describe the interactions between actors in complex decision-making situations including and representing interdependencies, actors' agency, and path dependency of decisions. They constitute therefore an appropriate approach for this thesis.

In Section 1.1, we position this research in the field of decision-making on large infrastructure systems, and introduce the main research aim of the thesis. Subsequently, in Section 1.2, we introduce game concepts as the approach for reaching this aim, and explain why this is an interesting and promising approach. In Section 1.3, we present the research questions. The concept of Complex Adaptive System (CAS) for the Dutch railway sector is further elaborated on in Section 1.4. This section also explains how this thesis aligns with and continues on previous research regarding decision-making in the Dutch railway sector. Finally, Section 1.5 provides an overview of the structure of this thesis and also briefly elaborates on the applied overall methodology.

1.1. DECISION-MAKING ON INFRASTRUCTURE SYSTEMS

Decision-making on large infrastructure systems has been researched in various domains such as energy, water, information, communication, gas, and public transport (Herder and Verwater-Lukszo, 2006). These studies have investigated different problems, ranging from the limited dynamics of contracts in a tendering process (Scharff, 2013), the unknown impact of decisions on large infrastructures for future evolution of the systems (Nikolic et al., 2009), the neglectance of the human aspect in the design of socio-technical systems (Ottens et al., 2006), and the change in strategic behavior (Oruc, 2014) and collaboration between actors (Ligtvoet, 2013) in the energy transition. In order to deal with these problems, a plethora of approaches and methods has been suggested, and applied, to better understand or support the decision-making process for these systems. Examples are, amongst others, agent-based models (Nikolic et al., 2009), gaming simulations (Meijer, 2012b), and case study research (Van der Lugt et al., 2013).

Most of the aforementioned studies have acknowledged the change in the way decisions on infrastructure systems are made. Where decision-making used to follow a

[1] Every day 1.2 million passengers make use of the Dutch railway network that consist of around 7000 km of tracks and 400 stations. In 2018, the punctuality of the system, i.e., trains arrive within 5 minutes off schedule at their destination, was 92.6%, which is high compared to other European countries (ProRail, 2018a). The number of passengers as well as freight transport by rail is increasing in the Netherlands (CBS, 2018) and therefore there is need for more capacity (Meijer, 2015).

top-down approach, it is nowadays following a process in which a complex network of actors needs to contribute to the decision resulting in a much more dynamic situation (De Bruijn and Ten Heuvelhof, 2018). This change in the decision-making structure requires new rules for playing the decision-making game. As a result of those new rules, or the lack of them, new coordination mechanisms have appeared (Idenburg and Weijnen, 2018).

Knowing which mechanisms exist helps in understanding, and eventually steering the process of decision-making. However, identifying these mechanisms in a decision-making process on infrastructure systems and characterizing the process as such has, to our knowledge, not been done so far. In particular, a focus on the actor constellation, including their responsibilities and power relations, and covering the dynamics of such relations has not yet been properly addressed. In this thesis, we aim to characterize decision-making processes by identifying their interaction patterns, coordination mechanisms, and so called strategic games. This leads to a better understanding of the mechanisms that play a role in decision-making processes on large infrastructure systems. Apart from characterizing the decision-making process, we also aim to provide a perspective of action for the actors involved in such processes. Game theory offers the perfect approach to achieve both aims.

1.2. RESEARCH APPROACH

To characterize the strategic games and coordination mechanisms in a decision-making process, game theory is a natural choice. As Osborne and Rubinstein (1994) state: "Game theory is a bag of analytic tools designed to help us understand the phenomena that we observe when decision makers interact." Game theoretical concepts are therefore considered to be applicable for this thesis.

Game theoretical concepts are able to structure inherently complex empirical decision-making processes. Such concepts describe both the behavior of, and interaction between, actors who have to make decisions. Game theory assumes that decision makers take into account their knowledge and expectations of the behavior of other decision makers, i.e., that they reason strategically (Osborne and Rubinstein, 1994). Through analysis of different scenarios, game concepts are able to prescribe possible outcomes, something which is not present in the description of empirical processes. Although game theory is useful for structuring empirical decision-making processes it has been criticized for simplifying the situation too much (Binmore, 1987). It has been said to reduce the rich empirical decision-making process such that outcomes do not match real-world decision-making processes anymore (Bennett, 1987). While the aim of game theory is to find stable or optimal outcomes, this is not necessarily the same for real-world decision-making processes. One of the basic assumptions of game theory is that decision makers are rational, which is not necessarily the case in real-world decision-making processes (Tversky and Kahneman, 1986). Furthermore, game theory mainly addresses static situations which does not align with the dynamics of real-world processes (De Bruijn et al., 2010).

On the other hand, there have been various attempts to overcome this criticism by introducing bounded rationality of actors (Simon, 1972), dynamic games (Aumann, 1995), nested games (Tsebelis, 1988), and elements such as values, norms, and beliefs into the formal apparatus of games. New streams of game theory are, amongst others, Generalized

Game Theory, which extends game theory by incorporating social theory introducing new concepts such as institutions, norms and roles of actors (Burns and Gomolińska, 2001); Epistemic Game Theory, which includes the notion of belief (Bacharach, 1994, Battigalli and Bonanno, 1999); and Behavioral Game Theory, which attempts to explain decision-making using experimental data (Camerer, 2003).

In this thesis, we follow this broader approach and, in line with the definition of Osborne and Rubinstein (1994), we see game theory as a bag of analytic tools, and thereby include game concepts from different fields. *Game concepts* describe interactions between decision makers in a decision-making situation. The concepts can be mathematically defined, as in game theory, but they can also be more descriptively explained and empirically substantiated. The discrepancy, sometimes called disconnection (Lavertu and Moynihan, 2012), between the game concepts and the empirical real-world decision-making processes, as illustrated in Table 1.1, makes this an interesting approach to investigate.

Table 1.1: Features of empirical decision-making processes versus game concept characteristics.

Empirical decision-making	**Game concepts**
Chaotic, messy, complex	Structure elements, characterize process
Predominantly descriptive	Predominantly prescriptive
Rich	Reduction
Dynamic	Static
Multiple interdependent decisions	Single decision
Large solution space	Optimal, stable outcomes
Multi-rational actors	Single-rational actors
Narrative	Analysis of different scenarios

1.2.1. MOTIVATION

The game concept approach provides structure in the ill-structured, and sometimes messy, decision-making processes by making the game elements precise. Moreover, it creates a perspective of action, since the game concepts allow for analysis of different scenarios and result in possible outcomes.

What distinguishes our approach from a formal game theoretical analysis is the identification of multiple game concepts in a decision-making process as opposed to simplifying the process to a single, predefined, model. Furthermore, the game concept definitions include the context in which they could exist. To capture the dynamics of the process and the dynamics of the relations between actors, we address the interaction between game concepts and substantiate this with empirical evidence. We do not specify an optimal, or right-versus-wrong, outcome, but present different scenarios and thereby provide a perspective of action. Moreover, we do not make the assumption of rationality of actors explicit, but focus on incentive structures, responsibilities and ownership of actors, i.e., actors' agency, and dilemmas existing in the decision-making process. Additionally, we make the game concepts applicable to real-world decision-making processes and to a variety of users.

In short, in this thesis, the game concepts are used to *describe* empirical case studies, and *prescribe* a perspective of action as will be elaborated upon further in the next section.

1.3. Research aim and research questions

Having introduced the approach used in this thesis, we now present the main research aim:

> *Understanding and supporting complex decision-making processes by using game concepts.*

To reach this aim, we split the thesis into four different parts, each of which focuses on different research questions.

- Part I contains the selection and definition of the game concepts. Our aim is to select a set of game concepts that covers a wide range of interactions between decision makers. This leads to the following research question:

  > (RQ1) Which minimal set of game concepts could cover a variety of decision-making situations? (Chapter 2).

- Part II characterizes decision-making processes using the game concepts. It has a *descriptive* nature. In this part, we aim to identify patterns of interactions taking place in these processes. This results in the following research questions:

  > (RQ2) What is the complexity of the decision-making process and how did the process develop for the six case studies we conducted from the Dutch railway sector? (Chapter 3).

  > (RQ3) Which game concepts can be identified in the case studies, and to which extent can game concepts explain the essence of the decision-making process? (Chapter 4).

  > (RQ4) Which patterns of game concepts appear when taking a temporal, multi-level, and interaction perspective? (Chapter 5).

- Part III has a *prescriptive* nature. The focus now shifts from researchers using the game concepts to describe the decision-making process to decision makers using the game concepts to potentially steer the process. The game concepts are translated into a tool such that applications of game concepts used by practitioners can be evaluated. We aim to understand decision makers' usage of the game concepts, and how this eventually impacts the future process. Furthermore, we aim to link the elements of the game concepts to game design to facilitate the game design process. In this part, we answer the following research questions:

  > (RQ5) How should a game concept identification tool be designed and tested such that it enables users without prior knowledge of the game concepts to identify game concepts in a decision-making process? (Chapter 6).

(RQ6) To what extent are participants able to select the right game concepts when given a hypothetical scenario by using the game concept identification tool? (Chapter 6).

(RQ7) What aspects from a game theoretical analysis can be translated to game design and in what way? (Chapter 7).
(RQ8) To what extent can the design of a meaningful game be determined from a game theoretical analysis? (Chapter 7).

(RQ9) What strategic and operational practices do potential users identify when they together characterize a decision-making process by using game concepts? (Chapter 8).
(RQ10) What are the consequences of such a characterization by using game concepts on the (future) behavior of users? (Chapter 8).

- Now that we know the interaction patterns of game concepts (Part II), and how practitioners use the game concepts (Part III), modeling different scenarios of the decision-making process could further improve our understanding of as well as support for decision-making processes. Part IV formalizes one of the game concepts, i.e., the Multi-Issue game. The aim of this part is to formalize the Multi-Issue game as a first step to be able to model decision-making situations that resemble a Multi-Issue game situation, but also to eventually model interactions between game concepts. In this part we answer the following research questions:

  (RQ11) How can the Multi-Issue game be formalized? (Chapter 9).
  (RQ12) How can the formalization of the Multi-Issue game contribute to the analysis of real-world decision-making processes? (Chapter 9).

At the end of this chapter, we give a more detailed overview of the different parts of the thesis, the corresponding chapters, and how they are connected.

As we already mentioned at the beginning of this chapter, the railway network is very important in the Netherlands. Each day a large number of passengers travel by train and it is a dense and occupied network. Despite its intense usage, the performance of the railway system is high compared to other European countries (Nash et al., 2014). Due to its national importance, both political and public attention is large. In particular, at this moment, as the railway sector is facing, and already starting to implement, large system changes like high frequency timetables and a new safety system to address the need for more capacity (Meijer, 2012a). These system changes require both coordination between and collaboration of the actors involved. They have to make many decisions and given the path dependency of decisions the quality of those decisions is important.

In the next section we present the Dutch railway sector as a Complex Adaptive System (CAS) and highlight earlier research on decision-making in this sector.

1.4. COMPLEX ADAPTIVE SYSTEMS

Researchers on railway systems have adopted different perspectives for analyzing the system, e.g., studies interpreted the system as a Socio-Technical system (Trist, 1981, Trist and Bamforth, 1951), as a System-of-Systems (DeLaurentis, 2005), or as a large technological system (Hughes, 1987). In this thesis, the Dutch railway sector is viewed as a Complex Adaptive System (CAS) (Holland, 1995, 2006, Miller and Page, 2007). According to the CAS perspective, the system consists of interdependent subsystems, which need to be aligned to let the entire system function. The relations between subsystems are dynamic, and as a result the system shows emergent and chaotic behavior (Holland, 1992).

1.4.1. An actor perspective on Complex Adaptive Systems

Previous research on railway networks has already proven that the railway sector can be considered a CAS from a *system perspective* (Collis et al., 2014, Roungas et al., 2018d). In this thesis, we take an *actor perspective* on the railway sector. This implies that we focus on the network of actors as being the system consisting of different (groups of) actors who represent the subsystems that need to be aligned. The relations between actors are dynamic and, as a result, the actors display (strategic) behavior. We redefine the notion of a CAS with an actor perspective (Bekebrede and Meijer, 2009, Holland, 2006):

1. At an individual level, a CAS consists of *multiple actors* and each actor is responsible for a subsystem;
2. At a collective level, actors *interact* by exchanging information and behave according to decision rules;
3. The system shows *emergent behavior*: Actors want to optimize their own subsystem, they cannot oversee the entire system, and thus perform and adapt their (strategic) behavior.

1.4.2. The Dutch railway sector as Complex Adaptive System

In the Dutch railway sector, these actor characteristics, as outlined in the previous section, of a CAS are present as well:

1. Multiple actors with different responsibilities and interests towards the railway system are involved.
2. These actors need to interact and need to align to let the system function. This interaction and alignment is necessary to reach consensus on decisions. The responsibilities of each actor are formally defined in a management plan (in Dutch: beheerplan) which aims to steer the behavior of the actors.
3. To obtain the most preferred outcome at an individual level the actors try to optimize their own subsystem. However, at the same time at the collective level, they coordinate with other actors to obtain the best outcome for the overall system. This results in actors behaving strategically.

The multiple actors of the Dutch railway sector, as referred to in the first point, include three main actors and several other actors. The three main actors that take part in decision-making processes in the Dutch railway sector are ProRail, the infrastructure manager who is responsible for maintenance and extension of the railway network as well as allocating the capacity and traffic control; NS, the main passenger operating company is responsible for driving the trains on the main lines of the network and thereby achieving performance indicators; and the Ministry of Infrastructure and Watermanagement (I&W) who must oversee the public interest and is responsible for budget and contracts with operators and the infrastructure manager (Van de Velde et al., 2009).

To elaborate on the second point, despite formally defined responsibilities of actors, observations of real-world decision-making processes show that the relations at the collective level are in fact dynamic (Van den Hoogen, 2019). It appears to be difficult to maintain the responsibilities, or to pinpoint to whom certain responsibilities belong, due to the many interactions on multiple levels of the organizations. Furthermore, new types of decisions demand for changes at boundaries of responsibilities, which then require close collaboration between actors (Bekius et al., 2018a). It is this point that shows why characterizing the dynamics of decision-making processes by game concepts is expected to be valuable for understanding of decision-making on infrastructure systems and in particular for the Dutch railway sector.

The existence of a CAS entails multiple levels:

i. the *system level* includes the (technical) components of the railway network,

ii. the *first-order actors level* contains the actors who directly interact with the system, and

iii. the *second-order actor level* consist of the actors who take decisions regarding the system.

In Figure 1.1 these levels and the interactions within and between levels are illustrated. In this thesis, we focus on the interactions between the second-order actors while also taking into account the first-order actors and the system level. This means that we mainly focus on *strategic* decisions.

In short, this thesis aims to understand and support complex decision-making processes by identifying patterns of interactions by using game concepts. We consider the Dutch railway sector as a CAS by taking an actor perspective, and we focus on the interactions between the second-order actors who take strategic decisions regarding the system.

1.4.3. DECISION-MAKING IN COMPLEX ADAPTIVE SYSTEMS

Considering infrastructure systems in general, or railway systems in particular, as a CAS is not new (Bekebrede and Meijer, 2009, Brous et al., 2019, Herder et al., 2008, Roungas et al., 2018d, Van den Hoogen, 2019, Van der Lei et al., 2010). Previous research in the railway sector involved specific model-based methods for reducing the uncertainty in decision-making processes. Examples of such studies include, for instance, optimization of timetables and rolling stock (Albrecht, 2009, Demitz et al., 2004, Dollevoet et al., 2018, Goverde, 2005, 2007, Hansen, 2010, Hansen and Pachl, 2008, Huisman et al., 2005).

Another field of research used to support decision-making in the Dutch railway sector is the development and application of gaming simulation. Particularly since 2009, the infrastructure manager (ProRail), in collaboration with Dutch Railways (NS), has been developing and using gaming simulation to, for example, test innovations and future

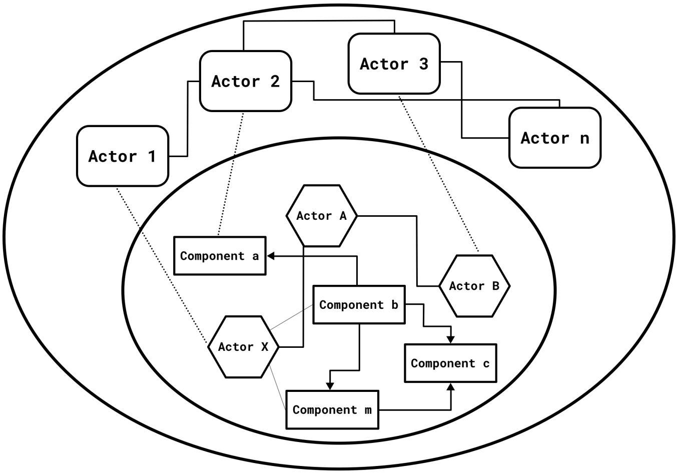


Figure 1.1: Complex Adaptive System: system level (components a-m); first-order actors (A-X); second-order actors (1-n).

changes in the infrastructure and timetables (Meijer, 2012b). Their intention is to test such innovations in a safe environment. In relation to the development of gaming simulation in the Dutch railway sector, and in particular at ProRail, design, validation, debriefing, and knowledge management of gaming simulations have been the object of research (Lo et al., 2013, Meijer, 2015, Middelkoop et al., 2012, Roungas et al., 2018a,b,e, Van Lankveld et al., 2017, Van Luipen and Meijer, 2012), as well as the human aspect (Lo and Meijer, 2014, Lo et al., 2014) and the general mechanisms that play a role in driving systemic innovations in the Dutch railway sector (Van den Hoogen and Meijer, 2012, 2015). Van den Hoogen (2019) has identified four macro-level mechanisms that explain volatility in innovation processes.

As a result of this earlier research on supporting decision-making by developing and using gaming simulation new questions have arose. How can we further professionalize the use of gaming simulation for decision-making? Furthermore, how can we reduce the *uncertainty* in decision-making processes by using the methods of previous studies?

We build on earlier research by further investigating the mechanisms that play a role in decision-making processes, thereby also taking into account the dynamics of the process and actors' responsibilities and incentive structures, i.e., actors' agency. The game concepts are used to perform a systematic characterization of the interactions between actors who are involved in the decision-making process, while at the same time taking into account their responsibilities in the system and power relations. This could provide insights into the dynamics of the decision-making process. Additionally, the characterization of such dynamics in the form of game concepts might help to take action in or steer the decision-making process eventually with the use of gaming simulation. Both a better *understanding* of the process dynamics and gaining a *perspective of action* could help in reducing the uncertainty in a decision-making process.

1.5. STRUCTURE OF THE THESIS

The thesis is structured in four different parts which have been previously introduced in Section 1.3. In this section, a road-map is provided showing how these parts are connected and which chapters they consist of. Finally, we discuss the overall methodology of the thesis. The methodology of and methods used in the different parts and chapters are further introduced in the corresponding chapter.

The questions of Part I are addressed in Chapter 2 which presents the theoretical perspective of the thesis. First, the theoretical perspective is compared with other decision-support approaches, and second, a set of game concepts is selected and defined.

Part II consists of Chapter 3, Chapter 4, and Chapter 5, and entails the description of empirical case studies by using the previously defined game concepts. Chapter 3 presents six case studies analyzing decision-making processes occurring in the Dutch railway sector. In Chapter 4, these decision-making processes are characterized using the defined game concepts. Following this, in Chapter 5, a meta-analysis of the appearance of the game concepts is presented. This results in a classification of game concepts and interaction patterns between game concepts.

Part III contains Chapter 6, Chapter 7, and Chapter 8, and discusses the application of game concepts. In Chapter 6, a tool to identify the different game concepts is developed and evaluated. To establish a link between game theory and game design this tool is then applied by game designers in Chapter 7. In Chapter 8, the game concepts are applied by decision makers in a real-world decision-making process and the usage of the game concepts is evaluated.

The last part, Part IV, consists of Chapter 9 in which we make a first step toward formalizing (one of) the game concepts. Finally, Chapter 10 presents the conclusion of this thesis. Figure 1.2 illustrates the different parts and chapters, and how they are connected.

1.5.1. METHODOLOGY

In the thesis, we adopt a pragmatic epistemology with a multiphase research design, and use the game concepts as theoretical perspective (Creswell and Cresswell, 2018).

The pragmatic epistemology focuses on the understanding of the problem, and allows for using various approaches and methods. Furthermore, pragmatism emphasizes the fact that research occurs in a certain context, which steers the actions, situations, and thus its results. In this pragmatic epistemology, the game concepts are used as theoretical perspective. However, this does not mean that the game concepts are static and cannot be further developed, enriched or generalized. As will become clear from the multiphase research design, the function of the game concepts varies in the research phases, and this requires the use of different methods in different parts of the thesis.

Furthermore, a multiphase research design is chosen since we use both qualitative and quantitative methods throughout the thesis. Moreover, the multiphase research design allows for the different parts and research phases to exist both sequentially and in parallel, as is illustrated in Figure 1.2.

In this thesis, we explore the tension between the structure that game concepts prescribe on the one hand, and the complex and ill-structured problems in real-world decision-making processes on the other hand. The combination of the structure of quantitative research and the flexibility of qualitative inquiry make the mixed method approach suitable. Furthermore, the combination of both quantitative and qualitative methods gives a more complete understanding than either one of the methods alone. Additionally, the assumptions made, the role of theory, and the use of case studies and experiments, vary between the different research phases.

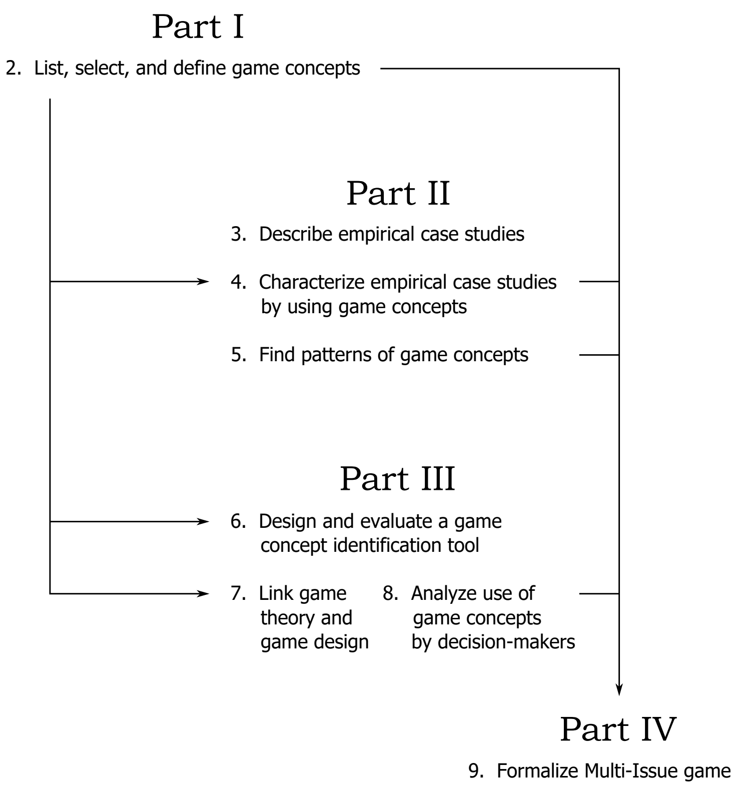


Figure 1.2: Structure of the thesis.

I

Theoretical perspective

2

Theoretical perspective

In this chapter, we introduce the theoretical perspective of the thesis: the game concepts.

- Game concepts describe the behavior of and interaction between actors who have to make a decision.
- They are potentially relevant to structure complex decision-making processes. We aim to select a limited number of game concepts that together cover a variety of different decision-making situations and thereby do justice to the complexity of such process by being able to explain the essence of the process.
- A selection of such game concepts allows to reduce and provides insight into the complexity in a responsible way.
- The game concept approach is first compared with several other decision support methods, like formal (game theoretical) modeling and gaming simulation. The aim of this comparison is to position the game concept approach in the broader field of decision support methods.
- Subsequently, a list of game concepts is composed. The concepts have their origin in different fields - ranging from formal mathematics to public administration.
- This list is categorized in a taxonomy. The taxonomy is based on characteristics such as the number of actors and the type of relations between actors. It structures the list of game concepts in different categories.
- The taxonomy is used to select a limited number of game concepts that cover the different categories of the taxonomy and thus represent different characteristics of complex decision-making processes.

Parts of this chapter have been presented at and published in conference proceedings PICMET, IEEE (2016) (Bekius et al., 2016) and Social Simulation Conference (SSC), Springer Verlag (2018) (Bekius and Meijer, 2018b).

2.1. INTRODUCTION

We introduce the theoretical perspective of the thesis, the game concepts. They are used in this thesis for different purposes: for the characterization of empirical decision-making processes (Part II), for application by game designers and to enable decision makers in a decision-making process (Part III), and for formalization, and eventually simulating or modeling real-world situations (Part IV).

In this chapter, we define the notion of a game concept and make a selection of game concepts to be used throughout the thesis. The game concepts originate from different fields; in this thesis, they are a combination of game theoretical models from the field of game theory, and games described in the literature on complex networks.

Game theory is founded in the field of economics and mathematics and provides mathematical models of strategic interactions between rational decision makers (Harsanyi, 1967, Osborne and Rubinstein, 1994, Rapoport, 1970, Schelling, 1960, Shubik, 1981, Von Neumann and Morgenstern, 1944, Von Neumann and Morgenstern, 1953).

Complex networks, also called policy networks, originate in the field of public administration which studies decision-making in a network structure of interdependent relations between actors and issues (De Bruijn and Ten Heuvelhof, 2018, Kickert et al., 1997, Klijn and Teisman, 1997).

Our approach combines games from both fields to provide a bridge between the structure of game theoretical models, and, on the other hand, the richness and dynamics of game descriptions in decision-making processes on complex networks. To recall, we are interested in combining these two traditions in order to provide structure in the ill-structured, and sometimes messy, decision-making processes, and to create a perspective of action. The structure is provided by making the game elements precise, and an action perspective is created since the game concepts allow for the analysis of different scenarios which result in possible outcomes. In short, the game concept approach addresses the *dynamics* of the process and relations between actors in a structured way. Moreover, it represents the actor constellation including actors responsibilities, power and ownership, i.e., and actor's *agency*. These features distinguish the approach from other methods and approaches that are used to understand and support decision-making processes as we will show in the next section.

The context in which the game concepts are applied in the next chapters are decision-making processes on large infrastructure projects. We restrict the study to decision-making processes from the Dutch railway sector and focus on decisions taken at strategic level. In this context we aim to identify the strategic games and coordination mechanisms that exist within these processes. By doing so, we characterize the interaction patterns between actors in order to gain understanding of the complexity of the decision-making process. Furthermore, we apply the game concepts in a decision-making process by operationalizing them for game designers and decision makers.

The chapter is structured as follows: Section 2.2 introduces a selection of decision support methods and positions the game concept approach in the broader field of decision support methods. In Section 2.3, the origin of the game concepts is described which results in a list of game concepts presented in Section 2.4. This list is classified in a taxonomy in Section 2.5 before we present the final selection of game concepts to be used throughout this thesis.

2.2. METHODS TO SUPPORT DECISION-MAKING

In this section, we introduce a selection of approaches and methods that are used to gain understanding of decision-making processes or support decision-making on large infrastructure systems. Each approach is briefly introduced and we explain how the use of game concepts as theoretical perspective is different or complementary to the approaches and methods discussed.

2.2.1. FORMAL GAME THEORETICAL MODELING

Many examples of formal application of game theoretical models to support decision-making exist (Cantarelli et al., 2013, Chen et al., 2012, Hollander and Prashker, 2006, Osman and Nikbakht, 2014). Game theoretic modeling often simplifies the situation to one game and therefore explains only a small part of the process (Cohen, 2015). In contrast to the formal application, we identify *multiple* game concepts in a decision-making process, and are interested in the interactions between identified game concepts. This allows us to represent the dynamics of the process to a certain extent. Furthermore, we want to know why the game concepts appear such that we can enrich the game concept definitions, and thereby better identify the game concepts in a process. Hence, we include the context in the definitions of game concepts.

The existence of multiple games at once in a decision-making process is acknowledged by Marks and Gerrits (2017) and is called the associative approach. The associative approach has been studied in two experiments, but has not been applied to a characterization of real-world decision-making processes in which the games are identified.

Another feature of formal game theoretical modeling is that it aims at finding an optimal or stable outcome and thereby assumes the rationality of actors (Rasmusen, 2007). This assumption is quite strong, especially when we consider the fact that actors have different responsibilities and thus perceive an outcome differently. An optimal outcome for one actor does not need to be an optimal outcome for another actor. The game concept approach rather presents different scenarios and outcomes with potential risks to 'relax' the rationality assumption. Furthermore, the game concept approach contributes to game theory by stretching the application domain to dynamic and empirical processes.

2.2.2. SYSTEM DYNAMICS

System Dynamics (SD) research has made numerous contributions to supporting decision-making processes. The methodology has been developed in the 1950s to help with the understanding of industrial processes. It assists in understanding the complexity of the system and, nowadays, it is widely applied for policy analysis and design of policies (Forrester, 1958, Senge et al., 1994, Sterman, 2000). Mannaerts et al. (2013) provide an example of an SD application in the Dutch railway sector. They performed a modeling study of the interrelations of modal split, mobility and operations using SD. Improvements of the model are necessary to cover the unstructuredness of the problems.

In a participatory setting, causal loop diagrams are used in Group Model Building (GMB) sessions to let participants build a model themselves regarding a certain problem or issue (Andersen et al., 2007, Rouwette et al., 2000, Vennix, 1999). The SD approach originates from the engineering disciplines (Morecroft, 1988), and thus has a markedly rational character (De Bruijn and Herder, 2009). The result is that it tends to model the system and to a certain extent also the actors, their interactions, and institutional rules, but it does not address the responsibility and ownership of and power relations between actors. The game concept approach does include these elements, and, additionally, incorporates the dynamics of the process.

2.2.3. DESIGN THEORY

The decision-making processes of the Dutch railway sector that are investigated in this thesis are about the design of the railway system concerning, for example, new tracks, a new timetable, or a new safety system. Therefore, it is interesting to see what design theory frameworks have to offer to support decision-making. Several design theory frameworks are available that distinguish between product, actors, and institutional rules (Reich, 1995, Reich et al., 1996). Moreover, multiple models suggest that the components somehow need to be connected to or reflecting upon one another (Geels, 2004, Geyer and Davies, 2000, Hardy et al., 2005, Hermans et al., 2013). This means that, if the product changes this has immediate consequences for the actors involved and institutional rules applied, and vice versa. However, the problem with those methods, which is why they are less suitable for application, is that they either do not involve all three components, or the design frameworks are not fully operationalized. For example, CK theory [1] discusses the transfer of knowledge, but does not involve strategic behavior of actors (Hatchuel and Weil, 2009). Especially the latter feature makes these methods not suitable for further analysis of a concrete case study.

The PSI framework (Meijer et al., 2014, Subrahmanian et al., 2011a,b) is a design theory framework that deals with both problems and that can be applied to a concrete case such as the redesign of a timetable. In particular, this framework can be used to identify misalignments in the process (Bekius and Meijer, 2018a). The game concepts can then be used to explain why the misalignments take place since they address the behavior of actors and dynamics of the process. In this sense, the game concept approach is complementary to the PSI framework.

2.2.4. GROUP DECISION SUPPORT SYSTEMS

Group Decision Support Systems (GDSS) are specific ICT applications for the support of group interaction and decision-making (Fatta et al., 2002, Mayer and De Jong, 2004). They have been applied in several decision-making situations (Ackermann and Eden, 2011, Eden, 1992, Geurts and Joldersma, 2001, Mayer and De Jong, 2004). Eden (1992) assumes that supporting decision making with GDSS is only viable when the decision-making is ill-structured, complex, and involves strategic behavior. Moreover, he highlights that evaluating its use and effect is only feasible when applying this in a real-world situation. A limitation of such GDSS is that they do not accommodate the political dimensions of multi-actor decision-making processes (Mayer et al., 2005). As a solution Mayer et al. (2005) introduce a hybrid decision-support method including both GDSS and gaming simulation.

The game concept definitions take the context of the decision-making process into account, and are designed to also reflect the political dimensions of the decision-making

[1] C standing for 'concepts' and K standing for 'knowledge'

process. In particular, we address the constellation of actors with their responsibilities in a structured manner and we cover how this influences the dynamics.

2.2.5. DECISION SUPPORT SYSTEMS

Some well-known decision support systems or models are Multi Criteria Decision Analysis (MCDA) (Ishizaka and Nemery, 2013), Cost-Benefit Analysis (CBA) (Flyvbjerg et al., 2008) and Analytical Hierarchy Process (AHP) (Zahedi, 1986). An overview of group decision MCDA frameworks can be found in (Nikas et al., 2018). Deng et al. (2014) even propose a game theory framework that addresses the process of MCDA in a competitive environment. The models compare different alternatives, or variants, based upon various evaluation criteria that can have different weights. Usually, the criteria are measures which can be made quantitative (Dodgson et al., 2009).

This also shows the difficulty in using these models. Namely, in complex decision-making processes not all aspects of the process are quantifiable. Especially context elements such as the impact of the political environment on the decision-making process are not covered. Moreover, the decision-based models tend to specify one optimal solution. However, the question then becomes, an optimal solution for who? Given that actors have different responsibilities towards the system, they also perceive and value the solutions differently. An optimal solution for one actor does not need to be optimal for another actor too. The characteristics of the decision-based models to rank different solutions is a limitation of the model.

In two case studies of the Dutch railway sector, these decision-based models were unable to show the difference between two decision-making processes since they focus mainly on technical criteria. Apparently, there are aspects of the process that are not taken into account but do influence the outcome of the process (Bekius et al., 2018a). The game concept approach is able to show the difference between the two processes by including the context dynamics of the process and focusing on the incentive structures and responsibilities of actors.

2.2.6. GAMING SIMULATION

The use of gaming simulations to support decision-making on infrastructure systems has been applied in various studies (Bekebrede and Meijer, 2009, Mayer et al., 2004). Games for decision-making have particularly been used in the Dutch railway sector (Lo et al., 2013, Meijer, 2012a, 2015).

A follow-up question that raised is, are we designing the right game, or performing the right simulation, to support the decision-making and thereby reducing the uncertainty in the process? Answering this question is difficult, and has, to the best of our knowledge, not yet been done. However, knowing which mechanisms and strategic games are being played could be of help to decide on the elements to include, or exclude, such as actors and actions, in the design of the gaming simulation (Salen and Zimmerman, 2004). What would be particularly helpful is a structured way to gain insight into the actor constellation, including their responsibilities and power relations, and how the constellation of actors evolves, or could evolve, over time. Van den Hoogen (2019) has identified mechanisms at a macro-level that explain volatility in innovation process in the Dutch railway sector. We continue this research by further investigating the mechanisms that play a role in decision-making processes at multiple levels and taking into account the dynamics of the process and actors' responsibilities, and incentive structures, i.e, agency.

A first step towards making the link between game theoretical elements, game concepts, and game design choices is presented in Chapter 7.

2.2.7. STAKEHOLDER OR ACTOR ANALYSIS

Several methods of stakeholder or actor analysis exist. Operational research is a discipline which has developed a plethora of methods and tools to support decision-making processes (De Gooyert, 2016). Problem Structuring Methods (PSM), and as subcategory Game Structuring Methods (GSM), are examples of decision support methods (Cunningham et al., 2014). PSM are usually applied by a group of people to structure a situation one wants to change. Furthermore, it assumes that there is not a single representation of the problem and finding an optimal solution is not possible. Such methods rather facilitate reaching consensus or at least facilitate negotiation on what needs to change (Mingers and Rosenhead, 2001).

Hermans and Thissen (2009) present an overview of actor analysis methods and their limitations and potentials. Thereby, they focus on the trade-off between analytic quality and practical usability. The most popular methods are known as stakeholder analysis (Bryson, 2004, MacArthur, 1997), social network analysis (Kenis and Schneider, 1991, Scott, 2000), cognitive mapping (Axelrod, 1976) and conflict analysis (Fraser and Hipel, 1984). In these actor analysis methods a distinction is made between methods focusing on values, perceptions, or resources of actors.

Bryson (2004) classifies different stakeholder identification and analysis techniques in four categories depending on their purpose: organizing participation, creating ideas for interventions, building a winning coalition for a certain proposal, and implementing, monitoring, or evaluating strategic interventions. These techniques are fairly simple and mainly rely on the key stakeholders, their interest, and their information.

Although features of the various stakeholder and actor analysis methods overlap with the game concept approach, and one could even call it a PSM or GSM, there are three important characteristics that distinguish the approach: (i) game concepts focus on the behavior of actors and interactions between them including an actor's agency, i.e., responsibility and ownership of the system resulting in power relations, (ii) game concepts characterize the process of decision-making and thereby include the dynamics, and (iii) game concepts will be developed in such a way that they are applicable by decision makers themselves. The first and the second point are addressed in Chapter 4 and Chapter 5. Regarding the third point, as also mentioned in work of De Gooyert et al. (2017), the precise role of stakeholders in such settings, for example, how they apply the game concepts, and what the effect of this application is on the decision-making process, are only addressed in a limited way (Franco and Hämäläinen, 2016). In Chapter 8, we consider the role of stakeholders when using the game concepts to characterize a decision-making process and discussing the potential future effect on the process.

2.2.8. MODELING

Modeling as an approach to represent real-world decision-making processes, thereby including the dynamics of the process, uncertainties of the system, and behavior of actors, is still a major challenge (Balke and Gilbert, 2014, Baumgärtner et al., 2008, Schlüter et al., 2017). There has been various research performed in the field of agent-based modeling to cover actor aspects (Becu et al., 2003), as well as in the field of simulation of large systems to cover the system aspects. Moreover, addressing both the actor and the system aspects has been researched too (Nikolic et al., 2009). However, since the models of the real system cannot include the dynamics, behavior of actors, and uncertainties of the system, and their interactions, at once, their value to support decision-making is limited (Nilsson and Darley, 2006).

The game concepts are not able to cover all these aspects either, however, the identification of the game concepts, and the interactions between them in the real-world decision-making process, contributes to the observation of patterns of game concepts. These patterns provide empirical evidence which could be used as input for the modeling of such systems. In Chapter 9, we formalize a game concept which is a first step towards modeling of such complex systems.

In this section, we have shown how and why the game concept approach as theoretical perspective is different from other approaches investigating and supporting decision-making processes. What is missing in these methods is a structured way to address the constellation of actors including their responsibilities, and power relations and the dynamics. The game concept approach addresses these aspects.

Now that we have positioned our theoretical perspective we can introduce the origin of, and criteria for, our selection of game concepts.

2.3. GAME CONCEPTS

In this section, the origin of the game concepts is introduced resulting in a list of game concepts. We introduce the concept of a *policy network*, *unstructured problems*, and *dynamics*. These three aspects explain the complexity of decision-making processes, and result in a set of criteria characterizing decision-making processes. These criteria are used to select the game concepts in the next section.

2.3.1. POLICY NETWORKS

A policy network, or just network, is a concept that can be applied to the study of decision-making processes (Atkinson and Coleman, 1992, De Bruijn and Ten Heuvelhof, 2002, Knoke, 1990, Marin and Mayntz, 1991). A network describes patterns of relations between interdependent actors who are involved in a process of public policy making. Public policy making includes decision-making on large infrastructure systems such as railways (Teisman, 2000).

The concept of networks is rooted in organizational science, policy science, and political science. Organizational science contributed to the concept with the resource dependency approach which says that actors are dependent upon each others' resources. Policy science has influenced the concept by seeing policy (decision) making as a multi-actor process with complex interactions between the actors. Political science affected the concept by envisioning the process in relatively closed communities of actors, meaning that the actors meet again in future decision-making processes (Kickert et al., 1997). Networks consist of:

- Interdependent relations between actors.
- A variety of actors with different incentives and goals.
- Relations between actors that have a more or less lasting nature.

Interdependency between actors implies that actors cannot achieve the goal of the process by themselves, but that they are dependent upon actors' resources and information. The only way to obtain the goals is to act collectively, which is opposed to the idea that decision-making processes are hierarchically structured and the final decision is made by one actor.

Networks explain for a large part why decision-making processes are complex. However, we introduce two more characteristics that contribute to the complexity of the process: unstructured problems and dynamics (Bekius et al., 2016).

2.3.2. UNSTRUCTURED PROBLEMS

Networks entail problems that are unstructured or, so called, wicked problems (Churchman, 1967, Rittel and Webber, 1973). "Wicked problems have incomplete, contradictory, and changing requirements, and solutions to them are often difficult to recognize as such because of complex dependencies. It has been stated that, while attempting to solve a wicked problem, the solution of one of its aspects may reveal or create another even more complex problem" (Rittel and Webber, 1973). Such problems are also termed as social messes (Ackoff, 1974), muddling through (Lindblom, 1959), or ill-structured (Simon, 1973). Information is contested since there is disagreement about data, systems boundaries, methods, and there is no consensus on how to weigh the different criteria. System criteria may be extremely varied, encompassing, for example, factors of economy, environment, as well as health and safety (De Bruijn and Leijten, 2007).

Dealing with wicked problems in a network is to a large extent a problem of interaction. On this point, the traditional approaches to wicked problems fall short since they are unable to characterize these interactions (Bueren et al., 2003).

2.3.3. DYNAMICS

Another characteristic that explains the complexity of decision-making processes is the dynamics of the context in which the decision-making takes place. This means that during the process the interdependencies, as well as the definitions of the problem can change. In a network, decision-making processes rarely evolve in a sequential order. Linearity in a decision-making process presupposes that one actor can decide on goals and can plan up front and can subsequently execute this planning. In a network of interdependencies this is not possible. In such a network a decision-making process is by definition a process that is based on interactions between different actors which occur in nonlinear order (De Bruijn and Ten Heuvelhof, 2000).

In short, networks, unstructured problems, and dynamics explain why decision-making processes are complex. All three explanations stress that it is the *interaction* between actors that is of importance. One way to characterize these interactions between actors is by using games.

2.3.4. CRITERIA OF COMPLEX DECISION-MAKING

The elements of the previous sections including networks, unstructured problems, and dynamics can be summarized in a number of criteria that are essential for decision-making in complex networks.

1. Multiple actors with different incentives are involved in the process.
2. The actors form a network of interdependencies.
3. Within these networks hierarchical relations might exist, usually between two actors.
4. Reaching a collective decision is the aim of the process.
5. However, individual strategic behavior plays a role as well.
6. The decision-making process is dynamic.

These characteristics play an important role in the selection of game concepts for investigating complex decision-making processes as will be elaborated on later in this chapter.

2.3.5. GAMES

Decision-making processes can be considered as 'games'. These games describe (strategic) interactions between actors focused on influencing the decision-making process to reach a certain outcome (Allison, 1971, Axelrod, 1984, Crozier and Friedberg, 1980, Groenleer et al., 2012, Scharpf, 1997). Games can be played in different *arenas*, i.e., places where the games take place both in formal and informal settings (Koppenjan and Klijn, 2004). Games can develop in different *rounds* of the decision-making process. Each round has its own problems, solutions, and decisions. The rounds-model emphasizes the interaction between actors, and can be used to analyze the interactions between decisions taken in different rounds (Teisman, 2000). The outcomes of a game can consist of substantive decisions, changed strategies, and institutional effects, which then eventually lead to reduction of uncertainty (Bueren et al., 2003).

In the literature covered in this chapter, we found several examples of games including, for example, the Multi-Issue game, win-win game, keeping options open (Axelrod, 1984, De Bruijn and Ten Heuvelhof, 2018, Marin and Mayntz, 1991). A list containing these games can be found in the next section.

FORMAL DEFINITION OF GAME THEORETICAL CONCEPTS

The essential elements of a game theoretical concept are: the actors or players, the actions, their payoffs, and information (Rasmusen, 2007). These elements are also known as the *rules of the game*. Additionally, the actors follow *strategies*, where a strategy is a collection of actions for each moment in the game. Given the combination of strategies for all players, also known as an *equilibrium*, the game results in an *outcome* (Morrow, 1994, Straffin, 1993).

Based on this definition and the fact that we use games from different fields, we present the following definition of a game concept.

A game concept describes a situation in which **actors** perform **actions** (or strategies) based on **information** to reach a certain **outcome**.

2

CLASSES OF GAMES

In the game theory literature many different types of games and classes of games can be found. To our knowledge no complete overview of these games and classes of games exists. Therefore, we provide a first attempt of listing and classifying games that can be found in general game theory textbooks. We classify them according to the game class that is most applicable. It should be noted that game classes are not mutually exclusive and game theoretical concepts can belong to multiple game classes. In the next section, a game list, categorized by game classes, is presented.

2.4. LIST OF GAME CONCEPTS

Table 2.1 presents a list of game concepts from the literature.

Table 2.1: List of game concepts.

Game concept	Game class	Reference	Game concept	Game class	Reference
Volunteers Dilemma	Social Dilemma	Diekmann (1985)	Beer-Quiche game	Signaling game	Myerson (1997)
Diners Dilemma	Social Dilemma	Gneezy et al. (2004)	Buyer-Seller game	Signaling game	Myerson (1997)
Public goods game	Social Dilemma	Schelling (1960)	Contract-Signing game	Signaling game	Morrow (1994)
Divide the dollars	Social Dilemma	Straffin (1993)	Sender-Receiver game	Signaling game	Myerson (1997)
Blotto games	Social Dilemma	Rasmusen (2007)	Reputation game	Signaling game	Morrow (1994)
Tragedy of the commons	Social Dilemma	Webster (2009)	Selten game	Signaling game	Rasmusen (2007)
Sanitarian's Dilemma	Social Dilemma	Webster (2009)	Two-player unanimity	Coalition game	Myerson (1997)
Battle of the sexes	Coordination game	Rasmusen (2007)	Landowner-worker game	Coalition game	Osborne (2003)
Prisoners Dilemma	Coordination game	Rasmusen (2007)	Three-player majority	Coalition game	Myerson (1997)
Chicken game	Coordination game	Rasmusen (2007)	Unanimity game	Coalition game	Osborne and Rubinstein (1994)
Stag-Hunt	Coordination game	Rasmusen (2007)	Multi-Issue game	Dynamic game	De Bruijn and Ten Heuvelhof (2018)
Travellers Dilemma	Coordination game	Morrow (1994)	Cascade game	Dynamic game	Easley and Kleinberg (2010a)
Matching pennies	Coordination game	Rasmusen (2007)	Hub-Spoke game	Dynamic game	Adler (2005)
El farol bar	Coordination game	Goeree and Holt (1999b)	Peel and pulp	Dynamic game	De Bruijn et al. (2010)
Peace War game	Coordination game	O'Neill (1994)	Camel Nose	Dynamic game	Volokh (2003)
Deadlock	Coordination game	Morrow (1994)	Centipede game	Dynamic game	Aumann (1995)
Rock, paper, scissors	Coordination game	Leyton-Brown and Shoham (2008)	Inspection game	Dynamic game	Owen (1982)
Principal-Agent game	Principal-Agent game	Rasmusen (2007)	Two level game	Dynamic game	Putnam (1988)
Multiple-Principal-Agent game	Principal-Agent game	Laffont and Martimort (2002)	Allocation game	Resource Allocation game	Chevaleyre et al. (2006)
Dictator game	Principal-Agent game	Laffont and Martimort (2002)	Cake division	Resource Allocation game	Brandt et al. (2016)
Ultimatum game	Principal-Agent game	Rasmusen (2007)	War of Attrition	Timing game	Osborne (2003)
Trust game	Principal-Agent game	Morrow (1994)	Grab the Dollar	Timing game	Rasmusen (2007)
Screening game	Principal-Agent game	Osborne (2003)	Revelation principle	Mechanism Design	Myerson (1997)
Marriage problem	Matching	Roth and Sotomayor (1992)	Umbrella game	1-player game	Webster (2009)
School selection	Matching	Roth and Sotomayor (1992)	Minority game	Congestion game	Rosenthal (1973)
Kidney exchange	Matching	Roth and Sotomayor (1992)	Voting game	Voting game	Brandt et al. (2016)
Non-Transferable Utility	Cooperative game	Osborne and Rubinstein (1994)	Cournot game	Cournot games	Straffin (1993)
Transferable Utility	Cooperative game	Osborne and Rubinstein (1994)	Stackelberg game	Stackelberg games	Myerson (1997)
Hedonic games	Cooperative game	Airiau (2013)	Dollar auction	Auctions	Rasmusen (2007)

In the next section, we explain how we select game concepts from the list in order to use the selection in the remainder of this thesis.

2.5. TAXONOMY OF GAME CONCEPTS

Classification of game theoretical concepts has been done based on classes of games, e.g., zero-sum games, symmetric games, and (in)complete information games (Bornstein, 2003, 2008), or type of players (Beckenkamp, 2006), e.g., individual versus team, or cooperative versus non-cooperative players (Da Costa et al., 2009, Fudenberg and Tirole, 1984). Distinguishing between complete and incomplete information games is game theoretically interesting, but when investigating real-world processes a complete information game[2] almost never occurs since knowledge is not shared with everyone,

[2]Knowledge about the game and the players in the game is common knowledge (Rasmusen, 2007).

and even if this is done, it is unlikely that one knows exactly what is on the agenda of the other actors involved. Therefore, we present a taxonomy based on criteria regarding the dynamics of complex decision-making processes as obtained in Section 2.3.4. These criteria easily translate into the following bipartite characteristics:

- Number of actors: two actors versus multiple actors.
- Relation and institutional structure: network versus hierarchy.
- Strategy: collective decision-making versus individual strategic behavior.
- Process and context: dynamic versus static.

These four characteristics, with each compromising two opposite values, lead to 16 different groups of game concepts as shown in Figure 2.1.

Subsequently, we categorize the game concepts from the list of games in Table 2.1 into 16 groups depending on their characteristics. The resulting taxonomy of game concepts can be found in Table 2.2.

Table 2.2: Taxonomy of game concepts.

(1)	Sender-Receiver, Grab the dollar, Peel and pulp, **Cascade game**, Two-player unanimity, Matching*
(2)	Stag-Hunt, **Battle of the Sexes**, Chicken game, Matching Pennies, Deadlock
(3)	Peel and pulp, **Camel Nose**, Centipede game, Peace War, War of attrition, Blotto games, Cournot games, Cake division
(4)	**Battle of the sexes**, Stag-Hunt, Prisoners Dilemma, Travelers Dilemma, Chicken game, Matching Pennies
(5)	**Two-level game**, **Cascade game**, **Principal-Agent game**, Matching*
(6)	Voting games*
(7)	**Principal-Agent game**, Screening game, **Camel Nose**, Stackelberg game, Inspection game
(8)	Ultimatum game, Trust game, Dictator game, Screening game
(9)	**Multi-Issue game**, **Allocation game**, **Cascade game**, Congestion game, Tragedy of the commons, Coalition games*, Cooperative games*, Signaling games*
(10)	El farol bar, Voting games*
(11)	**Multi-Issue game**, **Allocation game**, **Camel Nose**, Tragedy of the commons, Cournot games, Signaling games*, Auctions*
(12)	**Volunteers Dilemma**, **Diners Dilemma**, Public goods game, Divide the dollars, El farol bar, Rock, paper scissors, Voting games*
(13)	**Cascade game**, **Two-level game**, Signaling games*, Coalition games*
(14)	Voting games*
(15)	**Hub-Spoke**, **Camel Nose**, Multiple-**Principal-Agent game**, Stackelberg game, Signaling games*, Mechanism design*, Auctions*
(16)	Multiple-**Principal-Agent game**, Voting games*
game* means that the game represents a larger class of games.	

2

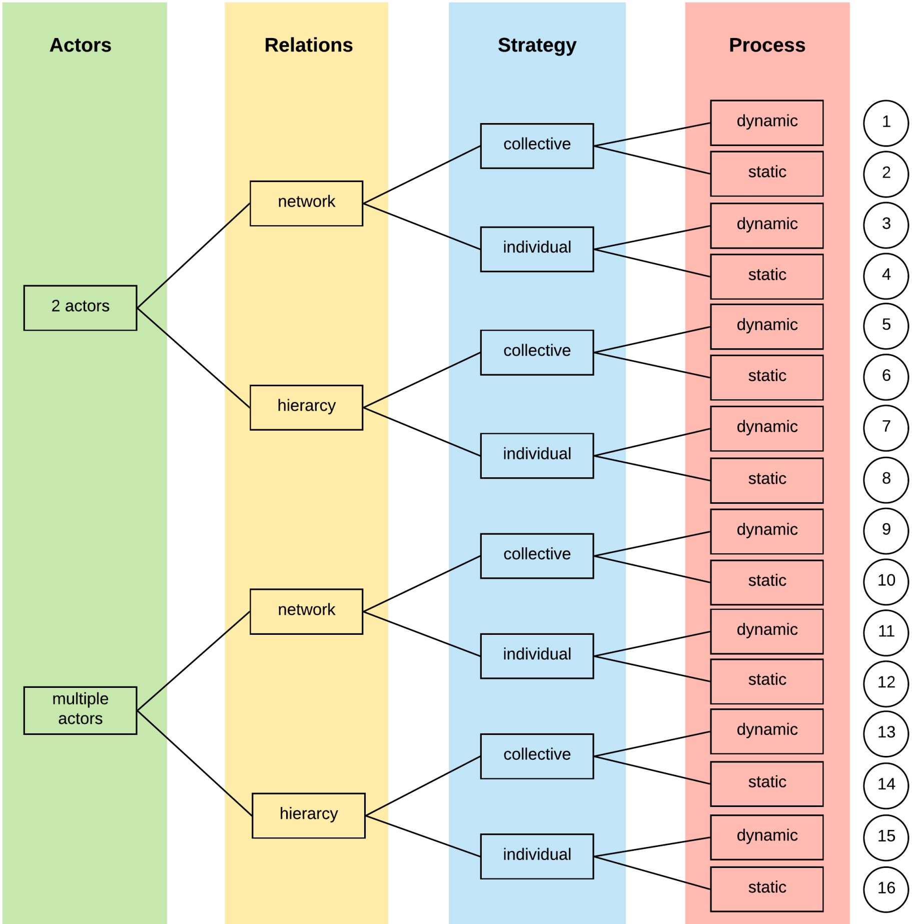


Figure 2.1: Taxonomy of decision-making characteristics.

2.5.1. SELECTION OF GAME CONCEPTS

From the game taxonomy we select 10 game concepts that represent a wide range of interactions between actors in real-world complex decision-making processes. Our selection indicates that we are mainly interested in game concepts that describe multiple actors in a network structure who have to make a collective decision in a dynamic environment (group 9). However, we know that strategic behavior exists in the multi-actor setting (groups 11 and 12), and in hierarchical relations as well (groups 13 to 16). On the other hand, interactions between two actors, potentially in a hierarchical relation, also impact the decision-making process (groups 1 to 8). In short, the selected game concepts should together span a large number of different groups of the taxonomy.

The first selection of game concepts comprises the game concepts indicated in bold in Table 2.2. Their characteristics are different due to the combination of game concepts from different fields. Some of these game concepts are mathematically defined, such as the Volunteers Dilemma, while other have only been observed empirically, such as the Multi-Issue game. To provide coherent definitions of the game concepts we list the characteristics of each game concept.

The following research was taken into consideration for the selected game concepts: Multi-Issue game (De Bruijn and Ten Heuvelhof, 2002, De Bruijn and Ten Heuvelhof, 2018, Sebenius, 1983, Winter, 1997), Principal-Agent game (Braun and Guston, 2003, Cantarelli et al., 2013, Cole et al., 2014, Dodgson et al., 2009, Gintis, 2000, Laffont and Martimort, 2002, Stauvermann, 2004), Cascade game (Anderson and Holt, 1996, Bikhchandani et al., 1992, Conradie et al., 2015, Easley and Kleinberg, 2010b), Hub-Spoke game (Adler, 2005, Adler et al., 2010, Adler and Smilowitz, 2007, De Bruijn et al., 2010, Elrod and Fortenberry, 2017, Markusen, 1996, Takebayashi, 2015), Volunteers Dilemma (Archetti, 2009, Diekmann, 1985, Goeree and Holt, 2000), Diners Dilemma (De Bruijn and Ten Heuvelhof, 2018, Gneezy et al., 2004, O'Donovan et al., 2013, Teng et al., 2013), Battle of the Sexes (Binmore, 2007, Camerer, 1997, Easley and Kleinberg, 2010b, Goeree and Holt, 1999a, Rasmusen, 2007, Shoham and Leyton-brown, 2008, Van Benthem, 2014, Vollmer, 2013), Camel Nose (Rizzo and Whitman, 2003, Volokh, 2003), Allocation games (Chevaleyre et al., 2006, Cole et al., 2014, Gilles, 2010, Muthoo, 1996, Takai, 2010), and Two-level game (Iida, 1993, Matsubayashi et al., 2005, Putnam, 1988, Schoppa, 1993, Teisman, 2000, Xiao et al., 2005). For each game concept we made a list of key terms, and this process was terminated when two new papers do not add any new characteristics. Subsequently, the characteristics are clustered and we describe for each game concept its essence, context, process, results and potential risks. To select a game concept for a given situation we should be able to distinguish between them, and thus we are interested in the game concepts that have distinguishable characteristics, i.e., they are dissimilar in certain aspects.

Taking this into account we reconsider the selection of game concepts. The Camel Nose (Volokh, 2003) and the Allocation game (Goeree and Holt, 2000) have characteristics that do not distinguish them from other game concepts. More precisely, given a certain situation in a decision-making process it will be difficult to make them explicit and therefore we decided to not incorporate them in our final selection. The characteristics of the Two-level game (Putnam, 1988) and the Cascade game (Easley and Kleinberg, 2010a) turn out to be similar and therefore we selected only one of the two game concepts.

As a result, the final selection contains seven different game concepts: the Multi-Issue game, the Principal-Agent game, the Cascade Game, the Hub-Spoke game, Volunteers Dilemma, Diners Dilemma, and Battle of the Sexes.

2.5.2. DEFINITION OF GAME CONCEPTS

This chapter concludes with definitions of the game concepts selected, including the context in which they appear, the process they characterize, their possible results, and potential risks.

MULTI-ISSUE GAME

The Multi-Issue game (M-I game) characterizes a situation with multiple actors having different incentives. They aim to reach consensus in a decision-making process that was in a deadlock in the first place.

Multi-Issue game	
Context	Multiple actors, different incentives, network of relations. One issue leads to a deadlock and pressure does not help.
Process	Actors introduce new issues and form coalitions such that linkage between, negotiations about, and exchange of issues takes place. The focus is on the actors involved and on the process, i.e., the plan follows the negotiations.
Results	A broadened agenda that contains "pain and gain" for each actor and that creates room for consensus. Negotiated knowledge, incentives for cooperation, participation in process, learning about content, knowledge about actors and their relations, and peer pressure take place.
Risks	The game develops in a 'free-fight' or becomes over-complex due to too many actors and issues.

PRINCIPAL-AGENT GAME

The Principal-Agent game (P-A game) represents a hierarchical relation between principal and agent. The principal is dependent on the agent because of its knowledge and expertise regarding a certain decision. The game explains the power position of the subordinate, i.e., the agent.

Principal-Agent game	
Context	Principal and agent exhibit a hierarchical relationship, and (usually) have conflicting interests and/or objectives. Asymmetric information between principal and agent exist, the agent has more expertise on the subject and knowledge about actions, the principal knows more about the objective.
Process	Usually a contract is signed between the principal and the agent defining a reward for the actions performed by the agent on behalf of the principal. Agent presents actions performed or decisions made to the principal. Decision-making authority is delegated to the agent and the principal cannot control his actions.
Results	Agent accepts or rejects the proposed contract by principal. Agent provides a certain outcome that either satisfies the principal or not. Principal accepts or rejects outcome of actions by agent.
Risks	Principal is the affected party, his payoff depends on the actions performed by the agent. By not accepting the decision of the agent the principal damages the relationship with the agent, and vice versa, by not performing the expected decision/action the agent damages the relation with the principal. Furthermore, increasing the asymmetry of information is a risk.

CASCADE GAME

The Cascade Game (CG) shows the tendency of intelligent actors, in case of uncertainties, to follow the decisions of others independently of the quality of the content of the decisions.

Cascade Game	
Context	Decisions are made at different levels of the organization or different parts of the organization. Path-dependency between decisions exists and they are taken in sequence. The decision space is usually limited.
Process	A decision taken at one level forms the input for a decision taken at the next level. Actors have private information and observe decisions of others (the action not the knowledge) on which they base their own decision. The question is, do we follow the decision of the others or not?
Results	A decision can spread through the various levels of decision-making since actors base their decision on advices or decisions taken at other decision levels. A decision can be blocked. Irrational decision-making can be explained by the game. Furthermore, it can specify how (in)correct information or actions lead to a final decision.
Risks	A cascade of decisions can be wrong, it can lead to sub-optimal outcomes and occurs easily in round-the-table sessions. Furthermore, the solution space converges during the game which might result in missing out of new solutions.

HUB-SPOKE GAME

The Hub-Spoke game (H-S game) describes a situation with multiple actors (spokes) having different incentives who are steered by one actor (hub) via a command-and-control style. The game creates an incentive for inflated claims, the spokes can reach agreements among each other and create strategic issues for the hub.

Hub-Spoke game	
Context	One main actor, called the hub, has a plan or decision and the other actors, called the spokes, need to be convinced. Hub and spokes are (usually) organized hierarchically. Focus is on one issue or decision.
Process	The hub negotiates (bilaterally) with each spoke individually and in sequence. The negotiation follows a plan in command-and-control style. The spokes communicate with each other and can therefore influence the negotiations by asking "as-much-as-you-can".
Results	After a number of negotiation rounds the spokes might all agree with the plan, or (part of) the spokes is not agreeing with the plan.
Risks	The game might create separation between actors, and it is risk for the game developing in an "ask much as you can" game. Furthermore, non-cooperative behavior and limited learning are characteristics of the game. Spokes might block the decision-making process which is unfortunate if hub and spokes meet in future processes again. The sequence of information resulting from the spokes communicating might create strategic issues for the hub. Due to the many negotiations with the different spokes the process can be time consuming.

VOLUNTEERS DILEMMA

The Volunteers Dilemma (VD) explains why one or more actors take the responsibility for the group to prevent a worst-case scenario from happening. Performing wait-and-see behavior is beneficial, but increases the risk of a bad outcome of the decision-making process.

2

Volunteers Dilemma	
Context	In case of a 'dangerous event or belief' that might lead to unfavorable outcomes, and if pressure and diffusion of responsibilities are present, at least one player needs to sacrifice him/herself against a certain cost for the group. The optimal decision for the individual (waiting for someone else to act) contrasts with the optimal decision for the group (someone should act). The game applies when all possible volunteers are equally capable of doing what has to be done.
Process	Each actor makes individual considerations on volunteering or not. A reasons to volunteer is, someone takes responsibility for the group to prevent the worst-case scenario from happening. A reason to not volunteer is, expecting personal blame. The game has a big incentive for 'free-riding' and 'wait-and-see' behavior.
Results	No action means that everyone loses (or ends up in the worst outcome). A volunteer might be blamed for taking the action. A volunteer can be followed by the other actors and therefore not blamed.
Risks	No actor feels the need to volunteer since costs are too high or everyone expects the others to volunteer. A volunteer is blocking the process too early and thus only delays the process. Available volunteers are not discovered since they are too subtle or present at other levels of the organization.

DINERS DILEMMA

The Diners Dilemma (DD) represents a situation in which multiple actors come to an agreement about the process of decision-making (e.g. collaboration and mutual interaction). Due to the agreements made it becomes attractive to be the first one to violate the agreements.

Diners Dilemma	
Context	In a setting a group of actors reaches an agreement regarding collaboration, way of working, etc. For example, in a restaurant the group gathers for a dinner, and there is an unspoken agreement to divide the bill. Moreover, there is a cheap and an expensive menu on offer and the actors agree on the cheap option.
Process	There is a great incentive for 'free-riding' by, for example, by choosing the expensive meal. Every actor performs individual balancing concerning violating the agreement or not. It is beneficial to be the first one to be dishonest and violate the agreement made. When the same group meets repeatedly under the same (bill-sharing) agreement, cooperation may develop, leading to a better overall (dining) experience.
Results	Every actor pays 1/n times the bill of the dinner. If there is at least one actor who violated the agreement the costs for the dinner are, for this particular actor, less than the cost of the expensive meal. For the actors who did not violate the agreement the costs for the dinner are more than expected.
Risks	Everyone violates the agreement by choosing the expensive menu, so no one benefits from 'free-riding'. In this situation, actors do not feel the urgency to cooperate.

BATTLE OF THE SEXES

The Battle of the Sexes (BS) describes a case in which two actors are completely dependent upon each other. Moreover, they share the same goal, but have different incentives. In order to reach a decision one of the two actors needs to adopt the others idea.

Battle of the Sexes	
Context	In the two-actor game the shared goal is to coordinate strategies. The actors share the same objective/goal, for example, going out together. The actors have different interests, for example, actor A wants to go to a football match and actor B wants to go to the theater. But they prefer being together, say, in the others' preferred activity, rather than being alone.
Process	Decisions are made simultaneous, and actors are unable to communicate. Each needs to anticipate on the others strategy.
Results	Each actor has two possible strategies and there are four possible outcomes: both actors go to the football match; both actors go to the theater; actor A goes to the football match and actor B goes to the theater; actor B goes to the football match and actor A goes to the theater. The first two outcomes are the Nash equilibria of the game, in those cases one of the actors' incentives are represented. In the latter two outcomes the shared goal of going out together is not reached. A third result is that the actors made a compromise in which both incentives are partly represented and the goal has been reached.
Risks	Anticipating the expected strategy of the other wrongly due to not acknowledging the incentives of the other. A compromise between the two actors does not lead to the intended goal or is a sub-optimal solution.

IN this chapter, the theoretical perspective of the thesis was introduced.

- A comparison of the game concept approach with other decision support methods showed its uniqueness on two main aspects:

    i. It addresses the actors' *agency*, meaning who is responsible for what, in a structured way, and

    ii. It represents the *dynamics* of actor relations, and the dynamics of the process.

- The final result of this chapter is a selection of seven game concepts:

    Multi-Issue game: multiple actors having different incentives aim to reach consensus in a decision-making process that was in a deadlock in the first place.

    Principal-Agent game: a hierarchical relation between principal and agent is present in which the principal has more power than the agent. However, the principal is dependent on the agent because of its knowledge and expertise regarding the decision.

    Cascade game: the tendency of intelligent actors, in case of uncertainties, to follow the decisions of others independently of the quality of the content of the decisions.

    Hub-Spoke game: multiple actors (spokes) with different incentives are steered by one actor (hub) via a command-and-control style. The game creates an incentive for inflated claims, the spokes can reach agreements among each other and create strategic issues for the hub.

    Volunteers Dilemma: one or more actors take the responsibility for the group to prevent a worst-case scenario from happening. Performing wait-and-see behavior is beneficial, but increases the risk of a bad outcome of the decision-making process.

Diners Dilemma: multiple actors come to an agreement about the process of decision-making (e.g. collaboration and mutual interaction). Due to the agreements made it becomes attractive to be the first one to violate the agreements.

Battle of the Sexes: two actors are completely dependent upon each other. Moreover, they share the same goal, but have different incentives. To reach a decision one of the two actors needs to adopt the others idea.

- These game concepts were selected from a list of game concepts and were categorized in a taxonomy.
- The taxonomy entails characteristics regarding actors, relations, strategies, and the process. It divides the list of game concepts in different categories.
- The game concepts were selected because they cover a variety of decision-making characteristics, and they are clearly distinguishable from each other.
- In the remainder of the thesis, the game concepts are used for different purposes.
- In Part II, empirical case studies of the Dutch railway sector are first described, and then *characterized* using the game concepts. Furthermore, general patterns of game concepts in these case studies are identified.
- In Part III, the game concepts are applied in two situations to *support* decision-making. First, to support decision makers when designing a game in a decision-making process. Second, to support decision makers of the Dutch railway sector in an ongoing decision-making process.
- In Part IV, one of the game concepts is *formalized* in order to serve as input for modeling of decision-making processes.

II

Empirical observations

3

Case Studies of the Dutch Railway Sector

This chapter consists of six case studies, i.e., decision-making processes on large infrastructure projects of the Dutch railway sector.

- The case studies are classified in three different families of case studies: rebuilding emplacements, frequency increase, and safety transition.
- Each case study is investigated using the same methods, and the result of this investigation is a case description.
- The case descriptions consist of an explanation of the technical, actor, and context complexity, and the essence of the decision-making process.
- The case descriptions are later used to identify the game concepts to characterize the decision-making processes.

The structure of this chapter is as follows: In Section 3.1, we distinguish three complexity levels in order to describe the complexity of the decision-making processes. Subsequently, in Section 3.2, we explain the different families of case studies. Their similarities and differences are specified according to the technical, actor and context aspects of the process. Then, in Section 3.3, the methods used to investigate and describe the process are presented. Finally, in Section 3.4, we provide a case description for each case study by stating the complexity at technical, actor and context level, and the essence of the process.

Parts of this chapter have been published in Research in Transportation Economics **69** (2018) (Bekius et al., 2018a) and in the International Journal of System of Systems Engineering **8**, 4 (2018) (Bekius and Meijer, 2018a).

3.1. COMPLEXITY LEVELS IN DECISION-MAKING PROCESSES

The selection of the case studies is based on criteria from literature on networks (De Bruijn and Ten Heuvelhof, 2018, Kickert et al., 1997, Klijn and Teisman, 1997, Koppenjan and Klijn, 2004, Rhodes and Marsh, 1992, Teisman and Klijn, 2008) as is introduced in Chapter 2. These criteria explain why decision-making processes are complex:

1. Unstructured problems: there are many technological uncertainties, problems and solutions.
2. Networks: multiple stakeholders with different incentives are interdependent.
3. Dynamics: context and environment continuously change.

To study the complexity of decision-making processes several researches propose to distinguish between a system perspective rooted in the engineering sciences on the one hand, and a decision, actor, institutional, or social perspective from the social sciences on the other hand (Bueren et al., 2003, De Bruijn and Herder, 2009, Hughes, 1987, Thissen and Walker, 2013, Williamson, 2000).

In line with the aforementioned criteria, we distinguish three types of complexity: a technical level, an actor level and a context level.

Technical level The system under study is complex and can be abstracted or viewed along three lines:

- Functionally organized in aspect systems (Veeke et al., 2008). The different aspect systems define the main responsibilities for the actors involved. For the system to function, these aspects need to be aligned - so an entire-system approach is necessary.
- Geographically organized - the system can be divided into regions, where its functions come together. These regions can be called subsystems (Checkland, 1981, Sage and Cuppan, 2001, Veeke et al., 2008). Not saying that the system can just be simplified by looking at its subsystems since many decisions impact several subsystems.
- The system can be distinguished in operational and strategic levels. For the system to function well these levels need to be aligned as well.

Actor level Decision-making processes on complex systems usually involves multiple actors with different perspectives and interests. These actors are not hierarchically organized, but they are mutually dependent and they are responsible for different parts of the system. As a result, they together form a network of interdependencies. In such a network, the course of the decision-making depends on the behavior of and interactions between these actors (De Bruijn and Ten Heuvelhof, 2018). This results in an often messy, spaghetti-like structure. To make this even more complex, the formal structures actors have to work in and work with, are often hierarchical, which might give some actors a special position.

Context level During the process of decision-making both the network of actors involved and the content of problems and solutions might change over time. The dynamics is for a large part the result of the many interdependencies - a change in one regional subsystem has effect on the national system, a change of actor A's behavior might impact the behavior of actor B. Moreover, decision-making processes are always impacted by unforeseen external developments such as political decisions, media attention and technical innovations (Priemus, 2010).

In the next section, we introduce the families of case studies and summarize their main characteristics according to the different complexity levels.

3.2. FAMILIES OF CASE STUDIES

The overall aim of the selected decision-making processes of the Dutch railway sector is to increase the capacity of the railway system, meaning to allow more trains running in the system. One could achieve this by changing the system, for example, building more infrastructure, increasing the frequency of trains or letting trains run closer to one another. Each of the aforementioned options requires a different set of assumptions, actors, technical requirements, contextual factors etc. In the following subsections the three families of case studies are introduced and their characteristics are summarized in Table3.1.

3.2.1. FAMILY 1: REBUILDING EMPLACEMENT

Decisions regarding changes of emplacements, i.e., stations, and surrounding infrastructure, belong to this family of case studies. The case studies investigated are part of the High-Frequency Rail Program (in Dutch: Programma Hoogfrequent Spoor (PHS)) which aims to increase the number of passenger and freight trains without building completely new infrastructure. In order to accommodate more trains and support the flow-through of trains several emplacements and surrounding infrastructure need to be rebuild. We have studied the following cases:

1. Station Amsterdam

2. Station Nijmegen

During these decision-making processes infrastructural aspects of the emplacement and surrounding infrastructure are the main focus, such as tunnels, switches, but also noise standards and transfer of passengers. The aim of changing the emplacement and surrounding infrastructure is to be able to drive more trains on the network. However, it does not take into account how operation can be improved to actually drive more trains. Decisions on these infrastructural aspects are always taken before actual decisions about increasing the frequency in the timetable are made, and thus before the customer can see the results of the construction works. Budget restrictions are an important aspect of decision-making process regarding rebuilding emplacements. The PHS program has to divide its budget among the different projects of which station Amsterdam and station Nijmegen are part.

3.2.2. Family 2: frequency increase

Decisions regarding the increase in frequency of trains per hour at one of the busiest corridors of the Netherlands are part of this family. We investigated and followed three different decision-making processes:

1. Better for More 2015
2. Better for More 2016
3. Redesign of the timetable 2017

The A2 corridor, between Amsterdam and Eindhoven, is the busiest part of the Dutch railway network. Since the number of passengers is expected to increase in the near future there is a need for more capacity, which means running more trains per hour. This, however, cannot be done at the expense of the performance level of the system, e.g., measured in number of delays (Tweede Kamer der Staten-Generaal, 2015a). Many improvements of the system, such as constructing new infrastructure, changing behavior of operators and introducing new trains, are planned to be, or partly have been, implemented to support the increased capacity. Therefore, ProRail and NS have to decide: has the performance of the system improved enough in order to increase the frequency of the number of trains per hour at the A2 corridor?

The decision-making process has been performed two times, in year 2015 and year 2016 respectively. The processes are similar since in both situations the same decision needs to be taken by the same actors and both processes are supported by the same improvement program, called Better for More. Moreover, the decisions are made in uncertainty since the performance level of the system is not known at the moment of decision-making and the technical complexity of the system did not change. Interestingly, the final decision, i.e., the outcome, of both processes is different (Bekius et al., 2018a).

Decisions made in the processes Better for More 2015 and Better for More 2016 are input for the design of the timetable for the Dutch railway sector. Once it has been decided to increase the frequency of number of trains per hour at the A2 corridor this provides a new, additional, requirement for the design process of the timetable.

In 2017, the timetable for the Dutch railway sector is completely redesigned. This means that, instead of adapting last year's timetable, the design of the timetable started from a blank paper. Compared to the yearly timetable design cycle, the first design phase is constructed fundamentally different and this influenced the subsequent design phases. Apart from the process being technically complex, since designers are given more freedom to explore new ideas, it changes the behavior of actors and the influence of context elements. Additionally, the major changes need to be included in a standing engineering process. Not only the product, i.e., the timetable, and the exchange of information of one design phase to the other is of importance, but also the actor and context perspective matters in this case (Bekius and Meijer, 2018a).

3.2.3. Family 3: safety transition

Decisions regarding a transition towards a new safety system are part of this family. These decisions belong to a single case study: the European Rail Traffic Management System (ERTMS). The ERTMS program has the goal to replace the existing analogue safety system with a digital safety system to meet European obligations and to enable benefits in terms of safety, interoperability, capacity, speed and reliability (Schuitemaker et al., 2018, Van den Top and Sierts, 2009). The ERTMS program considers one aspect of the railway system, namely the safety, and facilitates the entire railways. Behavior of operators are considered since the new technique requires their behavior to change, however, the aim is not to improve the performance of the system.

Having introduced the three different families we summarize a number of their different characteristics in Table 3.1.

In the following section, we outline the methods used for investigation of the case studies.

3.3. METHODOLOGY

The methodology entails multiple methods that are used to make a case description (Ragin and Becker, 1992, Yin, 2009). We decided to discuss the complexity levels and the essence of the process in order to be able to include the main aspects necessary for identification of the game concepts in the next chapter. Moreover, we aim to identify generic patterns of game concepts, and thus needed to investigate multiple case studies. We acknowledge that this comes at the cost of describing the details of the decision-making process. By not describing these details we are not saying that they are not important for the process of decision-making.

In this section, we introduce the methods used to obtain data from the case studies, to analyze and structure the data, and to validate the case description with experts. For obtaining data of the case studies we used interviews, documentation, and observations. Specifications of the obtained data are summarized for the different case studies in Table 3.2. We analyzed the data using a case description template. The data was coded in themes and by performing interpretation sessions. This results in a case description for each decision-making process. Finally, we validate the case description for each case study with experts involved in the decision-making process.

3.3.1. DATA COLLECTION

Data is collected in interviews, from documentation, and during observations (DeWalt and DeWalt, 2002).

INTERVIEWS

Semi-structured interviews were held with actors from the different organizations involved in the process, and at different levels within these organizations (Weiss, 1994). Our main focus are the operational and strategic decision makers involved in the process and the people involved at the tactical level. The operational and strategic decision makers are the ones who actually make the decision. However, we are also interested in the perspectives of people at the tactical level since they design, organize, and inform decision makers during, the process of decision-making. Particularly, these persons are able to present an overview of the entire process rather than only the specific decision moments. Participants of the interviews were asked to answer the questions from their role within the organization.

We chose to perform semi-structured interviews such that, on the one hand, interviewees were completely free to answer the question in their own way. On the other

Table 3.1: Distinction families of case studies.

	Rebuilding emplacement	**Frequency increase**	**Safety transition**
Technical level			
Aspect systems	Multiple infrastructural aspects	Multiple system aspects, including operational aspects, human behavior	Single aspect
Subsystems	Single subsystem	Few subsystems	Multiple subsystems
Technical uncertainties	Mainly infrastructure aspects	Effect of improvements (system and human) together unknown	New technology in development and entire system integration
Performance system	No particular focus	Main focus, performance should improve	No particular focus
Actor level			
Main players	ProRail, NS, I&W, municipalities, other operating companies	ProRail, NS, I&W	ProRail, NS, I&W, Parliament, European Union, other operating companies, freight operators, contractors
Final decision by	Minister	NS	Parliament
Diversity in incentives	Different responsibilities, sometimes different goal	Different responsibilities but same goal	Large variety in cost to cover and time lines
Visibility of decision	New station after constructions	Availability to travel more frequent	Very limited
Context level			
Influence politics	Budget restrictions	Pressure to perform	Assignment from EU
Influence other decisions	Budget divides among PHS projects	Implementation Utrecht station	No 4 tracks at OV-SAAL corridor

hand, the questions with predefined answers steer the participant such that it is easier to compare the answers of participants afterwards. Open questions, multiple choice questions and raking questions were asked covering the following themes: actors, their function, their interests, strategies performed, explanations for the decision, important moments, complexity of the decision, uncertainty, information, issues on content and context, and possible improvements of the process.

The interview protocol was designed in close collaboration with experts from the Dutch railway sector to make sure questions asked were understandable by decision makers and made sense for the decision-making process under study. Moreover, it secured that the multiple choice options were reflecting the options applicable for the process at hand.

Interviews took approximately one hour and were, after permission of the interviewee, recorded. Afterwards, the recordings were used to make interview transcriptions. Table 3.2 gives an overview of the total number of interviewees per case study and reflects how many interviews were conducted from which organizations and different levels of organizations. For two case studies, Redesign timetable 2017 and ERTMS, the interviews were conducted in two rounds. In between the rounds a validation session was held, see Section 3.3.3.

DOCUMENTATION

Documentation available to the researchers consisted of agendas and notes of meetings, project plans, letters to Parliament, progress reports and internal documentation. The documentation was used as a reference for decisions made, issues discussed, and to check the time line of events. The type of documentation used to investigate the different case studies is presented in Table 3.2.

OBSERVATIONS

For some case studies it was possible to be present in director meetings, program meetings, steering groups or gaming sessions. Moreover, during one decision-making process, the researcher could be present in the daily office of the program Better for More. This way we could observe the issues and status of the decision-making process on a weekly basis.

Table 3.2 provides an overview of the various methods used and how this applies to the different case studies.

The data we obtained from the previously introduced methods are used to make a case description. The next section explains how we structured and analyzed the data to develop such a case description.

3.3.2. DATA STRUCTURING AND ANALYSIS

We analyzed the data by designing a template, coding and clustering the data based on different themes, and performing a first round of interpretations. The coded data was processed into the template, and subsequently, several rounds of interpretation and refinement of the case description were performed by the researchers. Finally, the case description was discussed with experts involved in the case under study for validation (Boeije, 2010).

DESIGN OF A TEMPLATE

The case description includes the complexity and the essence of the process of decision-making. A distinction is made between the technical, the actor, and the context complexity of the decision-making process as introduced in Section 3.1. For the description of the process of decision-making, we include the essential elements of the process and identify different rounds (Teisman, 2000).

Table 3.2: Various methods of obtaining data.

Cases	**B&M 2015**	**B&M 2016**	**Timetable 2017**	**Amsterdam**	**Nijmegen**	**ERTMS**
Interviews						
Total number of interviewees	16	12	8	13	12	8
Strategic level (ProRail)	1	1	1	2	1	1
Operational/ tactical level (ProRail)	4	2	3	4	6	1
Strategic level (NS)	3	2	1	1	0	1
Operational/ tactical level (NS)	5	6	3	0	1	0
Ministry	2	1	0	1	1	2
Other operators	0	0	0	0	0	1
Freight operators	0	0	0	0	0	2
Others (municipalities, consultants)	1	0	0	5	3	0
Documentation						
Agendas, notes project meetings	x	x	x	x	x	x
Agendas, notes steering groups	x	x	-	x	x	x
Memos	x	x	-	x	-	-
Program documentation	x	x	-	-	-	x
Progress reports	x	x	-	-	-	-
Project proposals	x	x	-	x	x	x
Letters to/from Parliament	x	x	-	x	-	-
Design choices	-	-	x	x	x	-
Scenario timetable design	-	-	x	-	-	-
Examples of design conflicts	-	-	x	-	-	-
Newspapers	-	-	-	x	-	-
Internal advice	x	x	-	-	-	x
Assignment letter ProRail-I&W	-	-	-	-	-	x
Covenant I&W-NS	-	-	-	-	-	x
Collaboration agreement ProRail-NS	-	-	-	-	-	x
Observations						
Program/project meeting	-	x	-	-	x	-
Steering group	-	x	-	-	-	-
Gaming session	-	x	-	-	-	-
Workshop session	-	-	-	x	-	x

Table 3.3 presents the subjects which follow from the three types of complexity and are addressed in the case descriptions of the case studies.

Table 3.3: Themes and subjects in case description.

Technical complexity	**Actor complexity**
Sub, and aspect systems	Main actors
Dependencies between systems	Incentives, opinions, responsibilities
Design requirements	Worst-case scenarios
Budget restrictions	Influence of trust
Decisions and issues	Dilemmas and conflicts
Technical uncertainties	Relations
Context complexity	**Process of decision-making**
Political sensitivity	Essential moments
Media attention	Behavior of actors
Dynamics of actors and issues	(Sub) decisions
Influence other decisions	Major issues
	Formal decision structure
	Information quality and availability

CODING AND CLUSTERING IN THEMES

The template and corresponding subjects introduced in the previous section form the basis for coding the interview transcriptions. The program Atlas.ti has been used for most case studies. Moreover, information from documentation and observations was clustered according to the above-mentioned subjects. Tables containing the interviewees and documentation sources on rows and subjects on the columns are the result of such coding procedures. They provide the input for the case description and interpretation of the decision-making process.

Additionally, we identified different rounds in the decision-making process. To identify the rounds we considered important decision moments and context events to define where a round starts and ends. The following characteristics indicate an important decision moment:

- Change in direction of the process, for instance, different content of the conversation, or dilemma appears.
- Change in constitution of actors.
- Change in interactions between actors, for example, new agreements about collaboration or conflicts arise.
- Increase or decrease of technical uncertainties or issues.
- Change in context elements.

For each round we specify the actors, their role, and their incentives, and the strategies used. Furthermore, the interdependencies between issues and actors as well as the context elements and influence of, for example, politics on the process is defined.

INTERPRETATION AND REFINEMENT

We performed several rounds of interpretation of the case description in order to interpret and refine the information from the different sources. The aim of these interpretation rounds was to develop a case description that includes the themes of the template, is consistent with the real-world process and is readable for someone not involved in the process.

3.3.3. VALIDATION OF DATA

Validation of the final results, i.e., description of the decision-making process, was performed by experts involved in the decision-making process. At least two experts received the case description and were invited for a meeting to discuss the case description in person. The main questions we asked were: Did we misinterpret some information, and are we missing any essential information? Based on the experts' comments and suggestions the case descriptions and interpretations were again refined. For the case study Redesign of the timetable 2017, the time line of the process is validated after three interviews, and a second round of interviews in conducted to obtain the perspectives of the different actors and disciplines involved. A similar set-up is used for the case study ERTMS. First, we conducted two interviews with the main stakeholders and dossier holders before a time line of the process was validated by experts, and a new round of interviews was performed. The final case description was again validated by experts.

3.4. Case descriptions

This section contains the case descriptions of the case studies. The case descriptions of Better for More 2015 and 2016 are published by Bekius et al. (2018a). The case description of the Redesign process of the timetable is published by Bekius and Meijer (2018a). The case descriptions of Amsterdam and Nijmegen are rewritten and shortened, but based upon master thesis written by De Kwaasteniet (2018) and by Van Dulken (2018). The case description of ERTMS is not published yet.

3.4.1. Better for More 2015

The A2 corridor, between Amsterdam and Eindhoven, is the busiest part of the Dutch railway network. Since the number of passengers is expected to increase in the near future there is a need for more capacity, which means running more trains per hour. This, however, cannot be done at the expense of the performance level of the system, e.g., measured in number of delays (Tweede Kamer der Staten-Generaal, 2015a). Many improvements of the system, such as constructing new infrastructure, changing behavior of operators and introducing new trains, are planned to, or have partly, been implemented to support the increased capacity. Therefore, ProRail (infrastructure manager) and NS (main operating company) have to decide: has the performance of the system improved enough in order to increase the frequency of the number of trains per hour at the A2 corridor?

The decision-making process has been performed two times, respectively in years 2015 and 2016. The processes are similar since in both situations the same decision needs to be taken by the same actors and both processes are supported by the same improvement program. Moreover, the decisions are made in uncertainty since the performance level of the system is not known at the moment of decision-making and the technical complexity of the system did not change. Interestingly, the final decision, i.e., the outcome, of both processes is different. The different outcomes cannot be explained from a (single) technical perspective, for example, comparisons of lists with feasibility of various (technical) aspects of the process do not reveal why the outcome is different. Therefore, we take into account the actor and context dynamics of the process: actors may adopt new roles or responsibilities, and the request from the political environment may change.

Technical complexity

The railway system consists of several interdependent sub and aspect systems and each of them requires specific knowledge. The system needs to improve in order to keep the current performance level, measured by, among others, defects on infrastructure and delays of trains, while increasing the frequency of trains. The complexity lies in the fact that it is not known whether the improvements on the various sub and aspect systems together would result in the desired performance level. “First, the performance of the system needs to be improved, before we can do something else” (project manager, main operator). Moreover, the collective of improvements on the system are not visible at the moment of decision-making. For example, do improvements on the infrastructure together with improvements on trains and driving behavior of operators mean that the overall system performance is improved? Therefore, no one could ensure the desired performance at system level.

ACTOR COMPLEXITY

Three main actors are involved in the decision-making process: ProRail, NS and the Ministry of Infrastructure and Watermanagement (I&W). ProRail and NS are functionally organized and have separate responsibilities regarding the system. They cooperate to let the entire system function. Currently, there is a shift from separate decision-making with formal transitions between ProRail and NS, towards a process with joint preparation and actual decision-making without change of responsibilities between the organizations. This new type of decision-making includes performance levels, and the operational measures, explicit in the process of decision-making. The performance levels are established in contracts with the government (Van de Velde et al., 2009). ProRail and NS have a joint interest to achieve the desired performance levels. In the decision-making process, the decision is taken at different decision-making levels. This means that the decision made at one level forms the input for the decision taken at the next level. In these decision levels, the different actors, as well as the strategic and operational levels, of the organizations are included. The strategic level fears out-of-control situations while the operational level is more concerned with daily disruptions. “We are mainly concerned with big disruptions since this has a major impact on our reputation” (strategic level, infrastructure manager). The interest of I&W is to have the high frequency timetable implemented since they invested money in it. Moreover, they constitute the contracts including the performance levels.

CONTEXT COMPLEXITY

The context of the decision is important for the decision-making process and several elements can be enumerated. The media reports about full trains during rush hours. Alignment and commitment of organizations is necessary for the collaboration program to succeed. Issues such as reputation, culture of the organizations, overpromise and under deliver play a role, and discussions around the Parliamentary investigation have an impact (Tweede Kamer der Staten-Generaal, 2015b).

PROCESS OF DECISION-MAKING

Uncertainty increases The inclusion of performance levels in the decision-making process leads to many uncertainties. They include technical uncertainties regarding the system, but also institutional and actor uncertainties. For example, conflicts regarding who decides about what and when appear. “It was clear that alignment was necessary, but it took quite a long time to decide who had the final vote on which aspect” (operational director, infrastructure manager). Multiple system issues which result in involvement of different departments across the organizations emerge. Some issues focus on the A2 corridor, such as the implementation of new trains, while others have an effect on the entire country, for instance the introduction of new operational procedures at the control centres. As a result, many actors with different responsibilities regarding the system and different perspectives on the decision to be made are involved. Additionally, time pressure towards taking a decision is present which makes the existence of many uncertainties problematic. “There is a huge barrier for people to communicate a red box,[1] they rather prefer to communicate an orange box while saying we will fix it” (operational director, infrastructure manager).

Operational level initiates decision Towards the decision deadline, operational decision makers are asked to assure the performance level of their part of the system. It is their responsibility to provide an advice about the decision to increase the frequency of trains or not. Given the history and culture of the Dutch railway sector, no one is expected to say ‘no’. However, the implementation of new station Utrecht (Flow Trough Station Utrecht, in Dutch: DoorStroom Station Utrecht (DSSU)) together with a frequency increase might cause too many problems and burden the performance levels in case of disruptions. Close to the decision deadline, the responsibility for the issue is taken by one actor at operational level resulting in a negative advice from operational level. “First it needs to be better, before we can actually have more trains” (infrastructure manager, main operator). Consequently, the advice spreads through the various levels of decision-making and is followed up by the decision makers at those levels.

Decision is accepted Finally, the decision is adopted at strategic level and communicated to I&W. They are surprised by the outcome of the decision at a moment they cannot influence it anymore. “For a number of people the decision came as a surprise, when the decision was already made we got informed” (ministry). Their influence is limited since the deadline for making changes in the new timetable has already passed. Therefore, I&W accepts the decision, but with the additional desire for a positive, meaning ‘yes’, decision next year. “Everyone is committed to a positive decision” (ministry). A so called burden of the past is created.

ESSENCE CASE BETTER FOR MORE 2015

- The pressure to make a ‘go’ decision.
- The increase of substantive technological uncertainties regarding the performance of the system.
- Institutional, i.e., non-technological, uncertainties regarding who decides what and when.
- Two main issues left: the ‘good days, bad days’ issue and the reconstruction of the Utrecht subsystem.
- Context elements such as a Parliamentary investigation and media attention.
- A period of non-decision-making due to the uncertainties regarding issues, actors’ responsibilities, and the course as well as the outcome of the decision-making process.

[1] The assessment framework communicates the feasibility of the frequency increase by then end of year 2017 based upon several aspects that are assigned a red, orange, yellow or green box. A red box means that the aspect does not contribute to the feasibility of the frequency increase.

- The key decision regarding subsystem Utrecht which is seen as a showstopper for the decision.
- A conflict between two departments of the same organization.
- The series of 'no-go's' that followed.
- The decision of I&W to accept the decision of ProRail and NS after being informed of an unforeseen result.
- The burden attached to this decision: next time a 'go'.

3.4.2. BETTER FOR MORE 2016

TECHNICAL COMPLEXITY

The technical complexity is the same as in the case description Better for More 2015. However, even more (content) issues arrive during the process.

ACTOR COMPLEXITY

The actor complexity is similar to the case description Better for More 2015. A difference with the previous year is that actors are familiar with the process and are more aware of the incentives of other actors involved.

CONTEXT COMPLEXITY

The context complexity is similar to the case description Better for More 2015. However, the history of the decision-making process in the year 2015 plays a role. Moreover, the dynamics increases since new actors with limited railway experience enter the process which is of influence on the decision-making. "There are different players, a new CEO at the main operator company, the governance is arranged differently and people have a different role" (strategic level, main operator).

PROCESS OF DECISION-MAKING

The process of decision-making continues from the end of the last round of case study Better for More 2015.

New start of the process: still many uncertainties exist Half a year after the 'no' decision, the improvements of the system, necessary to ensure the desired frequency increase, are still not visible in the operation. At this stage, the operational level is the main representative of the process. Wait-and-see behavior is observed and issues such as ownership and responsibility become evident. "We are one year further, and we are playing the same game, one level higher, based upon periodic progress reports" (operational director, infrastructure manager).

Strategic level interferes Because of the ownership and responsibility issues, the strategic level gets involved and urgency regarding the improvements spreads through the system. A shift in power and control regarding the situation, from operational level to strategic level, is observed. The stabling and serving problem becomes a major issue as well as the future stability of a high frequency timetable. “Major issues are and will be the stabling and serving problem and the future stability” (program manager, main operator). Unless issues which influence the performance levels negatively arrive at the table none of them seems to be a showstopper for the decision. Or, in other words, no one takes the responsibility for those issues and frames them as being critical issues regarding the desired performance level. Additionally, the promise towards I&W of last year becomes part of the discussion, even as reputation and the necessity of the frequency increase concerning the fact that trains are full. “Full trains is becoming an issue, especially at the A2 corridor, and why are we increasing the frequency, to solve the full trains issue” (strategic level, main operator).

Decision has to be made: changing roles Pressure from strategic level, in a final stage of the decision-making process, results in intensive collaboration at operational level. “Focus has improved and the game became more serious” (infrastructure manager). At this stage I&W becomes part of the decision and is willing to utilize the space available within the contract regarding the performance level. There are shifts in power and responsibilities between actors from strategic and operational level, as well as, between ProRail and NS, and I&W. It is in the interest of the Ministry to have ProRail and NS deciding positively since they promise a high frequency timetable to the Parliament. This shows that the power position of I&W is different towards NS and ProRail, and towards the Parliament. In fact, this results in a second burden of the past.

Two consecutive processes regarding the same decision conclude in different outcomes. One could say that the promise of a positive decision made after the ‘no’ in the first year leads to the different result. However, this explanation is too simple. Clearly, many more elements play a role. In interviews, decision makers involved are asked to score the importance of several aspects of the process when comparing both years. Technical aspects, such as complexity of the process and performance improvement, received the same evaluation for both years. Aspects that scored differently are involvement of new actors, time pressure and ownership. In Chapter 4, we interpret the difference in outcomes of our case studies by using the game concepts.

ESSENCE CASE BETTER FOR MORE 2016

- Negative decision of previous year with the additional desire for a positive decision next year. The decision to be made is the same, but contextual factors are different. For example, new actors with limited railway experience enter the process.

- Half a year after the ‘no’ decision improvements of the system are still not visible in operation. Operational managers are main representatives of the process, wait-and-see behavior is observed and issues such as ownership and responsibility become evident.

- Shift in power and control from operational to strategic management is the result of a spread of urgency regarding the improvements and involvement of more context issues. Time pressure starts playing a role.

- Major issues arrive at the table, but no one turns out to be critical regarding the desired performance level. Additionally, the promise towards the Ministry becomes part of the discussion.
- Pressure from strategic level, in a final stage of the decision-making, results in intensive collaboration at operational level.
- There are shifts in power positions and responsibilities between actors from strategic and operational level, as well as within the main actors involved.
- Moreover, the Ministry becomes part of the decision and is willing to utilize the space available within the contract regarding the performance level.

3.4.3. Redesign timetable 2017

Once every ten years the timetable for the Dutch railway sector is completely redesigned. This means that, instead of adapting last year's timetable, the design of the timetable starts from a blank paper. Compared to the yearly timetable design cycle, the first design phase is constructed fundamentally differently and this influences the subsequent design phases. Apart from the process technically being complex, since designers are given more freedom to explore new ideas, it changes the behavior of actors and the influence of context elements. Additionally, the major changes need, at some point, to be included in a standing engineering process. Not only the product, i.e., the timetable, and the exchange of information of one design phase to the other is of importance, but also the actor and context perspective matters in this case.

Technical complexity

Different from the usual process, a complete redesign of the timetable is performed. A complete redesign is necessary to optimize the entire timetable. Three goals are specified: improve the punctuality, increase customer satisfaction and create more profit by fully utilizing the infrastructure built in recent years. Regarding this last point, the year 2017 is the perfect moment for such a redesign since the renovation of Utrecht Central station (a central node in the Dutch railway system) and its surrounding infrastructure was completed by the end of 2016, four new tracks became available at the south of Amsterdam (another major node in the Dutch railway system), and a frequency increase at one of the busiest corridors in the Netherlands is planned. Therefore, the main railway operator (NS) and the infrastructure manager and allocator of the capacity of the railways (ProRail) decided to start the design process together.

Over time, the design process develops over several design phases, and a change in one design component should lead to changes in other components. When at a certain point this does not happen, it is called a misalignment: one component changes, while others remain static.

Actor complexity

The design process starts with two actors, ProRail and NS, in the predesign phase. Since they start designing from scratch it is beneficial to have not all Railway Undertakings (RUs) at the table from the beginning. However, this decision creates issues in the later stages of the process. Another complicating aspects of the process is the change in role and responsibility of ProRail. In the beginning they are part of the decisions about the basic timetable, they work closely with NS, and the decisions are steering the process heavily. While at some point in the process they change their role and become the independent capacity allocator.

Context complexity

Decisions made in the context can influence the timetable design at any moment in the process. An example is the decision of increasing the frequency of trains per hour at the A2 corridor. In the beginning this was expected to happen and thus included as requirement in the design of the timetable. However, as becomes clear from the Better for More cases, these decisions made at strategic level can change easily due to unexpected factors. Another issue that popped up during the process is the storing and stabling of trains, and in the later design phases it becomes clear that this is problematic. Such issues impact the design process.

Furthermore, since the redesign process includes the entire country also international trains need to be included. The result is that decision regarding these train lines influence the process as well.

Process of decision-making

This section describes the design process from first draft to final implementation by providing a time line of the process in different phases. An overview of the different design phases is presented in Figure 3.1.

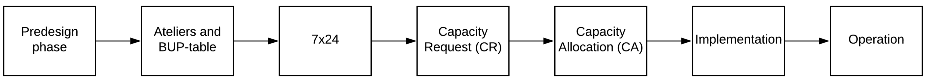


Figure 3.1: Design phases in the redesign process of the timetable.

January 2014 - June 2015: Predesign phase The predesign phase (in Dutch: Voorontwerp) is the starting point of the design process.[2] It is an iterative process of several rounds. Usually NS carries out this phase herself, but since in 2017 the design starts from scratch, they decide to include ProRail in this design phase as well. NS has a prioritized list of requests to be included in the timetable. The assignment is that new infrastructure, built during the last ten years, should be used optimally in the new timetable. The final product of the predesign phase is a one hour pattern (in Dutch: Basis Uur Patroon (BUP)) which includes as many requests of the NS as possible.

The design team consists of six people representing the disciplines logistics (providing a timetable according to the plan rules), traffic management (robustness and feasibility of the plan), commerce (commercially attractiveness of the plan) and a process leader.

[2] Before the predesign phase many pre-studies are performed which guide the predesign phase, however, for the description of the design process we indicate the predesign as a starting point.

The designers start from scratch and have the freedom to introduce a plethora of new ideas. However, actor behavior and politics limit the solution options. The designers face restrictions such as operational staff not willing to drive the same path over and over again, NS wants to have the least number of trains necessary in operation, and starting the design from the city Zwolle. In addition, assumptions are made about the possible wishes of other Railway Undertakings (RUs). Boundary conditions that need to be checked during the predesign phase are the availability of infrastructure, railway safety,[3] level crossing safety, transfer safety, sound level, traction-power supplies and local aspects.

July 2015 - December 2015: Ateliers and BUP-table Every year the design process for the new timetable starts with the Ateliers and BUP-table phase. However, for the complete redesign, planned in 2017, the predesign phase has a different composition since ProRail is also involved. The Ateliers and BUP-table phase aims at solving conflicts in requests from the different RUs. ProRail collects the requests from the RUs and proposes an order to discuss the conflicting requests based on geographical areas. Collection is not according to formal rules, but happens on an informal basis and RUs are not obliged to participate. Searching for resolutions for the resulting conflicts happens in Ateliers. Ateliers consist of designers from the respective RUs and, similar to the predesign phase, representing the disciplines logistics, traffic management and commerce. However, designers, especially logistic planners, involved in the Ateliers are not necessarily involved in the predesign phase. Designers involved in the predesign phase have an advantage since they have more information, know exactly why certain choices are made and are thus able to reason faster. The Ateliers are hold in sequence and the order of the Ateliers is suggested by the process leader. The process leader has the overview since he is involved in all Ateliers.

A conflict between requests of RUs expands if more and more train paths get involved, hence it is important to choose the boundaries wisely. Again, this is the responsibility of the process leader. In case no resolutions for a conflict are found, the Ateliers escalate to the BUP-table. The BUP-table consists of representatives of RUs involved in the Ateliers and it is chaired by ProRail. The BUP-table does not design themselves and has more decision power than the Ateliers. The BUP-table either decides on a certain resolution in case of several propositions, changes the requirements such that the solution space expands and gives it back to the Ateliers, or leaves the conflict unresolved. In the latter case, instead of a resolution, an 'agree-to-disagree' is the final result of the respective Atelier. ProRail makes, in a later phase, the final decision based on formal rules from the Dutch rail network allocation statement (in Dutch: Netverklaring). During this phase, municipalities, provinces or local experts are contacted if necessary, but they are not involved in the Ateliers or the BUP-table.

An example of a conflict, which resulted in an agree-to-disagree, is the integration of the international train from/to Brussel and the cargo trains at the Brabant route. The requests for this train paths belong to different RUs, to simplify we call them the international RU and the cargo RU. Assumptions about requests of the cargo RUs are made during the predesign phase, however, they appear to be different during the Ateliers phase. This is the reason why the conflict arises in the first place. Another fact that makes the situ-

[3] The design is in each phase checked on railway safety by the DONNA system.

ation more difficult is the that the Betuweroute is out-of-service for some time. Therefore, cargo trains have to take other routes such as the Brabant route. Additionally, the plan exists to increase the frequency of passenger trains at the A2 corridor and, in that case more passenger trains on the same route will be expected. Both previously mentioned arguments lead to a busy Brabant route and the conflict becomes more problematic. The fact that no resolution is found is influenced by decisions made at management level and design choices made in the predesign phase. Hence, both the actor and context decisions, as well as the engineering decisions influence the size of the solution space.

The final product of the Ateliers and BUP-table phase is an one hour BUP together with a set of agreements, or agree-to-disagrees, between RUs regarding the way in which they perform the capacity request. The capacity request is the official application for the capacity of the railways for the next year. Fewer remaining conflicts leads to a simpler and faster capacity allocation process which benefits ProRail as well as the RUs. In the Ateliers and BUP-table phase designers have less freedom than in the predesign phase. The fact that more actors are involved makes it more complex, more restrictions such as speed limits of cargo trains arise, and international agreements on travel times complicate finding a resolution even more.

January 2016 - April 2016: 7x24 In the 7x24 phase every RU and ProRail multiplies the BUP for the entire day, night and week. Many aspects are already contained in the BUP, however, the main difficulty of the 7x24 phase is including the transitions. For example, the transitions from peak to off-peak hours and changing frequencies on weekend days are incorporated. Compared to the previous design phases the number of logistic planners increases significantly. Apart from ProRail and RUs, consumer organizations get involved in this phase of the design process such that they can provide feedback on and make requests for the timetable. The final product delivered is a timetable for 24 hours a day and 7 days a week.

April 2016: Capacity Request (CR) The CR is the official moment, eight months before the introduction of the new timetable, when RUs and ProRail apply for the capacity of the railways for the next year, in this case December 2016 to December 2017. ProRail provides a CR for maintenance works and structural infrastructure exclusions. Although the CR is performed by each party individually, it is influenced by the agreements made in previous design phases.

April 2016 - August 2016: Capacity Allocation (CA) ProRail is responsible for allocating the capacity of the railways to the different RUs given their CR and takes into account the resolutions from the Ateliers and 7x24 phase, agreements made at the BUP-table and feedback of consumer organizations. New conflicts arise, since up to this moment no maintenance works, structural infrastructure exclusions and special trains are included in the design. In case of conflicts ProRail is forced by law to follow the rules of the Netverklaring. In the first week of July the RUs receive a draft of the CA for consultation and reaction. The final product of this design phase is a conflict free timetable, meaning no planned red signals, satisfying as many requests as possible and in line with the rules of the Netverklaring.

August 2016 - December 2016: Implementation After the official CR deadline, RUs can still make requests. If this does not create any conflicts ProRail accepts them. If it does create a conflict a discussion starts, but the RU that received the capacity in the first place has the right to use it. In the current step of the design process, RUs provide timetables for staff, maintenance and rolling stock based on the CA. ProRail uses this period for fine-tuning the timetable and adding weekend-out-of-orders, event and seasonal trains.

December 2016: Operations Every Sunday after the second Saturday of December the changes in the timetable are in operation and the customer travels according to it. Operational staff of ProRail and RUs make sure everything works and errors or flaws are taken care of. Traffic control processes the final requests from RUs up to 30 minutes before departure of trains, for example in case of delayed freight trains. Additionally, they perform ad hoc changes to the timetable in case of delays or disruptions. The final product of this phase is a situation in which operation can deal with the new timetable and no problems or mismatches occur.

Essence case Redesign timetable 2017

- A complete redesign of the timetable is performed. Hence, a design made from scratch needs to be included in the regular design cycle.
- The predesign phase is an unusual situation of only two actors being involved who start the design of the timetable from scratch. This design needs to be included in the regular yearly design cycle later on.
- The actors make assumptions about the interests of actors who are not involved (yet). There is freedom to include plethora of new ideas in the design, however actor behavior and politics limit the solution space.
- In the next design phase, the responsibilities of one actor change, he is now (formally) assigned the role of independent capacity allocator and decides on the order of the different parts of the design to be discussed in the Ateliers. In this design phase many more actors get involved who have their own requests for the timetable.
- At the same time, hierarchical relations exists between representatives at the BUP-table and designers in the Ateliers. The BUP-table can decide on a certain resolution, change requirements or remain the conflict unsolved ('informally' agree to disagree).
- Assumptions made in the previous design phases turn out to be not always correct and result in conflicts, for example, regarding the integration of the international train from and to Brussel and cargo trains at the Brabant-route.
- The situation becomes even more complex when it is decided that the frequency of passengers trains will be increased on the A2 corridor which impacts the conflict described before. The final result is an agree-to-disagree between two actors.
- An agree-to-disagree means a difficult situation for the capacity allocator who has to solve this issue later on.

3

- In the 7x24 design phase, the number of logistic planners increases significantly. Moreover, consumer organizations and thus new actors get involved.

- On the other hand, actors separate since they individually apply for the capacity of the railway network by performing a capacity request.

- New conflicts arrive or old conflicts return when allocating the capacity among the actors since the capacity request is influenced by the informal agreements and agree-to-disagrees from the previous design phases.

- Finally, a conflict free timetable will be in operation. The final design is the constitution of a cascade of decisions, based upon institutional decisions, technical choices, agreements and rules, both formally and informally.

3.4.4. Amsterdam

The use of public transportation in region Amsterdam will increase. In 2030, the expected number of passengers at the station Amsterdam Central is 280.000 compared to 185.000 passengers in 2014 (ProRail, 2018b). Also at station Amsterdam Zuid the number of passengers is expected to increase. To still be able to transfer these passengers there is a need to run more trains per hour from and to Amsterdam. However, the current infrastructure and capacity at the stations is not sufficient. Different measures need to be taken to increase the capacity on the infrastructure and stations. At the start of the PHS project Amsterdam a budget of 431 million euros is available for plan development and changing the current infrastructure (ProRail, 2014).

In June 2014, the decision-making process regarding the plan development phase started and in June 2018 a final decision about the design of the infrastructure in and around Amsterdam was made.

Technical complexity

The case study focuses on the design of the infrastructure and stations of Amsterdam Central and Amsterdam Zuid. The current situation is as follows:

- Amsterdam Central: 14 tracks of which 10 tracks are continuing tracks; 4 island platforms and 2 side platforms; international train services (Thalys, ICE, Eurostar) stop at Central.

- Amsterdam Zuid: 4 tracks; 2 island platforms; no international train service stop at Zuid.

To increase the frequency of trains per hour, the following logistical and infrastructural dilemmas are present.

1. International train service stop at Amsterdam Zuid instead of Amsterdam Central.

2. Organization West branch (in Dutch: West-tak) of Amsterdam, either extending the metro lines on existing tracks or introducing a S-Bahn construction, i.e., high frequent connection with Sprinter trains.

3. Reduction of the number of tracks at Amsterdam Central to 9 or 10 tracks due to the broadening of platforms and stairs. Since fixed corridors are introduced and the tracks are unbundled the system is more robust.[4]

4. Expansion of the number of tracks at Amsterdam Zuid to 6 tracks, or keep the current situation.

The choices to be made regarding the before mentioned dilemmas are steered by the different preferences of actors on these different points. Moreover, the dilemmas are influenced by context which creates several additional interdependencies.

ACTOR COMPLEXITY

Various actors are involved in the process of decision-making, we list the main actors and their incentives.

ProRail acts as one actor towards the outside world, but consists of departments with different responsibilities. The department of Transport and Timetables (in Dutch: Vervoer en Dienstregeling (V&D)) is responsible for the capacity analysis and modeling of the timetable. Their incentive is to provide a future stable and robust railway system. The Project department manages the Amsterdam project and is responsible for realization of the project as a whole and finishing on time and within budget. Both V&D and the Project department focus on the content discussion while the relation management department of ProRail takes the role of 'trusted advisor' towards stakeholders involved and aims to create support and reach consensus on resolutions for the Amsterdam region. This shows the different incentives within an organization.

NS is the operator in region Amsterdam and their interest is to satisfy the passengers.

I&W wants more capacity in the railway system such that it is ready for high frequency timetables. They are responsible for the budget of the entire PHS of which Amsterdam is part. The final decision is made by I&W.

The **Municipality of Amsterdam** is responsible for creating economical and spatial conditions for developments in the Amsterdam region. Their interests include a future proof and robust transport system that connects the different parts of the region in an optimal way.

The **Transport Region Amsterdam** (in Dutch: VervoersRegio Amsterdam (VRA)) provides the connection between 15 different municipalities in the region of Amsterdam regarding public transport. They represent the interests of the passengers within this region.

The **Port of Amsterdam** uses the railway system for freight transport. Their interest is to have enough capacity to transport the various goods, and having flexible options for capacity in the timetable.

The actors introduced are part of the steering committee PHS Amsterdam. The steering committee advices the Sector team and the Director Meeting PHS (in Dutch: Directeuren Overleg (DO) PHS), consisting of ProRail, NS, I&W and the KNV. Moreover, the steering committee PHS Amsterdam advices the Administrative Meeting (in Dutch: Bestuurlijk Overleg (BO) MIRT) which includes I&W and municipality of Amsterdam. In the BO MIRT

[4]This follows the same flow-through station vision as the rebuilding Utrecht station (Van den Hoogen, 2019).

the final decision about the alternatives is made. Furthermore, coordination meetings on content with various stakeholders, and coordination meetings between client (I&W) and contractor (ProRail) take place which influence the decision-making. Moreover, every actor has its own internal decision-making within the organization.

CONTEXT COMPLEXITY

The following developments in the context influence the of the decision-making process:

- Growth of Schiphol Airport: increase in the number of passengers taking the train from and to Schiphol airport.
- Housing increase in Amsterdam: until the year 2040 around 230.000 houses are build in Amsterdam, this requires investments in public transport as well.
- Noord-Zuid metro line: due to the commissioning of this line more passengers pass through station Amsterdam Zuid.
- Port of Amsterdam: the decision regarding the so called 'kolenbesluit' is made and entails the transport all coal that arrives in the port of Amsterdam by rail in 2030. The port is connected to the railway system and is expected to be used more frequent in the near future.
- Amsterdam Central station is a monumental building and is situated in the middle of the city. This results in restrictions on the rebuilding options the station.
- PHS projects on other corridors affect or are affected by the decisions regarding Amsterdam Central station. For example, the initial plan of running 6 trains per hour at the OV-SAAL corridor (between Amsterdam and Almere) are affecting the decision.
- Municipal elections are taking place around the moment of decision-making and influence the process. Moreover, Rutte III presents its coalition agreements with more investments in the railway sector.

Mainly at the final stage of the decision-making process media attention, from both regional and national media, was present. A letter from NS to I&W let to newspapers discussing the different solution options. Moreover, politics interferes in the process of decision-making because of municipality elections just after the final decision needs to be made.

PROCESS OF DECISION-MAKING

The process of decision-making is studied from the start of the plan development phase (June 2014) until the decision by I&W (June 2018).

Development plan PHS Amsterdam In June 2014 the State of Secretary I&W decides on the scope of project PHS Amsterdam Central: increasing the capacity of the station by broadening the platforms and stairs, extension of the East tunnel and improvement of the track layout.

Multiple issues are discussed in this round, both on content and on context, which increase the complexity of the decision-making.

The rebuilding of the East tunnel affects part of the Royal waiting room in the station. This is a monumental room and thus the municipality of Amsterdam is not agreeing with the plan. An alternative plan is made together with ProRail and NS. The actors agreed with the new plan, however, the costs of the project increase with another 3 million euros.

An unexpected issue is the IJ-viaduct. It turns out to be not able to carry the load of more trains as proposed in the new plan. Initially, the IJ-viaduct was not part of the scope of the project. However, the results of a study by ProRail show that reinforcement of the IJ-viaduct is necessary and this costs an extra 200 million euros.

In the meantime, ProRail discusses in the media the idea of having metros, additionally to trains, running over existing railway tracks between Amsterdam and Schiphol to increase the capacity. The issue affects multiple regional parties and the VRA, together with I&W and NS, takes the initiative to investigate whether it is possible to drive metros on existing railway tracks. In short, NS prefers to have Sprinters, i.e., trains, and the VRA prefers metros between Amsterdam and Schiphol.

Thereafter, the National Market and Capacity Analysis (NMCA) research presents the transportation bottlenecks of the coming years. The main bottleneck is the transfer at Schiphol, and the current situation cannot deal with the increasing number of (international) passengers.

Early 2017, the increase of such issues result in a shift in the process of PHS Amsterdam. The plan for Amsterdam Central are not sufficient to deal with the increasing number of passengers towards 2030. Hence, the project scope is enlarged by investigating the possibility of having a 5th and 6th platform at station Amsterdam Zuid. The new project is called 'Groot Amsterdam' which entails the design of smart solutions for PHS Amsterdam and resolving bottlenecks in the region Amsterdam.

Changes in scope of project PHS Amsterdam Due to the new scope of the project, the role and behavior of actors change. NS asks broadening questions regarding the larger Amsterdam region and future-proofness of the new plan. They prefer to enlarge the scope to 2040 instead of 2030. At the same time, more regional parties get involved and they get a more prominent role. Since station Amsterdam Zuid is part of the scope of the project, uncertainty about the feasibility of the original PHS plan to have 6 trains per hour running towards Almere arises among managers of Almere. This is an example of how the broadening of the scope leads to more actors becoming involved and more issues enter in the process.

Financing of a third platform of Amsterdam Zuid cannot be fully covered by the PHS budget. I&W asks the municipality of Amsterdam to provide additional budget. Initially, they perform wait-and-see behavior, but agree by providing additional requirements to the decision.

Dynamics in the context of the decision-making process is the municipal elections in March 2018. A decision about Groot Amsterdam is preferred before those elections since they expect commitment to the decision from the current members of the municipality of Amsterdam. After the elections the situation might be different and this increases the pressure on the decision-making process.

The results of the investigation regarding the West-tak of Amsterdam, metros or Sprinters driving on existing railway tracks between Amsterdam and Schiphol, are favoring NS. Namely, the advice is to have more Sprinters running on these tracks. In June 2017, the DO PHS takes decides to set the scope of Groot Amsterdam until the year 2030. ProRail V&D makes a plan and the decision information for the final decision by I&W needs to be ready before end of the year. The study of ProRail results in four different alternatives resolving the problems in Amsterdam:

A. 10 tracks at Amsterdam Central and 4 tracks at Amsterdam Zuid, with international services at Amsterdam Central and Sprinter trains at the West-tak.

B. 9 tracks at Amsterdam Central and 4 tracks at Amsterdam Zuid, with international services at Amsterdam Central and the North-South line (metro) connected with Schiphol.

C. 9 tracks at Amsterdam Central and 6 tracks at Amsterdam Zuid, with international services at Amsterdam Zuid and high frequent Sprinter trains at the West-tak (S-Bahn).

D. 10 tracks at Amsterdam Central and 6 tracks at Amsterdam Zuid, with choice of station for international services and choice for InterCitys or Sprinters at West-tak still open.

Once the alternatives are at the table the different opinions of actors become clear. NS prefers option D since it leaves options open and this option is future proof. The municipality of Amsterdam seems to prefer option D, but is internally not completely aligned. ProRail prefers option C, which is 150 million euros less expensive than option D, since it creates a robust and future proof railway system. I&W does not state a preference yet and leaves the discussion to the other actors. However, I&W puts pressure on the decision information being ready before the municipal elections take place.

In December 2017, ProRail presents the results of the study Groot Amsterdam to the DO PHS and the Exco of ProRail. This results in ProRail stating its preference for option C which is not in line with NS's preference for option D.

No consensus, politics interferes In this round the results of the studies performed in the previous round are the input for the decision-making at the strategic level.

In January 2018, the preferences of NS and ProRail remain the same. I&W prefers option C since the costs are lower. Similarly, the municipality of Amsterdam and the VRA prefer option C. The port of Amsterdam prefers C since it provides more capacity at Amsterdam Central for freight trains. Rover, the consumer organization, has no preference for a certain option and keeps options open.

In February 2018, I&W visits station Amsterdam Zuid to discuss the situation with the municipality of Amsterdam, ProRail and NS. She confirms that there are two options for resolving the problems in region Amsterdam: options C and D. In a letter to I&W in March 2018, NS explains its worries regarding option C. The media gives attention to this letter and the decision-making process in general. Other actors, such as the port of Amsterdam, are surprised by the opinion of NS and ask for explanation from ProRail.

Just before the municipal elections everyone is ready for the final decision by I&W. However, the decision is postponed at the very last moment since some political parties seem to disagree with the amount of money to be invested in the plan for Groot Amsterdam. For many actors involved in the process the postponed decision moment came as a surprise.

Towards a final decision The municipal elections result in a new political party being responsible for the Traffic and Transport in Amsterdam and it was uncertain how this affects the decision-making regarding Groot Amsterdam.

In the meantime, ProRail and NS still disagree on the preferred options and, after several meetings, conclude that their incentives regarding and perspectives on the problem are still different. They agree on better collaboration in the future.

However, on June 18, 2018, the final decision is made for option C: 9 tracks at Amsterdam Central and an additional 5th and 6th track at Amsterdam Zuid. This allows the international service to stop at Amsterdam Zuid and leaves capacity for freight trains at Amsterdam Central station.

ESSENCE CASE AMSTERDAM

- In order to deal with the expected rise of passengers and the ambition to have more trains running per hour rebuilding of Amsterdam Central station is necessary.

- There are many technical aspects of the railway system than can be changed and therefore a large number of choices available. At the same time budget constrains exist.

- Multiple contextual issues arise such as the fact that Amsterdam station is a monumental building, increase of passengers resulting in transfer issues at Schiphol and major (unexpected) costs because of the IJ-viaduct.

- The scope of the project is broadened because of the many issues that appear and this leads to a stop-go effect. A process that was stalled by many issues and therefore the impossibility to find a solution to the problem gets fluid again. Instead of only looking at Amsterdam Central station also Amsterdam Zuid is taken into account, so called Groot Amsterdam.

- The Dutch infrastructure manager (ProRail) receives the assignment from the Ministry (I&W) to start a study for Groot Amsterdam.

- ProRail performs the studies in close collaboration with other actors involved (Dutch Railways, municipality of Amsterdam, etc.) resulting in two solutions: A and B. One actor prefers B which is the more expensive solution but it reflects its incentives the best, the others prefer A.

- Just before the decision needs to be made support for a decision is missing at the political level since they see a worst-case scenario. The Secretary of State decides to postpone the decision and puts the process on-hold.

- Two actors sit together to discuss their concerns regarding the two solutions (A and B). They cannot come to an agreement but declare the intention to collaborate more closely in future projects.

- Finally the Secretary decides for solution A which is as expected.

3.4.5. NIJMEGEN

Nijmegen is part of the Schiphol-Utrecht-Nijmegen (SUN) corridor. In 2021-2022, NS is planning to run a high frequency timetable at the SUN corridor. The requirements from PHS for running a high frequency timetable at this corridor are: 6 intercity trains in a 10 minute service per hour, 1 ICE international train to Germany per hour, and 4 to 6 Sprinter trains per hour. At this moment, a total of 11 to 13 trains running per hour is not feasible. In order to make the high frequency timetable feasible, changes to the infrastructure at station Nijmegen need to be made. A budget of 86 million is made available from the total PHS budget (ProRail, 2017). Another aspect that motivates the rebuilding of the infrastructure in and around station Nijmegen is the expected passenger growth by 2030.

TECHNICAL COMPLEXITY

Taking into account the PHS requirements and expected passenger growth, the following changes need to be made at Nijmegen: An additional platform; increased transfer capacity at the station, for example, by widening stairs and extend platforms; switches need to be replaced to let trains arrive at the right platform; and a new stabling and servicing yard for trains must be created.

Since an additional platform is necessary the tunnel under the platforms needs to be extended too. Furthermore, issues concerning electrification of the Maaslijn and rebuilding the station hall are out of scope.

Having set the scope of the project, multiple dilemmas regarding the design of the station and surrounding infrastructure exists:

- A new stabling and servicing yard requires space, and space is limited since the station is located in the middle of the city. The way in which the space is used impacts the functionality of the yard. The closer to the station, the less functionality the yard has for servicing trains.

- The location of the new platform can be either symmetrical or asymmetrical with the other platforms which influences the connection and transfer time from one train to the next.

- Since the new platform is an island platform at the west-side of the station it is also possible to make two platforms.

- Increasing the speed of trains at station Nijmegen from 40 km/h to 80 km/h. For the north side of the station this is necessary to fulfil the requirements for the high frequency timetable. For the south side it is optional. Increasing the speed of trains further increase the costs.

Two main alternatives are object of study in this decision-making process:

i. Alternative 10' has a direct connection to the stabling and servicing yard, and is asymmetric with the existing platforms.

ii. Alternative 11' has no direct connection to the stabling and servicing yard, and is symmetric with the existing platforms.

ACTOR COMPLEXITY

Various actors are involved in the process of decision-making, we list the main actors and their incentives.

ProRail receives the assignment from I&W to make Nijmegen ready for a high frequency timetable. Different departments of ProRail have a different role in the project. The department of Transport and Timetables (in Dutch: Vervoer en Dienstregeling (V&D)) are responsible for the capacity analysis and modeling of the timetable. The department of Asset Management is responsible for construction and maintenance of the infrastructure. The department of Traffic Management is responsible for the performance of the system and thus that the timetable is implemented well. The Project department manages the Nijmegen project and is responsible for realization of the project as a whole and finishing on time. In general, ProRail wants to reach consensus between the actors involved and make the system ready for high frequency timetables.

NS and **Arriva** are the operating companies at Nijmegen. NS is the main operating company and has two departments separately functioning in this process: NS Passengers (in Dutch: NS Reizigers) and NS Stations. NS Reizigers' interest is to optimize the passenger transfer between NS trains and the storing and servicing of trains. The Nijmegen project is particularly important to them. NS Stations is responsible for the real estate and its layout. Arriva operates on the Maaslijn which is not part of the scope of the project, however, they are interested in good connections with the trains of NS.

The **Ministry of Infrastructure and Water management (I&W)** is responsible for the budget of PHS in general, and the project Nijmegen in particular. They are interested in keeping the cost low and having the system ready for high frequency timetables.

The **Municipality of Nijmegen** and **Province Gelderland** are responsible for the environmental permits, and for example, changes in the tunnel of the station. The province is interested in good public transport, for example, the transfer between NS and Arriva train is important to them.

Royal Dutch Transport organization (in Dutch: Koninklijk Nederlands Vervoer (KNV)) represents the freight operators in the process and is interested in having enough time slots in the high frequency timetable to have freight trains running.

The actors introduced are part of the steering committee Nijmegen. ProRail, NS, I&W, the municipality of Nijmegen and the province Gelderland are the main actors in the process. For the municipality PHS Nijmegen is an important project, for the other actors Nijmegen is one of their PHS projects. The steering committee advices the Director Meeting PHS (in Dutch: Directeuren Overleg (DO) PHS) who makes the final decision about the alternatives. NS, ProRail, I&W and KNV [5] are part of DO PHS. A project team within ProRail advices the steering committee and consults a large internal project team

[5] At the end of the year 2017 the KNV left the DO PHS.

(in Dutch: groot intern projectteam (IPT)). Moreover, every actor has its own internal decision-making within the organization.

During the process actors involved remain the same, however, individuals within actors changed. This resulted in delay of the process since some discussions had to be repeated. Moreover, it influenced the trust level between actors.

CONTEXT COMPLEXITY

Local politics in Nijmegen are interested in the developments in and around the station of Nijmegen. Nijmegen wants to remain an accessible city. Currently, there is dissatisfaction about the layout of the station which has increased since Arnhem has recently opened a new station.

At the A2 corridor, between Amsterdam and Eindhoven, a high frequency timetable is running since the beginning of 2018 and this is a success. As a result, the high frequency timetable is highly desired at the SUN corridor too.

Within the SUN corridor, Nijmegen is the last project, meaning stations and infrastructure around and between Utrecht, Arnhem and Schiphol are (almost) ready for the high frequency of trains. Consequently, time pressure is part of the process.

The introduction of more trains per hour and more shunting and servicing of trains close to the station has an impact on, for example, the noise production. The expectations are that environmental requirements can create an obstacle in the decision-making process.

PROCESS OF DECISION-MAKING

The process of decision-making is studied from the beginning (June 2014) until the end of the alternative study phase (summer 2018).

Determining the scope In June 2014, ProRail has been commissioned by the DO PHS to prepare Nijmegen for running a high frequency timetable at the SUN corridor. A steering committee is set up and they define the scope of the project in December 2014. The study of PHS project Nijmegen started with 20 different alternatives that would allow for running the high frequency timetable. In June 2015, the 20 alternatives are reduced to two alternatives: 10' and 11'. By choosing between these two alternatives the dilemma regarding the speed increase is resolved by taking the cheapest option, only 80 km/h at the north side of the station. A first estimate of the costs for these alternatives was 110 million euros, an exceeding of the budget by 24 million euros.

Project on-hold In December 2015, the project was put on hold by the DO PHS because of the estimated budget overruns. Not only project Nijmegen but also other PHS projects were exceeding their budgets. A budget variant was needed, and I&W puts pressure on the project team (which mainly belongs to ProRail) to present an alternative fits within the budget. However, this appears to be impossible without reducing the functionality, i.e., not meeting the PHS requirements. A worst-case scenario, mentioned by almost all actors is a cancellation of the project which would result in no high frequency timetable at the SUN corridor. Hence, the steering committee puts pressure on DO PHS. A year after the on hold phase started, DO PHS gives permission to restart the project with an unchanged scope.

Multiple issues on the agenda The project restarts in September 2016 and alternatives 10' and 11' are further developed. They make decisions on the type of platform which requires to extend the tunnel under the station. The municipality wishes to completely extend the tunnel and create a second entrance for the station at the west side. This results in four alternatives: 10' or 11', with or without fully extended tunnel. Since the tunnel is not necessary for PHS, I&W does not want to provide budget for it. However, the municipality and province come to an agreement regarding the financing of the tunnel. This changes their role in the process, from participant and stakeholder to financier.

Two issues (partly) outside the scope of the project enter the process in this round. As a consequence, complexity of the decision-making process, and pressure to make a decision increases. The first issues entails a switch replacement earlier in the process. NS is highly in favor of this option due to better connections with the trains to Den Bosch. However, the early replacement of the switch results in extra costs. After some discussion it has been decided that the province bears the extra costs since it also favors the accessibility of the province. The second issue is the rebuilding of the station hall. This issue arrives multiple times on the agenda. It is not part of the scope of the project, but in particular the municipality and NS Stations report their wishes. However, no one takes the responsibility to pay for it. Hence, the issue remains but not on the top of the agenda.

Then, it appears to be that the remaining alternatives 10' and 11', both with tunnel, seem to be unfavorable for the transfer of passengers. The alternatives are designed from an infrastructure perspective and did not fully take into account the transfer aspects. A new alternative, called 11", could be designed that includes the transfer perspective, however, this alternative is not worked out sufficiently yet to make it part of the decision-making process. There are thus till two alternatives to decide upon.

Decisions to be made The decision about the two alternatives need to be made by the end of 2017. Informally, everyone believes that consensus is reached for alternative 11'. However, NS declares her preference for alternative 10' since it enables to better stable and service the trains which reduces their costs. While, on the other hand, alternative 11' has the benefits of easier transfer to Arriva trains. Internally within ProRail, Traffic Management prefers alternative 10' since this creates more adjustment options in the operation. The other departments of ProRail prefer alternative 11'. Finally, the steering committee agrees on 11', including NS, with the requirement to develop 11' to a new alternative 11". If it happens to be the case that the new alternative 11" is not feasible, or not better than 11', then the actors need to take place at the decision table again. At this moment, alternative 11" is worked out in detail, and if everyone still agrees and no external dynamics change the scope of the project, then by the end of 2019 it is decided by DO PHS to realize this alternative. I&W has promised that there will be enough budget for the project, however, this is still an uncertainty. The desire of the municipality of Nijmegen about rebuilding the station hall is again on the agenda, and this time the CEOs of ProRail and NS visit Nijmegen to discuss this point. The tone of the discussion is different this time, instead of 'no, unless' they move towards 'yes, but'.

ESSENCE CASE NIJMEGEN

- The goal is to support high frequency timetables at the SUN corridor by rebuilding station and emplacement Nijmegen. The scope of the project needed to be determined and budget issues were present from the start. Other limitations, such as space available for new tracks or a new platform, restrict the solution space.

- In the meantime high frequency timetables start running at other corridors which increased the pressure for project Nijmegen.

- The existence of a powerful actor imposed decisions on the steering committee of the project by putting the project on hold due to the budget issues.

- A worst-case scenario would be to cancel the project, and this was agreed upon by the majority of the actors. An investigation showed that cheaper alternatives would reduce the functionality of the station and thus not contribute to the high frequency timetable. Finally, I&W agreed to continue with an unchanged scope.

- The tunnel issue raised questions regarding responsibilities of actors and was resolved by the municipality and province taking care of the budget for the tunnel. This also changed their role in the process.

- The process started with many alternatives and during the process several alternatives failed which resulted in two final alternatives: 11' and 10'. After internal decision-making within organizations it seemed that everyone prefers option 11', but one actor prefers option 10'.

- Then, a new issue popped-up: transfer had not been well enough consider in the two alternatives and turned out to be problematic. The result is a new alternative 11" which all actors seem to agree upon.

- Two operators arrive and depart from this station and a new platform requires them to coordinate to find an optimal way to provide transfer options for the passengers. Their different incentives led to a conflict which is to be resolved in the timetable design process.

- An issue in the context is the rebuilding of the station hall itself. From the beginning it was decided to not include this in the scope of the project, however, the issue was often at the table and did not always benefit the relation between actors.

- Although the actors decided on alternative 11" many uncertainties remain regarding the feasibility of the alternative, whether it fully satisfies the preferences and wishes of the different actors, and the availability of budget.

3.4.6. ERTMS

The European Rail Traffic Management System (ERTMS) is a European project to standardize the control and improve safety of the railway system. The aim of the project is to "enhance cross-border interoperability and signaling procurement by creating a single Europe-wide standard for railways with the final aim of improving competitiveness of the rail sector" (Schuitemaker et al., 2018). Introducing ERTMS in the Dutch railway system means a transition from and analogue system towards a digital system for the entire country.

HISTORY OF ERTMS

In 2012, the committee Kuijken concluded in a report that implementation of ERTMS leads to an increase in capacity of the railway system. As a result, decisions were made to introduce ERTMS at corridors such as the Betuweroute and the HSL.

In 2014, a preferred decision (in Dutch: voorkeursbeslissing) is made which entails a roll-out of ERTMS at the busiest passenger corridors and freight train corridors between 2016 and 2030. I&W is in the lead and NS, responsible for trains, and ProRail, responsible for infrastructure, represent a separate part of the system with clearly different incentives.

In 2016, a new collaboration structure between I&W, ProRail and NS is organized. Moreover, ProRail starts to see the benefits of ERTMS and writes a position paper. NS is not completely in favor yet, but is loyal to I&W. Freight train operators are not involved at this moment.

In 2017, it becomes clear that freight train operators have to upgrade their trains and, due to Dutch law, are only supported for 50% of the costs contrary to passenger operators who are supported for 100%.

TECHNICAL COMPLEXITY

ERTMS is a technical specification for interoperability of steering the signaling system. The current safety system is located in the infrastructure and the train driver is informed by signals outside the train. ERTMS requires communication between technical systems that belong to both the train and the infrastructure.

The technology of ERTMS is new and developing. The status of the technology today is not the status it will have at the moment that the trains actually drive with the new system on replaced infrastructure. In the Netherlands, the current decision-making process is about the introduction of ERTMS level 2, but it might be the case that level 3 is available at the moment of implementation.

The Dutch implementation strategy for ERTMS is first replacing the trains, and then replacing the infrastructure. Doing it the other way around would take too much time and money. However, first trains and then the infrastructure involves and requires coordination between operators and infrastructure managers.

Another difficulty with decision-making about the introduction of ERTMS is that the content is very complex. One has to to have quite some knowledge on the technical aspects in order to make decisions. At the same time, the decisions are very political and thus the way in which content is described is important. Moreover, the decisions are dependent upon one another which introduces another level of complexity.

The European Union (EU) has set a number of specifications for ERTMS at the functional level. The industry has to make the technical interpretation based on these specifications. The result is a grey area in which different countries have freedom to choose their own technical requirements. One could request for dispensation for some specifications, however, this might decrease the possibility of interoperability between different countries.

Multiple interdependencies exist between the technical aspects of ERTMS. For example, the roll-out strategy of the infrastructure has immediate consequences for the timing of replacing the trains. Moreover, new technological innovations in the future might require new investments which should replace current investments in, for example, new trains.

Actor complexity

We describe the perspectives of the actors involved in the decision-making process. The perspectives reflect the actors' role, incentives and their main issues and dilemmas in the process.

Ministry of Infrastructure and Water management (I&W) They provide budget for the ERTMS program and report to the Dutch Parliament twice a year about the progress, the budget and the main issues. The main incentive of I&W is to have a decision-making process based on the right information reflecting the pros and cons of each decision. Moreover, they want progress in the process by decisions being supported by the actors.

The main issues of I&W in the decision week are the governance of the ERTMS program, finance of the program and expectation management of politics, such as planning and framing benefits of ERTMS for capacity increase.

I&W sees risks if the program gets much more expensive than expected, which might result in pressure from the EU because of not meeting deadlines and budget restrictions. Moreover, actors not being aligned can have non-linear effects on the planning and eventually results in political issues.

ProRail They want a feasible plan for the roll-out of ERTMS over the entire country. Such a plan need to be financially feasible, potential risks need to be covered and the governance should be clear. Furthermore, ProRail has a replacement task for the safety system of the infrastructure. The time lines for this task are not always in line with the time lines of introducing ERTMS. The responsibility of ProRail is to rebuild the seven corridors in the order and planning as has been decided upon. The main issues of ProRail in the decision week are the roll-out of ERTMS in the entire country, innovation and technology, and flexibility of the program in terms of scope, technical aspects and planning.

NS They want a undisturbed operation for the railway passengers. This translated to having sufficient time to implement and test the new safety system. Moreover, their vision should also be present in the documentation of ERTMS. The interests of NS in the program are large since it connects to many aspects of their core business such as the performance KPI's, the concession until the year 2024, and the upcoming midterm review. The government decision about the roll-out of ERTMS influences the decisions of NS regarding, for example, the planning of buying new trains. Hence, NS needs to balance between their own decisions and the steering of the program ERTMS.

The main issues of NS during the decision week are the planning regarding readiness of the infrastructure, having one or two system suppliers, and having a test corridor.

NS sees risks when the decision is postponed, since the final deadline will not be postponed anymore, and problems regarding feasibility might arrive.

Freight operators They form a group of around 20 different operators. The different operators differ in size, capacity and financial situation, and thus have different perspectives on the decision to be made. This results in freight operators being the least committed to the process.

The introduction of ERTMS confronts freight operators with high cost for the investments of new trains. The investments are for 50% be supported by the Dutch government. Hence, the business case for freight operators is negative, and since they have small margins this will be the case for the coming 10 years.

Freight operators are involved in the ERTMS program from 2016. It is in their interest to delay the process for two reasons: One, after some years they will have to replace their trains anyway so they will not lose money by investing now and two, they already invested in an older version of ERTMS in an earlier phase of the process, and are afraid to invest again since they expect future changes in the technology.

The main issues of freight operators during the decision week are their own business case, the agreements between I&W and operators about funding options, and the roll-out strategy of corridors.

A risk for the progress of the decision-making process is when freight operators start lobbying with political parties as a way to get their arguments at the table and to reopen the discussion on their position in this process again.

Regional passenger operators They get involved in the beginning of 2018, and from that moment take part in the steering group. They are worried about the assurance of costs and the role of NS in the entire program. To ensure their competition position, nationwide agreements about train investments should be made. Furthermore, they question whether short connections outside the main rail network also get ERTMS in the near future.

For many regional operators the introduction of ERTMS is a far future situation since the corridors they are running on are not part of the roll-out strategy as discussed at this moment.

Regional operators see risks in high expectations of politics not being managed well. This might result in a decision which states that ERTMS is too expensive. The fact that many large infrastructural projects in the Netherlands are delayed and exceed their budgets does not help either.

The Parliament They are informed by I&W and make the final decision about the roll-out of ERTMS. Their interest is finalizing the implementation of ERTMS within time, money, and scope. In 2016, it was expected to start with 12 corridors, but due to delay and unexpected costs this is decreased to 7 corridors. The Parliament is not particularly happy with this direction, especially given the delay in other large infrastructural projects.

Because of the EU obligations, there is political commitment for the program ERTMS. Hence, the role of politics is large and necessary in this process. This results in a dilemma between execution of the program and the caution of politics. On the other hand, politics set a 'political' deadline and focus on the short term due to the next elections.

European Union (EU) They made agreements with each country about specific parts of the railway network that needs to have ERTMS before a certain deadline. Once the EU has the feeling that the Netherlands is not able to meet these deadlines they put pressure. The EU has set functional specifications for ERTMS and countries could request exemptions for them. However, this results in a dilemma for the EU because offering exemptions will also lead to less interoperability between countries.

Contractors They have a double role in the process since they have contracts with operators hence they share their interests. On the other hand, contractors gain money from the implementation of ERTMS because they are actually rebuilding the infrastructure and the trains.

Leasing companies They are the owners of rolling stock which they lease to operators. Leasing companies are part of the process since they also have to rebuild their trains. However, their position is different from operators and they are thus not involved at the decision table.

To summarize, the main actors, ProRail, NS, I&W, and freight operators, have different perspectives on time lines which results in the following dilemmas:

- I&W wants a fast implementation of ERTMS with the available budget.
- ProRail has a replacement assignment for which the time lines vary.
- NS wants to practice and test extensively before using ERTMS in the operation.
- Freight trains operators have a financial dilemma since they have to invest themselves and rather postpone the investments.

The main actors introduced are part of the steering committee ERTMS. The steering group member from the freight operators also represents the leasing companies and contractors. The program ERTMS organizes the process of decision-making and advises on the decisions to be made. Internal decision-making within organizations is input for collective decision-making at strategic level, which forms input for the board of directors, which is eventually input for the steering committee.

Context complexity

The decision-making process has been influenced by various elements from the context:

- System aspects influence the ERTMS decision-making. For example, there is a general need for more and larger emplacements to store and service trains overnight.
- Previous made decisions assumed the implementation of ERTMS. For example, a decision to not build additional tracks at the OV-SAAL corridor was made since ERTMS would allow trains to run closer and thus increase the capacity. This would safe money, and therefore, it was decided to include the OV-SAAL corridor in the ERTMS roll-out strategy.

- Decisions for NS regarding their concession and midterm review influence their incentive and commitment to the process.
- Freight train operators are included in the process for two years. They have difficulties with their businesses and the investments in ERTMS trains does not help the sector. A masterplan freight companies is set-up by I&W to promote freight transport via rail.
- Political pressure is large and everyone feels this. The pressure origins from the EU requirements to introduce ERTMS at certain corridors between 2024 and 2030. Additionally, the core network needs to be ready in 2031, and the entire network in 2050.
- Developments of the technology, which will take place in the near future, influence the decision-making regarding ERTMS.
- Decisions of neighboring countries about specifications for the ERTMS technique impact decision-making in the Netherlands.

PROCESS OF DECISION-MAKING

The case description considers a specific part of the decision-making process regarding the roll-out of ERTMS starting from April 2018, when preparations for a decision week start, until beginning of the year 2019, when the results of the BIT [6] test arrive.

Preparation for decision week In the beginning of 2018, freight operators send a letter to the Parliament about their worries regarding the introduction of ERTMS. As a result, they become part of the steering committee. For the freight operators it is unclear which costs they need to cover and no agreements are made regarding this issue. Another letter, from contractors, is send to the Parliament. Also they express their worries regarding the process and want to confirm their position.

When freight and regional passenger operators start participating in the steering group the field of stakeholders become more complex given that they introduce new perspectives to the decision table.

In April 2018, the actors in the steering group agree on the ERTMS dossier and a list of issues to solve and investigate before decisions can be made. A process agreement to finalize this dossier before summer is made. At the same time, the evaluation of the ERTMS program starts and the most important evaluation step is the start of the BIT test. The main goal of the first decision week is to decide on whether the ERTMS dossier is ready to start this test.

Consulting companies get involved to think along about the decision list and budget space. The focus of the process so far has been mainly on content issues and new issues arrive constantly because of the complexity of the system transition and many uncertainties that exist and arise. Close towards the decision week the focus on content shifts more towards the actors involved and their incentives.

[6] The BIT test is a necessary test for all major ICT programs in the Netherlands.

A couple of weeks before the first decision week, I&W and freight operators discuss the Masterplan freight transport. Exchange of issues takes place in return for freight operators being committed to ERTMS. Decisions made in the Masterplan influence the position of freight operators in the ERTMS decision-making. Another important, non-technical, issue is the responsibility for the ERTMS program. I&W does not have the railway knowledge and ProRail is, given its knowledge and position, the best candidate. The question to be answered in the decision week is, do the other main actors agree with the steering of the program by ProRail? The decision week is prepared in a very short time, resulting in limited time for reflections on the decisions to be made and communication and information was late. This affects the pressure on and quality of the decisions to be made. The actors are asked for their opinion on the decisions and the program of ERTMS used these opinions for ordering the decisions and organizes preparation meetings to solve issues and require new information.

During the preparation of the decision week, the ERTMS program and I&W put pressure on deadlines. Their main aim is to decide positively on the decisions prepared and finally decide on starting the BIT test after summer. Moreover, they do not want to delay the process any further. Collaboration between actors happens, however, the freight operators are not always in line with ProRail, NS and I&W. There seems to be a distinction between collaboration on content and on context level issues.

The first decision week The decision week is set-up as a 'cascade' of decisions which need to be made by the different layers of the organizations. First, the different organizations discuss the decisions on the list within their own organization. Then, the actors meet at the Director Meeting (in Dutch: Directeuren Overleg (DO)) and discuss the list of decisions again. Some decisions are immediately accepted, while others such as the framing of the capacity increase due to ERMTS, the roll-out strategy, and one or two system suppliers need more time for discussion and require changes in the formulation of the decision.

Subsequently, the DO-meetings provided input for the Board of Directors (in Dutch: Raad van Bestuur (RvB)) before the final decisions made by the ERTMS steering committee at the end of the week.

Decisions to be made are connected to one another. We give a couple of examples:

Regarding the framing of the benefits of ERTMS decisions made in the past are connected and thus influence the outcome of the decision. Based on the idea that ERTMS would increase the capacity of the railway system, the number of tracks at the OV-SAAL corridor is not increased. At the same time, I&W does not want to promise too much, while freight operators say, if we are not creating more capacity, then why are we doing it?

The issue regarding one or two system suppliers is connected to the number of corridors that could be equipped with ERTMS given the available budget. Having a test corridor also affects the number of corridors that can be included in the roll-out strategy.

Freight train operators did not agree with the order of the introduction of the seven corridors. Three different scenarios are presented and only the freight operators disagree with starting the ERTMS roll-out at corridor Kijfhoek-Roosendaal. There are clear EU requirements for this corridor. However, freight operators claim they will get all the first-time issues and thus prefer the scenario which starts in Haarlem. The conflict is resolved by assuring a test corridor. Exchange of issues takes place since the program of ERTMS did not want a test corridor in the first place since it would be too expensive and take too much time. ProRail and NS want a test corridor to ensure a smooth transition. Another question raised by ProRail and NS is whether after the introduction of the seven corridors budget is reserved for the remaining corridors.

An issue for which no solution is found during the decision week is the ATB-NG issue. ProRail is responsible for replacing a part of the old safety system before ERTMS will be introduced. According to ProRail it would be better to introduce ERTMS immediately. However, this raises several new issues concerning the roll-out strategy as is decided upon, the investments of new trains earlier than expected, the alignment with time line using multiple migration steps to reduce problems with implementation, and the tendering of this new corridor. In short, many issues and questions arise regarding this issue which are not in line with the philosophy used in the ERTMS program so far. The AM department of ProRail wants do set their own agenda and acts independent of I&W.

During the decision- week, everyone was committed to provide clarity to the steering committee at the end of the week. Postponing decisions to after summer was not the aim and even the freight operators did not challenge this in the decision week. Trust between actors plays a major role during the entire process, and in particular during the decision week. Most actors see a high trust level which is reflected by the fact that actors agree that the right decisions are made during the decision week.

After the decision week, the starting point for the introduction of ERTMS is clear, but certainly not everything is set. For instance, still no (formal) agreements with freight operators about the exact costs and the train specifications are made.

Completion of tasks after decision week Although freight operators agreed during the decision week on the decisions, afterwards they claim that they need more time and disagree with some decisions. The freight operators, leasing companies, and contractors have different perspectives and are thus split-up. Also, ProRail, NS, and I&W send letters to the ERTMS program with additional wishes and issues.

Some actors organized themselves and consult by political parties to influence the political level. A reason for their reaction could be that the consultation with freight operators has been mainly on content level, and the BIT test was not so important for them, but now the real question is asked, do you agree with implementation of ERTMS? In particular, the director level of freight operators are not very much involved in the process.

It has been decided in the decision week that ProRail steers the ERTMS program. The program is positioned as independent actor, meaning separate from the organization ProRail itself. The role of the program is, for example, to challenge project plans from the Asset Management department of ProRail who is responsible for the new infrastructure with ERTMS.

The period after the decision week and before the start of the BIT test appears to be too short to address all remaining aspects of the decision week. NS is worried about aspects concerning the planning of infrastructure and readiness of the test corridor.

Towards the second decision week The goal of the second decision week is to decide whether the ERTMS program can move from the planning phase to the realization phase. The decision to be made is: Is the ERTMS dossier ready for the decision by the Council of Ministers in April 2019? Depending on their decision, in June 2019, the decision will be reconsidered by the Parliament. If their decision is positive, the tender process for new rolling stock and infrastructure can start.

During the second decision week the remainder of the decisions from the previous decision week will be discussed including new issues that arrive from the evaluation tests. The decision week is organized similar to the first decision week, starting with decision-making at DO-level, then decision-making at RvB level, and finally the steering committee ERTMS decides.

Rumors about freight operators disagreeing and having problems exist, but this is not so clear for the other actors involved. At this moment (January 2019), the planning dossiers do not contain enough support from freight operators and contractors towards the decision to be made. Meetings are organized to come to agreements concerning specifications of rolling stock. Moreover, the differences between NS and regional and freight operators become more clear which are expected to be even larger in the remainder of the process and finally in the operation. In the meantime, the advice from the BIT test arrives and points out the issue of the governance of the ERTMS program. They should control and provide guidance on content towards the main actors. The advice suggest to present additional rules to the governance of the program and this could be a starting point for new negotiations and issues.

ESSENCE CASE ERTMS

- In a split-up field of actors: different incentives, unequal responsibilities, and diffuse powers; technological uncertainties with many unknowns and a highly dynamic context a series of decisions need to be made.

- New actors arrive at the decision table with new perspectives and they bring new issues at the table.

- An agreement among the actors is made to finalize the ERTMS dossier, which requires to make several decisions, before summer such that the BIT test can start immediately afterwards.

- A list of decisions is made and constant new issues are added resulting in an over-complex situation and a focus on content issues.

- Shift of focus towards context issues before the first decision week when, among others, Master plan freight transport and the responsibility of the ERTMS program is discussed.

- Pressure towards first decision week increases due to limited time and the many uncertainties that exist. Main question remains, what to decide on first, and how to get everyone aligned?

- The first decision week consist of a cascade of decisions through the different decision levels of the organizations. No one particularly blocked a decision, however, some decisions need to be revisit, and it turns out that some issues cannot be discussed in isolation.

- Commitment between the actors exists to arrive at decisions during the decision week to not delay the process. However, after the decision week still new additions and changes are requested by the actors.
- In particular, freight operators are dissatisfied with some decisions and claim that they need more time. Some actors even violate the agreements made an consult the political level.
- The role of the ERTMS program, and thus of ProRail, changes to the position of an independent actor who is, for example, assigned to challenge project plans and solve issues between operators.
- A second decision week is organized in the same fashion as the first one: a cascade of decisions through the different levels of the organizations. Now the question is not about the start of a test, but the real implementation of ERTMS.
- The situation remains a diffuse field of actors, many uncertainties, and high political sensitivity.

3.5. CONCLUSION

The main findings that are reflected in the case studies are the following. Uncertainties regarding who decides what and in which order, ownership, and responsibility issues were present in all case studies. This led to conflicts, sub-optimal results, delay and unforeseen changes of the direction of the process. Additionally, the power, roles and responsibilities of actors were not static but dynamic. Actors shifted in power relations and responsibilities of actors changed. Moreover, actors tend to follow other actors in case of uncertainties.

We observed an important temporal component: at first, the focus is on the technical aspects while the influence of politics and context issues increased towards the end of the process. This is also reflected by the increased pressure, uncertainties regarding issues, and over-complexity when the deadline of the decision comes near. Furthermore, a stop-go effect is observed after new issues and new actors arrive in the decision-making process.

Sometimes individual actors have blocking power, in two cases (Amsterdam and Nijmegen) one actor blocked the decision-making process by stating a different preferred outcome from the other actors resulting in a delay of the process. A decision can be blocked at different decision levels. Either at the operational level when the technical uncertainties are leading, or at the strategic or political level when promises context issues play a major role.

We found a discrepancy between engineering decisions and strategic/political decisions in all case studies, however, the impact of these types of decisions on the final decision varied. Either, the engineering decision is leading (in cases B&M 2015 and Nijmegen); the strategic/political decision is leading (in cases B&M 2016 and ERTMS); or, both the engineering and strategic/political decision play a role (Timetable 2017 and Amsterdam).

THE result of this chapter is a description of six decision-making processes concerning large infrastructural projects of the Dutch railway sector.

- The descriptions consist of an explanation of the technical, actor, and context complexity of the decision-making process.
- Moreover, they describe the essence of the process by distinguishing different rounds.
- The case descriptions include the various perspectives of actors involved in the process and were validated by experts.
- The main findings that are reflected in the case studies are:
  1. Uncertainties regarding who decides what and in which order, ownership, and responsibility issues were present in all case studies.
  2. Power, roles and responsibilities of actors were not static but dynamic. Actors shifted in power relations and responsibilities of actors changed.
  3. We observed an important temporal component: at first, the focus is on the technical aspects while the influence of politics and context issues increased towards the end of the process.
  4. A stop-go effect is observed after new issues and new actors arrive in the decision-making process.
  5. Sometimes individual actors have blocking power, in two cases (Amsterdam and Nijmegen) one actor blocked the decision-making process by stating a different preferred outcome from the other actors resulting in a delay of the process.
  6. We found a discrepancy between engineering decisions and strategic/political decisions in all case studies, however, the impact of these types of decisions on the final decision varied. Either, the engineering decision is leading (in cases B&M 2015 and Nijmegen); the strategic/political decision is leading (in cases B&M 2016 and ERTMS); or, both the engineering and strategic/political decision play a role (Timetable 2017 and Amsterdam).
- The six case descriptions form the input for the next chapter in which the decision-making processes are characterized using the game concepts.

4

Characterization of Case Studies by using Game Concepts

In this chapter, we characterize the case studies using the game concepts as defined in Chapter 2.

- Different methods for identification of the game concepts are applied. These methods include free interpretation of the case description in several rounds, independent interpretation by different researchers, coding of interviews transcriptions, identification of game concepts by experts, and validation with experts.
- We used at least two different identification methods involving multiple researchers and experts for each case study to cross-check the identification of the game concepts.
- For each case study we show which of the seven game concepts are present and we summarize their main characteristics.
- Furthermore, the explanatory power of the identified game concepts is addressed. The explanatory power entails the elements and dynamics of the decision-making process explained by the game concepts.

The structure of this chapter is as follows: Section 4.1 explains the methods used for, first, identifying the game concepts, and second, assessing their explanatory power. In Section 4.2, we discuss the game concepts identified in the different decision-making processes. Furthermore, the characteristics for each game concept and their explanatory

---

Parts of this chapter have been published in Research in Transportation Economics **69** (2018) (Bekius et al., 2018a) and have been presented at the CESUN conference Council of Engineering Systems Universities in Tokyo, Japan, June 20-22 2018 (Bekius et al., 2018b).

power are described. In Section 4.3, we summarize the main elements of the game concepts for each case study and conclude with general observations across the case studies.

4.1. Methodology

This section explains how we identified the game concepts in the case studies. First, an interpretation method is used. Section 4.1.1 introduces a free and an independent interpretation of case descriptions. Second, a verification method is applied as explained in Section 4.1.2. For the different case studies different combinations of methods for game concept identification are used. However, we ensure that at least two different methods are used for each case study. Each of these methods are discussed in detail, and an overview of the use of these methods in the different case studies is provided at the end of this section.

We acknowledge here that selecting seven game concepts and looking through these game concept glasses to the decision-making process increases the chance of actually finding these game concepts. In the final chapter of this thesis this is mentioned as a limitation of the study. However, we are not only interested in which game concepts are identified, but even more which part of the process they explain, how the games are played, and how they impact the decision-making process.

4.1.1. Interpretation

The interpretation of the case descriptions to identify the game concepts happened in two ways, a free interpretation with a group of researchers in several rounds, or a independent interpretation by several researchers with a triangulation session afterwards (Jick, 1979, Leech and J. Onwuegbuzie, 2007).

Free interpretation of case description

Case studies Better for More 2015 and Better for More 2016 have been interpreted given the case description of the decision-making process and the definition of the game concepts. This interpretation happened in several rounds with multiple researchers. Each round brought up new questions, which were answered by checking the interview transcriptions, documentation or consulting an expert involved in both processes.

Independent interpretation and triangulation

Game concept identification for case studies Timetable 2017, Amsterdam, Nijmegen and ERTMS was first performed independently by different researchers based upon the case description. For the identification of the game concepts they used the definitions of the game concepts, and the game concept identification tool which is introduced in Chapter 6. Subsequently, the researchers discussed their results. In most cases, the researchers identified the same game concepts. Moreover, when identification and interpretations were different this led to questions which then were asked to experts or verified with interview data.

First, independent interpretation and then triangulating the identified game concepts resulted in a set of game concepts present for each case study. Moreover, during the interpretation sessions, the order in which the game concepts occurred was established. This resulted in an overview of the game concept appearance over time.

4.1.2. VERIFICATION

For the verification of the game concepts identified in the different case studies we used either coding of interview transcriptions, validation with experts, or identification of game concepts by experts.

CODING OF INTERVIEWS

The interview transcriptions of the case studies Better for More 2015, Better for More 2016, Groot Amsterdam and Nijmegen are coded for the elements of the game concepts. This means, we investigated the interview transcriptions and marked sentences that cover aspects of the elements of the game concept. For example, a sentence in the interview transcription representing an aspect of the context elements of the Multi-Issue game is coded by M-I_C. Context, process, results and risk elements of the game concepts are part of their definitions and can be found in Chapter 2. Subsequently, we scored the elements per game concept per interviewee. When at least two different elements of the same game concept were mentioned at least once during the interview we said that the game concept was present, and thus we identified the game concept in this interview.

VALIDATION WITH EXPERTS

Remaining questions from (independent) interpretation and triangulation sessions have been asked to experts involved in the decision-making process under study. Examples of such questions were details about order of events, and behavior of actors regarding an issue or at a particular moment in time. Moreover, for the ERTMS case experts contributed to the interpretation sessions, and for the Better for More cases experts validated the interpretation of the game concepts.

IDENTIFICATION BY EXPERTS

During the investigation of cases Amsterdam and ERTMS, workshop sessions with decision makers involved in these decision-making processes have been organized. In such sessions, the decision makers identified one or more game concepts using a game concept identification tool and discussed its potential consequences for the process of decision-making. More explanation on the workshop sessions and their results can be found in Chapter 8.

Both the coding of interviews and the involvement of experts for validation or identification of game concepts contributed to the verification of the game concepts identified in the process.

Table 4.1 provides an overview of the game concept identification methods used in the different case studies. For all but one case study, a method for interpretation and a method for verification of the interpretation is chosen. Moreover, for each combination of methods, the game concepts identified in the interpretation were in line with the game concepts identified by verification which strengthens our conclusions regarding the identification of the game concepts.

Table 4.1: Methods of game concept identification.

Cases	**B&M 2015**	**B&M 2016**	**Timetable 2017**	**Amsterdam**	**Nijmegen**	**ERTMS**
Number of researchers	3	3	3	4	4	3
Interpretation of game concepts						
Free interpretation	yes	yes	yes	no	no	no
Independent interpretation	no	no	yes	yes	yes	yes
Verification of game concepts						
Coding interviews	yes	yes	no	yes	yes	no
Validation with experts	yes	yes	no	no	no	yes
Identification by experts	no	no	no	yes	no	yes

4.2. GAME CONCEPTS IN CASE STUDIES

In this section, we list the game concepts identified for each decision-making processes. We specify the elements of the process that are characterized by the game concepts. Additionally, we highlight the *explanatory power* of the game concepts, meaning the dynamics of the process the game concepts explain.

The game concept characterizations are published by Bekius et al. (2018a) for case studies Better for More 2015 and 2016. Since these case studies have been compared in the paper, we characterize both decision-making processes in one section, but as will follow from the results, the identified game concepts are different in both processes. The game concept characterization of the Timetable 2017 case was presented at a the CESUN conference Council of Engineering Systems Universities (Bekius et al., 2018b). The game concept characterization of case studies Amsterdam and Nijmegen are rewritten and shortened, but based upon master thesis' (De Kwaasteniet, 2018, Van Dulken, 2018). The game concept characterization of case study ERTMS has not been published yet.

4.2.1. BETTER FOR MORE 2015 AND BETTER FOR MORE 2016

In both case studies Better for More 2015 and Better for More 2016, we identified the M-I game, the P-A game, and the CG. Additionally, the VD and BS are present in Better for More 2015.

MULTI-ISSUE GAME

The M-I game is present in both processes. The decision-making process involves multiple actors with different responsibilities regarding the railway system. Interdependencies between actors exist and they have different interests. During the decision-making process several new issues are introduced, hence the agenda is broadened. On the agenda, potential pain and gain is present for every actor. The previous mentioned items indicate that the M-I game is present. Table 4.2 categorizes aspects of the M-I game that contribute to the outcome of the decisions.

Table 4.2: Multi-Issue game.

Better for More 2015	Better for More 2016
Room for 'no' is created	*Room for 'yes' is created*
Uncertainty, analysis of performance levels and the implementation of Flow Through Station Utrecht (DSSU).	I&W is willing to utilize the space available within contracts regarding the performance level.
Linking of issues	*Linking of issues*
Happens mainly inside A2 corridor.	Happens also outside A2 corridor.
Incentives for cooperation	*Incentives for cooperation*
One example of a part of the system that is not ready is sufficient to conclude that the entire system will not improve, thus cooperation is less necessary.	Cooperation is necessary since issues arise at the boundaries of responsibilities and the only way to handle them is by cooperation between actors.
Type of issues	*Type of issues*
Content issues are more important.	Context issues are more important.

Explanatory power In the first year, the main focus is on content issues and limited linking between those issues led to limited collaboration and no real give-and-take game. This made it difficult to reach consensus in the first place. Together with the situation being over-complex room for another type of decision was created.

In the second year, focus on both content and context issues, and linking issues made the game more externally oriented. Interfering of the strategic level led to peer pressure at the tactical level and collaboration resulting in issues being solved at boundaries of responsibilities. The agenda was broadened by the principal who was willing to exchange issues, and thereby changing its role and responsibility. All together contributed to finally reaching consensus.

PRINCIPAL-AGENT GAME

The P-A game is present in both processes. ProRail and NS together are the agents with operational knowledge regarding the system. I&W is the principal with little operational knowledge and is interested in more trains. The super-principal is the Parliament since I&W has to justify the outcome of the decision to the Parliament. The before mentioned elements indicate that the P-A game is activated. Table 4.3 presents the aspects of the P-A game that distinguish the outcome.

Another P-A game, present in Better for More 2016, is clearly present because of pressure of I&W on the strategic level of the organizations ProRail and NS. For the strategic level to deal with this pressure they put pressure on their agent, i.e., the operational directors of ProRail and NS. The operational directors need to convince the strategic directors of the 'go' decision. As a result the operational directors start intensive collaborations. Since the issues they need to solve lie at the intersections of responsibilities this is beneficial for the result, and finally, they can positively convince the strategic level.

Explanatory power In the first year, asymmetry of knowledge between principal and agent resulted in a surprise by the principal when the agents decided 'no'. As a result the principal demanded a 'yes' next time.

Table 4.3: Principal-Agent game.

Better for More 2015	Better for More 2016
Burden of the past is not explicitly present, however, since the railway sector has a culture of deciding 'yes' this is what the principal (I&W) expects.	*Burden of the past* is present since, in 2015, the agent (ProRail & NS) promises a 'yes' outcome to the principal (I&W). The principal has a burden of the past since they promise 'yes' to the super-principal (Parliament).
The outcome	*The outcome*
The principal is confronted with the decision of the agent after the decision has been taken.	The principal is involved in the decision-making process and even takes a part of the decision for their responsibility.
Asymmetric information	*Asymmetric information*
The principal is unaware of the discussion and arguments prior to the decision.	The principal knows the issues that arise during the decision-making process.

In the second year, knowledge asymmetry was present between operational and strategic level. Strategic level wanted convincing results since it felt pressure from their principal. Knowledge asymmetry between strategic level and I&W was limited because of lessons learned last year. The result were no surprises and the principal took responsibility for the decision.

CASCADE GAME

The CG is present in both processes. A sequence of advises and decisions at different decision levels across organizations is executed before the final decision is taken. The output of one level provides the input for the next decision level. The actors of the different levels have knowledge about a specific part of the system and thus regarding the decision. Moreover, the decision space is limited. The elements discussed before indicate that the CG is activated. Table 4.4 identifies the aspects of the CG that separate the outcomes of the decisions.

Table 4.4: Cascade game.

Better for More 2015	Better for More 2016
Sequence of decisions known late in the process. This results in a conflict.	*Sequence of decisions* known early in the process, hence there are no conflicts.
Decision made by operational decision makers, the 'no' advice spreads through the different decision levels.	*Decision made by* NS in the end, the 'yes' advice is adopted on each decision level. The strategic level is involved in the process because of the burden of the past. Moreover, new decision makers want to know the details.
(Private) information	*(Private) information*
All information is present for the decision makers.	More information is present since more analysis of issues is performed.

Explanatory power In the first year, support for the decision was initiated at operational level. Major risks addressed the fear from strategic level.

In the second year, different steps in the game were known early in the process explaining that no conflicts occurred. The focus was on convincing the strategic level this time since they could potentially block the decision-making process.

VOLUNTEERS DILEMMA

The VD is activated in the Better for More 2015 case, but not in Better for More 2016. The case study includes multiple actors with separate responsibilities. When the deadline for the decision is near, pressure to take a decision increases. The uncertainty about the overall improvement of the performance level and analysis of the situation leads to more pressure. As a result, decision makers start to perform wait-and-see behavior and individual balancing of the different options occur. Hence, the VD is activated. Table 4.5 differentiates the aspects of the VD according to the outcomes of the decisions.

Table 4.5: Volunteers Dilemma.

Better for More 2015	Better for More 2016
Pressure from a deadline, culture of organizations, uncertainty about overall performance of the system.	*Pressure* from a deadline, uncertainty about overall performance of the system, and burden of the past.
Individual balancing and predicting individual chance of failure. No one is expected to say ‘no’.	*Individual balancing* less necessary since issues are resolved in collaboration, more openness in the process and trust between decision makers exists.
VD is activated and the *showstopper* was the implementation of Utrecht station at operational level.	VD is not activated, no *showstopper* identified.

Explanatory power In the first year, limited collaboration and over-complexity of the decision-making process provided room for another decision contributed to a volunteer stepping out. Furthermore, the major risk, i.e., the showstopper Utrecht station, for which everyone has a responsibility explains why the volunteer was not blamed and everyone followed.

BATTLE OF THE SEXES

The BS is present in Better for More 2015. Two actors, one responsible for the timetable and the other representing the Better for More program, advice the steering group on increasing the frequency on the A2 corridor. They have the same goal: giving an advice that is best for the railway system. However, they give their advice from a different perspective (is it feasible in the timetable versus is it feasible for the performance of the system) and thereby optimizing their own subsystem. Once both actors realized that they had a conflicting advice to the steering group the situation needed to be discussed.

Explanatory power Institutional uncertainty regarding who decides or advices higher decision levels about what to decide and when contributed to the existence of the conflict. The situation was resolved by involving decision makers from higher levels.

4.2.2. Redesign timetable 2017

The redesign process of the timetable 2017 is characterized by the M-I game, the P-A game, the CG, the H-S game and BS.

Multi-issue game

In the Ateliers, different issues, i.e., conflicts between operators' requests for the timetable, are at the table. Each Atelier consist of the operators and other actors driving trains in the area in which the conflict occurs. The actors have different interest regarding, for example, the number of time slots they prefer for a certain track. Each Atelier tries to solve a different conflict and is restricted to find solutions within the particular geographical area. The main focus is on the conflicts rather than on the actors involved and thus linkage between issues is limited. The result is that the design process in an Atelier ends in a deadlock. A deadlocks could be resolved at the BUP-table since they have the overview over the different Ateliers and they have the power to broaden the solution space.

Explanatory power As a result of remaining conflicts within the Ateliers, the representatives of the operators at the BUP-table started to exchange these conflicts. The result was that some conflicts were resolved while others concluded with an agree-to-disagree. Sometimes, the BUP-table decided to change the requirements in order to broaden the solution space with the aim to prevent an agree-to-disagree and end with consensus. Since there were many conflicts, each one involving a different sets of actors on different geographical areas, no one had the overview and the situation could easily become over-complex.

Principal-Agent game

The BUP-table is the principal and the Ateliers are the agents in the P-A game. Agents are able to provide solutions for conflicts between operators. They are assigned to provide such solutions. The BUP-table has the power to change requirements to increase the feasibility of finding a solution. A second P-A game can be observed between strategic levels of the organization, i.e., the principal, and the BUP-table, i.e., the agent.

Explanatory power Decisions made in the context at the strategic level or in other parts of the organization changed the operators' requirements and thus impacted the possibility for the agent to find solutions for a certain conflict. Frequent exchange of information between the BUP-table and the Ateliers prevented long searching for solutions which were impossible to find. The BUP-table not being aware of the difficulties and potential solutions in other areas (Ateliers) explains why conflict resulted in an agree-to-disagree.

Cascade game

Each design phase can be seen as a different decision level that builds on the assumptions and decisions made in the previous design phase. The predesign phase is crucial since it defines the basis for the next design phases, and since it consists of only two actors it makes assumptions about the requirements of other actors. Agreements made at the BUP-table form the input for the formal capacity requests. However, informal agreements are not always kept until the formal procedure starts.

Explanatory power During the Ateliers, it became clear that assumptions made in the predesign phase about requirements of operators were not correct. This can explain the existence of many conflicts. Furthermore, the fact that solutions needed to be found in restricted geographical areas and had to satisfy requirements from higher levels of the organizations led to sub-optimal results.

HUB-SPOKE GAME

Once the predesign phase is finished the yearly design cycle of the timetable starts. ProRail takes its role of independent capacity allocator and can been seen as the hub of the process. The operators are the spokes, each of them having capacity requests for the next years' timetable. The goal of the hub is to have a conflict free timetable. The game play changes once the operators have to submit their official capacity request.

Explanatory power The hub tried to solve conflicts by organizing the Ateliers and BUP-table process. The fact that system boundaries are reached makes it more difficult to find solutions. Therefore, remaining conflicts were solved in the formal procedure of allocating the capacity using the the Dutch rail network allocation statement (in Dutch: Netverklaring). When actors are aligned, no major conflicts remain, and thus the allocation process becomes easy. On the other hand, when actors are not aligned, they can create strategic issues for the hub by not applying according to the agreements made at the BUP-table. In that case, the hub has to follow the rules of the Netverklaring which might result in sub-optimal outcomes for other actors or the railway system in general.

BATTLE OF THE SEXES

In the predesign phase, two actors are present: ProRail and NS. They share the same goal of designing an optimal conflict free timetable. However, their incentives are different. ProRail aims to allocate the capacity to the different operators in an efficient way which means to optimize the use of (new) infrastructure as well as meet the requests of the different operators. NS wants the timetable which improves the punctuality, increases customer satisfaction and creates more profit by fully utilizing the infrastructure built in recent years.

Explanatory power During the process several situations occurred in which the two actors were not agreeing on a certain solution since different solutions favor the different incentives. A compromise between the two solutions did not always result in an optimal solution, hence they needed to make a choice. The process manager in this case showed the advantages and disadvantages of each solution using a multi-criteria decision method.

4.2.3. Amsterdam

In the case study of Amsterdam, we observed the M-I game, the P-A game, the VD, DD, and two types of BS.

Multi-Issue game

The actors involved in the case study are part of the M-I game and their incentives are presented in the previous chapter. Several issues, both on content (East tunnel) and context (IJ-viaduct, Schiphol), arrive at the table during the decision-making process. As a result, the scope of the projects changes. Uncertainty and time pressure increases due to the many (new) issues on the agenda. Actors differ in their preferences due to their divergent incentives and importance they give towards various issues. All actors prefer option C, but one actor prefers option D. The decision-making results in a deadlock and no consensus among the actors is reached.

Explanatory power Many issues from the context led to a change in scope of the project towards broadening the solution space. Positions of actors changed accordingly and new issues enter the process (future-proofness, municipal elections, West-tak investigation). Exchange of issues occurred and led to collaboration between actors (for example on financing). However, not all actors' preferences were reflected in the finally chosen option, hence no consensus was reached.

Principal-Agent game

Multiple P-A games are observed in the decision-making process. In the first P-A game, I&W is the principal and ProRail the agent who gets the assignment for Amsterdam Central station. When the scope changes to the larger Amsterdam region (Groot Amsterdam) the assignment and the role of actors change. The municipality of Amsterdam becomes a principal as well since they cover a part of the budget, and ProRail collaborates closely with NS and VRA. Among the agents, the preferences regarding the solutions diverges, and ProRail, as main agent, relates to the incentives of the principal, i.e., keeping costs low and scope until 2030. In the second P-A game, I&W is the agent and the political parties are the principal. By blocking, and thereby postponing the decision-making to a later stage, the principal shows its power.

Explanatory power Changes in game play of the first P-A game are explained by changes in the scope of the project. The agent related their preference over outcomes to the preference of the principal (low costs). Hence, asymmetries of power and information were not remarkable. In the second P-A game, (municipal) elections played a role in the context of the decision-making process. The information asymmetry between principal and agent was too large, hence the principal used its power to delay the decision.

Volunteers Dilemma

The political parties block the decision-making process by putting the decision on hold. A worst-case scenario according to them is investing more money in Randstad while not investing in regional areas. The final decision might change when it is made after the municipal elections since they could influence the budget available from the municipality.

Explanatory power Municipal elections, no support of the political parties, and those parties having power led to a delay of the final decision.

DINERS DILEMMA

Budget restrictions are a major problem in this decision-making process and during the process several issues come up which further increases the costs. To find a solution the agreement is made to reduce costs where possible, however, some actors try to violate this agreement by requesting more.

Explanatory power The municipality of Amsterdam had the incentive to 'freeride' regarding the East tunnel issue. The tunnel issue addressed their core business and a financial solution was found. NS had the incentive to 'freeride' regarding the final list of options. Their preferred option was the most expensive, but also the best option for the future. A possible strategy was to delay or, at least, rethink the decision.

BATTLE OF THE SEXES

Although multiple actors are present in the decision-making process, a conflict in preferences regarding the different options exists between ProRail and NS in the first BS. Their goal is the same, increasing the capacity of infrastructure and stations in region Amsterdam. However, their incentives are different. NS gives importance to future-proofness until year 2040, while ProRail believes envisioning until year 2030 is enough and ProRail wants to keep the costs low. In the second BS, VRA and NS have a different incentive on the issue of the type of transportation on the West-tak. NS is in favor of Sprinters and VRA is in favor of metros, but both have the same goal of increasing the capacity between Amsterdam and Schiphol airport.

Explanatory power In the first BS, the conflict appeared when actors had to reveal their preferences, and received media attention when NS sent a letter to I&W about its worries and provides arguments for a certain outcome. The conflict was finally resolved by the Minister who made the final decision. In the second BS, an investigation on the issue resulted in an advice to use Sprinter trains at the West-tak instead of metros. Hence, the conflict was resolved by adding new information, which in this situation was also accepted by both actors.

4.2.4. NIJMEGEN

In the decision-making process regarding rebuilding of station Nijmegen, we identified the M-I game, several P-A games, the CG, a H-S game, the VD and DD.

MULTI-ISSUE GAME

The actors introduced in the case study are part of the M-I game. An issue that is present during the entire process is the restriction on the budget. In the beginning, thi issue creates a deadlock in the decision-making process and as a result the process is put on hold. After continuation of the process, various new issues arrive at the agenda. Content issues (extension of the tunnel, transfer), and context issues (station hall, replacement of switch) are linked, and exchange of issues occurs. The focus of the process is on the issues, but tends towards an actor focus later in the process.

Explanatory power Collaboration on some issues took place resulting in changing roles of actors. The transfer issue broadened the solution space and a new alternative seemed to resolve sub-optimal aspects of previous alternatives. The result of the decision-making process was consensus among the actors.

Principal-Agent game

Multiple P-A games exist in this decision-making process. In the first P-A game, the DO PHS is the principal and the steering committee is the agent. Their assignment is to advise the principal on different alternatives. The principal puts the process on hold when costs are expected to exceed the budget. In the second P-A game, I&W is the principal and ProRail is the agent who receives the assignment to design the infrastructure and station of Nijmegen in such a way that running high frequency timetables is possible.

Explanatory power In the first P-A game, the principal used its power when information was missing and other PHS projects exceeded their budget. Not being able to run a high frequency timetable at the SUN corridor was a worst case scenario for the agent. The agent convinced the principal by showing that the functionality of the system does not improve when a cheaper alternatives is chosen. Hence, the project restarted with the same scope. In the second P-A game, information and power asymmetry was not visible in the process. The principal and the agent were aligned, however, the principal was enlarged by the municipality of Nijmegen and the province of Gelderland when they decided to finance the tunnel.

Cascade game

The formal process of decision-making is designed as a cascade of decisions from project team to steering committee to DO PHS, where final decision is made, with internal decision-making within organizations in between. Internally, the decision-making of ProRail is also designed as a cascade, the project team advises the large project team (IPT), who advises the Ecxo, who subsequently takes the final decision.

Explanatory power Issues arriving late in the process, such as the transfer issue or NS declaring their preference for 10', could block or delay the decision-making process. However, the different decision-making steps in the process were known and communicated clearly.

Hub-Spoke game

The project team is the hub and the different departments of ProRail are the spokes. The goal of the hub is to collect information about design requirements and their feasibility from each spoke. Subsequently, the hub processed the results and discussed the final results with the spokes.

Explanatory power Since the information was collected in one-to-one situations, the spokes had no insight in the total of design requirements and how these aspects were connected. As a result, the transfer issue was recognized late in the process. Finally, all spokes seemed to be in line with the alternative 11' and only one department preferred 10'.

VOLUNTEERS DILEMMA

The transfer perspective is neglected in the design of alternatives. One person realizes this, steps out, and the other actors follow.

Explanatory power A new alternative was designed as a result of the proposed issue, which changes the outcome of the decision-making process. Since the process was taking place in a transparent and collaborative environment, it was easy for the volunteer to step out, and no blame followed afterwards. It turned out that it even had a positive effect on the alignment of actors on the finally chosen alternative.

DINERS DILEMMA

Everyone thinks that all actors have agreed on a certain alternative. However, NS expresses her preferences for another alternative.

Explanatory power The incentive to express another alternative is explained by the fact that it is beneficial for the connection to the stabling yard. Moreover, no consensus leaves room for other issues to be dealt with since it delayed the process. However, the impact of this action was not very large since the transfer issue led to a new alternative that also covers the preferred option of NS.

4.2.5. ERTMS

In the case study ERTMS, the M-I game, several P-A games, a CG, the H-S game, the DD and BS, are identified.

MULTI-ISSUE GAME

The actors introduced in the case description are involved in the M-I game. Content and context issues are on the agenda, with a focus on context issues during the first decision week. The investment of new trains for freight operators creates a deadlock in the decision-making process. A clear M-I game strategy is played by I&W regarding the Masterplan freight transport; smart connections between decisions at the Masterplan table and ERTMS are made.

Explanatory power The focus on content explains the over-complexity of the process. Collaboration between the main actors resulted in a shift in focus towards the actors and their incentives. Exchange of issues resulted in broadening of the solution space. However, still many issues remain and new issues are expected, hence no consensus is reached (yet).

PRINCIPAL-AGENT GAME

Several P-A games exist, the assignment is in each game the same, however, the actors are different. The assignment is to implement ERTMS according the the EU agreements. In the first P-A game, I&W is the principal and the railway sector (ProRail, NS, operators) is the agent. In the second P-A game, the Parliament in the principal and I&W is the agent. In the third P-A game, the EU is the principal, and I&W and the Parliament are the agent.

Explanatory power In all P-A games the pressure to meet deadlines resulting from EU agreements and budget specifications influenced the relation between principal and agent. Moreover, technical uncertainties influenced the relation in the first P-A game. For the principal being able to address the power and information asymmetry they organized the process as such that the program of ERTMS is an independent actor and referee in conflict situations. Part of their power is thus distributed to the program director, and on the other hand, the ERTMS program serves as vehicle to close the knowledge asymmetry gaps. In te second P-A game, information asymmetry is minimized between the principal and the agent by providing the principal with insight in documentation. As a result, the the principal and the agent share the same incentives which means that pressure from the principal is not necessary. In the third P-A game, the Parliament of the Netherlands is one of the multiple agents for which the EU is the principal. Hence, pressure from the principal can also be a result from issues taken place in other principal-agent relations.

Cascade game

The first and second decision week are organized as CG. The decisions need to be adopted by the various predefined levels involving representatives of the different organizations.

Explanatory power The effect of the decision weeks being organized as CG is that the entire process before and after the decision week converged to and builds forth on the CG structure. No real objections were made during the week, but the fact that time was limited and information was late resulted in objections of actors after the decision week. This could be translated to having obtained sub-optimal results. The main decision level is the steering committee, but representatives of freight operators needed to reflect on a variety of opinions which made this a situation that could be subject to blocking the CG.

Hub-Spoke game

The H-S game is designed to provide steering of the process by the program direction of ERTMS (the hub). The spokes are the passenger and freight operators, infrastructure manager, leasing companies, and contractors. The goal of the ERTMS program is to facilitate and steer the process of introducing ERTMS.

Explanatory power The spokes in this game were not aligned, and, moreover, the exact responsibilities of the hub were not fully clear. The result is that spokes created strategic issues easily, which delayed the process and created chaos. This is in line with the advise of the BIT test to have a more strict and controlling hub who does not leave room for conflicts and issues between spokes to occur.

Diners Dilemma

The freight operators and I&W made agreements in the Masterplan freight transport regarding ERTMS. The actors agreed upon the decision list for the decision week and the shared goal is to let the BIT test start after summer.

Explanatory power Some freight operators violated the agreements made by lobbying by political parties. It is in their interest to delay the process since investments in the future will be necessary anyway. NS does not have the incentive to particularly delay the process, but they want to have enough time to prepare operation before introducing ERTMS. Moreover, they want to maintain their autonomy.

BATTLE OF THE SEXES

An example of a technological issue is the choice for building a certain antenna in the train or in the infrastructure. ProRail is in favor of building it in the train, and NS wants it to be build in the infrastructure, since this will reduce the costs in for them in each case. Both actors have the same goal of introducing ERTMS in a feasible and good way.

Explanatory power The conflict appeared between ProRail and NS since no one can overrule the other by using its power or information. Moreover, a compromise is not possible in this case. The fact that institutional uncertainty exist, i.e., no one decides on the issue, can delay the process and affect the (trust) relation between the actors. A solution, as proposed in the BIT advice, is to provide more steering and guidance as the ERTMS program (the hub) towards the actors involved in a BS. For instance, by taking the role as referee instead of letting the actors resolve it themselves.

4.3. SUMMARY OF MAIN ELEMENTS GAME CONCEPTS

The previous section introduced the game concepts identified in each case study, and their explanatory power. An overview of the game concepts present in each case study and their main characteristics and results are presented in Table 4.6.

Some observations made from Table 4.6 are:

- M-I game and P-A game are present in all case studies.
- Multiple P-A games are present at different decision levels.
- Game concepts influence each other. For example, the hub resolves the BS, and the VD activates the CG.
- H-S and CG seem to be organized or designed on purpose, which is different from P-A and M-I which seem to be present by default.
- VD, DD and BS seem to have impact on decision direction, create chaos and delay the process.
- Different context conditions such as political pressure, technological uncertainties, trust and alignment between actors influences which game concepts appear, and how the games are played.
- The distinction of the case studies in different families, as introduced in Chapter 3, does not reveal a clear pattern of the existence of game concepts in types of decision-making processes.

Conclusions on the elements of the process characterized and explained by the game concepts in the different case studies of this thesis are presented in the next section.

4.4. Conclusion

In the concluding section of this chapter we summarize game concept characterization. For each game concept we present the characteristics and elements of the decision-making processes they explain.

Multi-Issue game

Multi-Issue game explains a stop-go effect, (non)consensus between actors, and over-complexity of the process.

A broadened solution space can cause a fundamental change in the direction or an acceleration of the decision-making process. New issues on the agenda and smart connections between issues together with the involvement of new actors creates a *stop-go effect* on the process. Moreover, it facilitates collaboration between actors. The M-I game explains the stop-go effect and how this eventually leads to consensus among the actors.

Alternatively, when the solution space is restricted and the actors focus on one type of issues - usually content issues - deadlocks in the decision-making process remain. The game then explains why no consensus is reached.

In case the many issues at the table and the multiple actors involved lead to uncertainties regarding responsibilities of actors and future effects on the system while the pressure to take a decision increases, the situation can become over-complex. As a result, the process does not move forward anymore. The game explains the over-complexity and stagnation of the process.

Principal-Agent game

Principal-Agent game explains how the information-power relation between the principal and the agent affects the decision-making process and the responsibilities of actors.

Uncertainties regarding (technical) issues prevent the agent from communicating this to the principal. This results in asymmetry of information and misalignment between principal and agent. In the end, the principal is faced with surprising and unforeseen results. The game explains why the principal eventually uses its power to steer the agent (towards the goal of the principal).

The asymmetry of information between principal and agent is well-managed. There is thus no need for the principal to use its power and eventually the principal takes more responsibility for the decision. The explains the alignment of the agent and the principal and a potential change in responsibility of the principal.

Furthermore, the existence of multiple P-A games shows the dual role of actors - being principal and agent at the same time - in a different P-A game. The game demonstrates the compositional nature of actors responsibilities and complexity in decision-making processes.

Cascade game

Cascade game describes the dependencies between decisions, including actors' agency, at different decision levels and indicates sub-optimal results, a (potential) blockade of decisions, and the arrival of conflicts.

Decisions can be blocked at different decision levels - operational, tactical, strategical, political - and we observed different actors that needed to be convinced to prevent them from blocking the decision. After we know that the cascade of decisions is blocked, the game indicates at which level this is the case.

Time pressure, new issues which arrive late, uncertainties regarding actors responsibilities and the order of decisions make that the course of the game is unknown. As a result, conflicts arrive or the process is delayed. The game indicates where these conflicts arrive, and thus why the process is delayed and sub-optimal results are obtained.

The opposite situation, a clear course of the game without actors blocking the decision, is also observed. The game then indicates a flow of decisions through the different decision levels.

Hub-Spoke game

Hub-Spoke game explains to which extent the hub and the spokes are aligned and how this impacts the decision-making process.

The spokes follow the plan of the hub and there is agreement on the finally chosen outcome or alternative. The game explains the alignment between the hub and the spokes.

Since the spokes do not know the perspectives of other spokes, the spokes optimize their own perspective. Hereby they create strategic issues for the hub who has to make a trade-off between all these solutions that can never satisfy the perspectives of all actors. The result is a sub-optimal outcome for each actor which can lead to conflicts, disagreements and eventually delays the process. The game thus explains the misalignment between the hub and the spokes.

Conflicts exist between spokes that need to be resolved by the hub. Uncertainty about responsibilities and power of the hub explains why the conflicts arrive or escalate.

Volunteers Dilemma

Volunteers Dilemma involves a responsibility dilemma - act or wait for someone else to act - an actor is facing when confronted with a major risk that could have negative effects on the outcome of the process. It explains a change in direction of the process or an on-hold situation.

The presence of a showstopper that addresses a shared responsibility, pressure for a deadline, and the expectation that other actors will follow make a volunteer act. In the case study B&M 2015, the expectation was to decide 'yes' on the decision regarding the frequency increase of trains per hour at the A2 corridor. However, one actor took the responsibility to argue against the decision and mentioned the implementation of station Utrecht Central was a showstopper. In this case, the other actors followed this actor and as a result the direction of the process changed. Moreover, because the other actors followed, the volunteer is not blamed for his action. The game explained the change in direction of the process.

A worst-case scenario, context issues and pressure for a deadline activates a volunteer. The result is a process which is put on-hold and more investigation of the worst-case scenario is required. The game explains the on-hold situation.

Diners Dilemma

Diners Dilemma entails the dilemma of either violating the agreements made or not and explains the impact of 'freeriding' on the decision-making process.

In case that the incentives of an actor are opposed or not represented in the decision-making process or the final outcome, the decision to ‘freeride’, and thus violate the agreements, is easily made. In the case studies Amsterdam as well as in Nijmegen, one actor prefers another alternative since its incentives are not fully reflected in the technical specifications of the alternative preferred by the other actors. The DD then explains which incentives, or which specifications as in the example, make the actor ‘freeride’.

Once an actor starts ‘freeriding’, other actors can follow. If actors follow it could eventually lead to an unforeseen change in or delay of the decision-making process. The game explains to which extent the first actor is followed by the other actors and how this impacts the decision-making process.

BATTLE OF THE SEXES

Battle of the Sexes explains a conflict between two actors who share the same goal but have different interests.

When actors reveal their preferences regarding outcomes or alternatives, a conflict between two actors becomes clear - both favor their own optimal solution - and it turns out that a compromise between the two solutions is impossible or leads to a sub-optimal outcome. The BS explains why this conflict is present and, in particular, why a compromise is not desirable.

The situation cannot be resolved by one actor using its decision power since the two actors have the same power. Hence, in many cases a third party gets involved, or new information in response to an independent investigation arrives, to solve the situation. Eventually, the process is delayed or the relation between the two actors is damaged. The game clarifies the non-hierarchical relation between the actors and pinpoints the uncertainty regarding responsibilities of the actors.

THE result of this chapter is an overview of the appearance of the game concepts in the six case studies.

- We discussed which of the seven game concepts were present in the case studies and outlined their main characteristics.

- For each case study and each game concept we summarized its explanatory power.

- From this we concluded that the game concepts are able to explain a large part of the essence of the decision-making process:

  Multi-Issue game explains a stop-go effect, (non)consensus between actors, and over-complexity of the process.

  Principal-Agent game explains how the information-power relation between the principal and the agent affects the decision-making process and the responsibilities of actors.

  Cascade game describes the dependencies between decisions, including actors’ agency, at different decision levels and explains sub-optimal results, a (potential) blockade of decisions and the arrival of conflicts.

Hub-Spoke game explains to which extent the hub and the spokes are aligned and how this impacts the decision-making process.

Volunteers Dilemma involves a responsibility dilemma - act or wait for someone else to act - an actor is facing when confronted with a major risk that could have negative effects on the outcome. When other actors follow the volunteer, the game explains a change in direction of the process or an on-hold situation.

Dinners Dilemma entails the dilemma of either violating the agreements made or not and explains the impact of 'freeriding' on the decision-making process.

Battle of the Sexes explains a conflict between two actors, who share the same goal but have different interests, and its impact on the decision-making process.

- The characterization of the decision-making processes using the game concepts led to a number of observations:

  i. Some game concepts are *always* (M-I, P-A) present while other game concepts only appear *incidentally* (VD, DD, BS);

  ii. Some game concepts exists at *multiple* (M-I, P-A, CG) decision levels while other game concepts only exist at a *single* (VD, DD, BS) decision level; and

  iii. Game concepts *interact* and the activation of a game concept can impact other game concepts both constructively and destructively.

- These observations provide the input for the next chapter in which we present a follow-up analysis of these three observations.

Table 4.6: Explanatory power of game concepts.

	B&M 2015	**B&M 2016**	**Timetable 2017**	**Amsterdam**	**Nijmegen**	**ERTMS**
M-I game						
Consensus	Yes	Yes	Conflicts remain	One actor against	Yes	Yes
Solution space	Restricted	Broadened	Restricted	Restricted	Broadened	Broadened
Direction decision	Changed	Unchanged	Unchanged	Changed	Changed	Unchanged
Over-complex	Yes	No	No	No	No	Yes
P-A[1] game						
Asymmetry relation	Information	Principal involved	Info-power	Limited	Convince principal	Info-power
Actors aligned	No	Yes	No	Yes	No	Not always
"Winner"	Agent	Both	Principal	Both	Agent	Both
Impact outcome	Principal surprised	No surprise	Agree-to-disagree	Continue process	Restart project	Principal in control
P-A[2] game						
Asymmetry relation	Limited	Convince strategic level	Info/power	Information	Limited	Inform principal
Actors aligned	Yes	Yes (later)	No	No	Yes	Yes
"Winner"	Both	Both	Principal	Principal	Both	Both
Impact outcome	Explain to principal	Continue process	Agree-to-disagree	Delay decision	Continue process	Normal process
P-A[3] game						
Asymmetry relation		Limited				Limited
Actors aligned		Yes				Not always
"Winner"		Both				Both
Impact outcome		Explain to principal				Continue process
CG						
Main level	Operation	Strategic	Formal rules		Strategic	Steering committee
Blocking	No	Operation	No		One actor against	Freight operators
Sub-optimal outcome	No	No	Agree-to-disagree		No	Adjust decisions
H-S game						
Strategic issues			Formal application		Focus on infra	Conflicts between spokes
Spokes aligned			No		Yes, but one	No
Impact outcome			Conflicts late or return		Change in outcome	Delay, budget, new issues, chaos
VD						
Conditions	Pressure, risk, uncertainty			Risk, uncertainty, political context	Single perspective	
Outcome	Everyone accepts			Everyone accepts	Everyone accepts	
Blame	No			No	No	
Impact outcome	Change decision			Delay but no change	New alternative	
DD						
Incentive 'free-ride'				Future proofness, delay	Incentives, delay	Politics, delay
Impact outcome				Chaos, delay, conflicts	New alternative, revisit decision	Delay, conflicts, chaos
BS						
Conditions	Institutional uncertainty		Conflicting incentives	Conflicting incentives		Institutional uncertainty
"Winner"	B&M program		Compromise	ProRail (1st), NS (2nd)		No compromise

5

Patterns in Strategic Decision-Making Processes on Complex Systems: A Comparison of Six Case Studies

In this chapter, we present a follow-up analysis and study the presence of game concepts in all case studies.

- In Chapter 4 we identified the game concepts for each case study, in this chapter we search for generic patterns of the presence of game concepts in empirical decision-making processes based on the six case studies.
- Why is it interesting to distinguish such patterns?
  1. Such patterns provide empirical evidence of the game play and dynamics of decision-making in the Dutch railway sector.
  2. They provide guidelines for the decision-making involved in the process.
  3. Subsequently, they can be used for applications of game concepts further on in this thesis in the areas of gaming simulation, modeling and organizational interventions.
- Three perspectives are discussed:
  1. The presence of game concepts over *time*,
  2. The existence of game concepts at *multiple levels*, and

iii. The *interactions* between game concepts.

- For each perspective we address the appearance of game concepts (the "what"), how the games are played (the "why"), and their impact on the decision-making process.

5.1. INTRODUCTION

In Chapter 3, we presented six empirical case studies of decision-making processes from the Dutch railway sector. In Chapter 4, we identified game concepts in these decision-making processes. The game concepts characterize elements of the process and have explanatory power. We concluded Chapter 4 by distinguishing the main consequences for the process, and results, of the game concepts identified in the case studies. This leads to a number of observations: (i) How do the game concepts exist over time? (ii) How are the game concepts present at different decision levels? and (iii) How do the game concepts interact, given their occurrence over time and across decision levels?

In this chapter, we answer these questions by taking three different perspectives:

i. A temporal perspective concerning the existence of game concepts over time,

ii. A multi-level perspective regarding the presence of game concepts at decision levels,

iii. A focus on interactions between game concepts.

Here, we take one more level of abstraction in which we build forth on the empirical work of Chapters 3 and 4. The purpose is not to compare the case studies of the previous chapters again, but to perform a meta-analysis on the game concept explanations of the case studies and only to use the cases for illustration.

The contribution of this chapter consist in providing more insight into appearance of the game concepts in decision-making processes (i.e. the "what") by specifying under what conditions they appear, and explain how they are 'played' (i.e. the "why"). The aim is to, on the one hand, have a scientific contribution by taking a higher level of abstraction and detect interaction patterns of, and between, game concepts' appearance over time and across decision levels. On the other hand, we address the impact of the results on the decision-making process, and thereby provide guidance to practitioners involved in the process.

In the remainder of this chapter the three perspectives are discussed for the game concepts identified in the six case studies. Section 5.2 addresses the temporal perspective. We specify how the game concepts appear over time, explain which conditions contribute to this, and conclude by answering the question of the meaning of the results for the decision-making process. In Section 5.3, we take a multi-level perspective. The presence of game concepts at different decision levels is indicated, and it is explained why this is the case before describing the impact on the decision-making process. The interaction perspective is presented in Section 5.4. We outline which interactions between game concepts take place, and for the most common interactions we provide an explanation and discuss the results for the decision-making process. In Section 5.5, we present the main findings from the three perspectives, and in Section 5.6, we return to the question of what the abstraction means, both scientifically and for the practitioner involved in the decision-making process.

5.2. TEMPORAL PERSPECTIVE

Game concepts are present for a certain period in the decision-making process. The temporal perspective considers the appearance of game concepts over time. In particular, it distinguishes between game concepts being present over the entire process and game concepts showing up for a short or fixed period.

Figure 5.1 shows the order of game concepts over time for each case study. The colors distinguish between the different game concepts. Moreover, the length of the bar shows an approximation of the period of time in which this game concept was present.

The analysis is based on the case descriptions of the case studies in the previous chapters. Each case description is translated into a timeline of events, and, together with the interpretation of the game concepts, this results in the order of game concepts over time.

5.2.1. OBSERVATIONS IN CASE STUDIES

First, we observe the differences between the game concepts' presence over time, and, second, we explain why the game concepts appear as such.

HOW ARE THE GAME CONCEPTS PRESENT OVER TIME?

The M-I game and the P-A game are present for the entire process in most case studies. The CG and the H-S game are present for a fixed period of time. The CG characterizes the situation towards the final decision moment, while the H-S game can also be present for a certain period earlier in the process. VD, DD, and BS are usually present for a short period and, in most cases, more towards the end of the process.

Figure 5.2 provides a representation of the temporal perspective by classifying the game concepts according to the duration of the process (entire time, fixed period, incidentally), and the phase of the process (start/middle, end).

WHY DO THE GAME CONCEPTS APPEAR THIS WAY?

In this section, we provide an explanation for the appearance of the different game concepts over time.

Multi-Issue game Why is the M-I game present during the entire process? The decision-making processes are defined by multiple actors being involved from the beginning, who have different incentives, and thus different opinions regarding the decision. The actors belong to compartmentalized organizations with different responsibilities which contributes to uncertainty about issues and eventual deadlocks. Furthermore, decision-making on large infrastructural projects is not about a single decision. One could talk about the final decision, but in the meantime various other decisions need to be made which are connected to one another. In the cases we investigated this dynamics starts early in the process. The aforementioned aspects define a typical M-I game situation and explains its presence over the entire process.

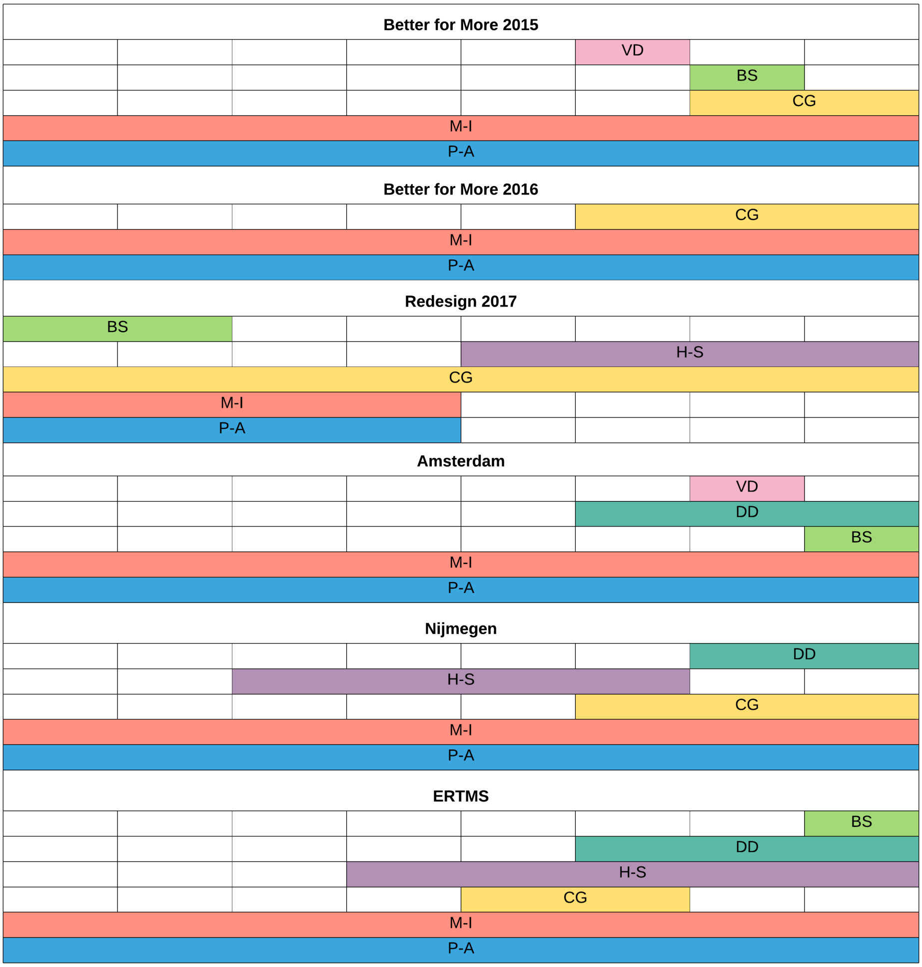


Figure 5.1: Temporal perspective on game concepts.

Principal-Agent game The constitution of organizations in the Dutch railway sector plays an important role in the existence of the P-A game during the entire process of decision-making. In most case studies, a P-A game is characterized between the Ministry who is the principal, and ProRail or railway operators who are the agent(s). The assignment, from principal to agent, is given in the beginning of the process, and the result, i.e., the decision or outcomes, is presented to the principal by the agent towards the end of the process. Although the existence of the P-A game might seem trivial, we observe that in many cases multiple P-A games exist within one decision-making process. Their interactions complicate the decision-making; we elaborate on this point in Section 5.4.

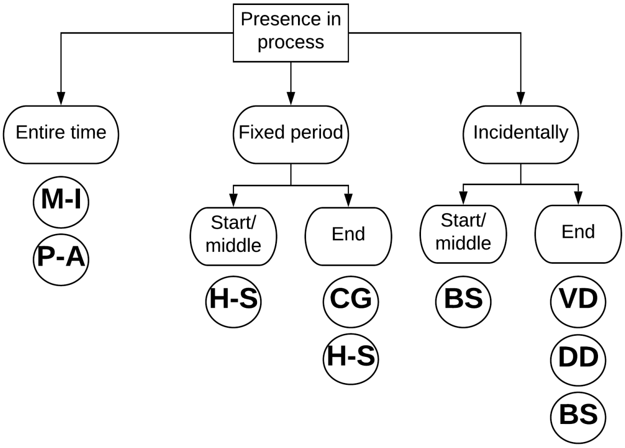


Figure 5.2: Temporal classification of game concepts.

Cascade Game Why is the CG present for a certain part of the process, usually preceding the final decision moment? The CG is present since decision makers from various decision levels need to contribute to the decision. Decision makers give advice to a higher decision level who base their decision on advice from lower decision levels. Usually, the commitment of the various decision levels is requested towards the end of the decision-making process. The fact that different actors, with different responsibilities and internal organizational structures, are involved in the process, and due to the fact that the involvement of actors is a dynamic process, the design of the CG differs from case study to case study. Notice that the presence of the CG can be explained because people actually 'design' the process in this way. As said before, the constitution of the Dutch railway sector has a network structure which does not prescribe one actor who decides, but it requires support of the different actors involved. The CG is in many cases chosen as the 'game' to achieve this.

Hub-Spoke game Why is the H-S present for certain parts of the process? The H-S game is present at the start or in the middle of the process when the hub can still oversee the different tasks and aspects of the decision-making process. In some cases the H-S game represents internal decision-making within organizations before the external decision-making takes place. Notice that, similarly to the CG, one can choose to use the H-S model as structure for (part of) the decision-making process. Another situation, in which the H-S is present more towards the end of the process, is when formal rules apply and prescribe the responsibilities of the hub and spokes. For instance, in the case study of the redesign of the timetable the capacity allocator ProRail serves as a hub for the operating companies who are the spokes.

The next three game concepts tend to be present late in the process, they incidentally appear. We explain why this is the case.

Volunteers Dilemma The VD appears when someone (suddenly) argues against the expected direction of the decision-making process. It costs the volunteer something to make this unexpected decision, therefore, one would like to wait until someone else starts, or until the situation can no longer remain in its current state according to the volunteer. The reasons why the volunteer takes the decision, i.e., steps out, can vary from technical uncertainties, to political reasons, to personal considerations.

Diners Dilemma The DD appears when someone starts 'free-riding' by violating the agreements made. The arguments for 'free-riding' can vary from trying to satisfy ones incentives, to getting other actors on board to support ones opinion. Towards the end of the process actors learn how other actors are playing the game, and whether 'free-riding' is necessary to steer the process into a direction that satisfies them.

Battle of the Sexes The BS is present because two actors share the same goal but have different interests, and this situation becomes problematic. A conflict between the actors arises when there is uncertainty about actors roles and responsibilities. Similarly to DD, actors learn during the process about other actors' incentives. Once the possible outcomes of the decision become clear, and actors actually take position, it turns out whether they are conflicting.

We observe that the game concepts VD, DD, and BS can be destructive for the process. They can change the direction of the decision, increase the complexity, and lead to conflicts between actors thereby creating chaos and delaying the process. Therefore, we take a closer look at the conditions of the decision-making process that lead to activation of those game concepts in the next section.

Conditions for activation of VD, DD, and BS

We notice that for the game concepts VD, DD, and BS there is a difference between activation of the game concept, and it actually having an impact. Therefore, the following two aspects are of importance: (A) the game concepts need to be activated, and (B) there needs to be enough critical mass of actors to align in order for the game concept to be of impact.

Considering the empirical case studies we list the conditions which contribute to aspect (A), the activation of either VD, DD, or BS.

- Uncertainty about the decision to be made.
  No one knows what is the best decision. In particular, we observed this at the tactical level or among operational directors. As a result, the uncertainty about the best decision translates to other decision levels, thereby increasing the uncertainty regarding the decision.

- Contested information and uncertainty regarding the effects.
  The previous point can be the result of contested information and uncertainty regarding the effect of proposed measurements or implementations. Moreover, if the sum of the uncertainties is large, then the effect of proposed implementations in the future is unknown.

- Uncertainty about how to reach a decision.
  No one knows how to reach a decision. Again, at the tactical level this uncertainty exists. It is unclear which actors should be involved at which moment in time, and what their responsibility is towards the final decision. As a result, there are no clear agreements between actors, and thus room for violating agreements exists and conflict between different actors at the tactical level could arise.

- Different perspectives of actors translate to conflicting advices or outcomes. It is a given fact that the perspectives of actors on the process are different, and their incentives too. However, when the assumed difference results in conflicting advices, preferences for alternatives, or outcomes of the process, this becomes problematic. This condition can appear at different decision levels, but usually towards the end of the process since only then the final outcomes are articulated and actors are asked to take a position.

- Future-proofness of decision is unknown.
  Alternatively, it might be the case that the future prospect of the decision does not satisfy at least one of the actors. As a result, they will try to convince other actors, and delay the process in order to obtain more information.

- Political or cultural pressure to take a certain decision exists.
  This results in pressure for a certain decision from the strategic level to the operational and tactical level.

- The decision turns out to be a major risk.
  This is either within or outside the project and the risk cannot be mitigated easily. Or, the other way around a (previous) decision in another project, creates a risk situation for the decision to be made.

Once a combination of these conditions is present (A), and it influences the actors in such a way that they become aligned and use their power, it can impact the decision-making process (B).

5.2.2. CONCLUSIONS

What does the analysis, from a temporal perspective, mean for the decision-making?

Two game concepts (M-I and P-A) are almost always present due to the constitution of the Dutch railway sector. There are formal hierarchical relations, compartmentalized organizations and multiple decisions connected to one another in an environment containing actors having different incentives. Moreover, the P-A game can be seen as consisting of different P-A games which are present at different decision levels and interact. This point will be elaborated on in Sections 5.3 and 5.4. The M-I game and the P-A game cause the occurrence of CG towards the end of the decision-making process. The CG is activated towards the end of the process since at that moment support for the decision of the variety of actors is needed. Similarly to the CG, the H-S game is present for a certain period in the decision-making process. The H-S game can either be chosen as a structure for negotiating and deciding internally within an organization, or it can be defined as a structure for decision-making due to formal rules.

Three game concepts (VD, DD, and BS) usually pop-up late and more towards the end of the process. Their impact depends on the availability of certain conditions (A), and once these conditions are present whether they align a critical mass of actors in such a way to impact the decision-making process (B). In that case, they can be destructive for the process by creating chaos, delays, or conflicts. They can also change the direction of the decision and increase the complexity.

5.3. MULTI-LEVEL PERSPECTIVE

Game concepts are present on different decision-making levels within a decision-making process. We distinguish four decision levels: operational level, i.e., departments of organizations; tactical level, i.e., organizations themselves, strategical level, i.e., the core network with actors having decision power, and political level, i.e., the broader network. Figure 5.3 specifies the existence of the game concepts at different decision levels for each case study.

The analysis is based on the case descriptions of the case studies in the previous chapters. Each identified game concept is investigated regarding the actors involved, resulting in the organization of game concepts across different decision levels.

	B&M 2015					B&M 2016			Timetable 2017					Amsterdam					Nijmegen					ERTMS					
Operational level	M-I		CG	VD	BS	M-I	P-A	CG	M-I	P-A	CG			M-I					M-I		CG	H-S		M-I	P-A	CG	H-S		BS
Tactical level	M-I	P-A	CG			M-I	P-A	CG	M-I	P-A	CG		BS	M-I	P-A			BS	M-I	P-A	CG			M-I	P-A	CG	H-S		
Strategic level	M-I	P-A	CG			M-I	P-A	CG	M-I	P-A	CG	H-S		M-I	P-A		DD		M-I	P-A	CG		DD	M-I	P-A	CG		DD	
Political level	M-I	P-A	CG			M-I	P-A	CG						M-I	P-A	VD			M-I	P-A	CG			M-I	P-A	CG			

Figure 5.3: Multi-level perspective on game concepts.

5.3.1. OBSERVATIONS IN CASE STUDIES

We observe that game concepts are present at different decision levels, and explain which conditions contribute to their presence.

HOW ARE THE GAME CONCEPTS PRESENT AT DIFFERENT DECISION LEVELS?

The M-I game, P-A game and CG are present at multiple decision levels. On the contrary, the H-S game exists at a few decision levels, either at the operational and tactical decision levels, or at the strategic decision level. The VD, DD, and BS occur at a single decision levels. However, once activated they can have an impact on other decision levels. BS usually starts at the operational or tactical level, VD exists on both the operational level and the political level, and DD is mainly observed at the strategic level.

Figure 5.4 gives a representation of the multi-level perspective by classifying the game concepts according to the number of decision levels they cover (many levels, few levels, single level), and their presence at low levels (operational or tactical) or high levels (strategic or political).

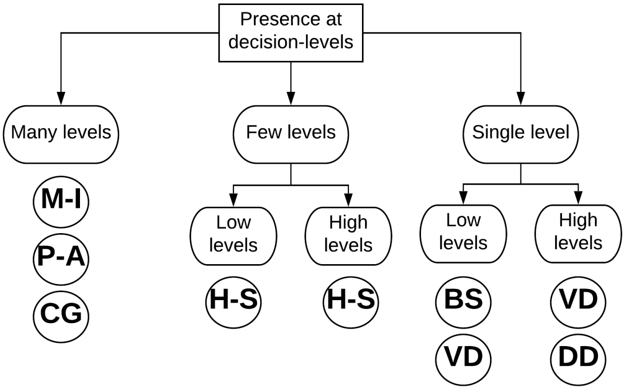


Figure 5.4: Multi-level classification of game concepts.

WHY ARE THE GAME CONCEPTS PRESENT IN THIS WAY?

In this section, we give explanations for the game concepts existing on most, few or single decision levels.

Multi-Issue game Why is the M-I game present at most decision levels? At each decision level new issues arise, and since the issues are interdependent, multiple decision levels are involved in the M-I game. To illustrate, an issue regarding the budget at the strategic level influences the issue of possible alternatives designed at the operational level. Furthermore, broadening the solution space usually requires involvement of different decision levels.

Principal-Agent game Why is the P-A game present at most decision levels? The P-A game represents a hierarchical relation between principal and agent who usually belong to different decision levels. For instance, the principal, i.e., the Ministry, who belongs to the core network, gives an assignment to ProRail, i.e., the agent, for the design of a new station. The different design alternatives are then developed further at the tactical or operational level. As introduced earlier, the P-A game usually consists of multiple P-A games which interact. A principal in a P-A game at the tactical level, denoted by $P\text{-}A^1$, is the agent in a P-A game at the strategic level, denoted by $P\text{-}A^2$. A representation of the P-A games present at different decision levels, for the different case studies, is presented in Table 5.1.

Cascade Game The CG is generally present at most decision levels since advices from the operational or tactical level needs to be supported by the strategic level to obtain acceptance of the decision at the political level. Dependent on the case study the political level is more or less involved, and needs to contribute to the decision, leading to the CG being present at this level or not. The CG can be seen as a choice in the design of the decision-making process in order to involve everyone and receive their decision.

Table 5.1: P-A games at different decision levels.

	B&M 2015	B&M 2016	Timetable 2017	Amsterdam	Nijmegen	ERTMS
Operational level		P-A^{1}	P-A^{1}			P-A^{1}
Tactical level	P-A^{1}	P-A^{1,2}	P-A^{1,2}	P-A^{1}	P-A^{1}	P-A^{1,2}
Strategic level	P-A^{1,2}	P-A^{2,3}	P-A^{2}	P-A^{1,2}	P-A^{1,2}	P-A^{2,3}
Political level	P-A^{2}	P-A^{3}		P-A^{2}	P-A^{2}	P-A^{3}
Number of P-A games	2	3	2	2	2	3

Hub-Spoke game Why is the H-S game present on a few decision levels? Internal decision-making within an organization is present at operational and tactical decision levels. At these levels the hub can, if the game exists, to some extent oversee the different aspects of the process. Once the decision-making involves the core network, and thus also the strategic level from other organizations, the H-S game is not capable of capturing the various perspectives and power relations between the actors. Moreover, at the strategic level, and given the complexity of the process, the decision-making style 'command-and-control' usually does not work to reach consensus among the actors.

The H-S game is present at the strategic level when formal institutional rules define a hub and its spokes. To illustrate, in case of the redesign process of the timetable, ProRail is the independent capacity allocator, i.e., the hub by formal rules of the Netverklaring, and the operators are the spokes who apply for the capacity.

Contrary to the M-I game, the P-A game, the CG, and the H-S game, the VD, DD, and BS are present at a single decision level. The main reason for their activation at a single decision level is because the actors in the VD, DD, and BS have the same power positions regarding the decision to be made. This means that all actors involved in the VD have the capability to step out and argue against the expected decision, everyone in the DD can violate the agreements made, and the conflict in the BS cannot be resolved by one of the two actors using its power. However, despite the VD, DD, and BS being activated at a single decision level, they do impact other, both higher and lower, decision levels. In the remainder of this section, we discuss the particular levels at which the game concepts are activated, and explain their impact on other decision levels.

Volunteers Dilemma The VD is activated at both the operational and the political decision level. As result of the activation at the operational level the game concept can activate the CG and thereby influences higher decision levels. On the other hand, an activation of the VD at the political level influences a P-A game, and thereby delays the decision-making process at lower decision levels.

Diners Dilemma The DD is present at the strategic decision level, why is this the case? One explanation could be that the main agreements are made at the strategic level, so this is also the decision level where one can violate them. The DD impacts other decision levels by creating chaos and potentially delaying the process of decision-making.

Battle of the Sexes Why does BS usually start at the operational or the tactical level? The compartmentalized organization culture is more visible at the operational and tactical level. This can, for instance, result in two departments working on the same issue and proposing a different outcome to the strategic level. Once they find out that they are planning to propose a different outcome, the conflict, and thus the BS, exists. At the strategic level the interdependencies between issues become more clear and it is more likely that the entire group of actors is involved in the conflict. However, the BS at the lower decision levels impacts the higher decision levels once the conflict is not resolved and results in, for example, a delay of the process.

5.3.2. CONCLUSIONS

The game concepts appear at different decision levels, but what do the explanations for their presence mean for the decision-making?

Three game concepts (M-I, P-A, and CG) are present at most decision levels. The game concepts represent both network and hierarchical relations between the actors involved. Furthermore, the separated responsibilities of actors requires them to support (or oppose) the decision. The CG is caused by the M-I game and the P-A games. The game reflects both the interdependence characteristics of a network structure, but also describes the information and power relations of a hierarchical structure.

One game concept exists in a few, both low and high, decision levels. The H-S game is present on the operational and the tactical decision level. It can represent internal decision-making within an organization, in this case one can choose to structure the (internal) decision-making as such. Once the strategic and the political level decision levels are involved, the H-S game is not able to capture the complexity of the process. However, when formal rules specify the hub and spokes the game can also exist at the strategic level.

Three game concepts (VD, DD, and BS) are activated at a single decision level. For conditions on the activation of those game concepts we refer the reader to Section 5.2.1. The actors involved in the VD, DD, or BS have the same decision power in the process, and thus they do not reflect hierarchical relations. However, after activation, the VD, DD, and BS, can impact other decision levels by interacting with other game concepts. In the next section, we will elaborate on the interaction aspect further.

Based on the conclusions from the temporal perspective and the multi-level perspective we categorize three types of game concepts.

1. *Dominant* game concepts: continuously present at most decision levels (M-I and P-A).

2. *Design* game concepts: present for a fixed period at most or a few decision levels (CG and H-S).

3. *Incidental* game concepts: incidentally present at a single decision level (VD, DD, and BS).

The first category is called *dominant* since we see those game concepts in the entire process and at most decision levels. The second category is called *design* since, in many cases, one can choose to design the decision-making process as such. The third category is called *incidental* since those game concepts appear irregularly and are dependent on the context in which the decision-making takes place.

As mentioned in both the temporal and multi-level perspective, interactions between game concepts occur. Moreover, the interactions between the game concepts are able to explain additional insight in the dynamics, complexity, and interdependencies between the elements of the decision-making process. The next perspective provides an overview of the different interactions between game concepts observed in the case studies. It concludes with specifying the main interactions, and explains how, and why, they take place.

5.4. INTERACTION PERSPECTIVE

In the temporal and multi-level perspective, we discussed the presence of game concepts over time and at different decision levels. We conclude on three types of game concepts and are interested in how, and why, they interact with other types of game concepts.

We first describe the method used to define the interactions between game concepts for each case study. This results in, so called, interaction diagrams as presented in Figure 5.5. Subsequently, we analyze the interaction diagrams to arrive at general conclusions regarding the most common interactions between (types of) game concepts and the explanations on how, and why, they interact.

5.4.1. METHOD TO DEFINE AND REPRESENT INTERACTIONS

We use the game concept identification of Chapter 4 to define the interactions between game concepts for each case study. The results are six different interaction diagrams, as illustrated in Figure 5.5. The game concepts are represented by their abbreviations and the arrows between them indicate the interactions. For example, an arrow from M-I to P-A means that the 'game play' or results of the M-I game influence the 'game play' or results of the P-A game. A double arrow means that the interactions exist in both ways. 'Game play' refers to the process described by the game concepts in which the actors perform actions leading to a final outcome.

Based on the game concept identification, and their explanatory power, presented in Chapter 4, we give a short description of the interactions between game concepts.

Better for More 2015 The over-complexity of the M-I game is a breeding ground for the volunteer to step out and thus to activate the VD. Everyone follows the VD which results in a cascade of decisions through the various decision levels (CG). In the meantime, uncertainty about the responsibilities of actors in the CG, and over-complexity of the M-I game, leads to a BS. Finally, the principal is informed about the decision by the agent (P-A) resulting in a surprise.

Better for More 2016 The principal participates actively in the M-I game showing the interaction between the P-A game and the M-I game. Furthermore, the different P-A games interact, and the strategic level puts pressure on the operational level since it feels pressure from the Ministry who feels pressure from the Parliament. The CG is designed early in the process, and influenced by the M-I game the P-A games.

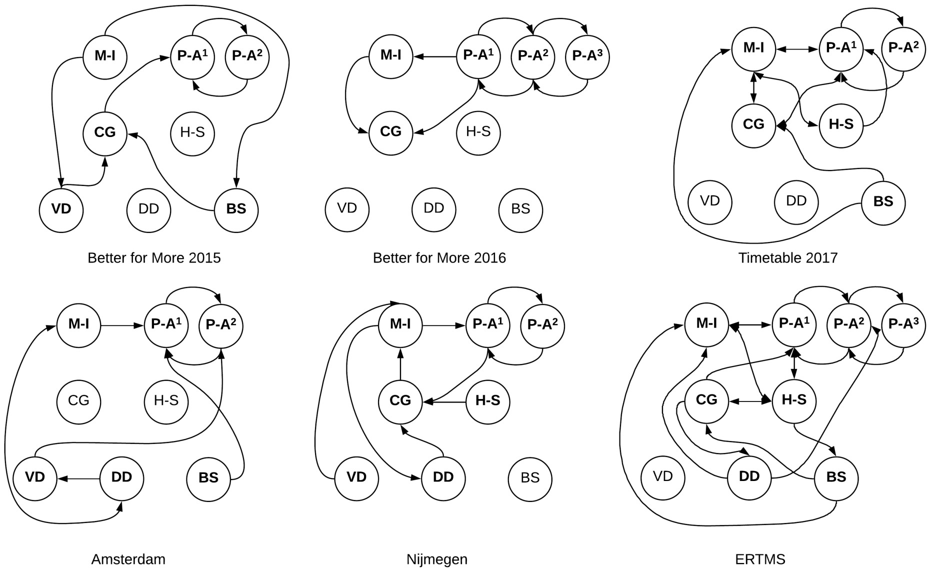


Figure 5.5: Interaction diagrams - interactions between game concepts.

Redesign timetable 2017 The design process starts with a BS interacting with the M-I game in the next design phase. The M-I game and the P-A game interact because of communications between the BUP-table and the Ateliers. From this point onward, the process is steered by the hub of the H-S game which is thus interacting with both the P-A game and the M-I game. The entire process can be viewed as a cascade of decisions adopted from each design phase to the next. Hence, the BS influences the CG which then interacts with the M-I game and the P-A games.

Amsterdam A restricted solution space in the M-I game leaves room for an actor to violate the agreement by claiming that the future-proofness of the decision is not addressed well enough (DD). Subsequently, activating a volunteer at the political level in the second P-A game results in a delay of the decision in the first P-A game. At the same time, the BS and the M-I game impact the decision in the first P-A game.

Nijmegen An internal H-S game provides input for the CG which influences the M-I game. The VD provides room for a new alternative in the M-I game which, consequently, leads to an actor violating the agreement (DD) which then also impacts the CG. Furthermore, the M-I game interacts with two interacting P-A games which then influence the CG too.

ERTMS In an over-complex M-I game, which interacts with various interacting P-A games, the H-S game is introduced to bridge the knowledge gap between principal and agent in the first P-A game. A CG is designed, influenced by the H-S game, the M-I game and the BS, and subsequently impacts this P-A game, the H-S game and the DD. The actor violating the agreement (DD) interacts with the second P-A game to increase information asymmetry at the political level, and complicate the process, together with the BS and the M-I game.

5.4.2. OBSERVATIONS IN CASE STUDIES

We translate the interaction diagrams to adjacency matrices to get an overview of the most common interactions between game concepts. The adjacency matrix, as shown in Table 5.2, has game concepts on the rows and columns. The number in a cell represents the number of arrows, i.e., interactions, that exist from the respective game concept on the row to the respective game concept on the column for the total of case studies.

Table 5.2: Number of interactions between game concepts.

	M-I	P-A^1	P-A^2	P-A^3	CG	H-S	VD	DD	BS
M-I	x	5			2	2	1	2	1
P-A^1	3	x	6		3	1			
P-A^2		6	x	2					
P-A^3			2	x					
CG	2	4			x	1		1	
H-S	2	2			2	x			1
VD	1		1		1		x		
DD	2		1		1		1	x	
BS	2	1			3				x

Next, we translate the interaction matrix between game concepts to the interactions between types of game concepts, i.e., between dominant, design and incidental game concepts.

Table 5.3: Number of interactions between types of game concepts.

	Dominant	Design	Incidental
Dominant	24	8	4
Design	10	3	2
Incidental	8	5	1

The results can be found in Table 5.3 from which we conclude that three types of interactions happen most often.

i. Between dominant game concepts.

ii. Between design and dominant game concepts.

iii. From incidental to dominant and design game concepts.

The next section discusses how, and why, these interactions take place.

5.4.3. WHY DO THE INTERACTIONS TAKE PLACE?

The most obvious answer is that because dominant game concepts exist during the entire decision-making process they will interact with each other and with other game concepts present. Moreover, in general, the interdependent, and messy, nature of these decision-making processes leads to interactions between game concepts. However, apart from the obvious answer, it is interesting to investigate how interactions between game concepts take place, whether we can define interaction patterns, and what the impact of the interactions is on the decision-making process. In this section, we provide explanations for the interactions between dominant game concepts, between design and dominant game concepts, and from incidental to dominant and design game concepts.

BETWEEN DOMINANT GAME CONCEPTS

Between dominant game concepts we see three forms of interactions.

P-A games influence the M-I game The principal of the P-A game steers the agenda of the M-I game. Possible results are a broadened agenda which gives room for give-and-take between actors and supports collaboration between them. A prerequisite is that the principal knows which issues are already discussed and which issues are fruitful for the discussion to add to the agenda. Hence, information asymmetry between principal and agent should be limited.

M-I game influences P-A games The other way around, the M-I game can steer the P-A game in two ways. The M-I game shows a plethora of interdependent issues. For a principal, who has limited knowledge of the content of the decision to be made, the M-I game increases his understanding of the complexity of the decision. Therefore, a principal participating in the M-I game reduces the information asymmetry between principal and agent. On the other hand, an over-complex M-I game can create suspicion by the principal, who has no idea what is going on, and who will eventually use its power to steer the process.

Recursiveness of P-A games Interactions between different P-A games are called recursive patterns. A recursive pattern exists when a principal in the first P-A game serves as an agent in the second P-A game. Because of this recursiveness of the P-A game, the actions of actors in the first P-A game influence the actions in the second P-A game, and the other way around. To illustrate, when actors at the political level put pressure on a certain deadline or decision, this is reflected by principals at lower decision levels also putting pressure on their agent(s). On the other hand, when an agent informs, and involves, its principal during the process the information asymmetry is limited. As a result, the impact of pressure from other (higher) principals will be less present. The existence of multiple recursive patterns makes the decision-making process complex, especially when these relations are not always clear.

BETWEEN DESIGN AND DOMINANT GAME CONCEPTS

The interactions between design and dominant game concepts can be observed in two directions.

Design game concepts influence dominant game concepts The *design* game concepts CG and H-S game can steer the P-A game. The H-S game can be used as an instrument to bridge the information asymmetry between principal and agent. In this case, the hub has the power and capacity to steer the agents, and at the same time inform the principal. The CG shows to which extent the decision makers from different decision levels agree on the outcome of the decision, and thereby inform the principal about commitment and possibilities to reach consensus which eventually influences the decision of the principal.

Dominant game concepts influence design game concepts The other way around, the M-I game and P-A game define how the CG is designed. The issues discussed in the M-I game, and the preferences of actors regarding these issues, determine the agenda of issues to be resolved before the final decision can be made. Moreover, the interdependencies between issues reflected in the M-I game can be crucial information on whether, and at which point in time, the CG might be blocked. Similarly, the relation between principal and agent define which decision level to include in the CG. The type of relation between principal and agent, information asymmetry and use of pressure, also defines the extent to which the CG can potentially be blocked.

From incidental to dominant and design game concepts

Since BS, VD and DD start at a single decision level, and for a short period of time, the outcomes of these game concepts influence the game play of other game concepts. From the summarizing table in Chapter 4, we conclude that the incidental game concepts can change the direction of the decision, delay the process, and result in conflicts. These effects happen in other game concepts in the decision-making process. We provide some examples of the impact of the aforementioned effects (change in direction, delay of process, and conflict) of the incidental game concepts on the dominant and design game concepts.

A change in direction of the decision, or creating a new alternative, changes the M-I game by broadening the solution space. Furthermore, a change in direction can activate the CG resulting in an unexpected outcome in the P-A game once information asymmetry exists.

Delaying the process impacts the game concepts present at that moment. The actors perform wait-and-see behavior in the M-I game, or put more issues on the agenda of the M-I game. As a result the CG does not continue, and the P-A game does not result in an outcome.

A conflict influences the relation between actors and thus impacts, for instance, the H-S game by creating strategic issues for the hub. Furthermore, the relation between principal and agent can be damaged, and conflicts in the M-I game do not contribute to reaching consensus, and can eventually create deadlocks.

5.4.4. Conclusions

The interaction perspective shows that the main interactions between types of game concepts are: between dominant game concepts, between design and dominant game concepts, and from incidental to design or dominant game concepts.

The impact of these interactions depends on the situation in which they occur. However, we draw some general conclusions for the decision-making process for each type of interaction. First, since dominant game concepts are always present, the interaction between the M-I game and P-A game is not a surprise. A principal can steer the actions and outcomes of the M-I game if he has the right information. The other way around, the M-I game can influence the actions of the principal.

Recursive patterns of P-A games show the complexity of the decision-making process. The more P-A games present, the more complex the relation between actors, i.e., principals and agents, becomes. Managing the information asymmetries between principal and agent is a way to deal with the complexity.

Dominant game concepts define the context in which the design game concepts can be introduced and structured. The CG is naturally caused by the game play in the M-I game and P-A game. On the other hand, the design game concepts influence the relation between principal and agent.

Incidental game concepts can create new solutions, delay the process or generate conflicts. These results impact the design and dominant game concepts by either creating opportunities for other directions in the process or making the process more messy.

5.5. Conclusion

In this chapter we applied a temporal, a multi-level, and an interaction perspective to the appearance of the game concepts in six different decision-making processes of the Dutch railway sector. We provided explanations for the appearance of each game concept, and conclude by discussing implications of the appearance, and the explanations for, the decision-making process.

After discussing the temporal and multi-level perspective we classified the game concepts in three types: dominant, design, and incidental game concepts. Dominant game concepts (M-I and P-A) are continuously present at multiple decision levels. Design game concepts (CG and H-S) are present for a fixed period at most, or few, decision levels. Incidental game concepts (VD, DD, and BS) usually pop-up late in the process and are present at a single decision level.

Based on the classification we distill the following main interactions between the types of game concepts: between dominant game concepts, between dominant and design game concepts, and from incidental to dominant and design game concept.

This chapter provides a scientific contribution by applying a higher level of abstraction to the game concept identifications. The result is insight into the appearance and cohesion of game concepts in real-world decision-making processes. We specify the "what", and the "why", of game concepts over time, decision levels, and interactions. On the other hand, this chapter has a more practical contribution by presenting guidelines for the decision maker by addressing the impact of the abstraction for the decision-making process.

5.6. Discussion

In this section, we discuss the implications of the "what", and the "why", of the temporal, multi-level, and interaction perspective for the decision-making process.

The presence of the M-I game and the P-A game is a given fact in decision-making processes. The constitution of the Dutch railway sector with actors having different incentives, compartmentalized organizations, multiple decisions connected to one another, and the existence of hierarchical relations contributes to this. Furthermore, in many cases, the M-I game and P-A game cause the activation of a CG since this game concept represents both network and hierarchical characteristics. Support from a variety of actors at different decision levels is needed towards the end of the process. Again, the existence of hierarchical relations in a network structure and separate responsibilities within the Dutch railway sector create this situation. Different from the M-I game and the P-A game, the CG is a concept one can choose in order to design the decision-making process. Similarly, the presence of the H-S game indicates a choice to structure the decision-making. However, this happens more in the beginning of the process and is mainly used for internal decision-making within organizations. Once formal rules define the decision-making structure as a H-S game the appearance of the game concept, and freedom to design it as such, does not exist.

The activation of the VD, DD, and BS usually happens late in the decision-making process among actors with the same decision-power. This is dependent on the existence of conditions concerning uncertainties about the outcome of the decision, the road towards the decision, alignment of actors, and influence of external factors. Once a critical mass of actors is aligned an activated game concept impacts the process by changing the direction of the decision, increasing complexity, or creating delay of the process.

In short, two game concepts (M-I and P-A) are always present by nature of the decision-making, and the decision maker has to deal with them. However, this does not mean that one cannot steer the game play. Two game concepts (CG and H-S) are mostly present since they are chosen as a decision-making structure, or as a result of the inherently present game concepts. These game concepts give the decision maker parameters to change in order to steer the process. Three game concepts (VD, DD, and BS) are not given facts, but can be activated, and if so, impact the process. Whether they are activated, and subsequently impact the process, is dependent on certain conditions of the decision-making process. Knowledge, and awareness, of these conditions help a decision maker to steer, or maybe prevent, the consequences of these game concepts.

THE result of this chapter is a classification of the game concepts. Based on the analysis of game concepts over time and at multiple decision levels we found the following types of game concepts:

i. *Dominant* game concepts (M-I and P-A) are continuously present at multiple decision levels.

ii. *Design* game concepts (CG and H-S) are present for a fixed period at some decision levels (these game concepts are called ‘design’ since one can choose to structure (part of) the process as such).

iii. *Incidental* game concepts (VD, DD, and BS) usually pop-up late in the process at a single decision level.

Table 5.4: Game concepts categorized over time and decision levels.

	Incidental	Fixed period	Continuous
Single-level	VD DD BS	H-S	
Multi-level		CG H-S	M-I P-A CG

These patterns of game concepts define empirical evidence of the game play and dynamics of decision-making in the Dutch railway sector. Moreover, they provide guidelines for decision makers by:

i. Specifying the game concepts that are inherently present in the process,

ii. Indicating the game concepts that one can choose to start at some point to structure the process, and

iii. Listing conditions that contribute to activation of incidental game concepts. Examples of such conditions are uncertainty regarding who decides on what and in which order, uncertainties concerning (future) effects of the decisions, and conflicting advices from different parts or levels of the organization.

So far, in Part II, we have used the game concepts to *describe* empirical decision-making processes. In the next part, in Part III, we study the *prescriptive* nature of the game concepts. The focus now shifts from researchers using the game concepts to describe the decision-making process to decision makers using the game concepts to potentially steer the process. The researchers also become the facilitators of interventions and one of the aims is that decision makers are able to identify the game concepts themselves.

- First, in Chapter 6, we design and evaluate an instrument to identify the game concepts in a process of decision-making, which can be applied by a variety of potential users without any knowledge of the game concepts.
- Second, this instrument is applied to support the decision-making process.
- In Chapter 7, the game concepts are used to provide recommendations for game design which are eventually used to support the decision-making.
- In Chapter 8, decision makers from the Dutch railway sector use the game concepts to characterize an ongoing decision-making process and discuss its consequences for the process.

III

APPLICATIONS

6

Design and Evaluation of a Game Concept Identification Tool

Since we shifted from describing empirical decision-making processes to intervening with the game concepts, and researchers also become facilitators of interventions, the game concepts need to be identified by a variety of users. In this chapter, we design and evaluate an instrument to identify the game concepts. Such an instrument should enable potential users without any knowledge of the game concepts to identify game concepts in a process of decision-making.

- The chapter consist of three phases: design, test, and evaluation.
- In the design phase, we select and translate the characteristics of the game concepts such that they are distinguishable from each other.
- Furthermore, we design scenarios, which describe decision-making situations of the Dutch railway sector, that represent one of the game concepts. These scenarios are used to check whether users are able to identify the matching game concept.
- During the testing phase we are particularly interested in why users make certain choices when they identify a certain game concept.
- The design and test phase iterate to include the different perspectives of users.
- After each test, the feedback of users is used to improve the design of the tool.
- Finally, we evaluate the use of the tool with a group of students and explain unexpected results.

6.1. Introduction

To be able to apply the game concepts in real-world decision-making processes by a variety of users we need to translate the rather abstract and theoretical game concepts to easily identifiable concepts. The concepts should align with the theoretical definition, entailing the context, the process, the results, and the risks, as introduced in Chapter 2. On the other hand, they should be easily identifiable for users without having prior knowledge of the game concepts.

There has been several research on the application of game theoretical concepts in various forms and domains (Hui and Bao, 2013, Merrick et al., 2016, Oruç and Cunningham, 2014, Shepherd and Balijepalli, 2015, Takai, 2010, Zhu-Gang et al., 2014). However, these applications serve a mainly analytic purpose. There has not been much research on the practical applications of such concepts in an organizational setting, in particular when this concerns *identification* of such concepts by decision makers themselves. The contribution of this chapter is therefore twofold:

6

1. Design and test a game concept identification tool (GCs-id tool).
2. Evaluate whether this tool identifies the matching game concept for a given a scenario.

Additionally, for the second contribution, we search for explanations if the matching game concept is not selected.

Difference in perspectives of potential users is what makes the design and evaluation of a game concept identification tool difficult. Decision makers have different perspectives on the process of decision-making since they have conflicting incentives, and for example, interpret information differently. As a result, the identification of game concepts varies among decision makers. In this chapter, we first alternate between design and testing, before we evaluate the GCs-id tool, in order to deal with the variety of perspectives. We are interested in the reasons why the participants make unexpected choices and use this feedback to improve the design.

We take a quantitative approach towards capturing and testing the subjective aspects of users having different perspectives on the process. Therefore, we define a measure of a successful identification of a game concept as follows: In a given situation, at least half of the participants are able to identify the matching game concept, and there is no discussion about which game concept applies since the percentages of other identified game concepts are remarkably lower.

The chapter is structured as follows: Section 6.2 introduces background on other tools and methods that apply game theoretical concepts. In Section 6.3, we outline the different methods used for design, test, and evaluation of the game concept identification tool. Then, in Section 6.4, the design process of the tool is explained involving multiple steps used for design and verification. In Section 6.5, we outline the testing process of the tool with professionals from industry, academia, and students. Section 6.6 elaborates on the evaluation process, i.e., the final test, of the tool with a group of students, and in Section 6.7 we provide explanations for the results and limitations of the tool. The conclusions are presented in Section 6.8.

6.2. BACKGROUND

Game theory models have been applied in various forms and domains for analytic purposes. Analytic here means structuring the elements of the process, and performing analysis on the combination of these elements such as finding optimal strategies or outcomes and calculating Nash equilibrium. The mathematical calculations are usually performed by researchers to show the capabilities of game theory in analyzing real-world situations. We can find many examples on the application of game theory in the area of decision-making such as analyzing transport systems, calculating the best strategy and allocating resources (Hollander and Prashker, 2006, Karras and Papademetriou, 2018, Ramesh and Whinston, 1994, Salonen and Wiberg, 1987, Thompson and Badizadegan, 2015). However, the practical application of game theory is limited, let alone, the use of game theoretical concepts as tool for users with no primary knowledge on these concepts.

There are two reasons for the limited research on this topic. In the first place, the number of practical tools in general is limited, hence practical tools based on game theory are even less available. Furthermore, game theory has a theoretical and mathematical foundation which makes it not straightforwards to translate to practical purposes. Secondly, the game concepts, as introduced in this thesis, are new in their constitution since they origin from other disciplines than just game theory.

In the remainder of this section we highlight some frameworks and tools that are based on game theoretical models, and that are, or potentially could be, practically applied to decision-making processes.

Game structuring methods (GSM) are examples of methods that origin from game theory, and that do not have a primary analytic purpose. They belong to a larger field of Problem Structuring Methods (Ackermann and Eden, 2011, Mingers and Rosenhead, 2004), and are defined as “a set of applied methods for finding strategic elements that shape decision processes in a complex problem setting” (Cunningham et al., 2014). Examples of such methods are analysis of options (Ackoff, 1974, Howard, 1971), conflict analysis (Fraser and Hipel, 1984), metagame analysis (Howard, 1971), graph model for conflict resolution (Fang et al., 1993), hypergames (Bennett, 1987), drama theory (Howard et al., 1993) and theory of moves (Brams, 1993). However, as Cunningham et al. (2014) indicate in their review paper, the practical application of GSM in organizations is very limited.

Some actor analysis methods are rooted in game theory, such as conflict analysis methods (Hermans et al., 2013, Hermans and Thissen, 2009), and Dynamic Actor Network Analysis (DANA) (Bots et al., 1999). As Hermans and Thissen (2009) state in their discussion, finding the balance between analytic quality and practical usability of the actor analysis methods is difficult, and game theory rooted methods tend to have more analytic quality than practical usability.

There are other examples of game theory used as policy evaluation tool (Hermans et al., 2014). The tools are used ex-ante to evaluate the process of policy and decision making (Hermans and Thissen, 2009). The results suggest that game theory can help to open up the ‘black-box’ of policy implementation. Furthermore, the potential lies not so much in the mathematical uses, but in the use of game theory as a formal modeling approach that adds structure and rigor to the study of decision-making processes.

Game theory as a tool for project management is an example of game theory applied within organizations (Bočková et al., 2015, San Cristóbal, 2015). These papers address the need for such a tool and conclude on a list of potential questions a project manager could think of in a negotiation process. However, they do not direct the project manager towards a certain type of game concept that is, or could be, applied in their daily work.

Zürn (1993) talks about a situation-structural approach to model real-world situations using game theory. The first step in this approach is identification of interaction patterns. The second step entails modeling of the situation by specifying the actors, their actions, and their preferences over outcomes. The remainder of the paper elaborates on the second step, and neglects the first step, which is the primary focus of this chapter.

Da Costa et al. (2009) develop a game theory-based tool for identification of the right game theoretical concept. It is constructed with concepts from classical game theory, thereby building forth on work of Brandenburger and Nalebuff (1995), with elements of business. The Strategic Game Matrix (SGM) is an analytic tool for interpreting, analyzing, clarifying and formulating business strategies and can be used by managers to identify which game can be played in a conflict of interest situation. The authors do not address the evaluation of the tool for practical purposes.

To conclude, analytic applications of game theoretical concepts for decision-making abound. The practical usability of these applications is limited, and identification of game concepts by decision makers, to our knowledge, does not exist. Hence, a translation of the game concepts to a practical tool is missing. Especially, when users have limited or no prior knowledge of the concepts and the tool should allow decision makers to identify and apply the game concepts during the decision-making process.

6.3. Methodology

The methods used in this chapter can be distinguished as methods for design, testing, and evaluation of a game concept identification tool. In this section, we provide an overview of the different steps taken as is illustrated in Figure 6.1. For a more elaborate discussion of the methods we refer to the corresponding sections.

The design of the GCs-id tool started with the selection of the game concepts. Their main characteristics were obtained by a literature review. These characteristics were evaluated on their distinguishability before we decided which characteristics to include in the GCs-id tool. The tool consists thus of game concepts characteristics and arrows between the characteristics which lead to end points, i.e., the game concepts. Additionally, we designed scenarios, i.e., decision-making situations, for each game concept. Those scenarios and the game concepts were verified.

The testing process of the GCs-id tool entailed three phases: individual discussions, a pre-test, and a pilot study. The feedback of each of these sessions is incorporated in the design of the tool before the next test phase took place. In each step of the testing process we were interested in why the participants made a certain choice while using the tool. This knowledge helped us to improve the design of the tool and the scenarios, and informed us about assumptions potential users make. The result of the design and testing process is a GCs-id tool.

The GCs-id tool is evaluated in a final test with a group of students. They evaluated the tool in an online version with the predefined scenarios.

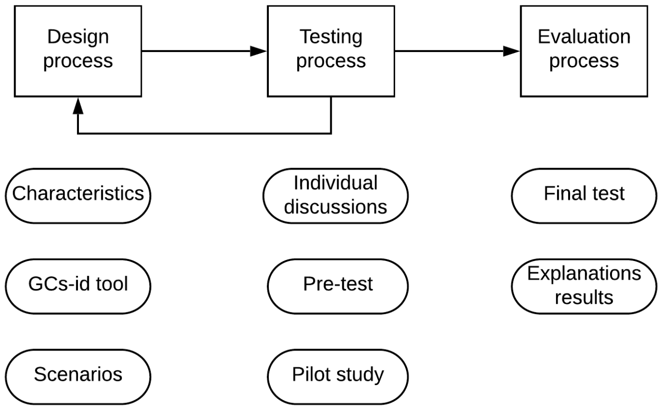


Figure 6.1: Methodological steps in the design, test and evaluation phase.

6.4. Design process

In this section, we present the design process of the game concept identification tool. First, we introduce the methods used, and second, present the results, i.e., a GCs-id tool and a set of scenarios.

6.4.1. Method

The method to design a GCs-id tool consisted of multiple steps including the selection of characteristics, ordering the characteristics, and defining scenarios for verification. To verify the tool we selected examples of decision-making situations of the Dutch railway sector which illustrate the game concepts.

Selection of game concepts

The procedure for the selection of game concepts is presented in Chapter 2. The result of the selection is a set of characteristics defining the game concept.

Identifying distinguishable characteristics of game concepts

We created a matrix with the characteristics of the different game concepts on the rows and the game concepts on the columns.

The characteristics vary in the extent to which they distinguish between game concepts. For example, the characteristic 'number of actors' distinguishes the game concepts in two groups, either the game concept represents two actors or multiple actors. Other characteristics are less distinctive, for instance, hierarchical relations could be present in the Multi-Issue game, but not necessarily. Table 6.1 shows the final selection of characteristics which are used in the GCs-id tool.

From matrix to GCs-id tool

The next step in the design process was the translation of the matrix, with characteristics and game concepts, to a road map of characteristics. In the road map one evaluates a

Table 6.1: Matrix with game concept characteristics.

Characteristics	**M-I**	**P-A**	**CG**	**H-S**	**VD**	**DD**	**BS**
Number of actors	multiple	2	multiple	multiple	multiple	multiple	2
Actor knows the incentives of others	x	yes					yes
Asymmetry of information and knowledge between actors		yes	x	x			
Formal hierarchical relation between actors		yes	x				no
Subordinate in the hierarchical relation has the knowledge and expertise		yes		x			no
Actors are completely dependent upon each other	x				x		yes
Actors have different incentives and share the same goal		no			x		yes
Number of decisions	multiple						
Decisions are connected	yes						
Reaching consensus is the aim of the process	yes			x			
One decision leads to a deadlock in the process	yes						
Number of decision-making levels	x	x	multiple	x			
Decisions made at one level provide input for decision at next level			yes	x			
Actors observe previous made decisions and base their decision on that			yes				
One actor leads the negotiations	no			yes	no	no	no
The one actor negotiates with actors separately				yes	no	no	no
Wait-and-see is beneficial for the actors	x				yes		
Taking action or deciding prevents a worst-case scenario					yes		
Agreements about collaboration are made		x	x			yes	
It is beneficial to be the first one to violate the agreements made						yes	

'x' means characteristic appears often but is not decisive for the game concept to exist.

characteristic, and based on the evaluation is steered to a next characteristic, etc., until one reaches an endpoint, i.e., a game concept. The final result of the GCs-id tool is presented in Appendix A.

Now the ordering of the characteristics became important. Our aim was to design the tool as such that the number of characteristics to be evaluated to arrive at a game concept is minimal. This means that characteristics that apply for, or distinguish between, multiple game concepts should be questioned first. The more you move towards the endpoints, the more specific the characteristics are for a certain game concept.

The ordering of the characteristics has been discussed in several ways during the verification and test sessions. Thus, our initial proposal on the ordering was updated several times during the design and test process.

The final step in the design process of the GCs-id tool was creating endpoints for situations which are not covered by one of the game concepts. Therefore, the tool includes end points referring to "other game concepts": OG-2 for situations involving two actors and OG-n for situations involving multiple actors.

SCENARIOS OF THE DUTCH RAILWAY SECTOR

The GCs-id tool is based on theoretical information of the game concepts. The purpose of the tool is to identify game concepts in a decision-making process. Hence, we needed examples of such decision-making situations that correspond to the game concepts. Together with experts from the Dutch railway sector we defined hypothetical scenarios, based on the experiences of the experts and case studies of Chapter 3. This resulted in a list of scenarios, one for each game concept. Subsequently, seven participants from academia and industry contributed to the verification of the hypothetical scenarios and the definitions of the game concepts. The participants received an email with both the game concepts descriptions and the scenarios. In a discussion with the researchers, the participants showed their matching between the game concepts and the scenarios, and explained why they chose for a certain match. Moreover, the participants were asked to explain which part of the scenarios were unclear to them.

6.4.2. RESULTS

The results of the design process is a game concept identification tool which contains characteristics of the game concepts, and arrows between characteristics. A sequence of characteristics leads to possible endpoints, i.e., the game concepts (see Appendix A). Furthermore, for each game concept a decision-making scenario of the Dutch railway sector exists. The scenarios are verified, meaning that participants were able to perform a correct matching between the scenario and the game concept definition without using the tool (see Appendix B for the final scenarios). The verification is necessary since else it would be unclear whether an incorrect match between scenario and result of the tool would be due to the design of the tool, or due to the scenario not fitting the game concept. In two cases of the verification step, two game concepts and scenarios were switched, but this was realized by the participants before the researchers asked about the explanation. The main feedback of the participants included comments on terms and sentences of the scenarios which are interpretative in multiple ways. Moreover, the participants pointed towards unnecessary information in the scenarios which confused them. Based on the feedback of the participants the text of the scenarios was adapted.

Before we evaluate the game concept identification tool with the predefined scenarios we perform a testing process. In the testing process, we tested the tool and the scenarios in three different phases, and iteratively, updated the design of the tool and scenarios according to the obtained feedback.

6.5. TESTING PROCESS

In several rounds, the tool itself and the scenarios were tested with professionals, from academia and industry, and students. In between these rounds the tool was updated according to the received feedback. The intelligence behind the testing process is that the researchers want to understand which path of characteristics participants chose for a certain scenario. Moreover, they wanted to find out why (due to text scenario, order or definition of characteristics in tool, background or perspective participant) the participants made an unexpected choice in order to, based on this feedback, improve the design of the GCs-id tool. The main question we state is: Are participants able to identify the right game concept given the corresponding scenario and the GCs-id tool?

6.5.1. METHOD

The testing process contained three different forms:

1. Individual discussions with 15 experts from academia and industry.
2. Pre-test (on paper) with a group of 13 master students from a master course.
3. Pilot test (online) with 14 experts from industry and academia.

Individual discussions and pre-test of the tool took place in the same time span. The pilot test is performed afterwards, and thus included the feedback from individual discussions and the pre-test.

INDIVIDUAL DISCUSSIONS

In total 15 participants from industry and academia received an email with the scenarios and GCs-id tool prior to a planned meeting. The assignment was as follows: Read the first scenario, evaluate the characteristics of the tool, thereby following and marking the arrows, and write down the number of the end point. Then, repeat this for the second scenario, the third scenario etc. In total nine scenarios needed to be matched to numbers, i.e., end points of the tool. Most participants were able to perform the matching before the meeting, in few cases the first part of the meeting was spend on the matching exercise.

During the discussion meeting we discussed the path of characteristics participants followed to an end point for each scenario. We were particularly interested why participants chose the evaluation of the characteristics. Moreover, participants were asked to specify unclear characteristics, or sentences in the scenarios that confused them.

After the discussion meeting the feedback was incorporated in the text of the scenarios and in the design of the tool before the next individual meeting was held. Participants thus received an updated version of the tool and the scenarios based on feedback of others. However, due to the planning of the meetings, it was not always feasible to sent the participants the newest version.

PRE-TEST STUDENTS

In total 13 master students participated in the pre-test. They signed an inform consent and received a tool, along with scenario A and scenario B. After an introduction to the test and its goal, the participants were asked to, first, read scenario A carefully, and second, use the tool to identify the corresponding game concept. In particular, they were asked to specify the path on the tool that led them to an end point. Subsequently, they preformed the same assignment for scenario B. Participants filled in an survey afterwards, and a small group of students gave additional feedback in a discussion right after the test.

PILOT STUDY

In total 18 participants from industry and academia performed an online pilot test. Of these participants, 10 participated for the first time, 4 participated already in earlier phases, and 4 participants only checked the pilot test on bugs, way of working, and design options.

Everyone received an email with instructions, points of attention, an attachment with three different scenarios, and a URL to start the test. The scenarios were distributed randomly to the participants and presented in a random order. Participants answered the questions for each scenario separately. After they had completed the test they filled in a survey and provided feedback.

The choice for an online test was made after feedback from the pre-test in which participants mentioned to think ahead when they were uncertain about the evaluation of a characteristic in a scenario. The difference with the test on paper is that the characteristics of the tool are translated to questions with two possible answers.

Everyone started with the same question regarding the number of actors involved, and based on the answer the next question was presented. Once the participant reached an endpoint, he received a screen with the name of the next scenario. The participants thus did not know which endpoint they reached. The results of the different ways of testing are presented in the next section.

6.5.2. RESULTS

In this section, we present the results of the individual discussion, the pre-test with a group of students, and the pilot test.

INDIVIDUAL DISCUSSIONS

The main feedback of participants during the individual sessions was on the way characteristics were presented in the tool, how they were ordered, and regarding the text of the scenarios. The feedback provided by experts from industry and academia differed. Experts from industry tended to evaluate the characteristics in a different way than expected, because they used their background knowledge on the decision-making process instead of staying close to information provided in the scenarios.

The following changes were made to the design of the tool, and the text of the scenarios during the process of the individual discussions.

- Distinguishability of characteristics of the game concepts resulted in changes in the tool. Similarly, the feedback on having easier questions first, let us adjust the order of questions.
- Several terms, such as decision-levels, actors, and goals versus incentives, needed clarification both in the tool as in the scenarios.
- Participants mentioned that they would look ahead to next characteristics in the tool when they were not sure about a certain answer. The feedback let us rethink the format of our tool.
- The text of the scenarios needed to be shortened, and confusing sentences needed to be clarified.
- Characteristics in the tool which were not mentioned in the scenarios needed to be added, or made more explicit, in order to prevent confusion while evaluating the characteristics.
- Another point mentioned by the participants was the perspective from which the questions should be answered. We adapted the text of scenarios. We will further elaborate on this point regarding the different perspectives in the discussion of this chapter.

6

PRE-TEST STUDENTS

The results of the pre-test are presented in Table 6.2.

Table 6.2: Results pre-test test.

Scenario	Correct matches	Incorrect matches	Percentages correct
A	5	8	38.46%
B	11	2	84.62%

Scenario A was matched correctly to the game concept by 5 participants, and 8 participants performed an incorrect matching. Participants provided a different answer than expected for characteristics number of decisions and decision levels. Scenario B was matched correctly by 11 participants, and 2 participant returned a different game concept.

The participants provided feedback on their interpretation of terminology both on the characteristics of the tool, regarding for example decision-levels and linking of decisions, and regarding the text of the scenarios. Furthermore, participants questioned their role by asking: “Should I stay close to the text of the scenario, or answer as if how I would solve the situation in an ideal world?”. Suggestions on the design of the tool are: use of less arrows, introduce colors, use numbers as end points instead of names of the game concepts, add explanation of terminology. Some redundancy of characteristics in the tool were identified. Comments on shortening the text of scenarios by using bullet points were mentioned. One of the most mentioned issues during the feedback was that the tool is designed as such that bias of looking to possible future characteristics influences the evaluation of characteristics and thus becomes problematic. For example, not willing the scenario to be a hierarchical relation, or not knowing the answer to this characteristic in the scenario, led to thinking ahead about possible characteristics one does recognize and subsequently steered the result. As a result of this particular point, which was also mentioned in the individual discussions, we decides to make an online version of the tool and scenarios in order to prevent bias issues. We organized a pilot test session as next step. Moreover, we updated the tool and text of scenarios based on the feedback, and improved the introduction to the test by including explanations of multiple interpretive or difficult terms.

Pilot study

Since 4 participants did not completed the test, we show the results of the 14 remaining participants in Table 6.3.

Table 6.3: Results pilot test.

Scenario	Number of takes	Correct matches	Percentages correct
1	4	2	50%
2	5	4	80%
3	5	3	60%
4	4	3	75%
5	6	5	83.33%
6	3	1	33.33%
7	5	3	60%
8	4	3	75%
9	6	1	16.67%

The percentage of correct matches of scenarios 1, 6 and 9 were less than, or equal to, 50%. Given that participants have different perspectives and backgrounds we considered everything above 50% as a good match. We analyzed at which characteristics the participants answered differently than expected and thus left the path to the correct game concept. For scenario 1, this was regarding the number of decisions and reaching consensus. For scenario 6, this was number of decisions, and for scenario 9, this was the difference between incentives and goals.

Participants gave feedback on the design of the online tool itself, regarding the possibility to go back to a previous question, and a missing screen to introduce a new scenario. Some confusion regarding terminology, such as wishes ("are they the same as decisions?"), and knowing each others' interest, in both the characteristics and in the scenarios, were pointed out. Additionally, suggestions for fine-tuning and streamlining the questions were made.

As a result, we made some changes in the appearance of the questions and different scenarios in the test. Furthermore, we streamlined the questions and adapted some scenarios based on the comments, and in particular, we had a close look at scenarios 1, 6 and 9. No changes to the order of characteristics in the design were made. To summarize the different forms of verification and testing, Table 6.4 gives an overview.

Table 6.4: Overview of different verification and testing sessions.

Test	**Number of participants**	**Input/ materials**	**Testing**	**Results**	**Main feedback**	**Adaptation tool**
Verification	7 experts (academia and industry)	Game concepts descriptions, 7 scenarios	Matching beforehand, individual discussion	Matching correct	Shorter text scenarios	Text of scenarios after each meeting
Individual discussions	15 experts (academia and industry)	GCs-id tool, 7-9 scenarios	Matching beforehand, individual discussion	Feedback on text and tool	Shorter text scenarios, order characteristics in tool	Characteristics and structure tool, text scenarios after each meeting
Pre-test	13 master students	GCs-id tool, 2 scenarios, survey	Assignment, oral feedback afterwards	Scenario A: 5/13 correct; scenario B: 11/13 correct	Biased by tool, design of tool, terminology scenarios and tool	Characteristics and structure tool, scenarios, design online test, instructions
Pilot test	14 experts (academia and industry)	Questions of GCs-id tool, 3 scenarios, survey	Online tool	6/9 scenarios > 50% match; 3/9 scenarios ≤ 50%	Streamline questions, terminology, design of online tool	Formulation of questions and text scenarios, design of online tool, no order or structure changes

The final result of the testing process is a game concept identification tool and a set of nine scenarios. Each scenario corresponds a game concept. We refer the reader to Appendix A for the final version of the GCs-id tool, and the text of the scenarios can be found in Appendix B.

6.6. EVALUATION PROCESS

In this section, we elaborate how we evaluated whether participants were able to match the game concepts to a given scenario using the GCs-id tool.

6.6.1. Method

We performed the test with students (N=108) of both graduate and undergraduate level from the faculty of Technology, Policy and Management (Technical University Delft). Students from four different courses participated and this resulted in four different sessions, see Table 6.5. Each session was set up in the same way.

First, an introduction about the game concepts and decision-making in the Dutch railway sector was given to provide the students with some context on the area of application. Second, the instructions for the test were presented together with some important concepts, such as a deadlock, decision-levels, and a description of the main actors. The slide containing these definitions remained visible during the entire test. After the instructions, students were handed out a two forms, an informed consent form that they need to sign, and a form that contained three different scenarios and an URL.

Students signed an informed consent form and started reading the first scenario. Afterwards they used a laptop, or in some cases a mobile phone, to visit the URL. When students finished scenario 1, they continued with scenario 2, and subsequently with scenario 3.

The nine different scenarios were distributed randomly, but in such a way that an equal number of students got each scenario first, second and third, but no one got the same combination, and the same order of the scenarios.

After answering the questions about the scenarios participants filled in a survey covering background and knowledge of participants, and an option to provide feedback or comments on the test.

Table 6.5: Overview of different participants testing the GCs-id tool.

<table>
<tr><th>Group</th><th>MSc or BSc level</th><th>Number of participants</th><th>Male / Female</th></tr>
<tr><td>1</td><td>MSc</td><td>48</td><td>40 / 8</td></tr>
<tr><td>2</td><td>BSc</td><td>20</td><td rowspan="2">23 / 9</td></tr>
<tr><td>3</td><td>BSc</td><td>12</td></tr>
<tr><td>4</td><td>MSc</td><td>28</td><td>19 / 9</td></tr>
<tr><td>Total</td><td>BSc and MSc</td><td>108</td><td>82 / 26</td></tr>
</table>

6.6.2. Results

Since the groups of participants are difficult to compare given their size and level of the students, we decided to consider the overall outcomes when taking all participants together. In Table 6.6, we provide an overview of the number of times a scenario is presented to the participants, and the number of times matching of a scenario with a game concept was correct. The number of correct matches is then translated to a percentage.

As already stated in the beginning of this chapter, the GCs-id tool is successful in identifying a game concept when two criteria are met: i. More than 50% of the participants reaches the right game concepts for a given scenario, and ii. The second most chosen game concept for that scenario differs more than half from the first most choice. Meaning, when the first most chosen outcome is 60%, then the second most chose outcome should be less than 30%.

Table 6.6: Results of correct matches per scenario in percentages.

Scenarios	Number of takes	Correct matches	Percentages correct	Number second best	Percentages second best
1	38	21	55.26%	9	23.68%
2	36	25	69.44%	4	11.11%
3	37	12	32.43%	11	29.73%
4	35	25	71.43%	3	8.57%
5	37	28	75.68%	4	10.81%
6	38	26	68.42%	8	21.05%
7	35	7	20.59%	11*	32.35%
8	34	19	55.88%	7	20.59%
9	34	19	55.88%	4	11.76%
Total	324	182	56.17%	-	-

*Actually, 11 is the number of matches to the first most (wrong) choice, and 9 is the number of matches to the second most (wrong) choice.

For seven out of the nine scenarios the two criteria were satisfied, and thus we can say that the game concept identification by the tool was successful. Once one of the criteria is not met the identification failed. In this case, scenarios number 3 and number 7 are not meeting both criteria.

For scenario number 3, 32.43% of the participants, which read scenario 3, reached the matching outcome. Moreover, 29.73% of the participants, which read scenario 3, did not reach the matching outcome and chose the same second most chosen outcome. For scenario number 7, 19.44% of the participants, which read scenario 7, reached the matching outcome, and this was only the third ranked outcome. Meaning, 30.55% of the participants, which read scenario 7, reached a ‘wrong’ first chosen outcome, and 27.77% of the participant, which read scenario 7, reached another ‘wrong’ and second best chosen outcome.

6.7. DISCUSSION

In this section, we list a number of possible explanations for the negative results of scenario 3 and scenario 7. The explanations are summarized in two themes: perspective of participants and design of the tool.

6.7.1. PERSPECTIVES OF PARTICIPANTS

The first type of explanations concern the interpretation of the characteristics, i.e., questions in the online version of the GCs-id tool, and the text of the scenarios, by the participants.

INTERPRETATION OF TEXT SCENARIOS

We organized four feedback sessions, each consisting of four students who participated in the pilot or the final test. We asked their perspectives on general assumptions such as:

dependency of actors, deadlock, decision-making level, worst-case scenario, negotiations and knowledge. Furthermore, we specifically asked them which other assumptions or information they used during the test.

Since the number of students involved in the feedback sessions is small, and the time between feedback sessions and the actual test varied, we cannot draw firm conclusions from the feedback sessions. Rather we use the feedback to find the main points that are shared between the participants, and that differ from our assumptions when we designed the GCs-id tool and the scenarios. This led to the following three categories:

One versus multiple decisions A decision was perceived as one decision for each decision maker. So, even when the situation entailed multiple actors taking one single decisions, this was perceived as multiple decisions by the participants in the feedback sessions. This interpretation could explain why scenario 3, which described a single decision with multiple actors, could reach an incorrect endpoint.

Decision-making levels They were interpreted as decisions made in different phases, or round of the process, rather than decisions made at different levels of the organization. This could explain why confusion about this question existed, resulting in incorrect outcomes.

Hierarchical relations They were assumed to exists in order to make final decisions. The Dutch railway sector is supposed to be hierarchically organized with the Ministry taking the final decision. Questions regarding one actor leads the negotiations, and hierarchical relation between actors exist, could thus be answered differently from what was described in the given scenario since participants in the feedback session were firm about this assumption.

6.7.2. Design of the tool

Design and complexity of the GCs-id tool itself is another possible explanation for unexpected results. We discuss the order and type of questions in the tool and the text of the scenarios.

Game concept identification tool Regarding the game concept identification tool we compared the length of the paths to the endpoints, i.e., game concepts, and we calculated the number of different possible paths. The longer the path to an endpoint, the higher the chance that someone made a mistake or interpreted a question differently. Furthermore, when multiple possible paths to the endpoint exist, the possibility to make mistakes increases too. Therefore, we state two hypothesis:

1. If the average length of possible paths to an endpoint is high, then the percentage of correct matches is low.
2. If the number of possible paths to an endpoint is large, then the percentage of correct matches is small.

Table 6.7 states the results of the average length of possible and chosen paths, and the number of possible paths for each scenario. Scenario 3 has the highest average length of possible paths to the correct endpoint (6.84 questions). Scenario 7 has the third highest average path length (6.69 questions). But also scenario 6 has a high average path length (6.79 questions). When we consider the average length of actually chosen paths by the participants, we observe that scenario 3 and scenario 7 have the highest average length of paths, respectively 7.42 and 9 questions. Regarding the number of possible paths to the correct endpoint, scenario 3 and scenario 7 belong to the scenarios with a high number of possible paths (respectively 7 and 8 different paths), but scenario 6 has even more possible paths to the correct endpoint.

We cannot confirm the hypothesis, but we conclude that a combination of average length of (chosen) paths and the number of possible paths can be an explanation for the results of scenario 3 and scenario 7.

Table 6.7: The average length and number of possible paths to correct endpoint.

Scenario	Average length possible paths	Average length chosen paths	Number of possible paths	Literally stated answers versus not literally
1	5.90	5	1	5 versus 0
2	6.28	6.52	4	5 versus 0
3	6.84	7.42	7	2 versus 3
4	5.57	5	1	3 versus 2
5	5.38	5.86	6	5 versus 1
6	6.79	7.31	9	5 versus 1
7	6.69	9	8	2 versus 4
8	5.71	6.05	3	4 versus 1
9	5.15	4.68	7	4 versus 1

6

Scenarios The structure of the text of the scenarios can explain the results of (in)correct matches. We expect two factors to play a role: (i) the structure of the text, i.e., the order in which characteristics are presented, and (ii) the balance between characteristics of game concepts stated literally in the text of the scenarios.

(i) Regarding the order of characteristics we did not find a difference between the different scenarios. In all cases the order of the characteristics was different from the order of the questions.

(ii) The balance between characteristics of game concepts stated literally or not does differ between scenarios. We observe that in the text of scenario 3 and scenario 7, the number of times a characteristics is stated literally is low compared to the other scenarios.

From Table 6.7, we can conclude that the number of literally stated characteristics of game concepts in the text of the scenarios can (partly) explain why these scenarios have less correct matches.

6.7.3. LIMITATIONS

The analysis in the previous section shows that the perspectives of participants, and the design of the GCs-id tool and scenarios to a certain extent explain why scenario 3 and scenario 7 have few correct matches. However, apart from the perspectives of the participants and the design of the tool, we can name several other limitations that could have influenced the results.

The test was performed with students from different study years. Their knowledge of concepts, such as actor and decision-levels, and their familiarity with decision-making in the Dutch railway sector varies. Moreover, the test was performed in both English (for master students) and Dutch (for bachelor students) which could influence the results.

In general, performing the test with students rather than experts in the field could be seen as a limitation since they are not the future users. However, we design this as a preliminary test of the tool to be applied by experts and evaluated in Chapter 7 and Chapter 8.

For the same reason we made use of hypothetical scenarios. The participants experienced the test sometimes as a reading comprehension test, but this is not the purpose the tool is designed for.

6.8. Conclusion

This chapter has two objectives: 1. Design and test a tool that enables users to identify game concepts for a given situation, and, 2. Evaluate whether the tool identifies the matching game concept by a majority of the users. Moreover, if the second objective does not apply to all cases we provide explanations for the incorrect ones.

As becomes clear in this chapter, objectives one and two cannot be separated. The process of designing and testing is alternated before the final evaluation is performed. The game concept identification tool, as result from the design and testing process, is presented in Appendix A. The second objective of this chapter is difficult to obtain due to different perspectives of users. Moreover, the scenarios we present them are very concise, hence, interpretation of the questions and the text of the scenarios varies and requires intensive testing during the design process. However, the fact that we traced why participants made certain (un)expected choices has contributed to many improvements of the design of the tool. As a result, during the design and testing process, the feedback of participants tended to be more towards details of text of characteristics and scenarios, and the interface of the online test.

The results of the evaluation process show that for seven out of nine scenarios the majority of the participants is able to reach the matching game concept for a given scenario. For the two remaining scenarios the results can be explained by the different interpretation of participants, and by the design of the tool. The average length of possible, and chosen, paths to the matching game concept is higher for those two scenarios compared to the other scenarios. Furthermore, the number of literally stated characteristics in the text of the scenarios is low compared to the other scenarios. Hence, we can conclude that the results of the test are fairly good, and the game concept identification tool has the potential to be used in real-world settings.

The participants of the final test are different from the potential future uses of the game concept identification map, and moreover, the scenarios used are hypothetical, and do not contain the complete details of a real-world process. Therefore, assessing the application of the GCs-id tool in real-world decision-making processes is necessary.

THE result of this chapter is an evaluated game concept identification tool (GCs-id tool) which can be applied by a variety of users who have no knowledge of the game concepts to identify game concepts in a process of decision-making.

- The tool consists of game concept characteristics ordered such that following a path of characteristics leads to a game concept.
- In the design of the tool, we aimed to include the smallest number of characteristics needed to identify the game concepts to keep the tool as simple as possible.
- Iterating the design and testing phases led to a final design that subsequently has been evaluated with a group of students.
- In the final evaluation of the tool, participants were given hypothetical scenarios, i.e., decision-making situations, from the Dutch railway sector and the GCs-id tool.
- For seven out of nine scenarios more than 50% of the participants made a correct match between the scenario and the game concept.
- The mismatch between scenarios and game concepts in the other two cases can be explained by the design of the tool and the perspectives of participants.
- We concluded that, taking into account the explanations of incorrect matches, the GCs-id tool has the potential to be used to support real-world decision-making processes.
- The next step is assessing the use of game concepts, as identified using the GCs-id tool, to support real-world decision-making processes.
- In Chapter 7, we establish a connection between the game concepts and game design.
- In Chapter 8, decision makers apply the game concepts in a real-world decision-making process.

7

THE GAME BETWEEN GAME THEORY AND GAMING SIMULATIONS: DESIGN CHOICES

In this chapter, we apply the game concepts to improve the modeling of gaming simulations. In particular, we focus on the design of gaming simulations to support decision-making. The result could assist game designers.

- First, we use the game concept identification tool, introduced in Chapter 6, to characterize the decision-making process.
- Second, we link game concept elements (actors, strategies, issues, etc.) and decisions regarding the gaming simulation components (scenarios, goals, etc.).
- Subsequently, we assess whether these two steps lead to the design of meaningful gaming simulations.
- Meaningful refers to a gaming simulation that addresses the problem at hand and thus supports the decision-making process.
- To assess this we apply the two steps to three case studies, i.e., gaming simulations, from the Dutch railway sector.

7.1. INTRODUCTION

Game theory (GT) and gaming simulations (games) are two terms which, despite their lexical resemblance, are used to describe two seemingly unrelated fields. GT is the study of mathematical models of conflict and cooperation between intelligent rational

This chapter has been published in Gaming & Simulation, **50**, 2, (2019) by Roungas, Bekius and Meijer (Roungas et al., 2019).

actors, which results in the definition of Game Concepts (GC) (Bekius and Meijer, 2018b, De Bruijn and Ten Heuvelhof, 2018, Myerson, 1997, Rasmusen, 2007).

Games are imitations of real-world systems (RS) designed to solve a problem; their primary purpose is not merely to entertain but to educate, train, steer decision-making processes, etc. (Michael and Chen, 2005, Zyda, 2005). In this respect, building a game out of an RS necessitates the use of modeling to reduce actual real-world complexity to a manageable level. The process of modeling and building a game out of an RS is characterized by the following challenges: (i) it can be time consuming, which translates both into delay and cost, (ii) it usually requires extensive experience on the part of the designers, as well as concrete knowledge of the system under study, and (iii) depending on the actual size of the system, it dictates multiple decision-making, thus increasing the probability that mistakes will be made in the course of the modeling process, especially when the system includes hidden personal agendas and a notion of politics.

Yet since both GT and games aim to describe and interpret the behavior of actors participating in complex systems (Holland, 1992), there does seem to be an area in which these two converge. The initial hypothesis in this chapter is that there are more correlations between these concepts than discrepancies, as may be inferred from both their definitions and tautological resemblance. This hypothesis is deemed to be verified by the fact that GT models are used (consciously or unconsciously) by game designers when designing games (Salen and Zimmerman, 2004).

This chapter intends to improve the modeling of games in two ways. First, GC are used to analyze and abstract the RS, thus pinpointing the problematic areas within this system and its worst-case scenarios. Second, a link is made between GC elements (actors, strategies, issues etc.) and decisions regarding the game components (scenarios, goals etc.). By making such connections, many less relevant game decisions can be filtered out, thus accelerating the modeling and prototyping of games and making the design decisions more rigorous. As a result, the methodology presented can be applied by less experienced game designers. This chapter therefore aims to address the following research questions.

1. What aspects from game theoretical analysis can be translated to game design and in what way?

2. To what extent can the design of a meaningful game be determined from game theoretical analysis?

Meaningful refers to a game that addresses the problem at hand, and thus fulfills its purpose.

In Section 7.2, a literature review reveals the interconnections between GT and games. In Section 7.3, a framework is proposed for modeling games through GT. In Section 7.4, the development and validation process for that framework is described. In Section 7.5, Section 7.6, and Section 7.7, results are presented from three case studies, which were used to test and refine the framework. In Section 7.8, the research questions are addressed, the limitations of the study are acknowledged, and future research steps are outlined.

7.2. BACKGROUND WORK

This section presents literature on serious game design as a stand-alone practice and on its relationship with GT, then further reviews the application of GT to games.

7.2.1. GAME DESIGN

While the vast majority of research in games has focused on its educational capabilities, this study is concerned with games for decision-making, as covered by the literature introduced below.

From the early days of games, there have been attempts to define and formalize game design. Duke (1974) proposed the use of conceptual maps combined with precise documentation of the design process. Such maps have the ability to ensure the games' correspondence with reality, ascertain that the appropriate level of abstraction is being adopted, and to confirm that the corresponding proposals can be implemented in the game design. The framework proposed in this chapter uses GC in the same way. While a claim cannot be made on whether GC are more effective than conceptual maps, they are selected in this case because they are part of a larger framework.

Harteveld (2011) discusses balancing reality, meaning, and play in game design. For each of these three pillars, he proposes several ways to implement them successfully within a game.

- **Reality.** Incorporating reality into a game is of the utmost importance. Harteveld (2011) proposes achieving this not only through familiarization with the RS under study, but by also enabling discussion with the client and subject matter experts. This in turn will allow accurate identification of the actors and objects involved and enable the building of relationships between them.

- **Meaning.** In the light of the RS it aims to imitate, the game has to have a specific purpose; it should transmit a particular message to the intended audience. The game designer should therefore define its purpose and develop a strategy on how to accomplish this, which in turn requires the implementation of certain game mechanics and feedback mechanisms, as well as reflection through debriefing.

- **Play.** Finally, the development of an engaging, immersive, and aesthetically pleasing game can facilitate its positive reception by participants, and thus improve its outcome.

Harteveld (2011) implicitly utilizes GT in several ways, but not fully. The goal of this study is to build upon his work, and more specifically to develop the first pillar of its triadic game design approach, i.e. reality, by explicitly linking game theoretical concepts with game design elements.

7.2.2. GAME THEORY IN GAMING SIMULATIONS

With regard to GT approaches in game design, Meijer (2012b) comments on the differences between GT and games but goes on to conclude that these concepts are often intertwined. He defines game theory as "the mathematical approach of analyzing calculated circumstances where a person's success is based upon the choices of others". In games, where the success of one player often depends on the choices made by others, GT hence provides a popular method for modeling artificial intelligence.

Bolton (2002) makes a case for the significance of GT in designing role-playing games, especially if these are to be successful at practical forecasting. Moreover, he observes that work to date on GT and role-playing games has dealt with highly simplified versions of the real world. In the same spirit, Ritterfeld et al. (2009) asserts that the systematic review process that GT provides could be a valuable heuristic for game designers.

Aligned with Bolton (2002), Salen and Zimmerman (2004) provide two reasons why GT can be useful for game designers. Firstly, GT analyzes situations which resemble simple games in a detailed way. Secondly, it focuses on relationships between decisions and outcomes. In effect, the authors think of actions and outcomes as the building blocks of meaningful play. They therefore believe that applying GT concepts is useful when designing such games. Moreover, they take a step towards proposing concrete ways in which GT can be used to actually help game designers. By looking at games as a series of strategic decisions, they suggest the use of several GT elements, such as:

- Decision trees, which allow the linking of different parts of a storyline, i.e., the order of the decisions made by the players;
- Utilization functions, which assist in quantifying players' preferences;
- Strategies, which can guide the players as they play; and,
- Pay-off matrices, which show the relevant outcomes of a game, depending on the players' decisions.

This approach by Salen and Zimmerman (2004) is a promising step towards formal use of GT as a game design tool, but it has a few restrictions.

1. The game has to be turn-based, or, in general, in discrete steps.
2. Players have to make a finite number of clear decisions with knowable outcomes.
3. The game has to be finite; it cannot go on forever.

These restrictions can be quite inhibiting in games with a decision-making purpose, where players do not take turns, the outcome of each decision is barely knowable, and the set of choices from which a decision can be chosen is infinite. In the proposed framework, decisions are not necessarily be linked to specific outcomes, thus freeing the designers to choose whichever they want to include.

Several case studies on the application of GT to game design have also been conducted. One of the most popular is the Beer Game (Sterman, 1989), which has formed the basis for further studies on optimization (Meng et al., 2010, Thompson and Badizadegan, 2015) and the modeling artificial intelligence (Kimbrough et al., 2002). Other less popular games, which have nevertheless incorporated GT in their game design are the approach by Mader et al. (2012) to develop a therapeutic game, where GT is used to examine the relationship between therapeutic activities and the players' motivation, and the attempt by Skardi et al. (2013) to apply cooperative GT to the control of total sediment yield in the watershed, vis-à-vis landowners conflicting interests.

Further to the above, Guardiola and Natkin (2005) use GT as a tool to model and understand local properties of gameplay by building game matrices for a video game. In effect, though, they are using GT to understand a game rather than to design it. Finally, Fullerton (2014) proposes the utilization of GT with various examples but only when the game involves dilemmas.

The literature reviewed in this second part illustrates that GT can contribute significantly to designing games. Nevertheless, research on this topic not only remains limited but also has severe limitations (restrictions, simplified games, etc.) or focuses only on specific games in the form of case studies. Throughout this chapter, it will be explicitly pinpointed wherever the proposed framework contributes in existing work and how it helps overcome limitations in previous research.

A point of criticism on the use of GT is that the method cannot cover the richness of empirical decision-making processes (Bennett, 1987, Binmore, 1987). It simplifies the situation to rational players who can only choose actions from a limited set of prescribed alternatives. When GT is applied directly to game design/science, the result is a game which scope is too narrow (Klabbers, 2018). Forcing the entire process into one game concept results in an oversimplification of the situation that is not useful for the decision maker or game designer when applying it to real-world cases. In order to mitigate the possible simplification we use multiple GC are used to characterize the process. The approach presented in this chapter is different from more general game theory applications since the concepts used are able to cover rich policy situations and give nuance to different incentives of different actors.

As a conclusion to the literature review, one may identify the absence of a framework for formalizing scientifically the application of GT on the whole spectrum of games. In the next section, the framework introduced aims at tackling this issue.

7.3. PROPOSED FRAMEWORK

This section proposes a framework for modeling RS through GT and for linking GC and games. The hypothesis tested in this respect is that the development of a game out of an RS - which undoubtedly translates into several design decisions and multiple individual game components - by default requires abstraction of the RS. As such, there is a need for a modeling framework able to guide the designer towards a game, which is an accurate representation of the system it simulates and is also feasible to build and maintain.

The proposed framework consists of: (i) a methodology for abstracting the RS and describing it through one or more GC; and (ii) a list of GC elements and, linked to it, the corresponding list of game design decisions. Establishment of the links is attempted through the use of the characteristics of the GC (actors, strategies, issues, etc.) and the different game design decisions (scenarios, goals, etc.).

The framework is depicted in Figure 7.1 and contains five blocks:

- The Real System (RS) represents the system under study. The RS contains actors operating in and on the system, as well as dynamics created by the interaction between the system and the actors. Depending on its complexity, the system can be characterized as either a complex adaptive system or a socio-technical system.
- The Game Concepts (GC) contain characteristics from the toolbox called Game

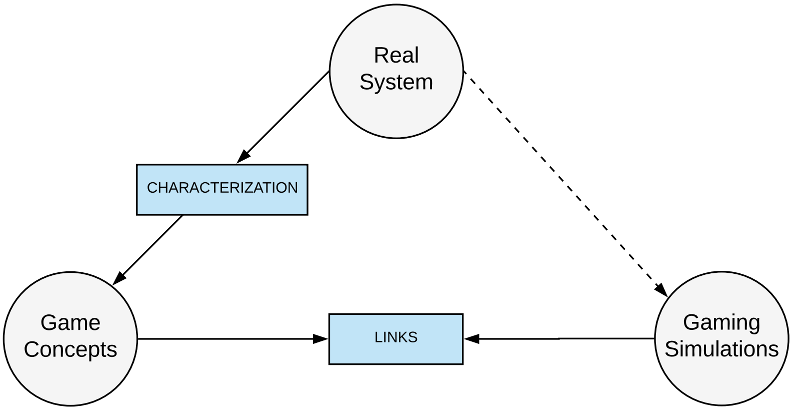


Figure 7.1: Framework for characterizing the Real System and linking the Game Concepts to game design decisions.

Theory (Osborne and Rubinstein, 1994) representing the game elements of the RS under study. GC describe the interaction between and behavior of actors who have to make a decision (Bekius and Meijer, 2018b). Some game concepts are mathematically defined, such as the well-known Prisoners Dilemma (Rasmusen, 2007), while others have only been observed empirically, for example the Multi-Issue game (De Bruijn and Ten Heuvelhof, 2018). Therefore, the characteristics of the GC vary between being empirically substantiated and mathematically proven. We refer to Chapter 2 for an overview of the game concepts used in this thesis.

- The Gaming Simulations (games) represents the game design decisions used in modeling the RS, after taking into account the complexity of the system the game is being designed for.
- The CHARACTERIZATION of RS into GC is the first step in the methodological process. The resulting GC should enable identification of the problematic areas and worst-case scenarios within the system, thus answering the second research question.
- The LINKS between GC and games is the second step in the methodological process and subsequently answers the first research question. This is the part that is more directly connected with Harteveld (2011) and with his triadic game design, since it is the one that eventually leads to game design recommendations.

The dashed arrow represents the game design literature as of to date, thus making even more explicit the contributions of this chapter. The direct link from the RS to the game shows that game design is usually based on the experience of game designers and rarely based on formal methods.

The following section elaborates on how the proposed framework was developed and validated. Particular attention is given on the two capitalized blocks of the framework, the CHARACTERIZATION and the LINKS.

7.4. METHODOLOGY

This section describes the methodology for developing and validating the proposed framework. That is in two parts, each corresponding with one of the rectangles in Figure 7.1.

- the CHARACTERIZATION of RS into GC.
- the LINKS between GC and games.

Three organizations are involved in the case studies discussed in this chapter, two from the Netherlands and one from Sweden. In the Netherlands, the organizations are ProRail and NS; ProRail is the government agency responsible for maintaining the national railway network infrastructure, allocating rail capacity and traffic control, whereas NS (Nederlandse Spoorwegen), also known as Dutch Railways, is the principal passenger train operator. In Sweden, the organization is the Stockholm County Council (Stockholms Läns Landsting, SLL), which is a regional government responsible for all health care provision in greater Stockholm.

In Subsection 7.4.1 and Subsection 7.4.2, an analysis of these two sections is provided. While in Figure 7.2, the complete methodology of the chapter is depicted in a graph. The white background indicates artifacts observed either in the real world or in literature; the grey background indicates games or game-related projects used throughout the methodology; the cyan background indicates artifacts related to the framework; the involved organizations in each case are shown in parenthesis.

7.4.1. CHARACTERIZATION

GT models describe interactions between actors, who make decisions in order to reach a certain outcome. They can formalize the mechanisms and patterns actors perform in RS and thus be used to characterize these systems (Goeree and Holt, 1999b, Helbing, 1994, Helbing and Balietti, 2011, Moss, 2001, Vollmer, 2013). Since several examples of such GT characterizations exist, choosing the right mechanism for the situation at hand is crucial, yet not always evident (Barreteau et al., 2007, Feld, 1997).

Bekius and Meijer (2018b) present a taxonomy of GT concepts (GC). These originate from both formal GT and public administration, in order for these concepts to have a richer and more descriptive definition. The characteristics of GC therefore vary between being empirically substantiated and mathematically proven.

The criteria used to design the taxonomy, which originate from theory on complex real-world decision-making processes (De Bruijn and Ten Heuvelhof, 2018, Kickert et al., 1997, Klijn and Teisman, 1997, Koppenjan and Klijn, 2004, Teisman and Klijn, 2008), are important for selecting the *right* GC. Multiple actors are usually involved in these processes, forming a network of interdependencies, and hierarchical relations can exist within those networks, most frequently between two actors.

The aim of the process is to reach a collective decision. However, individual strategic behavior plays an important role as well. Moreover, the decision-making process is

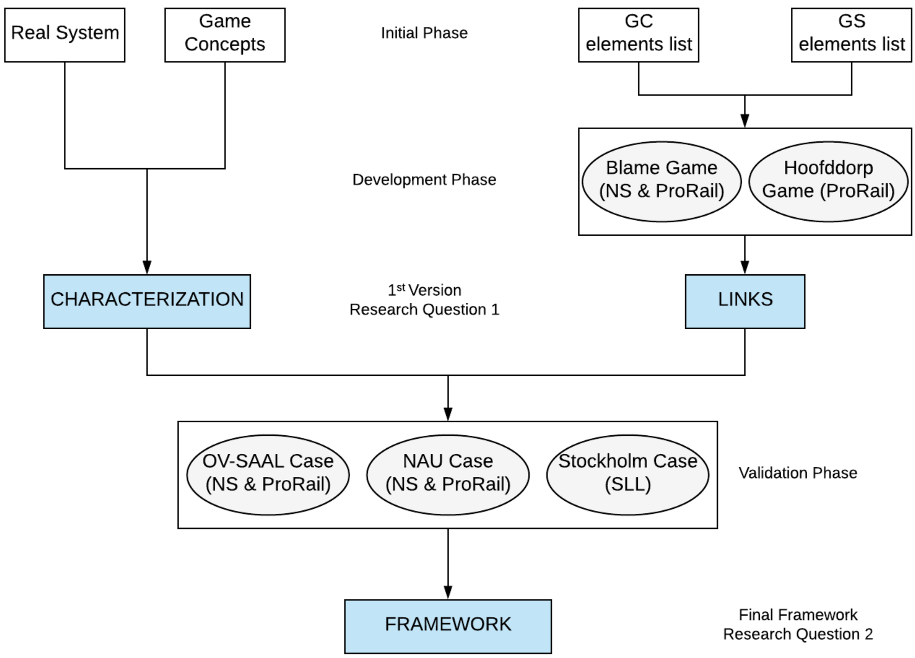


Figure 7.2: Methodology for the development and validation of the proposed framework.

dynamic. Therefore, the set of GC chosen from the taxonomy should, and does, cover a wide range of situations appearing in RS. A more detailed explanation of GC selection can be found in Bekius and Meijer (2018b), while a comparison of this approach with other characterization methods or decision-making tools can be found in Bekius et al. (2018a). In this thesis, Chapter 2 presents the process of GC selection.

With regard to games, the GT notions help us to analyze the situation and to *predict* worst-case scenarios. Since we obviously want to avoid such scenarios if at all possible, the ability to identify them in advance can be particularly helpful when making game design decisions.

7.4.2. LINKS

Two lists of GC characteristics and game design decisions are compiled in order to identify the elements linking GT and games. The compositions of these lists are based on literature. From a theoretical point of view, these two lists begin from a different start point, i.e., GT and game design, with the aim to be linked using two games. The two games are analyzed in order to formulate an initial assumption regarding the links. For each of these games, the content of each element included in the corresponding GC and game design lists is identified. On this basis, elements from the two lists are then linked.

For the GC characteristics, a list of 16 GC elements (De Bruijn and Ten Heuvelhof, 2018, Osborne and Rubinstein, 1994, Rasmusen, 2007) is used as a starting point. Overlaps between some of these elements necessitated the conduct of new research, which eventually introduced new elements. The resulting list of GC elements incorporated these, as well as merged versions of some of the original overlapping elements. The refined list is shown in the first column of Table 7.1.

For the game design decisions, additional literature is used in order to adapt and enhance the list of game elements for educational games, compiled by Roungas and Dalpiaz (2016), so as to fit in games with any purpose. The corresponding list of game design elements is shown in the second column of Table 7.1.

Two problems arise by creating these two lists.

1. The lists do not contain completely independent elements.
2. 1-to-1 correspondence between GC characteristics and game design decisions is not always applicable.

Problem 1 can be addressed by merging elements which appear within the same list. If one element is dependent or subordinate to another, it follows that the two can be merged. With regard to problem 2, 1-to-n, n-to-1 or no linking may be used as well.

The games To verify the proposed methodology, two games were used. Both are related to the railway sector. They have been called the Hoofddorp Game and the Blame Game. Interviews were conducted with the designer of each, asking specific questions in order to gain an insight into their design decisions and to retrieve the requisite information needed to identify the GC characteristics. Subsequent to each interview and establishment of its results, the substance of each element of the GC and game lists was ascertained independently. In other words, one researcher identified the GC characteristics and another the game design decisions. In this way, the probability of bias in creating the links was minimized. As described above, moreover, elements were merged when one was dependent on or subordinate to another. Such merges were effected only for elements appearing on the same list.

The Hoofddorp Game is a board game with a low fidelity level, which tests changes affecting the railway infrastructure in and around Hoofddorp station. Hoofddorp itself is a small town between Amsterdam and Leiden, but in the Dutch national railway network it is strategically situated close to the country's largest airport, Schiphol, on the main line linking it to some of the Netherlands' biggest cities, like The Hague and Rotterdam. Any changes affecting the infrastructure at Hoofddorp can thus have a severe impact on the connection between these cities and the airport.

The game has two different scenarios:

1. What happens if a fire breaks out in the railway tunnel under Schiphol Airport?
2. What happens in the event of disruption on the line to Leiden?

The output of the game has been used as input to help decide whether changes to the infrastructure at Hoofddorp are necessary or, alternatively, a whole new plan should be compiled.

The Blame Game is a role-playing game with a high fidelity level, which simulates a situation where two groups are "blaming" each other for incorrect planning. Subsequently,

Table 7.1: Links between GC characteristics and game design decisions.

GC	Games	Comments
Actors	Characters	Both contain the same people, since clients and facilitator(s) are included as Characters.
Actions	Rules, Challenges, Tasks	Rules, Challenges and Tasks are not completely independent and they all have overlaps with the Action Set from game theory. For the Blame game, Rules are not part of Actions because the game is quite open with few rules. Also, the rules that exist do not correspond 1-to-1 with the actions of the participants.
Strategies	Challenges, Motivation	Strategies are about the how (Challenges) but also about the why (Motivation).
Pay-offs	Motivation, Rewards	Pay-Offs are the sum of explicit (e.g. money) and implicit (e.g. satisfaction) rewards.
Information	Feedback	Information is influenced by many game elements, but we only link it with elements from the two lists when they match content-wise. Feedback is specifically included.
Context	Scenario, Fidelity, Type of game	The definitions and content of Context and Scenario fit almost completely. Context can define the level of Fidelity and Type of game. For the Blame game, Fidelity level is not linked because it is not a design decision.
Issues	Challenges, Pitfalls	Only for those issues which correspond with the content of the game and not issues related to its design. Define a new element "Pitfalls" for issues related with the game design.
Outcome	Goals, Debriefing, Purpose	Outcome is linked with Goals due to their similar definitions and with Debriefing due to the fact that that debriefing aims to maximizing the outcome of the game. Define a new element "Purpose" showing the purpose the game is designed for.
Iterative game	Repetition	Due to similar definition.
References: (Alessi, 1988, Apperley, 2006, Barreteau et al., 2007, Bekius et al., 2016, De Bruijn and Ten Heuvelhof, 2018, Rasmusen, 2007, Roungas and Dalpiaz, 2016)		

each player writes a report in which they nominate one or more members of the opposing group for dismissal.

The game has two scenarios:

1. In 2016, a decision was made to modify part of the railway infrastructure. But now, in 2018, the resulting performance has proven disappointing and passengers face frequent delays.

2. In 2016, it was decided that it would not be beneficial to make any changes to the infrastructure. But now, in 2018, performance is disappointing and passengers face frequent delays.

This game has been used to raise awareness among strategic decision makers of the interdependencies within the system and of the importance of team play.

The final links Actors (GC) have a 1-1 link with Characters (Games), because the latter are a subset of the former in the sense that they include the participants in the game, the client and the facilitator(s), all of whom are included as Actors (GC) along with the game designer(s).

The Action Set (GC) has a 1-n link with Rules, Challenges and Tasks (Games). The Action Set is defined by what participants need to accomplish in the game (Tasks), which in turn heavily influences the way they pursue their objectives (Challenges) based on the applicable restrictions (Rules). The only exception to the above are games like the Blame Game, which can be described as open games with minimal or no predefined rules. In these cases, the Action Set has a 1-n link with Challenges and Tasks (Games) only.

Strategies (GC) have a 1-n link with Challenges and Motivation (Games), because Strategies (GC) are about how a specific action from the Action Set (GC) is chosen (Challenges) and why (Motivation).

Pay-Offs (GC) have a 1-n link with Motivation and Rewards (Games) because, being the utility an actor receives, Pay-Offs (GC) can also generally be described as the sum of implicit (e.g. satisfaction) and explicit (e.g. money) rewards.

The Information Set (GC) has a 1-1 link with Feedback (Games) because the latter produces information about past (reaction to an action) and future (knowledge that can be used in the future) actions.

Context (GC) has a 1-n link with Scenario, Fidelity Level and Type of Game (Games). The definitions and content of Context (GC) and Scenario (Games) are almost identical, since both refer to the general situation surrounding the game. In addition, Context (GC) can determine Fidelity Level (Games) - low, medium or high - as well as the Type of Game (Games).

Issues (GC) have a 1-1 link with Challenges (Games), but only in the case of those issues which relate to the content of the game - not for the issues which relate to its design. Although Challenges (Games) seem to be the best match to Issues (GC), given the current list of game design elements it would be more appropriate to introduce a new game element including information pertaining to issues related to the game design. We have therefore introduced the term Pitfalls (Games), which is defined as any problems or mistakes occurring during the process of designing a game.

Outcome (GC) has a 1-n link with Goals and Debriefing (Games), due to its similar definition to Goals (Games) and the fact that Debriefing (Games) aims at optimizing the outcome of the game. Although Goals and Debriefing (Games) appear to be almost a full match with Outcomes (GC), there seems to be a gap regarding the purpose this outcome is used for; in other words, a game design element describing the purpose of the game is missing. Therefore, Purpose (Games) has been introduced as a new game design element defined as the function the game is designed for, e.g. training, decision-making, etc.

Iterative Game (GC) has a 1-1 link with Repetition (Games), because of their very similar definitions. Both terms show whether any, and if so how many, repetitions are needed in order to optimize the outcome of the game.

The methodology proposed is different from that of Salen and Zimmerman (2004), in the sense that it does not directly imply how the order of actions should be or which actions should belong to which outcomes. Instead, it specifies on a more high level the sets of actions or sets of outcomes that belong to certain design choices. Finally, when someone knows which game is "played" and is able to gain insight on the different GT elements, the table can be used as a structure to make your game design choices.

In the next two sections, the proposed framework and the subsequent methodology are validated through two case studies from the Dutch railway sector. A third case study, i.e. the Stockholm case, is used as a way to show (inexperienced) game designers how to use the proposed framework for future game design.

7.5. OV-SAAL CASE

The, so-called, OV-SAAL corridor (Schiphol-Amsterdam- Almere-Lelystad public transport) is part of the High-Frequency Rail Programme (Programma Hoogfrequent Spoor), which aims to increase the number of trains operating per hour in the Randstad conurbation. In order to raise capacity in this corridor, several options have been proposed by the various actors involved, two of which are ProRail and NS. One of these options is doubling the tracks around Weesp station.

7.5.1. THE GAME

The game was paper-based, using real timetables. The participants, playing the role of traffic controllers, were people from ProRail with at least with some experience in the role. The purpose of the game was to test the robustness of five pre-designed infrastructure enhancements in the face of medium-scale disruptions. The game resulted in an expanded set of solutions, which inhibited the participants from reaching a consensus, hence no final decision was made. As a result, the game was negatively received and criticized since it had failed to fulfill its purpose.

7.5.2. GAME CONCEPTS

In this case, four GC based on a *game-concept-selection tool* (Bekius and Meijer, 2018b), as presented in Chapter 6, were identified (this same tool was used in all the case studies). Those GC were the Multi-Issue game, the Cascade Game, the Volunteers Dilemma and the Battle of the Sexes. The predominant one was the Multi-Issue game, so that is further analyzed below.

Multi-Issue game is present when multiple actors with different incentives form a network of interdependencies and finally reach consensus in a decision-making process that was initially deadlocked. A large number of actors results in multiple issues coming to the table, which intensify and increase as the moment when a decision needs to be made approaches. Actors have broad agendas, which usually create room for consensus, negotiations, cooperation and participation in the process.

However, too many issues and actors with different ideas about them can result in over-complex situations. And, because of all these issues and actors, the process can be delayed. That was the case with OV-SAAL. During the design and the gameplay phase, the number of issues involved - and hence the number of scenarios (and runs) to be played out - increased. As a result, the complexity of the game did not reflect that of the actual situation. Moreover, major issues which were not supposed to be solved at that particular moment were also introduced, further increasing the complexity and the frustration among participants.

7.5.3. Game design recommendations

In the OV-SAAL case, the game could have been significantly improved using the proposed methodology. First, characterization of the problem as Multi-Issue could have been completed within a relatively short time, which in turn would have provided insights into the game design. Then, given the links shown in Table 7.1, several game design elements could have been better defined.

The game should have included not only participants from the operational layer of the organization but also from management, thus engaging the actual decision makers with the process. Alternatively, had that not been possible, the challenges and tasks within the game should have been simpler. That is, they should have involved fewer decisions in order to avoid over-complex situations with multiple issues per actor. This could easily have been achieved if Actions and Strategies for the Multi-Issue game had been explicitly defined. Finally, defining a set of Outcomes for the Multi-Issue game would have maintained the focus of the game on its initial purpose, thus providing an additional safeguard that the game would deliver valid and meaningful results and so be considered successful by the stakeholders.

7.5.4. Conclusion of the case

From the above analysis, it is clear how GC can help develop more robust and meaningful games. There are several areas of game design which GC can improve, but the most noticeable is the never-ending struggle of every game designer to create a realistic game while maintaining complexity at a reasonable level. The OV-SAAL case therefore provides a positive step towards validation of the proposed framework.

7.6. NAU case

Utrecht Centraal is the most centrally located and busiest railway station in the Netherlands. It is within an hour by train from Amsterdam, The Hague, Rotterdam, Nijmegen, and Eindhoven. Consequently, disruptions there can affect almost every other major station in the country. The primary purpose of the NAU case was to address such disruptions and to make Utrecht more resilient (Van den Hoogen and Meijer, 2012). Its secondary purpose was to alleviate the workload of the rail traffic controllers.

The complexity of the situation, which necessitated the use of games, lay in the fact that the operational layer of organizations like ProRail tends to resist implementing decisions made by the managerial layer (strategic decisions), thus increasing the uncertainty of their effectiveness. In this particular case, an additional reason for characterizing the situation as over-complex was the conflicting incentives of the actors involved. ProRail was focused on improving system performance, whereas NS was most keen to reduce the workload of the controllers.

7.6.1. THE GAME

The game used a paper-based model of the infrastructure, with low-tech interfaces but real timetables. The participants, playing the role of traffic controllers, were from different entities, including ProRail and NS (Van den Hoogen and Meijer, 2012). The purpose of the game was fourfold.

1. To test a pre-designed separation of traffic-control tasks into de-clustered zones of control (Van den Hoogen and Meijer, 2012).

2. To test a different traffic-control concept intended to mitigate second-order delays (Lo et al., 2013).

3. To limit abnormalities during major disruptions.

4. To adjust the division of labour at the traffic control center (Meijer, 2012a).

7.6.2. GAME CONCEPTS

In this case, two GC were identified: the Hub-Spoke game and the Battle of the Sexes. Of these, the Hub-Spoke was predominant and so is further analyzed below.

Hub-Spoke game consist of multiple actors (the spokes) with different incentives are steered by one actor (the hub) using a command-and-control style. The game creates an incentive to make inflated claims, as the spokes can make agreements among themselves and create strategic issues for the hub.

In the NAU case, the strategic level at ProRail is the hub and the different operational departments (including NS and other actors) are the spokes. The former wants to see its decisions implemented, while the latter need to be convinced of the usefulness and necessity of those decisions, which influence their way of working - a highly culturally sensitive factor. If the spokes are unwilling to implement the decisions and able to co-operate with each other, they make life difficult for the hub.

7.6.3. GAME DESIGN RECOMMENDATIONS

In the NAU case, the recommendations defined using the proposed methodology are mostly in line with those resulting from the game itself. This managed to actively involve both the strategic and the operational levels and to make the latter aware of its necessity and usefulness in creating a more resilient system. The two most important recommendations are as follows.

1. Reduce the number of decisions to be made and thus limit the design space of the game. This recommendation is similar to that resulting from the OV-SAAL case, but differs in the fact that, for NAU, the game designers explicitly limited the number of decisions (Van den Hoogen and Meijer, 2012).

2. Acknowledge the potential conflicts in the incentives driving the different actors. This increases the external validity of the game. Such incentive-based conflicts can occur both between organizations (in this case, between ProRail and NS) within them (in this case, between controllers and managers). Involving all relevant stakeholders in a game raises awareness of those conflicts, which in turn provides a more realistic overview of the situation.

7.6.4. CONCLUSION OF THE CASE

The NAU case resulted in a proof-of-concept which was later considered largely successful. In retrospect, then, the fact that the recommendations provided in this chapter were mostly in line with the actual implementation of the game is yet another positive step towards validation of the proposed framework.

7.7. STOCKHOLM CASE

In Sweden, Stockholm County Council (SLL) is a regional government responsible for all health care provision in greater Stockholm. However, home-care services (non-medical decision-making) are provided by local authorities, not SLL. Psychological and social care provision is split between local government and SLL. This makes the institutional environment rigid and not so easy to change.

The demand for health care in Stockholm is enormous and rising. The current system faces difficulties in meeting this demand, which makes it vulnerable. A large proportion of the demand comes from older people, who have multiple health issues. One possible solution is the use of sensors to control their well-being at home, thus potentially reducing unnecessary visits to health care facilities.

SLL wants to introduce digital innovations in health care by conducting tests at local teaching hospitals. Specifically, it wishes to start with three testbeds of 100 elderly people each. They will be supplied with sensors, which will be monitored.

7

7.7.1. GAME CONCEPTS

In this case, three GC were identified: the Volunteers Dilemma, the Principal-Agent game and Hub-Spoke game. The predominant one was the Principal-Agent game, so that is further analyzed below.

Principal-Agent game describes a hierarchical relationship between a principal and an agent, in which the former is dependent upon the latter because of their expertise in a certain subject. This GC reveals the power position of the subordinate in such a relationship.

In this case, SLL is the principal and the teaching hospitals are the agents. Similarly, a local authority could be seen as the principal and home-care centers as the agents. This immediately reveals the complexity of the decision-making processes, since multiple Principal-Agent games can take place simultaneously. This analysis focuses on the interaction between SLL and the hospitals.

The knowledge and expertise concerning the digitization of health care in general and the introduction of the testbeds, in particular is possessed by the hospitals. SLL is therefore dependent upon them unless it acquires more power.

During the game, the agent makes a decision regarding the test and the principal either accepts or rejects it. The agent's decision is modeled using the variable $y \in \{0,1\}$. This is defined as follows:

- $y = 0$ means that the agent is fully objective and not at all influenced by the hierarchical power and expectations of the principal.
- $y = 1$ means that the agent is fully subjective and makes the decision expected by the principal.

Given these two extremes, eight possible outcomes exist. Based on their probability of occurrence, the worst-case scenario can be identified. An overview of Principal-Agent Game is shown in Figure 7.3.

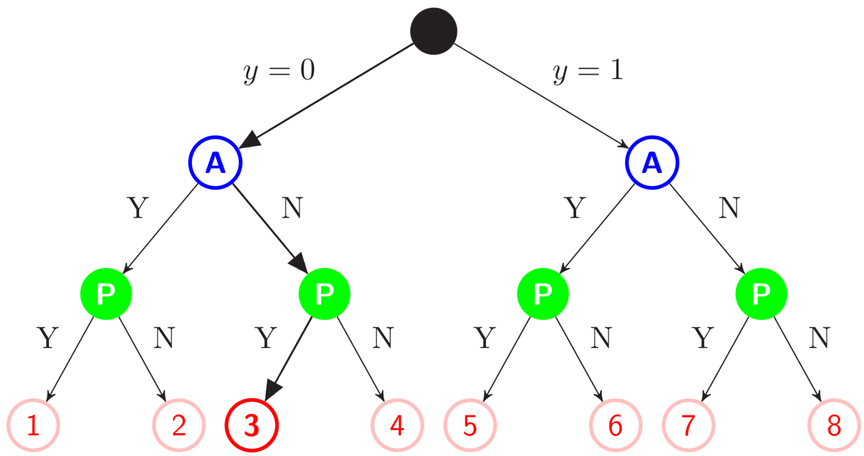


Figure 7.3: The Principal-Agent game in the Stockholm case.

From SLL's perspective, the worst-case scenario is when it wants the test performed and would thus prefer a "Yes" decision but the hospitals are fully objective and decide "No" (scenario 3 in Figure 7.3). SLL needs the hospitals to co-operate with it, otherwise it cannot solve the region's health care problems. When the worst-case scenario occurs, that damages the relationship between principal and agent, which is not beneficial for either of them.

7.7.2. GAME DESIGN RECOMMENDATIONS

Unlike the OV-SAAL and NAU cases, this project is still ongoing and a game has not yet been designed. Therefore, any recommendation provided would not be for research and validation purposes only but could also serve as an actual input for the forthcoming game.

Based on the analysis from the Principal-Agent Game, the worst-case scenario for SLL is when doctors decide not to go ahead with the tests. Of course, if such a decision is based purely on their medical or scientific assessment, then SLL should probably accept it. But if it is based on a lack of knowledge of new technologies and how they work, this is something a game can prevent. Hence, one design recommendation would be to develop a game for doctors focusing especially on the worst-case scenario. In other words, design a game which raises the doctors' awareness of modern sensors, how they work and how they can simplify their everyday job-related activities.

7.7.3. CONCLUSION OF THE CASE

The application of GC in this case shows yet another way in which GT can benefit the development of games. GC pinpointed the worst-case scenario in a quick and formal way, thereafter a game can be used to further explore and perhaps prevent it.

7.8. CONCLUSION

This chapter proposes a framework which contemplates a more efficient and effective modeling of games by formalizing their design decisions using GT concepts. Based on the reviewed literature and to the best of our knowledge, such a framework has never been proposed before. At present, however, it relies heavily on case studies in order to be fine-tuned and validated.

7.8.1. ANSWER TO RESEARCH QUESTIONS

With regard to Research Question 1 (What aspects from game theoretical analysis can be translated to game design, and in what way?), the answer lies within a continuum. At one end of this there is the direct translation of GC elements to game design choices (e.g., Actors → Characters, Pay-offs → Rewards, Outcome → Purpose), at the other the purely qualitative information (e.g., Actions, Strategies) which should be entrusted to the game designers, since their interpretation depends heavily not only on the purpose of the game but also on the particular requests made by the client (i.e., the person or company which owns and assigns development of the game).

With regard to Research Question 2 (To what extent can the design of a meaningful game be determined from game theoretical analysis?), the answer lies in the advantages of the proposed framework.

- The links between GC elements and game design choices, as defined in Research Question 1.
- Identification of the purpose of the game (the WHAT) by including the context of the decision to be made in the analysis of the situation.
- Identification of worst-case scenarios and problematic areas, as particularly shown in the Section 7.7.
- Prediction of the possible outcomes of the game. Even when the game does not explicitly steer participants towards a certain outcome and designers want to keep this broad, during the debriefing this could be a way to structure the discussion (e.g., What-if you had chosen A instead of B?).
- Prediction of how a situation characterized by a specific GC can evolve in the future into another GC.

Given these advantages in general, and the game design recommendations in particular, it is safe to conclude that, for the cases presented in this chapter, a meaningful game can be designed based on the proposed framework.

In addition to answering the two research questions, whether and the extent to which the proposed framework resolves the challenges associated with modeling games, as those were identified in Section 7.1, should also be addressed. While the introduction of the intermediate step of GT between the RS and games is not trivial, it does enhance the information for designers that can subsequently be part of the game design. For instance, in the OV-SAAL case, as it was shown, it was difficult even for experienced designers, let alone for inexperienced, to acknowledge how the multiple needs and wants of each actor would significantly increase the complexity of the game and as a result inhibit the final decision making process. In the Stockholm case, using a simple tree-like graph (Figure 7.3), the worst-case scenario was pinpointed relatively quickly. Most probably an experienced game designer would have found the same result but it would have been difficult to do it equally rapidly. Moreover, in this particular case, inexperienced designers would have had a hard time understanding the complexity of the Swedish health care system, abstract it and then identify the worst-case scenario. The LINKS part of the framework provides a roadmap for translating parts of the RS, through GT, to game design choices. While it can also be helpful for experienced designers as a reference, it is particularly useful for inexperienced designers because it gives them a "dictionary" on how a real world problem can be abstracted and translated into a game.

Finally, it should be noted that the proposed approach overcomes the restrictions imposed by the game theoretical approach of Salen and Zimmerman (2004), i.e., discrete steps, knowable outcomes and finite gameplay.

7.8.2. Limitations

Naturally, the novelty of the proposed framework entails some risks. Moreover, GT as a discipline has also its own limitations. Therefore, acknowledging and either eliminating or mitigating these inhibitors is of paramount importance.

The two lists were constructed based on a literature review in the fields of GT and game design. The use of literature almost entirely eliminates the risk of incorporating incorrect elements in either list, but only mitigates the risk of neglecting to include further relevant elements. With regard to the game design decisions list, the risk of not including important elements is further mitigated by the fact that this list is based mostly upon interviews with game design experts, who were called to comment as to whether an element was missing from the list.

The games used in this analysis have different fidelity levels, serve different purposes and, most importantly, address different professionals. Nonetheless, the first two games (OV-SAAL and NAU), which are the ones used to validate the framework, share one common characteristic: both relate to the railway sector. This represents a risk in respect of the validity of the framework.

While GT offers a vast toolbox for exploring social systems, it also comes with certain restrictions. The most important of these is that GT assumes that actors behave rationally, whereas more often than not social systems tend to behave in a seemingly irrational way. In order to mitigate that risk, the proposed framework does not force designers to choose a rational path for their game design; that is left open. Another significant limitation of GT is that it has only a restricted ability to reveal the reasoning behind certain choices made by actors. It is only during the actual gameplay of the game that their rationale may be revealed.

7.8.3. FUTURE WORK

The risk of inadvertently omitting certain GT elements can be mitigated by interviewing GT experts who have experience with complex real-world decision-making and are thus able to pinpoint whether any element has not been incorporated in the framework. Furthermore, additional case studies in fields other than the railways, as well as with games that have different characteristics (in terms of fidelity, purpose, intended audience and perceived success or failure) from the ones used in this chapter, will add further value to the proposed framework. Finally, game designers should test the framework in a real-world design situation in order for its validity to be further strengthened.

THE result of this chapter is a framework that connects game concept elements and game design decisions. The framework helps in designing a game, which eventually is used to support decision-making.

- The framework helps in filtering out less relevant gaming simulation decisions, it accelerates the modeling and prototyping of gaming simulations, and makes the design decisions for such a game more rigorous.
- As a result, the methodology can be applied by less experienced game designers.
- Three case studies (a successful case from the past, an unsuccessful case from the past, and a future case) were analyzed to evaluate whether the framework provides game design recommendations that lead to a meaningful game.
- In general, the framework identified the purpose of the game, worst-case scenarios, and problematic areas.
- Furthermore, it predicted possible outcomes and showed how game concepts can evolve over time.
- From these advantages, and the game design recommendations in particular, we conclude that, for the cases presented in this chapter, a meaningful game can be designed based on the proposed framework.

8

Decision Support Using Operationalized Game Concepts

In this chapter, the game concepts are applied by decision makers of the Dutch railway sector.

- We assess how decision makers use the game concepts and want to understand the potential consequences of its use for the decision-making process.
- In 10 workshop sessions, each addressing a different decision, the decision makers identify game concepts individually and discuss as a group which game concepts apply and what the consequences of the identification are for the process.
- We assess the topics discussed by participants after the game concept identification, before, during, and after the session by using both qualitative and quantitative methods like questionnaires and a frequency analysis of video recordings.
- We are particularly interested in whether more technical focused decision makers use the game concepts differently or learn from the game concepts in another way than more actor-oriented decision makers.

8.1. Introduction

In this chapter, we explore the use of game concepts as mediating instrument in a decision-making setting within organizations. The instrument is a game concept identification tool (GCs-id tool), as designed and evaluated in Chapter 6, and the game concept descriptions, as presented in Chapter 2.

We are interested in the use of game concepts, and the consequences of its use for the decision-making process. Meaning, how do people use them, what is the effect, and for what or who? This requires a specification of its potential *users*, and a classification of its potential *uses*.

Potential *users* are people from organizations involved in decision-making processes. In this chapter, we focus on professionals of the Dutch railway sector at the tactical level. This level includes both 'hard-core' engineers and strategic managers. Since their roles and background are different, they will also have a different perspective on the decision-making process. However, a distinction between engineers and strategic managers just based on their job title does not necessarily represent their perspectives (Hopkins, 1991). For example, a strategic manager can be former engineer who still adopts a technical perspective rather than a more actor or context perspective. Therefore, we distinguish between users identifying technical aspects of the process, such as uncertainties regarding the system, as most important versus users identifying actor aspects, such as trust and power-play between actors, as most important. We want to know how the two groups differ in their use of the game concepts. We expect that, in particular, users with a more technical focus benefit from the use of game concepts since they are introduced to a, for them, 'new' perspective including strategic actor behavior and context elements.

Potential *uses* vary from, more strategic, discussions on the content of the decision and the position of actors involved, to more operational, defining next steps in the process and creating another perspective. The potential uses or applications of the game concepts can thus have different effects. In this chapter, we propose a framework, based on the Bloom taxonomy (Bloom et al., 1956), that distinguishes between four, so called, Use Type (UT) levels. Moreover, it is designed as such that the development of the UT levels indicates a form of learning.

The game concepts (in the form of a GCs-id tool and the game concept descriptions), the two types of users (engineers and strategic managers), and the four different Use Type levels (see Section 8.2.2) are the building blocks of this chapter. In this context we address the following research questions:

1. What strategic and operational practices do potential users identify when they together characterize a decision-making process by using the game concepts?

2. What are the consequences of such a characterization by using game concepts on the (future) behavior of users?

To answer the research questions we organized workshop sessions with stakeholders from the Dutch railway sector involved in a decision-making process regarding the technical system. During the session, they identified game concepts for the process at hand using the GCs-id tool, and they discussed the consequences of the process characterization for the decision to be, or recently, made. Our expectations regarding the use of game concepts in terms of UT levels during the workshop sessions are translated to propositions. The evaluation of these propositions leads to the answers of the research questions.

The structure of this chapter is as follows: Section 8.2 provides theoretical expectations on the potential uses of the GCs-id tool in a decision-making process. Based on these potential uses we propose a framework to evaluate the use of the game concepts by defining UT levels. In Section 8.3, we outline the set-up of the session, the materials, the participants, and the cases. In particular, we distinguish between participants with a more technical focus and participants with a more actor focus. Additionally, we provide an overview of the data collected and describe how we analyzed the different types of data. Thereafter, in Section 8.4, nine propositions are presented which are either confirmed or invalidated in Section 8.5. In Section 8.6, we answer the research questions before we discuss the results of the propositions, the limitations of the study, and directions for future research in Section 8.7.

8.2. BACKGROUND

This section consists of theoretical expectations on the use of an instrument as decision support methods, such as the GCs-id tool, in a real-world and participatory setting. First, we give some examples of situations in which participants were enabled with game theory models. Second, we mention a couple of activities inspired by network theory with a particular focus on the evaluation of such activities. As a result of this section, we propose a framework that describes potential uses of game concepts by specifying different Use Type (UT) levels.

8.2.1. DECISION SUPPORT METHODS

In this section, two streams of decision support methods are highlighted.

GAME THEORY

As we already mentioned in Chapter 6, the number of practical tools rooted in game theory are limited, and the evaluation of such tools, and particularly how they are used, is rare or ad hoc (McEvoy et al., 2018). However, we present some examples of workshop sessions inspired by game theory and their outcomes.

Game Structuring Methods (GSM), as subcategory of Problem Structuring Methods, are applied in a workshop setting with participants in multiple case studies (Gomes et al., 2018, Slinger et al., 2014). Experiences of participants entail novel thinking and questioning of presuppositions (Slinger et al., 2014). Moreover, applying GSM in a village in Bangladesh provided insight into the problem of drinking water by the identification of new problems and solutions, dependencies between issues, discovering of new actors and their incentives, and the position and role of actors in the process. At the end of the session, participants saw the benefits of collaboration and realized that not all outcomes are satisfactory. Furthermore, the community attempted to design new rules to improve the current situation (Gomes et al., 2018).

Johnsson (2018) explores the potential of using Prisoner's dilemma as a workshop tool to stimulate learning and collaboration in the creation of innovation teams. The Prisoner's Dilemma was translated to workshop rules and used as a set-up for the workshop. Similarly, the iterated Diners Dilemma is used as experimental set-up for evaluating the influence of different levels of information support (Schaffer et al., 2018). This set-up is different from the set-up of the workshop sessions in this chapter. Rather than presupposing a game theoretical concept, or leave it completely open as in the GSM, we designate the identification of the game concept to the participants.

There are examples of project management methods inspired by game theory which are used to map stakeholders involved in a decision-making process. Da Costa et al. (2009)

developed a tool, based on game theory, for managers to use in conflict of interest situations faced by companies in their operating environments. The tool allows managers to identify which games can be played in order to solve the situation. Using the tool enables managers to prepare for their job since through its use they recognize that each situation of conflict of interests is different, and thus no standard solution exists. Furthermore, they evaluate the power and trust relations between players and subsequently decide on the most suitable strategy.

Network theory

Despite the scarce use of game theory models to support decision-making in an applied setting, methods and tools inspired by literature of complex networks theory cover a broad area of policy analytic activities (Thissen and Twaalfhoven, 2001). Methods used in these workshops with stakeholders are, among others, Problem Structuring Methods (PMS), Group Decision Support Systems (GDSS) and a variety of stakeholder analysis techniques. It goes beyond the aim of this chapter to provide an overview of these methods and tools and their potential uses. Instead, we refer the reader to Mingers and Rosenhead (2004) for an overview of different PMS methods and to Eden (1992) for GDSS. We highlight a couple of evaluation frameworks addressing the use of such methods in a participatory setting to support decision-making.

Group model building exercises are examples of PSM that can be used in a participatory setting to support decision-making (Franco and Hämäläinen, 2016, Rouwette and Vennix, 2006, White, 2009). Rouwette et al. (2009) propose a conceptual model, based on social psychology, to link the elements of the modeling process to its goals. The context, more or less political, in which the modeling takes place is determining, together with the intervention characteristics, the effect of the modeling exercise. Moreover, the impact of the modeling exercise can exist on individual, group, organization or context level (McCardle-Keurentjes et al., 2008).

Group decision support systems (GDSS) have been applied in several decision-making situations (Ackermann and Eden, 2011, Eden, 1992, Geurts and Joldersma, 2001, Mayer et al., 2004). Furthermore, a broad range of stakeholder identification and analysis techniques exist. For example, Bryson (2004) categorizes them in four categories depending on their purpose: organizing participation, creating ideas for interventions, building a winning coalition for a certain proposal, and implementing, monitoring, or evaluating strategic interventions.

Geurts and Joldersma (2001) introduce analytic and process criteria that a participatory policy analysis has to satisfy in order to be effective. They include aspects such as the framing of the problem, developing a broad overview of scientific insights, and developing options which are both creative and consistent. Moreover, the method adopted should allow for step-by-step learning, participation of relevant stakeholders, facilitation of communication of judgments of experts and stakeholders, and integration of scientific data and judgments of experts and stakeholders.

McEvoy et al. (2018) discuss three different decision support tools and introduce four metrics to evaluate such tools in a participatory setting. The metrics include learning effects (both social and individual), development of a shared understanding, the work products developed, and nature of participation.

Voinov and Bousquet (2010) address different types of stakeholder modeling tools and assess the effects of these tools. They distinguish between two main objectives of a participatory session: (i) increase the understanding of the dynamics of a system under various conditions, and (ii) identify the impact of solutions for a problem which is related to decision-making, policy or management. Moreover, they mention types of interaction between stakeholders as a potential results of a participatory modeling session at three levels: (a) extracting information from the group as diagnosis to support the decision-making process (extractive use), (b) synthesis and develop jointly such that the implications of it are passed to a decision-making process (co-learning), and (c) participants perform the synthesis together and include them in a joint decision-making process (co-management) (Lynam et al., 2007).

We have introduced a number of decision support methods and tools that are rooted in game theory and network theory and have been applied in a practical setting. Additionally, we discussed a few frameworks that mention the potential uses or effects of such methods and tools in a decision-making situation. The next step is translating these potential uses and propose a framework of UT levels.

8.2.2. USE TYPE LEVELS

We observe from the literature discussed in the previous section that the implications of participatory sessions exist at different levels. Researchers talk about social learning versus individual learning (McEvoy et al., 2018), sharing of information in different forms on different levels (Voinov and Bousquet, 2010), commitment to take a decision, identification of problems, identifying new solutions, and creating interventions (Bryson, 2004) to name a few. The variety of uses at different levels reminds us of the Bloom taxonomy. The Bloom taxonomy consist of six learning levels: remember, understand, apply, analyze, evaluate and create. The basic idea is that one achieves a higher level once one learns (Anderson and Krathwohl, 2001, Bloom et al., 1956). Thus, first understanding a concept, and then applying it means one has made a learning step. The Bloom taxonomy is applied several times to measure, assess, and evaluate learning levels in a variety of domains (Athanassiou et al., 2003, Granello, 2000, Tyran, 2010, Wang et al., 2017). We translate the learning levels of the Bloom taxonomy to Use Type (UT) levels with respect to using game concepts in a decision-making process.

The potential users of the game concepts are professionals in a technical sector, and the decision to be made is a decision regarding a technical system. In the beginning of the session, participants need to remember and understand the case study of the session, i.e., the decision-making process. Thus, the first UT level is: *remember* and *understand* the content and context of the process and decision.

The game concepts require the participants to think about the interaction between, and behavior of, actors in context of the case study. Participants apply the game concepts, and analyze the situation accordingly. Hence, the second UT level is: *analysis* of the position and perspectives of other actors involved, and *apply* the game concepts to the current situation.

In the discussions during the session, the participants are asked to identify the consequences of the game concept identification for the decision at hand. Participants evaluate the current situation by taking the future into account, and eventually *create* next steps or improvements for the process. Therefore, the third UT level is: *evaluation* of the process and design of next steps in the process of decision-making.

The final step is reflecting on the process of decision-making and the insights gained during the session. We question the extent to which the game concepts *create* new insights in the process. The fourth UT level is: a different view on the decision-making process.

To summarize, we link the individual learning levels of the Bloom taxonomy to four potential UT levels we expect to observe during the workshop sessions. Learning means moving from a lower to a higher level in the Bloom taxonomy, therefore, we will also evaluate the improvements of UT levels over the entire session.

Table 8.1: Use Type levels corresponding to levels of the Bloom taxonomy.

UT level	Explanation	Bloom taxonomy
1	Content and context of process and decision.	Remember Understand
2	Awareness of position and perspectives of actors involved.	Analysis Apply
3	Evaluation and design of next steps in the process.	Evaluation Creation
4	Different view or perspective on the decision-making process.	Creation

8.3. METHODOLOGY

In this section, we explain the methodology used in order to assess the usability of the game concepts by decision makers in a real-world decision-making process. In total we facilitated 10 sessions with each 3 – 6 participants. A total of 39 participants took part in the sessions. Each session discussed a unique decision that will be made in the near future or that has been recently made. The participants in the different sessions are, or were, involved in the decision-making process under study and had sufficient knowledge on the decision (to be) made.

In the remainder of this section, we specify the set-up of the sessions, the materials used, and the participants and case studies subject to the sessions. Furthermore, we present an overview of the collected data and how they are analyzed.

8.3.1. SET-UP SESSION

The sessions started with a short introduction about the aim of the session, explanation of the game concepts and a two hour time plan. One of the participants introduced the case study using a template which was created before the session. The participants discussed the different elements of the template during the session and adapted it if necessary. Subsequently, the participants signed an informed consent form before they filled-in the first questionnaire.

Thereafter, the participants used the GCs-id tool to identify the game concepts in the process of decision-making. They were asked to specify the path of different questions they followed to reach a game concept. To recall, the questions in the GCs-id tool cover the game concept characteristics. If participants were not certain about the answer for a certain question, they were requested to follow both paths in the GCs-id tool. As a result, participants could end up with multiple game concepts. After identifying the game concepts, the participants received the game concept descriptions and read those.

In the first discussion, the findings of the different participants were discussed, and they were asked to reach consensus on one (or two) game concepts that applied to the decision-making process at hand. Next, in the second discussion, the participants discussed the consequences for the decision-making of the chosen game concept(s). In particular, they focused on next steps in the process, or improvements of the past process.

Afterwards, a second questionnaire was filled-in, and finally, the participants reflected on the entire session during a wrap-up. Table 8.2 gives an overview of the set-up of the session, the time available for each part, and materials used in each part.

Table 8.2: Set-up session and materials used.

Time (min)	**Goal/task**	**Materials**
0-10	Introduction to session and game concepts	Plan of session
10-20	Explanation of case, i.e., decision (to be) made, by participant	Template case study
20-35	Pre-test: assessing the complexity of the case	Informed consent, questionnaire 1
35-55	Individual assessment of game concepts	Game concept identification tool, description game concepts
55-75	Discussion 1: Which game concepts characterize the process?	Description game concepts
75-90	Discussion 2: What are the consequences of game concept identification for the decision-making process?	Description game concepts
90-110	Post-test: evaluation and reflection on session and tool	Questionnaire 2
110-120	Wrap-up: reflections, comments, suggestions	-

8.3.2. MATERIALS

A template is used to define the main elements of the case study in each session. The elements of the template are: the decision (to be) made, the possible outcomes of the decision, moment in decision-making process, technical systems that are influenced by the decision, and the actors involved. It is created before the session by one of the participants and checked with other participants during the session. The facilitator emphasized that the decision-making process, as described in the template, is the object of discussion for the remainder of the session.

Participants signed a informed consent, and filled-in a pre-test (questionnaire 1) and a post-test (questionnaire 2).

Questionnaire 1 contained questions regarding the background of the participants such as work experience, position and education level, 24 statements on different complexity aspects of the process, one ranking question of the complexity aspects, and an open question about missing aspects of the process. Questionnaire 2 contained 27 statements on complexity aspects of the process and evaluation of the tool and session, one ranking question of the complexity aspects, and two open questions. The statements were scored on a scale from 1 to 7 (1 = completely disagree to 7 = completely agree), and there was an option to fill-in 'not applicable'.

The GCs-id tool was used by the participants to individually characterize the decision-making process. In short, the tool entails questions, i.e., characteristics of the game concepts, and dependent on the answer, an arrow leads to the next question which finally results in an endpoint, i.e., a game concept. Furthermore, for each game concept a description containing its context, process, possible results, and potential risks. These descriptions contained the game concept definitions as introduced in Chapter 2. The case template, GCs-id tool, and descriptions were available during both discussion rounds of the session.

The sessions were recorded with two video cameras for analysis of the sessions afterwards. Furthermore, the facilitator used a protocol during the session and made nodes on an observation scheme during the discussions.

8.3.3. Participants and cases

The participants of the sessions are, or were, involved in the decision-making process that was discussed during the session. Participants vary in their position within the organizations, working experience, and their perception regarding the complexity of the decision. We distinguish between participants valuing technical aspects (T-participant) and actor aspects (A-participants) of the case as most important. Examples of technical aspects are the existence of technical uncertainties and the impact of the decision on the technical systems. Examples of actor aspects are the level of trust between actors involved and the existence of conflicts.

Since someone's function title does not necessarily define the perspective on the process, we decided to divide the participants based on the aspects of the process they find important. Given that we distinguished between T-participants and A-participants, there were 8 mix sessions (both T-participants and A-participants)and two sessions consisted of only A-participants (sessions 7 and 8).

The case studies consisted of future decisions and decisions that were recently made. For the latter, the purpose of the workshop session was to evaluate the decision-making process. Four sessions discussed a case study in which the decision is recently made (sessions 3, 4, 6, and 9), and six sessions discussed a case study for which the decision is be made in the near future. Of these future decisions, three sessions had a relatively short time until the decision is made (sessions 2, 8, and 10), meaning within the coming weeks and the remaining sessions (sessions 1, 5, and 7) had a longer time (several months) before the decision is made.

Table 8.3 provides an overview of the sessions by specifying the variety of participants, the type of case study and the time left until the decision is made for each session.

8.3.4. Data collection and analysis

We collected the following data during the sessions:

Table 8.3: Overview of participants and cases per session.

Session	Number of participants	Number of T-participants	Number of A-participants	Type of case study	Time until decision
1	3	1	2	Future	Medium/long
2	5	1	4	Future	Short
3	4	1	3	Evaluation	-
4	3	1	2	Evaluation	-
5	4	3	1	Future	Medium/long
6	3	1	2	Evaluation	-
7	3	0	3	Future	Medium/long
8	4	0	4	Future	Short
9	4	2	2	Evaluation	-
10	6	2	4	Future	Short
Total	39	12	27	-	-

- Case study templates for each session, which are adapted by the participants during session.
- Results pre-test (questionnaire 1) including the background of participants, 24 statements on the complexity aspects of the decision-making process and ranking of the three most important aspects.
- Game concept(s) identified per participant including the path of characteristics leading to the game concepts.
- Video recordings and observations of discussion 1 and discussion 2.
- Results of the post-test (questionnaire 2) including 27 statements on complexity aspects of the process and evaluation of the tool and session, ranking of the three most important aspects, and insights gained during session (open question).
- Recordings and observations of the wrap-up at the end of the session.

In this chapter, we analyze the results of the pre-test and post-test, perform a frequency analysis of the discussions, and collect the main points of the wrap-up.

Based on the results of the pre-test we defined whether a participant has a mainly technical focus (T-participant) or mainly actor focus (A-participant) on the process. The statements of the pre-test are categorized according to technical and actor aspects. For each participant, we considered the ranking of the main aspects of the decision-making process: T-participants rank technological aspects as most important and A-participants rank actor aspects as most important.

A frequency analysis of the UT levels in discussion round 1 and discussion round 2 is performed to decided on the main UT level for each participant per discussion round. Based on our definitions of the UT levels we designed a scoring scheme for the discussions. The scoring scheme contains four different categories corresponding to the four UT levels, and each category entails some subcategories. We refer the reader to Appendix C for the scoring scheme. The discussions were scored by denoting the time and the number of the participant. For each participant, the frequency of a UT level in a discussion round was calculated by adding the number of entries of each subcategory of a UT level. The main UT level in a discussion round was decided by taking the UT level with the highest number. For instance, in discussion 1, a participant has 8 entries with UT level 1, 15 times UT level 2, 3 times UT level 3, and 0 times UT level 4, then the main UT level for the participant in discussion 1 is UT level 2. Note that if the frequency score of UT levels is equal or differs with one or two entries, then both UT levels will be defined as the main UT level for the participant in the particular discussion.

The statements of the post-test are categorized according to the four UT levels. For each participant we calculated the average score and standard deviation for each set of statements corresponding to a UT level. Furthermore, the answers to the open question regarding the insights of the session are collected and categorized in a similar way. The statements of the pre-test and the post-test can be found in Appendix D.

We noted the main points of the wrap-up of each session by looking at the recordings. The main points are clustered per subcategories of UT levels similarly to the coding of the frequency analysis and the answers of the open question of the post-test.

In the next section, our expectations regarding the UT levels of participants present during and after the session and the impact of the session on future processes are stated.

8.4. Propositions

In this section, we state our expectations regarding the use of the game concepts, made explicit by UT levels, in the different parts of the session. Additionally, we distinguish between the UT levels of participants with an initial technical focus (T-participants), and participants with an initial actor focus (A-participants).

Due to the heterogeneity of groups of participants, in terms of T-participants and A-participants, work experience, and position, we expect that participants apply a variety of UT levels in the first discussion round (proposition 1).

In the second discussion round, we asked participants to discuss the consequences of the game concept identification for the decision-making process. Thus, as a way to verify what we asked from the participants, we suppose that the third UT level will be predominantly used in discussion 2 (proposition 2).

However, since engineers stay engineers, even when they are presented with more actor and context oriented concepts, we think that technical oriented participants mention content aspects of the process more often compared to the actor oriented participants in the second discussion round (proposition 3).

In the post-test, we suppose that participants give high scores to statements related to reflection and creation of a different view or perspective on the process (proposition 4).

In general, we expect participants' UT levels to improve during the session. Meaning, they develop through phases from remembering and understanding, via analysis, application, to evaluation and creation. This is explained by the fact that the UT levels are based on the Bloom taxonomy which consist of different learning levels (proposition 5).

Furthermore, we expect that the improvement of UT levels for technical oriented participants is larger than for actor oriented participants (proposition 6). Moreover, since the game concepts focus on actor and context aspects of the decision-making process we think that technical oriented participants become more actor oriented participants during the session and thus value actor oriented aspects higher in the post-test (proposition 7).

Finally, we are interested in the consequences for the decision-making process mentioned by the participants. In this regard, we suppose that sessions on future decision-making process will define next steps in the process (proposition 8). For sessions on past decisions, we expect that participants indicate improvements for the process (proposition 9). To summarize, we list the following propositions:

1. Participants in a session will use a variety of UT levels in discussion 1.
2. UT level 3 will be predominant in discussion 2.
3. UT level 1 will be more often used by participants with an initial technical focus on the decision-making process in discussion 2.
4. UT level 4 will be predominant from statements filled in by participants at the end of the session.
5. Participants' UT levels improve during the session.
6. The expected improvement of UT levels for T-participants is larger than for A-participants.
7. T-participants will obtain an actor perspective during the session.
8. Sessions in which cases on future decisions are central will show better ability by the participants to define concrete next steps in the current decision-making process.
9. Sessions in which cases on past decisions are central will show better ability by the participants to evaluate the process and indicate aspects of the process that need improvement.

In the next section, the propositions are supported or invalidated based on the data collected during the sessions. In Table 8.4 we specify the data used in order to evaluate the propositions.

8

Table 8.4: Overview of data used for each proposition.

Proposition	**Data collected**				
	Pre-test	Discussion 1	Discussion 2	Post-test	Wrap-up
1		x			
2			x		
3	x		x		
4	x			x	
5	x	x	x	x	
6	x		x	x	x
7	x		x	x	x
8			x	x	x
9			x	x	x

8.5. RESULTS

In this section, we evaluate each of the aforementioned propositions using the data collected and specified in Table 8.4.

PROPOSITION 1

We consider the distribution of the number of participants over the UT levels in discussion 1. These UT levels are defined for each participant by a frequency analysis of the contributions in discussion round 1. The results are presented in Table 8.5 which shows that 22 participants mainly focused on content (UT level 1), 29 participants mainly discussed actor aspects (UT level 2), 8 participants mainly mentioned next steps (UT level 3), and 3 participants reflected on the process of decision-making (UT level 4). Note that the total of these number exceeds the total number of participants since participants can have more than one main UT level in a discussion round.

Table 8.5: Number of participants distributed over UT levels for each part of the session.

UT level	Discussion 1	Discussion 2	Post-test
1: content	22	14	6
2: actor	29	10	11
3: next step	8	37	8
4: reflection	3	2	21

To show how UT levels vary within sessions, we consider the distribution of participants over UT levels for each session as is presented in Table 8.6. In the first discussion round, the participants in a particular session had at least two different UT levels, and the main UT levels identified are UT level 1, focus on content, and UT level 2, focus on actors.

Table 8.6: Number of participants per session per UT level (discussion 1 and 2).

Session	UT level discussion 1				UT level discussion 2			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	3	1	-	-	1	-	3	-
2	2	4	2	-	2	1	5	-
3	2	4	-	-	2	-	3	-
4	1	2	-	-	1	1	2	
5	1	3	1	1	-	-	4	-
6	1	3	-	-	2	2	3	-
7	3	3	-	1	1	1	3	1
8	3	2	3	1	-	3	4	-
9	2	4	1	-	2	2	4	1
10	4	3	1	-	4	-	6	-
Total	22	29	8	3	14	10	37	2

PROPOSITION 2

Similarly to proposition 1, we consider the distribution of participants over UT levels in discussion round 2. The results are presented in Table 8.5 and show that 14 participants mainly focused on content (UT level 1), 10 participants mainly discussed actor aspects (UT level 2), 37 participants mainly evaluated or discuss next steps (UT level 3), and 2 participants mentioned having a different view on the process (UT level 4).

Considering the separate sessions, as illustrated in Table 8.6, we observe that in discussion round 2 in each session the majority of the participants evaluated the process and talked about next steps (UT level 3).

PROPOSITION 3

Regarding the UT levels in discussion 2, we distinguish between T-participants and A-participants and the results can be found in Table 8.7.

Table 8.7: Difference in UT levels between T-participants and A-participants in discussion 2.

UT level	T-participants	Percentages	A-participants	Percentages
1: content	8/12	66.66%	6/27	22.22%
2: actor	3/12	25%	7/27	25.93%
3: next step	11/12	91.66%	26/27	96.30%
4: reflection	0/12	0%	2/27	7.41%

When comparing the percentages of T-participants and A-participants for each UT level, we observe the largest difference for UT level 1: 66.66% of the T-participants and 22.22% of the A-participants obtained UT level 1. This confirms our proposition that T-participants use UT level 1 more often than A-participants in the second discussion round.

8

PROPOSITION 4

Similarly to proposition 1 and proposition 2, we consider the distribution of participants' UT levels given the statements they evaluated at the end of the session. The statements in the post-test are categorized according to the different UT levels and, for each participant, we calculated the average score over the set of statements for each UT level. The total number of participants belonging to each UT level is presented in Table 8.5. A total of 6 participants gave high values to statements on the content of the decision (UT level 1), 11 participants gave high values to statements on actor aspects (UT level 2), 8 participants gave high values to statements on evaluation and next steps (UT level 3), and 21 participants gave high values to statements on different view and perspective (UT level 4). Hence, we can conclude that the UT level 4 is stated by a majority of the participants at the end of the session.

Distinguishing between T-participants and A-participants regarding the UT levels from statements in the post-test gave the results as can be found in Table 8.8.

The largest difference between the percentages of T-participants and the percentages of A-participants is for UT level 2: 16.66% of the T-participants and 33.33% of the A-participants gave on average the highest score to statements regarding UT level 2. We found the opposite relation for UT level 4: 66.66% of the T-participants and 48.15% of the A-participants gave on average the highest score to statements regarding UT level 4. This shows that UT level 4 is predominant from statements in the post-test and, in particular, a majority of the T-participants evaluated UT level 4 statements on average the

Table 8.8: Difference in UT levels between T-participants and A-participants in post-test.

UT level	T-participants	Percentages	A-participants	Percentages
1: content	2/12	16.66%	4/27	14.81%
2: actor	2/12	16.66%	9/27	33.33%
3: next step	3/12	25%	5/27	18.52%
4: reflection	8/12	66.66%	13/27	48.15%

highest. Additionally, we observed that the ratio of T-participants with UT level 4 is higher compared to A-participants.

Proposition 5

For each participant, we consider its main UT level(s) in discussion 1, discussion 2, and the post-test. If, from one phase to the next phase, the UT levels increase, or remain the same, we say the participant improved its UT levels. In total, 28 participants improved their UT level over the entire session. Hence, a majority of the participants improved their UT level and thus, in terms of the Bloom taxonomy, they learn during the session.

Proposition 6

Taking into account the results of proposition 5, we distinguish again between T-participants and A-participants. From the 28 participants that improved their UT levels during the session, 11 participants were T-participants and 17 participants were A-participants. Thus, if we consider the ratio of T-participants versus A-participants we see that 91.67% (11/12) of the T-participants and 62.96% (17/27) of the A-participants improved their UT levels. Hence, a larger part of the T-participants than of the A-participants improved their UT levels during the session.

Proposition 7

In the post-test, we asked participants to rank the three most important aspects for the decision-making process. From the 12 T-participants, 5 participants mentioned actor behavior as one of the three main aspects, so they clearly moved from a more technical oriented to more actor oriented focus. Moreover, these participants gained a new perspective or at least were reminded of it since they indicated different aspects this time as most important.

Of the 7 remaining participants, 6 participants recognized problems and risks as important aspects, and one participant mentioned another perspective. Regarding the latter, the participant stated in an open question of the post-test about new aspects discussed during the session with respect to the decision-making process: “trust and consensus between actors.” Hence, the participant mentioned clearly actor aspects of the process.

Regarding the other 6 participants that indicated problems and risks as important aspects, we consider the recordings of the wrap-up and discussions to justify whether the type of problems and risks discussed by this person in particular, and the group in general, are more technically or more actor oriented. For 5 out of the remaining 6 participants, the discussions included issues such as internal and external actors involved in the process, change of actors during the process, the effect of performing wait-and-see behavior, alignment of actors, who takes the responsibility for which part of the process and the final decision. The problems and risks had a clear actor focus, and thus we conclude that these participants changed their focus towards more actor oriented. One participant mainly discussed issues on content, and thus remained its technical focus.

To conclude, 11 of the 12 T-participants obtain during the session an actor perspective on the decision-making process and value this as important.

PROPOSITION 8

Sessions 1, 2, 5, 7, 8, and 10 discussed future decisions.

In session 1, a proposed next step in the process is to define a go/no-go moment to decide on the implementation of a series of tests. Moreover, more actively involving the strategic level is a plan by reserving time on the agenda of the directors meeting to explain the proposed next steps.

In session 2, the participants concluded with ideas on how to prepare directors for the the decision moments in a few weeks. Based on the risks and problems defined in the session they defined a strategy: stop accepting and investigating new issues, organize (informal) meetings with some actors to increase the levels of trust, and make clear that this decision moment is not the final one.

In session 5, the participants realized that different game concepts are present in different phases in the process. The next step is to define who should be involved in which phase of the process, both internally and externally. Furthermore, they comprehended that they should be alert on the moment the game concept should change. Additionally, they like to evaluate the process with the game concepts after the decision has been made.

In session 7, the proposed next step is to continue with the current strategy. Participants realized that it is important to communicate the same story towards the internal actors and the external actors at the same time. Recently they started doing this by explicitly defining the story regarding the decisions to be made.

In session 8, the session provided input for a pre-decision meeting with the actors involved. The participants defined their strategy and approach for the meeting. They discussed the impact of the potential change in the role of one particular actor on the decision to be made. The concrete next step was to understand this preference of the actor taking into account its role change and potentially steer the process towards the best situation for the participants.

In session 10, next steps in the process were defined regarding the extent to which data of a series of tests needed to be analyzed, who to involve in the final decision, and who takes the responsibility for which part of the problem and decision. Not all aspects were completely defined, but at least participants understood that these aspects need to be defined.

PROPOSITION 9

Sessions 3, 4, 6, and 9 discuss past decisions.

In session 3, both improvements for the process and next steps for other decision-making process were defined. The participants realized that the internal decision-making within the organization can be improved, for instance, which departments need to be involved at which moment in time is not always clear. Furthermore, the incentives of external actors and its potential consequences for the process were not clear for some participants. Thinking ahead during the process of potential scenarios leading to outcomes and discussing the characteristics of the game concepts would enhance a shared understanding and reveal unknowns regarding the process. Finally, a part of the participants suggested to organize a session for another future decision to identify the game concept characteristics for this process too.

Session 4 did not result in concrete improvements for the decision-making process. The session was a confirmation that the roles the participants took initially matched with the roles in the identified game concepts. Moreover, the different styles of decision-making in the game concepts showed the possibility to experiment with new ways of decision-making in the future and to understand which decision-making style others use.

In session 6, the participants considered the game concepts as an instrument that could enhance transparency and openness in collaboration processes which are becoming more important these days. They realized that a structured evaluation of the decision-making process almost never happens. Performing a structured evaluation could be an improvement of decision-making in the Dutch railway sector in general.

In session 9, it is again mentioned that a general improvement of the decision-making would be to have a structured evaluation. Furthermore, participants felt 'relieved' that their way of dealing with the process fitted within a particular game concept. This game concept which indeed resolved some issues they were facing in the the game concept they were playing before. Earlier identification of the actors, the issues and potential solutions was proposed as an improvement of the process. The participants in this session were confirmed that the approach they eventually took to steer the decision-making process was suitable to reach the desired outcome. Furthermore, the participants started thinking about other decision-making processes they are currently involved in and discussed whether the choices made will eventually lead to the desired results.

To conclude, the sessions on future decisions were able to propose next steps for the process and sessions on recently made decisions were able to specify improvements for the process. Moreover, in some sessions, other future decision-making processes were discussed which could potentially benefit from an analysis using game concepts. However, the level of concreteness of the next steps and improvements and the degree to which they are implementable varied. From this we can conclude that proposition 8 and proposition 9 hold.

Given the results of the propositions, we provide an answer to the research questions of this chapter in the next section.

8.6. CONCLUSION

The sessions enabled discussions on content and context of the decision-making process (UT level 1), and behavior and perspectives of actors involved (UT level 2) after the identification of the game concepts. Additionally, participants evaluated the current situation of the process and define next steps (UT level 3) when we asked them to discuss the consequences of the game concept identification in the case study. Furthermore, results from the post-test and reflections showed that most of the participants obtained a different view on and structure to look at the process (UT level 4). This result is even stronger for participants with an initial technical focus on the process. They concentrated more on the content of the decision in the beginning of the session and at the end of the session they evaluated statements regarding a different view on the process with high scores. Moreover, initially technical oriented participants discussed or reflected on actor aspects towards the end of the session. Thus, participants' UT levels improved during the session and, in particular, participants with an initial technical-focus obtained an actor focus on the process. This answers the fist research question regarding the operational and strategic practices identified when participants together characterize a decision-making process by using game concepts.

Having such tool available beyond this experiment can be expected to have the following consequences on the behavior of the users (second research question). In general, participants discussed both content and actor aspects of the process in a structured way. Moreover, as participants stated, it provided them with an overview of the (potential) problems and risks of the process. In particular, more technically focused participants obtained a different view on the decision-making process and realized the importance of an actor and context perspective on the process. They see this tool being helpful to better understand the actor complexity of the process. The shift from initially technically focused participants to actor focused participants, at the end of the session, was confirmed by a quantitative analysis of the ranking of statements in the post-test, as well by a qualitative analysis of their reflection during and after the session. Furthermore, participants were able to define concrete next steps or improvements for the process of decision-making.

8.7. DISCUSSION

One of the observations during the different sessions was that questions on actors' agency in relation to the decision-making process were present in many discussions between participants. This entailed topics on responsibilities of actors, who decides on what?, and the order of decisions: who decides when?. But also more fundamental questions such as "what is the decision to be made?, and "who should be involved? were frequently brought up. These observations are resembling the results from the empirical case studies in which the uncertainty regarding 'who decides on what and in which order' is recognized in multiple case studies (we refer the reader to Chapter 3 of this thesis for the case descriptions). The observations, and the extent to which the game concepts address this point, are further addressed in the conclusion of this thesis in Chapter 10.

In the remainder of this section, we first discuss and provide explanations for the results of the propositions. Secondly, we discuss the limitations of the study and finally we propose some directions for future research.

8.7.1. RESULTS PROPOSITIONS

The variety of UT levels in discussion 1, as addressed in proposition 1, can be explained by three aspects: (i) heterogeneity of the group (both T- and A- or only A-participants); (ii) clarity of the decision (to be) made for participants; and (iii) time until decision will be made. Sessions in which the participants mainly have UT level 1 are sessions with a relative homogeneous group (sessions 7 and 8), and uncertainty about which decision needs to be made exist (sessions 1 and 10). Sessions in which participants mainly have UT level 2 are heterogeneous groups of participants and the decision (to be) made is clear to the participants (sessions 3, 4, 5, 6, 9). Sessions in which participants mainly have UT level 3 have a short time before the decision needs to be made (sessions 2 and 8).

Defining UT levels from statements (proposition 4), at the end of the session, is done by calculating the average score of the statements belonging to a certain UT level. However, different measurement are possible, for instance, one could look at the statements scored highest by the total of participants. This includes the following statements: "the discussion gave a good representation of the problems/risk of the case" (number 14, post-test) and "using the tool/session we have together evaluated the current situation of the process" (number 27, post-test). The first statement belongs to UT level 1 or UT level 2, depending on the type of problems and risks discussed for the case. The second statement belongs to UT level 3. These results are different from the results of proposition 4 where we looked at the average score of statements for each UT level. Thus, reconsidering the evaluation of the statements in the post-test could lead to a different perspective on the results.

Improvement of UT levels (propositions 5 and 6) is based on our definition of the UT levels and based on to the Bloom taxonomy. The propositions articulate the idea that participants learn over time since they are exposed to new concepts, and thus improve their UT levels. We find such a trend, however, the measurements of the UT levels before, during and after the session vary. We used a frequency analysis to score the discussions during the session and we analyzed statements of the first questionnaire to specify participants' type (T-participant or A-participant) before the session. The second questionnaire is used to indicate the obtained UT level(s) at the end of the session. We did not encounter for learning changes within discussion rounds. On the other hand, we allowed participants to have more than one UT level per discussion round. Performing a more detailed analysis of the discussions by not separating the two rounds and scoring the UT levels per participants over time can give a more detailed insight in the variation and change in participants' UT levels.

The pre- and post-test did not contain the exact same statements. This would thus be an improvement of the questionnaires in order to measure the shift from T-participants to A-participants (proposition 7). Moreover, during the session the participants discussed the game concepts which have an actor and context focus. It is thus not so surprising that the majority of the T-participants in the end of the session stated actor aspects as important to the process. Furthermore, the sessions contained a majority of A-participants, thus T-participants could be influenced by them. On the other hand, some participants did not change their focus and remained T-participants during the entire session.

There is variation in the extent to which participants were able to formulate concrete next steps and improvements for the process (proposition 8 and 9). This variety can be explained by several aspects. First, the complexity of the decision-making process had influence on the time needed to identify the game concepts and to understand how the game concepts apply to the process. In some cases, there was simply not enough time to deeply discuss the next steps in the process. Second, the time left until the decision takes place influenced the need for having concrete next steps, the sooner the decision is made, the more need for concrete next steps exists. Third, in some cases, the game concepts and discussions confirmed that the participants are, or were, doing the right things at that moment which reduced the need for concrete next steps or improvements. Regarding sessions on past decisions, some decision-making processes went quite well and thus little need for improvements existed.

8.7.2. LIMITATIONS

In the analysis of the sessions we mainly focus on the participant level, meaning what do the participants learn and how do they use the tool in different parts of the session. Another way to analyze the sessions is to take a session or group level perspective. We concentrated on the outcome of the sessions, but instead on could consider the interactions between participants, and how they eventually learned from each other. Moreover, we expect that participants have influenced each other by talking about a certain topic which eventually led to imitating UT levels.

Furthermore, we did not assess the impact of the sessions on the participants, or on the decision-making process, after the session. For instance, are the proposed next steps actually implemented and does it give the expected results. A couple of participants mentioned some time after the session that the game concepts were still in their mind, and they recognized the game concepts in other situations. Tracing the effect of the sessions on the decision-making process and the organization in general in the longer term is a direction for further research.

Due to the fact that we did not have full control on the selection of participants the composition of participants in the sessions varied. In some sessions teams that work closely together participated, while in another session there were participants who did not met before. This is a limitation of the research and influenced the degree to which defined next steps or improvements are concrete and implementable. Since participants had no knowledge on the game concepts before the session, and due to the limited time available, the participants could not read all game concepts descriptions in detail. Therefore, a large part of the session consisted in understanding what the game concepts are and what they mean for the process of decision-making. Either taking more time or introducing the participants to the game concepts earlier could result in different UT levels during the session and lead to more in-depth discussions on the future use of the game concepts. Hence, the composition of the group and the limited knowledge on the game concepts influenced the degree to which defined next steps or improvements were concrete and implementable.

Additionally, the number of sessions we organized was limited. Performing more case studies on decision-making processes within the Dutch railway sector will increase the number of participants and allows for more (statistical) analysis of the data.

Another limitation is the fact that in the post-test the number of statement per UT is not balanced. Furthermore, the scoring of the video data could reveal more insights when the sessions would be transcribed and analyzed accordingly. Additionally, available sources and time prevent us from scoring the data by independent researchers which we propose as a step for future work.

8.7.3. Future research

The case studies are decision-making processes within the Dutch railway sector. An interesting direction for future research is to investigate whether applying the game concepts to decision-making processes in a different infrastructure sector reveals the same results.

The game concepts identified during the sessions vary from session to session. However, in line with the results of Chapters 3, 4, and 5, one of the game concepts is almost always identified: the Multi-Issue game. The Principal-Agent game is not often identified since it belongs to the two-actor game concepts. The participants always mentioned multiple actors to be involved in the decision-making process, hence the design of the identification tool made the participants immediately skip the P-A game. Currently, the identification map is redesigned in close collaboration with experts from the Dutch railways sector. The fact that the decision-making processes always involve multiple actors made us remove the characteristics regarding the number of actors from the GCs-id tool.

Another aspect that returned in the different the sessions is that not one game concept can describe the entire process, and moreover, the game concepts interact. As one of the participants mentioned: "We should be aware that we change from the H-S game to the M-I game in time." Finally, a suggestion from participants was to enrich the game concept descriptions with practical suggestions on how to 'play' the game strategically. During the first part of the sessions in which participants discussed the template of the case study, we realized that thinking about and discussing the different elements of the template revealed the different perspectives of the participants. The same holds for going through the different characteristics of the GCs-id tool. Participants realized that they envision the process differently regarding, for example, its goal or number of decisions to be made.

Adapting the GCs-id tool, game concept descriptions and workshop set-up based on our experiences and feedback from the participants is the next step in order to assess and improve the application of game concepts by decision makers.

8

The results of the sessions in this chapter show how game concepts are used by decision makers.

- The sessions allowed for discussions on content and context of the decision-making process, and behavior and perspectives of actors involved after identification of the game concepts. Additionally, participants evaluated the current situation and defined next steps in the process.

- We found a difference in the use of game concepts between more technical focused and more actor focused participants.

- Decision makers with a more technical focus on the decision-making process in the beginning of the session shifted to a more actor focus at the end of the session.

- Moreover, they reflected that the session provided them with a new or different insight in the process of decision-making.
- In general, the participants of the sessions were able to define next steps in the decision-making process or identify points to improve the process based on the discussions after the game concept identification.

IV

Formalization

9

FORMALIZATION OF THE MULTI-ISSUE GAME

IN this chapter, we formalize the Multi-Issue game.

- The M-I game is one of the most frequently observed game concepts in the empirical decision-making processes (Part II), as well as identified by decision makers in the workshops of Chapter 8 (Part III).
- In formalizing, we make the elements and properties of the M-I game explicit and we develop algorithms for analyzing the M-I game. Furthermore, formalization of not-yet formalized game concepts is a first step towards modeling and simulating real-world decision-making processes.
- Our approach is based on the formalization of *ceteris paribus* preference statements using Conditional-Preference networks (CP-nets) (Boutilier et al., 2004).
- The *ceteris paribus* interpretation means that dependence of preference statements is given under the assumption "all else being equal" and is claimed to be an intuitive way to represent someone's preferences.
- CP-nets are used to specify relations between issues and are efficient structures to represent preferences of actors.
- The contributions of this chapter are:
  1. A multi-actor extension of CP-nets and different notions of consensus.
  2. A formalization of the Multi-Issue game in terms of this multi-actor extension.
  3. Insights and explanations of the M-I game formalization in real-world decision-making processes.

This chapter is written in collaboration with dr. H.H. Hansen.

9.1. INTRODUCTION

In Chapter 4 and Chapter 5 of this thesis, it has been shown that the Multi-Issue (M-I) game is present in multiple case studies. The conclusions of these chapters outline the existence of the M-I game in the entire process of decision-making, at most decision levels, and the game interacts with other game concepts present. Additionally, the M-I game is frequently identified by decision makers during the workshop sessions as presented in Chapter 8.

To recall, the M-I game describes a decision-making situation with multiple actors having different incentives. When the actors do not agree on a single-issue, and the process results in a 'deadlock', a possible strategy is to introduce new issues which can be connected to one another. A game of give-and-take is created by broadening the solution space, which might eventually result in consensus among the actors involved. The situation described before is a pattern that is observed in empirical decision-making processes on complex systems, and is described by De Bruijn and Ten Heuvelhof (2018). Especially, the interdependence between issues, and the different perspectives of actors on this interdependence of issues, play an important role in the process of decision-making.

Although the M-I game is a frequent pattern observed in decision-making processes, a formalization of the game is missing. The motivation for formalizing the M-I game is that it makes the elements of the game explicit by stating definitions. It enables to prove formal statements about the properties of the M-I game and develops algorithms for analyzing the M-I game. Given a formal model of the M-I game, we can perform an analysis of the game for different scenarios. Further applications of such a formalization can be found in Agent-Based Modeling, simulation and gaming, or as input for interventions with decision makers.

9

In this chapter, the approach to formalize the M-I game is based on research on collective decision-making from Computational Social Choice (CSC) theory (Brandt et al., 2016), and in particular, we build upon the work of Boutilier et al. (2004) who formalize conditional ceteris paribus preferences using Conditional Preference nets (CP-nets).

The *ceteris paribus* interpretation of preference statements means that preference statements are given under the assumption of "everything else being equal". For example, one prefers a round table over a square table, given that everything else, such as the organization of the living room, size of the tables, and color of the wall, remain the same. The *ceteris paribus* preference statements are claimed to be the natural way of reasoning when people articulate their preferences and an intuitive manner to represent someones preferences (Hansson, 1996). We therefore believe that the *ceteris paribus* interpretation is appropriate for M-I game situations too. In the M-I game, the interdependence of issues is of particular importance, and we model these relationships and their context-dependence via CP-nets.

Boutilier et al. (2004) introduced CP-nets as efficient structures for representing conditional ceteris paribus. In general, it is difficult for actors given a complete description of their preferences over all possible outcomes. Especially, when the issues are dependent upon one another. CP-nets do not require each actor to provide all possible outcomes. Instead, a CP-net specifies preferences and their interdependencies in a graphical structure. This graphical structure is a compact and intuitive way to let decision makers represent their preferences regarding issues and is created as follows: One starts from a single, or a few issues, and further specifies the graph by adding issues and arrows. An arrow from issue A to issue B means that the preference with respect to issue B depends on what has been decided for issue A.

The contributions of the present chapter are:

i. A multi-actor extension of the theory of CP-nets in which different notions of consensus are considered. Additionally, we introduce the graded notion of k-optimality and an algorithm to compute this notion.

ii. A formalization of the M-I game in terms of this multi-actor extension. We introduce a model of the M-I game and discuss the dynamics.

iii. Insights and explanations of the M-I formalization in real-world decision-making processes. We suggest how the formalization can be used for analyzing different scenarios.

The chapter is structured as follows: First, in Section 9.2, we give an informal explanation of the M-I game using an example. In Section 9.3, the preliminaries on single actor CP-nets are presented. Section 9.4 introduces multi-actor CP-nets and the static model of the M-I game, before we propose several notions of consensus and analyze these notions for the M-I game setting. In Section 9.5, we describe how the dynamics of the M-I game could be represented. Finally, Section 9.6 concludes this chapter, and Section 9.7 proposes directions for future work.

9.2. THE MULTI-ISSUE GAME

The essence of a Multi-Issue game can be made clear with help of an example. Imagine there is a family. A father, a mother and three children: an 18-year-old daughter, a 16-year-old daughter and a six-year-old son. The father knows that the eldest daughter will be leaving home at the end of summer, which means this summer is the last ever opportunity for the family to have a summer holiday together. This is important to him and he is willing to fund a really special holiday. He analyses the situation, where has the family already been and where not? What activities do the family members enjoy and which not? What is the available budget?

After a thorough analysis, the father decides on a holiday on the East Coast of America in August. He now needs to secure the support of his family members. Not everyone likes the idea. One would like to go to the East Coast, but not with the whole family. The second keeps her options open and does not adopt a position. The third does not want to go with the whole family, may be tempted by America, but not the East Coast. The fourth wants to go to Europe. So the father has a problem. How does he solve it?

His first option is to consult his family. If they do not change their position then he can pressure them to adopt his preferred solution. Will that help? Probably not. Another option would be to take control over the agenda, by introducing new issues for discussion. A Multi-Issue game entails broadening the agenda, which is now not just about the holiday, but also asking the other players to come up with issues that matter to them. These new issues could be rules on going out, assigning household responsibilities, whether or not to have a pet, locations and dates for the summer holiday or a skiing holiday. Other issues could also be considered - perhaps someone is interested in passing the driving test or in visiting a famous museum. Each of the players must have a list of issues that are attractive, there needs to be a perspective of gain. But the list can also include issues that the players actually strongly oppose. The youngest daughter would really like a great skiing holiday in Italy, but is completely against having a pet, hence, there is some potential gain and pain on the agenda (Bekius et al., 2016).

The example shows that in order to reach consensus the setting of the agenda is crucial, and that furthermore how to set the agenda depends on how actors evaluate and connect issues. Before we can think of which issues to put on the agenda and in which order, we need to know how the actors involved perceive the dependencies between issues. The next section introduces a structure to represent such dependencies of issues.

The reader who is less interested in the mathematical background of the M-I game model is referred to Section 9.4.2 in which the definitions introduced in the next section are translated to the M-I game setting and subsequently the M-I game model is defined.

9.3. SINGLE ACTOR CP-NETS PRELIMINARIES

This section introduces the basic definitions of single actor CP-nets following Boutilier et al. (2004). For the most part, we use the notation of Boutilier et al. (2004), however, for clarity and consistence, we sometimes adapt it.

Preferences are formalized as total (linear) orders, which we also call *(preference) rankings*. That is, a ranking over a set Y of outcomes is a transitive relation $\succ$ on Y such that for all $y, y' \in Y$, we have that $y \succ y'$ or $y' \succ y$ or $y = y'$. Here, $y \succ y'$ should be read as "y is preferred over y'". Preferences are usually taken to be preorders, which provide the possibility of expressing indifference between two distinct outcomes, but we follow Boutilier et al. (2004) in ignoring the possibility of indifference in order to avoid some technical complications.

Let $\mathscr{X} = \{X_1, \dots, X_n\}$ be a set of *variables*. Each variable X_i has a domain, a set of values that X_i can take, denoted by $dom(X_i)$. Given a subset $U \subseteq \mathscr{X}$, a *U-assignment* is a function α_U that maps each $X_i \in U$ to an element of $dom(X_i)$, called its value. If $U = \mathscr{X}$, then α_U is a *complete assignment*, otherwise α_U is called a *partial assignment*. We denote the set of all U-assignments of $U \subseteq \mathscr{X}$ by $Asst(U)$.

If α_U and α_V are assignments to disjoint sets U and V, respectively, then a combination of α_U and α_V is denoted by $\alpha_U \alpha_V$. If, additionally, $U \cup V = \mathscr{X}$, then $\alpha_U \alpha_V$ is a *completion* of assignment α_U (and α_V).

A set of variables $U \subseteq \mathscr{X}$ is *preferentially independent* of its complement $V = \mathscr{X} - U$ if and only if, for all $\alpha_U, \alpha'_U \in Asst(U)$ and $\alpha_V, \alpha'_V \in Asst(V)$ we have: $\alpha_U \alpha_V \succ \alpha'_U \alpha_V$ iff $\alpha_U \alpha'_V \succ \alpha'_U \alpha'_V$. In other words, U-assignment α_U is preferred over α'_U *ceteris paribus*. Thus, the structure of the preference relations over assignments to $\mathscr{X}$ does not change when the other variables are fixed. Moreover, the structure is independent of the values these variables take.

We define conditional preferential independence similarly. Let $U, V, W \subseteq \mathscr{X}$ be non-empty and pairwise disjoint sets such that $U \cup V \cup W = \mathscr{X}$, i.e., U, V, W partition $\mathscr{X}$. The set *U is conditionally preferentially independent of V given a W-assignment α_W* if and only if, for all $\alpha_U, \alpha'_U \in Asst(U)$ and $\alpha_V, \alpha'_V \in Asst(V)$ we have: $\alpha_U \alpha_V \alpha_W \succeq \alpha'_U \alpha_V \alpha_W$ iff $\alpha_U \alpha'_V \alpha_W \succeq \alpha'_U \alpha'_V \alpha_W$. In other words, U is preferentially independent of V when W is assigned α_W. If this holds for all $\alpha_W \in Asst(W)$, then U is conditional preferentially independent of V given the set of variables W.

In the remainder of this section we use the previously introduced elements to define a representation of the preferences of actors over variables taking into account possible dependencies between variables.

A *dependency graph* on $\mathscr{X}$ is a directed graph $G = (\mathscr{X}, E)$. The nodes of the graph are the variables X_i, and an edge from node X_i to node X_j, for $i \neq j$, exists if the preference over X_j-assignments depends on the value assigned to X_i.

The set of variables that affect the preferences over X_i-assignments is the set $Pa(X_i)$ of *parent* variables. Thus, in a dependency graph every node X_i has the nodes $Pa(X_i)$ as its immediate ancestors, i.e., its parents. Formally, given $Pa(X_i)$ we have that X_i is conditionally preferentially independent of $\mathscr{X} - (Pa(X_i) \cup \{X_i\})$. We will generally assume that dependency graphs do not contain cycles. This means that if an issue X_i is conditionally preferentially *dependent* on an issue X_j, then it cannot be the case that also issue X_j is (indirectly) conditionally preferentially *dependent* upon X_i.

Given a dependency graph, we associate with every node X_i a *Conditional Preference Table* describing the user's preferences over X_i-assignments given every $Pa(X_i)$-assignment, i.e, combination of parent values. Formally, for each $\alpha \in Asst(Pa(X_i))$, the Conditional Preference Table maps α to a preference ranking $\succ^i_\alpha$ over $dom(X_i)$. Combining the dependency graph and Conditional Preference Table leads to the following definition of a Conditional Preference network, abbreviated by CP-net.

Definition 1 (CP-net)**.** A *CP-net* is a pair $\mathscr{C} = (G, CPT)$ where $G = (\mathscr{X}, E)$ is a dependency graph and CPT is a function that maps each variable $X_i \in \mathscr{X}$ to a Conditional Preference Table, thus $CPT(X_i) : Asst(Pa(X_i)) \rightarrow TotOrd(dom(X_i))$.

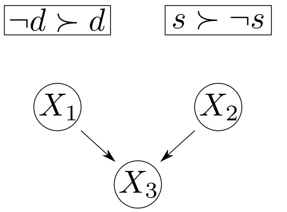
Given a CP-net, we can construct its induced preference graph. The *induced preference graph* is a complete description of the ceteris paribus preferences arising from the conditional preferences represented by the CP-net. The nodes of this graph are all $\mathscr{X}$-assignments, and an edge between two nodes $\alpha, \alpha' \in Asst(\mathscr{X})$ exists when they take a different value for exactly one variable $X_i \in \mathscr{X}$. A more precise definition is provided here.

Definition 2 (Induced preference graph)**.** Given a CP-net $\mathscr{C}$, we define its *induced preference graph* $PrG(\mathscr{C}) = (\mathscr{X}', E')$, by taking $\mathscr{X}' = Asst(\mathscr{X})$ and for $\alpha, \alpha' \in Asst(\mathscr{X})$, $(\alpha, \alpha') \in E'$ if there exists a variable $X_i \in \mathscr{X}$ such that for all $X_j \neq X_i$: $\alpha(X_j) = \alpha'(X_j)$ and $\alpha'(X_i) \succ^i_\alpha \alpha(X_i)$, where $\succ^i_\alpha = CPT(X_i)(\alpha\,|_{Pa(X_i)})$.

Note that the induced preference graph is not necessarily a total order on $Asst(\mathscr{X})$, and there can be several rankings of $Asst(\mathscr{X})$ that are consistent with the edge relation of $PrG(\mathscr{C})$.

An illustration of how to obtain an induced preference graph from a CP-net will be given in Example 1.

Example 1. Consider the simple CP-net in Figure 9.1 and its induced preference graph in Figure 9.2. They represent the preferences of the mother of the family regarding the



$d \wedge s$	$\neg h \succ h$
$\neg d \wedge s$	$h \succ \neg h$
$d \wedge \neg s$	$\neg h \succ h$
$\neg d \wedge \neg s$	$\neg h \succ h$

Figure 9.1: CP-net.

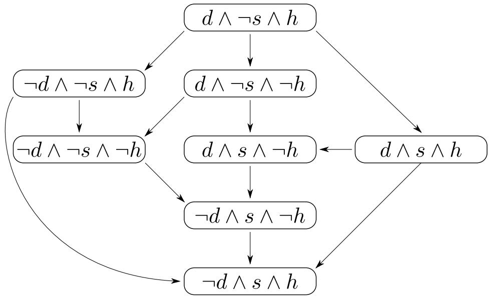


Figure 9.2: Induced preference graph.

summer holiday situation. This CP-net consist of three variables $\{X_1, X_2, X_3\}$ standing for *dog*, *sofa*, and *summer holiday*, respectively. The mother prefers no dog over having a dog, and a new sofa over no new sofa. Her preference regarding the summer holiday is conditioned on the combination of dog and sofa: if they get no dog and they do get a new sofa, the mother agrees with the summer holiday. Otherwise, if they do get a dog she does not want to leave it alone, particularly not with a new sofa. And, if there will be no dog and no new sofa there is not enough to gain for the mother and she disagrees with the summer holiday.

Having defined CP-nets and their induced preference graphs, we now define the notion of an optimal assignment.

Definition 3 (Optimal assignment)**.** An $\mathscr{X}$-assignment α is *optimal*, with respect to a CP-net $\mathscr{C}$, if in the induced preference graph $PrG(\mathscr{C})$, α has out-degree 0 ($out\_deg(\alpha) = 0$).

For an $\mathscr{X}$-assignment α, $out\_deg(\alpha) = 0$ means that there is no edge from α to another assignment, and hence no assignment exists that is preferred over α. We say that a CP-net $\mathscr{C} = (G, CPT)$ is acyclic and finite, if and only if, the underlying dependency graph G is acyclic and finite. Furthermore, if a CP-net $\mathscr{C}$ is acyclic and finite, then also the induced preference graph $PrG(\mathscr{C})$ is acyclic and finite. The following results from (Boutilier et al., 2004, Sec. 3.1) consider the CP-net instead of the induced preference graph, and will be used in Section 9.4 when computing consensus notions.

Lemma 1. *cf. (Boutilier et al., 2004, Sec. 3.1) For every finite acyclic CP-net $\mathscr{C}$ there exists a unique optimal assignment, and it can be computed in time linear in the number of variables*

9.4. FORMALIZATION OF THE M-I GAME

In this section, we formalize the M-I game using the previously defined CP-nets and induced preference graphs. However, first, we present a multi-actor extension of CP-nets with binary domains. After the M-I game model, we introduce several notions of consensus, and discuss how to improve a non-consensus situation.

9.4.1. MULTI-ACTOR CP-NETS WITH BINARY DOMAINS

In this section, we introduce multi-actor CP-nets with binary domains. As a first step we introduce a set of *actors* $A = \{a_1, \ldots, a_m\}$. Although actors involved have different interests, they are either in favor of or against a certain issue - you agree or you do not agree. Therefore, in CP-nets, we assume that that binary domains, i.e., for all $X_i \in \mathscr{X}$, $dom(X_i) = 2$ where $2 = \{0, 1\}$. Note that this is in line with the assumption stated in the previous section regarding the indifference of actors over values. We assume that actors are not indifferent regarding the outcome of an issue. In real-world decision-making processes it is observed that if actors are indifferent towards an issue, then this actor has no objection towards the issue being adopted. Thus, actors are either in favor of an issue, which also includes have no objection, or they are against the issue. It should be noted that we do allow for indifference between assignments which will become clear from the representation of assignments in the induced preference graph.

The assumption of binary domains simplifies the definitions of CP-net and induced preference graph. For binary domains, a *U-assignment* is a function $\alpha_U : U \to 2$. Hence, α_U corresponds to a subset of U, and $Asst(U) = 2^U$ where 2^U is the function space $\{f : U \to 2\}$.

In the definition of a CP-net, we have that $TotOrd(dom(X_i)) = TotOrd(2)$, and there are only two such total orders: $1 \succ 0$ and $0 \succ 1$. For the induced preference graph, we know that the number of vertices, $Asst(\mathscr{X})$, equals 2^n, where $n = |\mathscr{X}|$.

To summarize, we assume that the set of actors and the set of issues are finite, that actors are not indifferent over values of issues, and that the domain of all the issues is binary. As before, we assume the dependence graphs to be acyclic. The assumptions are made as such to let the formalization, on the one hand, be a suitable representation of the real-world, and on the other hand, be applicable by decision makers.

9.4.2. FORMALIZING PREFERENCES IN THE M-I GAME

The definitions of the previous section can be translated to the M-I game setting. The set of *actors* $A = \{a_1, \ldots a_m\}$ correspond to the decision makers who are involved in the M-I game. The set of variables $\mathscr{X} = \{X_1, \ldots, X_n\}$ corresponds to the *issues* in the M-I game. Issues are decisions that exist in the process, either on purpose, or because of external factors. Both the set of actors and the set of issues are assumed to be finite. The distinguished issue which, in the first place, results in a deadlock in the M-I game is denoted by variable X_0. In the example of the family, the distinguished issue is the summer holiday.

Since the M-I game involves multiple actors with potentially different interests they might assign different values to the issues, and dependencies between issues may vary between the actors.

Definition 4 (Static model of the Multi-Issue game)**.** Formally, the M-I game is defined by the following tuple:

$$\text{M-I game} = (A,\ \mathscr{X},\ X_0,\ \{\mathscr{C}_{a_i} \mid a_i \in A\}),$$

where, A is the set of actors, $\mathscr{X}$ is the set of issues, where for all $X_i \in \mathscr{X}$, $dom(X_i) = \{0,1\}$, X_0 is the distinguished issue, $\mathscr{C}_{a_i} = ((X_{a_i}, E_{a_i}), CPT_{a_i})$ is the CP-net that represents the conditional preferences over issues for the actor $a_i \in A$.

The static model of the M-I game describes the actors, the issues, and the conditional preferences of the actors. However, it does not describe the dynamics of the M-I game. In Section 9.5, we address the dynamics of the M-I game.

9.4.3. CONSENSUS NOTIONS

The ultimate goal of the M-I game is to reach consensus among the actors involved. Since we have defined the M-I game, we want to understand when consensus is reached in the game.

Recall the definition of optimal assignment (Definition 3), and that for each CP-net, there is a unique optimal assignment (Lemma 1). Since the M-I game involves multiple actors with different CP-nets, their optimal assignments can be different. In order for the actors to make a collective decision they need to agree on the outcome of the M-I game. In case the actors agree on the same outcome the actors reach *consensus*. In the remainder of this section we define different types of consensus.

Definition 5 (Consensus)**.** There is consensus on an assignment α if α is optimal for all $a_i \in A$.

We notice that this definition of consensus is quite restrictive, since it requires everyone to have the same optimal assignment. Given a situation with multiple actors having different preferences it is unlikely that such a form of consensus exists. Therefore, we define weaker versions of consensus which correspond to cases in real-world decision-making processes. Majority consensus requires only a majority of the actors to share the optimal outcome. Core network consensus requires the core network, i.e., the main actors at the strategic level or the actors who are most powerful, to have the same optimal assignment. We refer the reader to the multi-level perspective in Section 5.3 in Chapter 5 for out description of different levels within organizations.

Definition 6 (Majority optimal consensus)**.** An assignment α is *majority optimal*, if α is optimal for a majority of $a_i \in A$.

Definition 7 (Core optimal consensus)**.** An assignment α is *core optimal*, if α is optimal for the core network of $a_i \in A$.

Given the CP-nets for all actors, we can check whether consensus, majority optimal consensus, or core optimal consensus exists by adopting the following procedure.

1. Construct the induced preference graphs for all actors.
2. Compute the optimal assignment in the induced preference graph for all actors (cf. Lemma 1).
3. Compare the optimal assignment of the actors:
    - if all actors have the same optimal assignment, then consensus is reached.

- if the majority of the actors have the same optimal assignment, then majority optimal consensus is reached.
- if the, previously defined, core network of actors have the same optimal assignment, then core optimal consensus is reached.

It is not hard to see that none of the before mentioned types of consensus need to exist in a M-I game. We introduce a new notion, the distance to an actor's optimal assignment, to define another type of consensus.

The *distance* from an assignment α to an assignment α' is the usual graph distance in the induced preference graph, that is, the length of the shortest path from α to α', denoted by $d(\alpha, \alpha')$.

Definition 8 (k-optimal consensus)**.** An assignment α is *k-optimal* for $a_i \in A$ if in the induced preference graph $PrG(\mathscr{C}_{a_i})$, we have that $d(\alpha, \alpha') \leq k$ where α' is the optimal assignment. There is *k-optimal consensus* on an assignment α if for all $a_i \in A$, α is k-optimal for a_i.

Note that 0-optimal consensus is the same as consensus in Definition 5. The notion of k-optimal consensus will always exist for k at most 2^n where $n = |\mathscr{X}|$. It is interesting to find the smallest k for which there is an assignment α such that α is k-optimal for all actors. We propose an algorithm, based on Backwards Breadth-First Search (BFS) (West, 2000).

Given CP-nets $\mathscr{C}_{a_i}$ for all $a_i \in A$, first construct the induced preference graphs $PrG(\mathscr{C}_{a_i})$ and find the optimal outcome α_{a_i} for all $a_i \in A$.

9

Algorithm 1 Find smallest k for k-optimal consensus

Input: $PrG(\mathscr{C}_{a_i}) = (\mathscr{X}', E_i')$ and optimal assignment α_{a_i} for all $a_i \in A$.
Idea: Search through the graph starting from the optimal assignment and after each step compare the assignments of the actors that are included in the steps so far. Count the number of steps until the intersection contains at least one assignment α^*. This step is the smallest k for which k-optimal consensus exists, and α^* is k-optimal.
Output: k and $\bigcap_{a_i \in A} \text{Cur}_i$.

Initialization:
k := 0;
for $a_i \in A$ **do**
  $\text{Cur}_i := \{\alpha_{a_i}\}$
end for
Body:
while $\bigcap_{a_i \in A} \text{Cur}_i = \emptyset$ **do**
  for $a_i \in A$ **do**
    $\text{Cur}_i \leftarrow \text{Cur}_i \cup \{\alpha' \in Asst(\mathscr{X}) \mid \exists \alpha \in \text{Cur}_i : (\alpha, \alpha') \in E_i'\}$
  end for
  $k \leftarrow k + 1$
end while

Remark. The correctness of the algorithm depends on the existence of a path from every assignment α to the optimal assignment in the induced preference graph $PrG(\mathscr{C})$. Boutilier et al. (2004) implicitly show this in the proof of their Lemma 3.

9.4.4. ANALYZING (NON)CONSENSUS IN THE M-I GAME

In the M-I game, consensus is not present at the start of the process. Once more issues are placed on the agenda a game of give-and-take between the actors develops in order to reach consensus. The number of issues on the agenda can be large, and the different perspectives of actors, both regarding dependencies between issues, and their preferences over issues, make it unclear which issues need to be traded. It is thus valuable to specify which issues one needs to include in the give-and-take game while taking into account the different perspectives of actors. In the previous section, we provided a procedure for first, finding the smallest k for which k-optimal consensus exists, and second, achieving the list of issues that need to be traded before the actors can reach k-optimal consensus.

For practical applications of the M-I game formalization it is interesting to know which issues need to be placed on the agenda such that consensus can be reached on a larger set of issues. In other words, given a k-optimal assignment α, which issues need to be agreed upon by the actors in order to potentially reach consensus on a p-optimal assignment for $p < k$? Again we give a procedure which this time outputs a set of issues.

For all actors $a_i \in A$ there exists a shortest path from from optimal assignment α_{a_i} to k-optimal assignment α. This path consists of at most k assignments that are connected via edges in the induced preference graph. Each two assignments that are connected via an edge differ from each other at exactly one issue by definition of the induced preference graph (Def. 2, p. 183). Hence, with each edge on this path we can associate an issue, and with each path we can associate a set of issues. Let $\hat{X}_{a_i}$ be this set of issues for $a_i \in A$, called the *issue set*. On any shortest path between two assignments, each issue appears only once.

9

The issue set $\hat{X}_{a_i}$ of an actor a_i contains the issues to which a_i assigns a different value compared to its optimal assignment. Meaning, if the value of the issues in $\hat{X}_{a_i}$ change, then the k of the k-optimal can be reduced for actor a_i. Note that the intersection of the $\hat{X}_{a_i}$ for all $a_i \in A$ is empty, else we would have had $k-1$-optimal consensus. The issue sets can give insights into the constellation of actors that share parts of their issue sets.

- Issues that belong to $\hat{X}_{a_i}$ for many (or some) actors $a_i \in A$ are easiest to reach consensus on. Moreover, the issue sets specify which actors are the minority and thus need to be convinced.

- Issues that belong to $\hat{X}_{a_i}$ for half of the actors $a_i \in A$ are the issues that split up the actors in a group being in favor and a group being against. Again, the issue sets define who belongs to which side.

A way to use these issue sets strategically is by forming coalitions with actors that share issue sets. Taking into account the importance actors give to the different issues of the issue set is another level of analysis.

This section presented a multi-actor extension of CP-nets with binary domains. Furthermore, the M-I game model is stated together with its assumptions. Different notions of consensus are introduced, and we provided an algorithm for finding the smallest k to reach k-optimal consensus. The section ended with a procedure for discovering the set of issues that can be put on the agenda in order to reduce k.

9.5. DYNAMICS OF THE M-I GAME

So far we only discussed the static situation of the M-I game. In this section, we, informally, introduce our ideas on the dynamics of the M-I game. The dynamics of the M-I game can be represented by introducing different rounds. In each round, the father of the family (see Section 9.2), or some invisible person, can put new issues on the agenda in order to eventually reach consensus on this new set of issues. The introduction of new issues means that the CP-nets of actors change. This change can take different forms:

1. Issues are added to the CP-net, but no new dependencies between issues (arrows) are added. Hence, the Conditional Preference Tables remain the same.

2. Issues are added to the CP-net, as well as dependencies between issues (arrows), but there is no change in the already existing CP-net. As a result, the Conditional Preference Tables are enlarged by adding new dependencies.

3. Issues are added to the CP-net, and this requires changes in the dependencies between issues (arrows) of the existing CP-net. In this case, the Conditional Preference Tables change too.

Since the CP-nets of the actors change, the optimal assignments vary in different rounds, and thus the assignments on which there is consensus differ too. It is not necessarily the case that adding more issues immediately improves the k-optimal consensus, meaning that it leads to a smaller k for which k-optimal consensus holds, and empirical examples are needed to justify this. However, as we discussed in the previous section, the issue set could assist in selecting the issues for the agenda.

In each round, the algorithm for finding the smallest k could be used to find the set of assignments on which the actors reach k-optimal consensus at this stage of the game. Based on this set we define an issue set for each actor. The issue set then informs on which issues no consensus exists. Then, there are two options, either steer the negotiations such that the actors start exchanging issues on exactly those issues or introduce new issues that may possibly lead to consensus on those issues.

This section presented an idea on how to model the dynamics of the M-I game by introducing different rounds. We propose the dynamics as direction for further research, and are particularly interested in analyzing the game while including decision makers involved in a real-world case study.

9.6. CONCLUSION

In this chapter, we presented a formalization of the M-I game using the *ceteris paribus* interpretation of preference statements and the notion of CP-nets. We extended the notion of a single actor CP-net, as presented by Boutilier et al. (2004), to the multi-actor setting and defined a M-I game model. Thereby we contribute to the theory on representing preference statements in general, and CP-nets in particular. An important feature and goal of the M-I game is to reach consensus among the actors on a set of issues. The contribution of this chapter is the proposal of different notions of consensus, including k-optimal consensus, which relate to different real-world scenarios. Furthermore, we gave an algorithm that finds the smallest k for which k-optimal consensus exists.

This chapter provided insights in and explanations of the M-I game formalization in real-world decision-making processes. The formalization gives insight in which type of consensus exists. It has the potential to analyze non-consensus situations by defining an issue set for each actor on which the actor (dis)agrees. Moreover, it can assist in selecting issues for the M-I game agenda and during the 'give-and-take' game. Finally, we discussed the dynamics of the M-I game.

One of the main limitations of our formalization is that we assume the CP-nets to be acyclic. In real-world decision-making processes the preference statements of actors are not necessarily acyclic since "everything depends on everything". Moreover, although the assumption on binary domains reflects the real-world situation, it is a simplification of the model that in a way limits the type of issues that can be included in the model. Building forth on that point, we did not specify the term issues. From investigating real-world decision-making processes we learned that issues can be of different types. For instance, an issue can be like a proposal and the actors can be in favor or against, but an issue can also be more like a problem for which multiple solutions can be defined and actors can be in favor or against such solutions. Another point, which is not reflected in the M-I game model, are the (power) relations between actors. This is an important aspect of the M-I game and influences if and how consensus is reached.

We wrote this chapter as a first step towards modeling of real-world decision-making. Given the empirical evidence on the interactions between game concepts as presented in Chapter 5 of this thesis, the formalization of separate, not yet formalized, game concepts is a first step towards modeling of such interactions. In the next section we propose a future research agenda for the analysis of M-I game situations.

9.7. FUTURE WORK

The insights from and applications of the M-I game formalization in real-world decision-making processes can be further explored in several directions. In this section, we propose a few.

In Section 9.5, we proposed ideas on how to formalize the dynamics of the M-I game. Building forth on these ideas is a direction for future research. A theoretical question is, what does it mean to change the CP-net for the formalization? In other words, how do changes in the CP-net affect the consensus notions? A practical question is, how could we simulate the dynamics?

A theoretical question regarding the assumptions made for the M-I game models is how to relax the assumptions of binary domains and acyclic CP-nets. Especially the latter is a strong assumption and could be a restriction when applying the model in practical situations. Boutilier et al. (2004) already provide a discussion on the consequences of dropping acyclicity and we could start from there. Furthermore, including other aspects such as the power relations between actor and responsibilities of actors could be a next step to enrich the model.

Evaluating a decision-making process using the M-I game model could provide insight into its potential to assist in real-world decision-making processes. By identifying different rounds and the CP-nets of each actor involved, we could analyze to which extent the real-world dynamics and outcomes reflect the model and consensus notions.

Another direction for future research is applying the model in real-world situations with decision makers involved in a M-I game situation. In a workshop session decision makers could define their CP-nets, either individually or collectively, and the algorithm can be used to find k-optimal consensus. Which new insights regarding the decision-making process does such a session produce?

Finally, to be able to model interactions between game concepts we need to formalize other game concepts in such a way that the dynamics of these interactions can be represented.

IN this chapter, we proposed a formalization of the M-I game.

- The formalization was based on the *ceteris paribus* interpretation of preference statements and used CP-nets as structures to represent the preferences of actors by taking into account the interdependencies between issues.
- The preliminaries of single-actor CP-nets as introduced by Boutilier et al. (2004) are presented.
- We extended the notion of a single actor CP-net to the multi-actor setting and defined a M-I game model.
- The goal of the M-I game is to reach consensus among the actors, therefore different notions of consensus were defined.
- The best possible consensus for all actors is called k-optimal consensus.
- We proposed an algorithm that computes the smallest k for which k-optimal consensus exists.
- Subsequently, we discussed insights in and explanations of the M-I game formalization in real-world decision-making processes:
    i. The formalization provides insight in which type of consensus exists.
    ii. It has the potential to analyze non-consensus situations by defining an issue set for each actor on which the actor (dis)agrees.
    iii. It can assist in selecting issues for the M-I game agenda.
- Finally, this chapter gave an informal account on how to address the dynamics of the M-I game and proposed directions for future research.

10

CONCLUSION

IN this chapter the conclusions of the thesis are presented. Section 10.1 provides a synopsis explaining the problems we investigated and their relevance. Section 10.2 outlines the main findings of each part of this dissertation. In Section 10.3, the conclusions of the different parts are combined before we present the practical implications of the thesis in Section 10.4. The limitations of this dissertation are addressed in Section 10.5, and finally, in Section 10.6, we propose directions for future research.

10.1. SYNOPSIS

This thesis investigated complex decision-making processes on large infrastructure systems. Infrastructure systems are complex since they consist of various systems that are interdependent. These interdependencies exist within and between technical systems, but also between technical and social systems (De Bruijn and Herder, 2009). The latter relates to the involvement of multiple actors with different incentives, perspectives, and responsibilities towards the system. The actor complexity includes the concept of agency, i.e., who owns which part of the system, and power relations between actors (Sen, 1985). Given the interdependencies between infrastructure systems, actors' agency are diffuse and dynamic. As a result, decision-making in, and on, infrastructure systems is complex (Idenburg and Weijnen, 2018).

Research on decision-making on large infrastructure systems has acknowledged a change in the way decisions are made. Where decision-making used to follow a top-down approach, it is nowadays following a process in which a complex network of actors needs to contribute to the decision, resulting in a dynamic situation (Kickert et al., 1997). Additionally, the network structure explains the existence of uncertainties regarding responsibilities of actors. The change in decision-making structure requires new rules for playing the 'decision-making' game and, as a result of those new rules, or the lack thereof, new coordination mechanisms have appeared (Idenburg and Weijnen, 2018).

Knowing which mechanisms exist helps in understanding and eventually supporting the process of decision-making. A systematic characterization of decision-making processes that addresses the actor constellation, the responsibilities of actors, and the dynamics of the process is missing. In this thesis, we have investigated complex decision-making processes on large infrastructural projects by bringing together two traditions: empirical decision-making processes and game theoretical concepts.

The empirical descriptions of decision-making processes are rich and provide a deep insight into the unstructured, and sometimes even chaotic character of the decision-making process, which occurs due to *technical uncertainties*, the involvement of *multiple actors* with different incentives, and which is taking place in a *dynamic environment*. However, this richness has disadvantages since it is mostly descriptive, it is presented as a narrative, actors are multi-rational, the process entails multiple problems and a large solution space, and a perspective of action is missing.

Game concepts are more or less the mirror image of this. They reduce the richness and provide structure by characterizing and specifying the elements of the process. They are prescriptive in analyzing different scenarios and tend to focus on one problem and optimal outcomes.

We have brought these two traditions together to strike a balance between the richness of empirical decision-making processes and the structure of the game concepts. Hereby, we explain the course of decision-making by reducing it to a limited number of game concepts, yet we still capture the complexity and dynamics of the process. The discrepancy between the game concepts and the empirical decision-making processes makes this an interesting approach to investigate.

The area of investigation and application of this dissertation is the Dutch railway sector. We considered the system a Complex Adaptive System (CAS) and, contrary to a more system-oriented perspective, we utilized an actor perspective on CAS (Holland, 1995). Our main focus concerned the interactions between second-order actors at the strategic level, while taking into account the first-order actors at the operational level and the system level. Previous research in the Dutch railway sector used gaming simulation to support decision-making processes (Meijer, 2012b). Various aspects, such as design, debriefing, and the human aspect of gaming simulations have been studied and applied in different levels in the organizations (Lo and Meijer, 2014, Roungas et al., 2018c, Van den Hoogen and Meijer, 2015). Moreover, macro-level mechanisms that play a role in systemic innovations and are impacted by gaming simulations have been found (Van den Hoogen, 2019). One of the questions that resulted from this research was: How can we reduce the uncertainty in decision-making processes by further professionalizing the use of gaming simulation? In order to answer this question we needed to improve our understanding of the complex decision-making processes and investigate how this improved understanding can eventually reduce the uncertainty in decision-making processes with the help of gaming simulation.

In this thesis, the game concepts are used to characterize decision-making processes at the strategic level to gain a better understanding of the processes and to create a perspective of action that could help in reducing the uncertainty in decision-making processes.

In the next section, we describe the main findings of the thesis for each part and provide an answer to the research questions of each chapter.

10.2. MAIN FINDINGS

The overall research aim of the thesis is:

> *Understanding and supporting complex decision-making processes by using game concepts.*

Each part of the thesis has contributed to the research aim in a different way and the main findings of each part are presented in the following sections.

10.2.1. PART I: THEORETICAL PERSPECTIVE

In Part I, we selected and defined a set of game concepts, thereby answering the first research question:

> (RQ1) Which minimal set of game concepts could cover a variety of decision-making situations?

In Chapter 2, we presented the process of selecting and defining game concepts together with an extensive literature review on games in different fields. A game concept was defined as a notion that describes a situation in which actors perform actions (or strategies) based on information to reach a certain outcome.

Based on the concepts of networks, unstructured problems, and dynamics - which explain why decision-making processes are complex - we defined a set of criteria that are able to distinguish between decision-making situations. These criteria form the basis of a taxonomy of game concepts that was used to divide a list of game concepts into various groups. For this research, we were mainly interested in game concepts describing a situation with multiple actors in a network structure who have to make a collective decision and operate in a dynamic environment. However, two-actor games, hierarchical relations, and strategic behavior should also be represented by the game concepts. In the end, we selected a set of game concepts that together cover a large number of different groups of the taxonomy and are sufficiently distinguishable from each other. The selected game concepts are:

> Multi-Issue game, Principal-Agent game, Cascade Game, Hub-Spoke game, Volunteers Dilemma, Diners Dilemma, and Battle of the Sexes.

We defined the game concepts and included the context in which they appear, the process they characterize, their possible results, and potential risks.

The combination of game concepts is new and combines models from different fields - ranging from game theory to public administration. Therefore, the definitions of the game concepts vary from being mathematically defined to empirically substantiated and presented as a narrative (De Bruijn and Ten Heuvelhof, 2018, Rasmusen, 2007). This discrepancy makes it interesting to consider how the game concepts appear or behave differently in empirical decision-making processes. On the other hand, since the game concepts originate from different fields, we lost some of the characteristic features of the game concepts. For example, the Volunteers Dilemma is defined in such a way that if one actor acts, the other actors automatically follow since this provides them with the best payoff (Diekmann, 1985). However, in this thesis we also adopted the option of actors not following the first acting actor and instead blaming this actor. In this sense we lost some of the predictive features of game theory.

Furthermore, in Part I, we positioned the game concept approach in the broader field of decision support methods such as (formal) modeling, gaming simulation and stakeholder analysis techniques. The game concept approach distinguishes itself from other methods that aim to understand and support decision-making processes in mainly two ways:

(i) it addresses the actors' *agency*, meaning who is responsible for what, in a structured way, and

(ii) it represents the *dynamics* of actor relations and thus the dynamics of the process.

We noticed that other decision support methods did not fully cover those aspects (Bryson, 2004, Hermans and Thissen, 2009, MacArthur, 1997, Mingers and Rosenhead, 2001, Thissen and Walker, 2013). In this thesis, we have shown that the game concept approach can fill this gap and contributes to the existing theory of stakeholder and actor approaches by further developing the concept of agency and providing a better understanding of the dynamics of complex decision-making processes.

10.2.2. PART II: EMPIRICAL OBSERVATIONS

In Part II, the game concepts were used for a characterization of empirical decision-making processes of the Dutch railway sector. In Chapter 3, we stated the following research question:

> (RQ2) What is the complexity of the decision-making process, and how did the process developed for the six case studies we conducted from the Dutch railway sector?

Six different case studies from the Dutch railway sector were described using the same methods and a case description template. The description of each case study includes the system level, actor level, and context level complexity, and the essence of the process. The case studies were categorized in three families of case studies. The families were based on the types of decisions made, i.e., rebuilding of infrastructure, timetable design, and change of the safety system.

The main findings that were reflected in the six case studies are:

- Uncertainties regarding who decides what and in which order, ownership, and responsibility issues were present in all case studies.
- Power, roles and responsibilities of actors were not static but dynamic. Actors shifted in power relations and responsibilities of actors changed.
- We observed an important temporal component: at first, the focus is on the technical aspects while the influence of politics and context issues increased towards the end of the process.
- A stop-go effect is observed after new issues and new actors arrive in the decision-making process.

- Sometimes individual actors have blocking power, in two cases (Amsterdam and Nijmegen) one actor blocked the decision-making process by stating a preferred outcome different from the other actors, resulting in a delay of the process.

- We found a discrepancy between engineering decisions and strategic/political decisions in all case studies, however, the impact of these types of decisions on the final decision varied. Either, the engineering decision is leading (in cases B&M 2015 and Nijmegen); the strategic/political decision is leading (in cases B&M 2016 and ERTMS); or, both the engineering and strategic/political decision play a role (Timetable 2017 and Amsterdam).

In Chapter 4, we answered the following research question:

> (RQ3) Which game concepts can be identified in the case studies, and to which extent can game concepts explain the essence of the decision-making process?

We identified the game concepts in decision-making processes of six case studies, which are described in Chapter 3. We applied different identification and verification methods to cross-check the identification of the game concepts. For each case study, and each identified game concept in the case study, the characteristics of the game were presented. Additionally, we addressed the explanatory power of the particular game concept in that case study. This led to the following results:

- An overview of the game concepts present in different case studies.

- Potential insights regarding the existence of game concepts in the families of case studies.

- For each game concept, its characteristics and explanatory power for all case studies.

- Observations on why game concepts were present, the impact of game concepts, and the interactions between game concepts.

The first point is summarized in Table 10.1 which shows the presence of game concepts in the various case studies. However, this overview does not reveal how they were 'played', or why they were present. Regarding the second point, we did not find a clear pattern when comparing the various families of case studies.

To address the third point, the characteristics of game concepts we found in the various case studies were in line with their definitions. The essence of the explanatory power of each game concept is summarized below:

> **Multi-Issue game** explains a stop-go effect, (non)consensus between actors, and over-complexity of the process.

> **Principal-Agent game** explains how the information-power relation between the principal and the agent affects the decision-making process and the responsibilities of actors.

Table 10.1: Game concepts identified in the six case studies; ✓ means that the game concept is identified.

	B&M 2015	B&M 2016	Timetable 2017	Amsterdam	Nijmegen	ERTMS
M-I	✓	✓	✓	✓	✓	✓
P-A	✓	✓	✓	✓	✓	✓
CG	✓	✓	✓	-	✓	✓
H-S	-	-	✓	-	✓	✓
VD	✓	-	-	✓	✓	-
DD	-	-	-	✓	✓	✓
BS	✓	-	✓	✓	-	✓

Cascade game describes the dependencies between decisions, including actors' agency, at different decision levels and explains sub-optimal results, a (potential) blockade of decisions and the arrival of conflicts.

Hub-Spoke game explains to which extent the hub and the spokes are aligned and how this impacts the decision-making process.

Volunteers Dilemma involves a responsibility dilemma - act or wait for someone else to act - an actor is facing when confronted with a major risk that could have negative effects on the outcome. When other actors follow the volunteer, the game explains a change in direction of the process or an on-hold situation.

Dinners Dilemma entails the dilemma of either violating the agreements made or not and explains the impact of 'freeriding' on the decision-making process.

Battle of the Sexes explains a conflict between two actors, who share the same goal but have different interests, and its impact on the decision-making process.

We concluded that a large part of the essence of the investigated decision-making processes can be explained by the seven game concepts. We were able to grasp the dynamics of complex decision-making processes on large infrastructure projects that include technical issues, multiple (public) actors, and a dynamic environment. In particular, we addressed the dynamics of the decision-making processes by a characterization of the game concepts over time and at different decision levels. This revealed the compositional nature of complex decision-making processes. Moreover, a shift in the responsibilities of actors and power relations between actors were described, and we discussed how this impacted or changed the process of decision-making. Additionally, we highlighted the underlying reasons for the arrival of conflicts, (mis)alignment of actors, and the reaching of or failure to reach consensus.

Elements of the process that were not explained by the game concepts include: (i) events that take place in the broader context of the decision-making process that not (yet) do impact the process, (ii) non-events such as "I will not act as a volunteer", and (iii) the transition from one decision moment to the next decision moment. Sometimes it is clear why a certain decision moment in which game A is present leads to a new decision moment where game B occurs, but sometimes the games are loosely coupled and different games are played at multiple levels simultaneously. Further investigation of the non-explained dynamics of the process is left for future research.

The fourth point entails a number of observations regarding the presence of game concepts which were further analyzed in Chapter 5.

i. Some game concepts are present during the entire process, while others appear incidentally, or exist for a fixed period of time. It was thus natural to consider the sequential order of game concepts.

ii. The decision-making processes are inherently multi-layered, and the existence of game concepts on and across different decision levels led to the consideration of the multi-level perspective.

iii. The explanatory power of game concepts revealed that in some situations the dynamics can only be explained through the interaction of game concepts. This observation led to the investigation of an interaction perspective.

In Chapter 5, we answered the fourth research question:

> (RQ4) Which patterns of game concepts appear when taking a temporal, multi-level, and interaction perspective?

The temporal and multi-level perspective led to a classification of the game concepts into three categories: dominant, design, and incidental.

Dominant game concepts, the M-I game and the P-A game, were continuously present over multiple decision levels. They appeared due to the constitution of the Dutch railway sector and the complexity of the decision-making process. They activated another game concept, the CG, which was observed more towards the end of the process.

Design game concepts, the CG and the H-S game, existed for a certain period of time. CG was present at multiple decision levels, and H-S appeared at a few decision levels. They were chosen to structure the process in many cases. The H-S game was present in different forms, both in internal decision-making and in formal rules of the sector.

Incidental game concepts, the VD, DD, and BS, were activated under certain conditions, usually at the end of the process at a single decision level. Once activated they needed to align a critical mass of actors before they had an impact on multiple decision levels. Incidental game concepts showed to be both constructive and destructive for the process. Stability of the process, alignment of actors, and external events influenced the activation of those game concepts.

The interaction patterns between game concepts in the different case studies revealed another level of complexity. We recognized three main types of interactions: between dominant game concepts, between design and dominant game concepts, and from incidental to dominant and design game concepts.

The classification of the game concepts and the conditions under which they occur provided guidelines for decision makers and thereby has a practical contribution. It gives decision makers insights as to which game concepts they can always expect, which game concepts they can choose, and which game concepts could be activated depending on the stability of the process, alignment of actors, and external events.

Chapter 5 provided a scientific contribution by applying a higher level of abstraction to the game concept identifications. The follow-up analysis, based on the game concept characterization of Chapter 4, yielded insight into the appearance and cohesion of game concepts in real-world decision-making processes on infrastructure systems. It thereby connects to research on decision-making in infrastructure systems since the phenomena we describe are not necessarily unique for the Dutch railway sector (Herder and Verwater-Lukszo, 2006, Weijnen and Bouwmans, 2006). The game concepts are defined in general terms and, in particular, the context elements of the game concepts, like multiple actors with different incentives and actors being organized in a network structure, also apply to other infrastructure systems such as the energy sector, the water sector, and public transport in general (Cuppen et al., 2016, Fuenfschilling and Truffer, 2016, Leijten et al., 2010). Furthermore, responsibility issues and dynamics of actor relations are present in decision-making processes on other infrastructure systems, which shows the potentially general applicability of the game concepts (Brisbois, 2019). However, the classification of game concepts - dominant, design, and incidental - could be different in other infrastructure system domains. Therefore, application of the game concepts to other infrastructure domains is proposed as a direction for future research.

The game concepts could also be seen as coordination mechanisms that describe interactions between actors (Goeree and Holt, 1999a, Ramesh and Whinston, 1994). In this case, taking a decision does not need to be the final result of the process but one could think of the process of implementing of a decision. This also requires coordination between actors and, in particular when more infrastructure systems are involved, such coordination between actors is important and often criticized (Idenburg and Weijnen, 2018, Schubert and Gupta, 2013).

10

The resulting patterns of the presence of game concepts enrich the game theory discipline since we provided empirical evidence for the existence of novel dynamic games (Rudnianski and Bestougeff, 2010). Additionally, the interactions between game concepts open up a new area of research to address the complexity of decision-making processes. Furthermore, the domain of application is enlarged by investigating decision-making processes from the Dutch railway sector.

Similar to enriching game theory, bridging empirical decision-making processes and game concepts has contributed the field of public administration. For example, the principal-agent relation has been discussed in the field (Braun and Guston, 2003), however, it has not been considered as a game. The game concept approach facilitated a rigorous empirical analysis which is necessary to explain empirical relationships (Lavertu and Moynihan, 2012). By doing so, it confirmed the existence of the game concepts in, for example, the form of principal-agent relations, and yielded new insights into how and why the game concepts exist.

In brief, the identification of game concepts and, more generic, patterns that arose from the identification, provided structure in the chaotic and sometimes messy decision-making processes. Knowing which game concepts are present, how and why they are played, and the resulting patterns of game concepts improved our understanding of the decision-making process. Moreover, it provided a perspective of action which is elaborated on in Part III.

10.2.3. PART III: APPLICATIONS

Instead of *describing* decision-making processes by using game concepts, in this part of the thesis, the research had a *prescriptive* nature. While the game concepts were used by the researchers in the previous part, the game concepts were used by various users, such as decision makers and game designers, in an intervention in this part. The researchers became facilitators of such interventions. One of the aims was to let the variety of users identify the game concepts themselves.

In order for the game concepts to be applicable in real-world decision-making processes the rather theoretical concepts needed to be translated into a game concept identification tool that can be used without requiring prior knowledge of the game concepts.

Chapter 6 presented the procedure for the design, test, and evaluation of such a tool and addressed the following research question:

> (RQ5) How should a game concept identification tool be designed and tested such that it enables users without prior knowledge of the game concepts to identify game concepts in a decision-making process?

We used an iterative procedure consisting of designing and testing the tool. The characteristics of the game concepts provided the basis of the tool. In each round of testing the researchers asked why participants made certain choices when identifying game concepts. This feedback helped to further develop the tool in a way that perspectives of different participants were accounted for. After the design and test phase, the following research question was answered:

> (RQ6) To what extent are participants able to select the right game concept when given a hypothetical scenario by using the game concept identification tool?

The experiment showed that seven out of nine scenarios were matched to the corresponding game concept with the GCs-id tool. For the two scenarios that were not successful we found two explanations: (i) the perspectives of participants, and (ii) the design of the GCs-id tool itself. Regarding the latter point, the average length of possible and chosen paths to the matching game concept was greater for those two scenarios compared to the other scenarios. Furthermore, the number of literally stated characteristics in the text of the scenarios was low compared to the other scenarios. We can conclude that the results of the test are fairly good and the game concept identification tool has the potential to be used in real-world settings.

We assumed that users of the game concept identification tool have different perspectives on the process and thus can identify different game concepts in the same process. There could also be other reasons that explain why users identify a different game concept than intended. For instance, they have a blind spot for certain dynamics, they sail on their intuitions, or they do not want to give a certain answer for ideological reasons (Burke and Miller, 1999, Zajac and Bazerman, 1991). In our case, the final evaluation was preformed by students instead of decision makers which could also have impacted the results.

Application of the game concepts has value for game design. In Chapter 7, two research questions were stated:

(RQ7) What aspects from a game theoretical analysis can be translated to game design and in what way?
(RQ8) To what extent can the design of a meaningful game be determined from a game theoretical analysis?

To answer the first question we developed a framework that proposes links between game theoretical characteristics and game design choices. Having such a framework and the GCs-id tool assists game designers in identifying the purpose of the game, worst-case scenarios, and problematic areas. Moreover, it presents possible outcomes and provides future states of the process by specifying game concepts that could appear in the future. These elements help, and potentially shorten, the game design process.

Whether this also results in a meaningful game (RQ8) is evaluated by three case studies: a successful, an unsuccessful, and a future game. The recommendations for game design were in line with the design choices of the successful game, they proposed improvements for the unsuccessful game, and they addressed a problematic scenario in the future game.

The contribution of the application of game concepts for game design consist in strengthening its theoretical foundation by providing a structured representation of the actor constellation and dynamics of the process. This assists in designing the 'right' game for the situation at hand by addressing the problem and involving the appropriate actor. Rather than focusing on the different steps in the design process (Duke, 1974) or balancing between general elements such as reality, meaning, and play (Harteveld, 2011), the framework specifies particular design choices. Furthermore, the choice for game theory as theoretical foundation connects and builds on earlier research on the foundations of gaming simulation (Bolton, 2002, Ritterfeld et al., 2009, Salen and Zimmerman, 2004) and other research that used game theoretical analysis for design of gaming simulations (Gomes et al., 2018).

10

Roungas et al. (2019) argued that game theory and the game concepts in particular are necessary to design games for decision-making. The process of modeling and building a game for a real-world system is characterized by the following challenges: (i) it can be time consuming, which translates both into delay and costs, (ii) it usually requires extensive experience on the part of the designers, as well as concrete knowledge of the system under study, and (iii) depending on the actual size of the system, it dictates multiple decision-making processes, thus increasing the probability that mistakes will be made in the course of the modeling process, especially when the system includes hidden personal agendas and a notion of politics. The game concepts and the framework that connects game concept characteristics and game design choices addresses these challenges.

Van den Hoogen (2019) showed that gaming simulation influences the volatility in a process and this effect can be described by different mechanisms. He distinguished between explanatory (converging) and exploratory (diverging) gaming simulations. The results of this thesis connect to the mechanisms and add the ability of the game concepts to specify the agency of actors. In particular, for explanatory gaming simulations it is important to make the actors, their roles, and their responsibilities explicit which could be accomplished by using the game concepts. Moreover, in such situations the potential evolution of game concepts into other game concepts could be of help in prescribing the dynamics of the process.

Applications of game concepts by decision makers in a real-world decision-making process were addressed in Chapter 8 by stating the following research questions:

> (RQ9) What strategic and operational practices do potential users identify when they together characterize a decision-making process by using game concepts? and
> (RQ10) What are the consequences of such a characterization by using game concepts on the (future) behavior of users?

Workshop sessions with decision makers enabled discussions on content and context of the process, and as well as on perspectives and behavior of actors. Furthermore, the decision makers evaluated the process and discussed further steps or improvements in the process. These different operational and strategic practices (RQ9) developed over time and a majority of the participants stated at the end of the session to have obtained a different view on the process. Moreover, we found a difference in the type of practices between participants who were initially more focused on the technical complexity and participants who were initially more focused on the actor complexity. In particular, the technical-focused participants started with discussing the content of the process and created a new (actor) perspective on the decision-making process towards the end of the session.

We expect that having the game concepts (and such a tool) available beyond this experiment will have the following consequences on the behavior of the users (RQ10). In general, participants discussed both content and actor aspects of the process in a structured way. Moreover, as participants stated, it provided them with an overview of the (potential) problems and risks of the process. In particular, technical-focus participants foresee this tool being helpful to better understand the actor complexity of the process Furthermore, participants were able to define concrete next steps or improvements for the process of decision-making.

The results of this chapter showed that decision makers with a more technical focus, i.e., the engineers, applied the game concepts in a different way from the more actor focused participants, i.e., the strategic managers. These results relate to research on engineers as strategic managers (Hopkins, 1991) and how this impacts the performance of the organization (Wooldridge and Floyd, 1990). Furthermore, the conclusions of this chapter connect to research on the impact of engineering decisions on political decisions, and vice versa (Guth and Macmillan, 1986). It is known that political decisions are not always followed by the operational level since engineering decisions are not adapted accordingly (Steenhuisen, 2009, Van den Top and Steenhuisen, 2009). The other way around, engineering decisions can block the political decision in a late stage of the process (Bekius et al., 2018a). The game concepts provide a basis for discussions which can bridge the gap between engineers taking engineering decisions and strategic managers managing political decisions.

Furthermore, the results relate to discussions on the skills and responsibilities of an engineer (Brusoni and Prencipe, 2006, Chambers, 1985). Such discussions include leadership and communication skills (Rottmann et al., 2015) in areas such as innovation and entrepreneurship (Farr and Brazil, 2009, Nair, 1997). However, engineers in a large organization who have to navigate in a network of actors and a dynamic context are required to have different skills. The game concepts assist engineers in recognizing and applying agency aspects and dynamics of complex decision-making processes.

Apart from the skills of an engineer, a debate of the responsibilities of engineers in the decision-making process is being conducted (Bacharach et al., 1990). This discussion entails questions such as to which extent should engineers be involved in strategic decisions, and to which extent should they be able to take such strategic decisions (El-Akruti et al., 2013, Kiker et al., 2005, March, 1978). The game concepts help engineers to gain political sensitivity in complex decision-making processes.

10.2.4. PART IV: FORMALIZATION

In Part IV, we took a first step towards modeling of game concept patterns observed in empirical decision-making processes. The M-I game was dominant in multiple case studies and has not yet been formalized. Hence, a critical first step is a formalization of this decision-making situation. We stated the following research questions:

(RQ11) How can the Multi-Issue game be formalized?
(RQ12) How can the formalization of the Multi-Issue game contribute to the analysis of real-world decision-making processes?

In Chapter 9, we formalized the M-I game using Conditional-Preference nets (CP-nets) (RQ11). The CP-nets are efficient structures to represent preferences of actors, in particular, when the preferences regarding an issue are dependent on the value of another issue, which is the case for the M-I game. The assumptions of the M-I model entail binary domains of issues, acyclic CP-nets, and a finite set of actors and issues. Since reaching consensus is one of the central characteristics of the M-I game, we proposed different notions of consensus. We developed an algorithm that given CP-nets of multiple actors finds the smallest k for which k-optimal consensus exists. The algorithm can be used to analyze non-consensus situations and allowed us to define the issue set for each actor. Finally, the dynamics of the M-I game have been informally addressed and are proposed to be taken up for future research.

To answer RQ12, this chapter is a first attempt to show how the formalization, including the M-I game model, the consensus notions, and the algorithm, can contribute to real-world decision-making processes: (i) The formalization provided insight into which type of consensus exists, (ii) It has the potential to analyze non-consensus situations by defining the issue set for each actor on which he (dis)agrees, and (iii) It can assist in selecting the issues on the M-I game agenda and during the 'give-and-take' game to steer the decision-making process.

Further research is necessary to assess the practical contributions of the formalization. In this, we aim to connect the use of such formal models as intervention method with decision makers themselves (Voinov and Bousquet, 2010). The formalization of the M-I game is a contribution to computational social choice theory since we have extended the CP-nets to a multi-actor setting and proposed new definitions of optimal outcomes (Apt et al., 2008, Rossi et al., 2004). We included the different perspectives of actors on the issues and introduced new notions of consensus which relate to observations from real-world decision-making processes.

As we already mentioned, the formalization of the M-I game is a first step towards modeling of real-world decision-making processes by using the game concepts. It contributes to research on modeling and simulating in the Dutch railway sector (Hansen and Pachl, 2008, Lo et al., 2013, Roungas et al., 2018e, Van Lankveld et al., 2017). However, different from this earlier research, it focuses on the game play within the strategic, and between the strategic and tactical, levels of organizations rather than the operational level. Furthermore, the formalization is a way to represent actors' perspectives in such a way that it is in line with the dynamic context in which they are is being played. This adds to the existing literature on modeling of representations of stakeholders by specifying the preferences of actors in a formal way such that an analysis of different scenarios is possible (Becu et al., 2003, Lynam et al., 2007, Rossi et al., 2004). CP-nets are structures that are able to track the dynamics of the preferences of actors. How to formalize the dynamics as well as how to represent the actors' responsibilities and power relations are directions left for future research.

10.3. SYNTHESIS

In this section, we integrate the main findings of Part II and Part III. The thesis has operationalized the concept of agency in decision-making processes by applying the game concepts in different situations. In Part II, we focused mainly on the strategic actors involved in a decision-making process, while in Part III we considered the different layers in the organization and, in particular, how the engineers and strategic managers at the tactical level apply the game concepts.

ACTORS' AGENCY

One of the main uncertainties we encountered in the different case studies and during the experiments concerned the question: "Who decides on what and in which order?". This uncertainty is observed in public management research on the role of actors in decision-making processes. An increase in fuzziness of actors, issues, and power relations at the back end of the process is visible in different policy arenas (Baumgartner and Jones, 1991).

In this dissertation, we have shown that such responsibility issues are also present in decision-making processes in the Dutch railway sector. One could say that such confusion towards the end of the process is natural, however, we interpreted this as rather surprising and something we did not expect to play such a large role in the decision-making processes in a well-regulated sector [1] such as the Dutch railways.

Going one step further, we wonder whether the uncertainties regarding responsibility and ownership which are inherently present in the decision-making processes comprise a condition or a measure for the complexity of the decision-making process. In other words, is there a cause-effect relation between the uncertainty regarding the actors' agency and dynamics of the process (who decides what and in which order) and the complexity of the decision-making process?

[1] A regulated sector refers to the fact that the responsibilities of actors, ProRail, ministry, and operators, are described in the Netverklaring and secured in (yearly) contracts (Van de Velde et al., 2009, Van den Top and Steenhuisen, 2009).

MISALIGNMENTS BETWEEN DECISIONS

Another result that arrived both from Part II and Part III is the misalignment between *engineering decisions* taken at the operational level and *political decisions* taken at the strategic or political level (Grogan and Bayrak, 2018). This topic has been discussed in other areas including, for example, reaching strategic consensus at the operational level (Boyer and McDermott, 1999) and the influence of misalignments on the organizational performance (Floyd and Wooldridge, 1997). From earlier research we know that strategic goals and decisions taken at the strategic level are not necessarily implemented and adopted as such at the operational level (Steenhuisen, 2009, Van den Top and Steenhuisen, 2009). We add to this finding the fact that engineering decisions can block the decision-making process in a late stage of the process.

The existence of a misalignment between engineering and political decisions can be explained by the following two items: (i) The strategic level does not involve engineers at an early stage, hence engineers arrive late but can still block the decision-making, and (ii) Engineers at the operational and tactical level stay within their own silo, optimizing the solution while taking into account their own goals, but do not necessarily exchange information or cooperate with others within or outside the organization. Both points lead to misalignments between the engineering decisions and political decisions. Our analysis revealed that such misalignments tend to be discovered late in the process and this is problematic since changing the design at a late stage is difficult and managing politics when the final decision moment is near can be troublesome.

The thesis contributed to solving this problem in two ways. The *theoretical* contribution is that game concepts are able to characterize the process of decision-making. In particular, game concepts address the agency aspect and explain the essence of the process. Moreover, we showed that at the interfaces between game concepts the actors' agency changes which influences the process (Bekius and Meijer, 2018a). The game concepts are thus able to detect and partly explain misalignments in the process and their existence at different levels in organizations shows the compositional nature of the complexity in decision-making processes.

10

A *practical* contribution of the thesis is that game concepts provide insight into the game that is being played. In particular, it makes engineers with a technical focus aware of the broader context in which these games are played. As a result, it could prevent engineers from staying in their own silo. Moreover, the technical knowledge that could potentially block the decision-making can already be incorporated at the strategic level at an earlier stage. Hence, engineers enabled with tools that allow them to articulate the agency aspect of the decision-making process are able to analyze the situation from a more strategic perspective and take into account actor aspects while making engineering decisions.

BRIDGING DISCIPLINES

On a more general account, the thesis has contributed to bridging different disciplines.

The selection of game concepts compromises concepts that originate from different fields and, in particular, it combines game theory and public administration. The link between game theory elements and game design choices has strengthened the connection between formal game theory and gaming simulation. The application of the game concepts as decision support tool has enabled a more practical association of game theory models as decision support method and thus enforced the link between formal models and practical applications. Finally, the formalization of a concept from public administration using computational social choice theory is an example of bridging empirically substantiated patterns with formal theories.

10.4. PRACTICAL IMPLICATIONS

The main findings of this thesis have practical implications for decision-making on infrastructure systems and in particular for the Dutch railway sector.

In the introduction of this dissertation, we stated two questions that were brought up by ProRail as follow-up questions based on earlier research into gaming simulation and decision-making: (i) How can we further professionalize the use of gaming simulation to support decision-making?, and (ii) How can we reduce the uncertainty in decision-making processes by using the methods of the studies developed earlier on? The answers to these questions are the practical implications of this thesis.

Design of gaming simulations is generally time consuming since it requires the designer to fully understand the problem. Time translates to costs and, moreover, for a gaming simulation to be of impact, involving the right actors at the right time is important. Professionalization of the use of gaming simulation to support decision-making processes entails exactly these aspects: apply the gaming simulation at the right moment in the process, address the critical problem(s) of that moment, and involve the appropriate actors. The game concepts explained the essence of the decision-making process and can assist in specifying potential problems and different scenarios that lead to outcomes of the process. Moreover, the game concepts address actors' agency, its dynamics, and the dynamics of the process itself which helps in using gaming simulation at the right time and involving the appropriate actors.

To answer the first question, we have characterized several decision-making processes by using game concepts. Additionally, we have translated game theoretical elements (the game concept characteristics) to game design choices. The framework linking the two is presented in Chapter 7.

ProRail could use these results in educating decision makers and game designers. Being able to recognize the elements of the game concepts in different situations is a first step and the game concept identification tool could constitute a good starting point. Subsequently, in particular game designers can be helped by the framework that links game concept characteristics and game design choices. We recommend to educate game designers on how to use the framework and apply it to historical case studies to become familiar with it.

To answer the second question, this thesis has shown that the game concepts can be used to support decision-making processes in several ways:

1. Game concepts can be used to *design* a decision-making process beforehand, but also to *redesign* the process during the decision-making process.

2. Based on a game concept characterization, an overview of different scenarios can assist in *steering* the process in the desired direction.

3. The classification of game concepts - dominant, design, and incidental - provides the decision maker with guidelines regarding the parameters of the decision-making process they can adjust.

4. Game concepts can be used as an intermediate step for game design as is explained in the answer to the first question.

5. Game concepts can be used as intervention method in a decision-making process.

Whether these items contribute to a reduction of the uncertainty in a decision-making process has not been empirically proven and is mentioned in the next section as one of the limitations of this thesis. However, we have several indications that this is the case.

The first item has been operationalized by characterizing the game concepts in a decision-making process together with decision makers. Creating a timeline of events with the important historical and future moments in the process, the actors involved at each moment in time, and their incentives was a good starting point. Game concepts were subsequently identified by using the game concept identification tool or game concept descriptions in this case together with the researchers. The game concept characterization assisted in the design of an important time frame in which multiple decisions needed to be made. One of the main points was the order of decisions and how this was influenced by the different opinions of the actors towards these decisions. An evaluation of this time frame revealed that actors appreciated the way in which the period was organized. Moreover, it assisted the employees designing and organizing the time frame in which multiple decisions needed to be made by focusing on the actors, their incentives, and their role in the process.

Such a characterization can be performed before the decision-making process starts but also during the process and preferably a characterization by using game concepts is repeated a couple of times to account for the changing context in which the decision-making takes place. When the final aim of the decision-making process is clear, a game concept characterization provides possible scenarios that could lead to the desired outcome. Organizing and steering the process as such is the second item of this list. Again, thinking through these possible scenarios including the actors, the decisions, etc. and the desired outcome led to concrete actions.

Regarding the third item, the classification of game concepts can help a decision maker in understanding which aspects of the process can be changed, foreseen or even prevented, and which ones are given facts. For example, a Multi-Issue game is almost always present by default, however, how the game evolves depends on the actors involved, the issues on the table, and the order in which these issues are discussed. On the other hand, a Volunteers Dilemma towards the end of the process could be destructive for or delay the process and thus in most situations one wants to prevent this. Identification of possible volunteers and addressing their needs in an early stage is an example of how to foresee such a situation and act accordingly.

Game concepts used as intervention method let decision makers themselves identify the game concepts and collectively discuss the results and their potential consequences for the decision-making process. This thesis has shown that in particular decision makers with a technical focus benefit from the application of game concepts in a process they are involved in by obtaining a different and more actor focused perspective on the process.

Furthermore, different perspectives, conflicting assumptions, and underlying expectations are unravelled. Since the intervention is performed by a group of decision makers it could lead to a common view on the process.

The different ways is which game concepts can be used to support decision-making processes assist the individual decision maker as well as the group as whole. We demonstrated the use of the game concepts by decision makers at the tactical level, however, the practical implications could also apply to decision makers at operational, strategic, or even political levels.

To operationalize the game concepts within ProRail, we recommend to set the specification of characteristics, like the actors, responsibilities, incentives, etc, as a requirement for decision-making processes on large infrastructure project. The course of the process, its dynamics, and the agency aspect are parts of decision-making processes that have been criticized often and the game concepts address exactly these aspects. Game concepts could thus be a way to facilitate discussions by decision makers on these characteristics. Such discussions could be held at different levels of the organization and at different moments in time, but we recommend (based on this research) to educate decision makers and engineers at the tactical level of the organization in recognizing and applying such concepts.

Since this thesis focuses on the Dutch railway sector as case study, the findings cannot directly be translated to infrastructural systems in general. Nevertheless, we believe that the game concepts are able to explain the main coordination mechanisms that exist in decision-making processes on large infrastructure systems in general. This suggests that the implications of this thesis also hold for other infrastructure domains, which means that the game concepts can also be used to support their decision-making processes.

10.5. LIMITATIONS

In this section, we briefly elaborate on the research limitations. Selecting seven game concepts limits the elements of the decision-making that can be covered and thus it immediately excludes some of the process' dynamics. In Section 10.2.2 of this chapter we highlighted elements of the process that are not fully explained by the game concepts.

Another simplification, that is related to the previous limitation, is that we look at the world from a game concept point of view. This could influence the findings (Hermans et al., 2014), since when you are looking for certain game concepts, most probably one will find them in the real-world. We acknowledge this fact, but our main focus is on how and why these game concepts are "played".

The case study descriptions of Chapter 3 entail different complexity levels and the essence of the process. They describe the main elements of the process, however, they also leave out several details. We do not claim that these left out details are not important, but our aim was to compare different case studies in a meta-analysis and not providing an in-depth analysis of the individual cases. Furthermore, the essence of the decision-making process suffices for the identification of the game concepts.

The game concept identification tool was evaluated with students and hypothetical scenarios. The students are a different population than the intended users in real-world decision-making processes and the scenarios are only a short description of what has actually taken place. One could say that the evaluation of the tool is not fitting its purpose

(Eden, 1992). However, evaluating the tool before application with the intended users in a real-world situation is imperative.

The thesis consists of different parts and the case studies of Part II and Part III overlap for only two case studies. These two case studies are described and characterized by using the game concepts, and they were the object of study in the workshop sessions in which decision makers identified the game concepts themselves. As a result, the conclusions of Part II and Part III cannot be compared in a one-to-one manner.

The time span of this research limits the assessment of the impact of the use of game concepts on future decision-making processes. For example, the use of the game concept identification tool for game design has only been evaluated on gaming simulations that have been used in the past. The workshop sessions which decision makers took part in did entail current decision-making processes, but the impact of the sessions has not been evaluated afterwards. A question that has not been completely answered, nor proven with empirical evidence, is whether the game concepts reduce the uncertainty in a decision-making process.

A question we were asked often by professionals of the Dutch railway sector during this research concerns the strategies that one should apply in a certain game concept. Since the game concepts are not normative - one game concept is not necessarily better than another game concept - this question is not straightforward to answer. Moreover, the context in which the game concept takes place is of major influence on how the game evolves and whether this has a positive or a negative impact on the decision-making process. For instance, changing the situation to a Multi-Issue game can broaden the agenda such that new solutions can be found and consensus is reached, but adding too many issues can make the Multi-Issue game over-complex which then delays the process. Therefore, we did not talk about particular strategies to perform when playing a certain game concept in this thesis.

The next section proposes directions for future research to address the limitations mentioned in this section.

10.6. FUTURE WORK

Based on the main findings and the limitations of the thesis we propose several directions for future research.

To generalize the game concept patterns that we found in decision-making processes of the Dutch railway sector to infrastructural systems in general, an interesting direction consist in applying the game concepts to other infrastructure domains. Comparison of the patterns found, both for the different infrastructure domains and at different decision levels, could yield new insights on how to coordinate between different infrastructure systems which is one of the challenges for decision-making on infrastructure systems (Idenburg and Weijnen, 2018).

Another direction for future research is to shift from understanding and supporting the process towards assessing the impact of the use of game concepts. In this thesis, we have not looked at the impact of the game concept characterization on the decision-making process or on the quality of the decision itself. This would be an interesting direction for future research. To assess such impact we would have to design a methodology that evaluates the use of game concepts by game designers, researchers, and decision makers over a longer period time.

This thesis presents a formalization of the Multi-Issue game as a first step towards modeling game concept patterns. Formalizing more game concepts in a way that also enables modeling the interaction between game concepts is another direction for future research. Moreover, using the formalization of the game concepts as input to support decision-making processes in organizations through intervention methods is an area that can be further explored.

To address the limitations of this thesis we propose a number of improvements and extensions of the current research. The selection of seven game concepts limits the dynamics of the decision-making process we can explain. As a next step, we propose to investigate which dynamics of the decision-making process are not properly addressed. We can then expand the selection of game concepts with models that do cover these dynamics and study the presence of these game concepts over time, at decision levels, and observe how they interact with other game concepts.

To further improve the game concept identification tool, we propose to evaluate its design based on data from the workshop sessions with decision makers. Furthermore, in collaboration with the Dutch railway sector we discussed in what way they can use the game concepts. Their feedback could further improve the design. Additionally, we can investigate the use of game concepts by decision makers in an organization by improving the set-up of the workshop sessions and the assessment methods used. Finally, we can compare game concepts with other decision support methods and study the differences to gain additional insights into, for example, when to use the game concepts.

Although, we did not mention strategies to perform in a game concept due to the major influence of context on their effectiveness this is a direction that can be studied when investigating more empirical case studies. At the same time, a formalization of the game concept allows for the analysis of different scenarios and for studying the effect of different strategies on the outcome of the game. Combining the investigation of empirical case studies and (formal) analysis of different strategies is an angle we propose for future research.

References

Ackermann, F. and Eden, C. (2011). Strategic management of stakeholders: Theory and practice. *Long Range Planning*, 44(3):179–196.

Ackoff, R. (1974). *Redesigning the Future: A Systems Approach to Societal Problems*. Wiley, London.

Adler, N. (2005). Hub-Spoke network choice under competition with an application to western Europe. *Transportation Science*, 39(1):58–72.

Adler, N., Pels, E., and Nash, C. (2010). High-speed rail and air transport competition: Game engineering as tool for cost-benefit analysis. *Transportation Research Part B: Methodological*, 44(7):812–833.

Adler, N. and Smilowitz, K. (2007). Hub-and-spoke network alliances and mergers: Price-location competition in the airline industry. *Transportation Research Part B*, 41(4):394–409.

Airiau, S. (2013). Cooperative games and multiagent systems. *The Knowledge Engineering Review*, 28(4):381–424.

Albrecht, T. (2009). Automated timetable design for demand-oriented service on suburban railways. *Public Transport*, 1(1):5–20.

Alessi, S. M. (1988). Fidelity in the design of instructional simulations. *Journal of Computer-Based Instruction*, 15(2):40–47.

Alkire, S. (2008). Concepts and measures of agency. In *OPHI Working Paper 9*, pages 1–23, University of Oxford.

Allison, G. T. (1971). *Essence of Decision: Explaining the Cuban Missile Crisis*. Little Brown, Boston.

Andersen, D. F., Vennix, J. A. M., Richardson, G. P., and Rouwette, E. A. J. A. (2007). Group model building: Problem structuring, policy simulation and decision support. *The Journal of the Operational Research Society*, 58(5):691–694.

Anderson, L. R. and Holt, C. A. (1996). Classroom games: Information cascades. *The Journal of Economic Perspectives*, 10(4):187–193.

Anderson, L. W. and Krathwohl, D. R., editors (2001). *A Taxonomy for Learning, Teaching, and Assessing. A Revision of Bloom's Taxonomy of Educational Objectives*. Allyn & Bacon, New York, 2nd edition.

Apperley, T. H. (2006). Genre and game studies: Toward a critical approach to video game genres. *Simulation & Gaming*, 37(1):6–23.

Apt, K. R., Rossi, F., and Venable, K. B. (2008). Comparing the notions of optimality in CP-nets, strategic games and soft constraints. *Annals of Mathematics and Artificial Intelligence*, 52(1):25–54.

Archetti, M. (2009). Cooperation as a volunteer's dilemma and the strategy of conflict in public goods games. *Journal of Evolutionary Biology*, 22(11):2192–2200.

Athanassiou, N., McNett, J. M., and Harvey, C. (2003). Critical thinking in the management classroom: Bloom's taxonomy as a learning tool. *Journal of Management Education*, 27(5):533–555.

Atkinson, M. M. and Coleman, W. D. (1992). Policy networks, policy communities and the problems of governance. *Governance*, 5(2):154–180.

Aumann, R. (1995). Backward induction and common knowledge of rationality. *Games and Economic Behavior*, 8(1):6–19.

Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites.* Princeton University Press, Princeton.

Axelrod, R. (1984). *The Evolution of Co-operation.* Basic Books, New York.

Bacharach, M. (1994). The epistemic structure of a theory of a game. *Theory and Decision*, 37(1):7–48.

Bacharach, S., Bamberger, P., and Conley, S. (1990). Work processes, role conflict, and role overload: The case of nurses and engineers in the public sector. *Work and Occupations*, 17(2):199–228.

Balke, T. and Gilbert, N. (2014). How do agents make decisions? A survey. *Journal of Artificial Societies and Social Simulation*, 17(4):13.

Ballet, J., Dubois, J., and Mahieu, F. (2007). Responsibility for each other's freedom: Agency as the source of collective capability. *Journal of Human Development*, 8(2):185–201.

Barreteau, O., Le Page, C., and Perez, P. (2007). Contribution of simulation and gaming to natural resource management issues: An introduction. *Simulation & Gaming*, 38(2):185–194.

Battigalli, P. and Bonanno, G. (1999). Recent results on belief, knowledge and the epistemic foundations of game theory. *Research in Economics*, 53(2):149–225.

Baumgartner, F. R. and Jones, B. D. (1991). Agenda dynamics and policy subsystems. *The Journal of Politics*, 53(4):1044–1074.

Baumgärtner, S., Becker, C., Frank, K., Müller, B., and Quaas, M. (2008). Relating the philosophy and practice of ecological economics: The role of concepts, models, and case studies in inter- and transdisciplinary sustainability research. *Ecological Economics*, 67(3):384–393.

Beckenkamp, M. (2006). A game-theoretic taxonomy of social dilemmas. *Central European Journal of Operations Research*, 14(3):337–353.

Becu, N., Bousquet, F., Barreteau, O., Perez, P., and Walker, A. (2003). A methodology for eliciting and modelling stakeholders' representations with agent based modelling. In Hales, D., Edmonds, B., Norling, E., and Rouchier, J., editors, *Multi-Agent-Based Simulation III*, pages 131–148, Berlin, Heidelberg. Springer Berlin Heidelberg.

Bekebrede, G. and Meijer, S. (2009). Understanding complex infrastructure systems: The case of SimPort-MV2. In *Second International Conference on Infrastructure Systems and Services, Developing 21st Century Infrastructure Systems*, pages 1–6, Chennai, India. IEEE.

Bekius, F., De Bruijn, H., Cunnighmam, S. W., and Meijer, S. (2016). Structuring the Multi-Issue and Hub-Spoke games found in Public Administration. In *PICMET 2016, Portland International Conference for Management of Engineering and Technology*. IEEE.

Bekius, F. and Meijer, S. (2018a). The redesign process of the timetable for the Dutch railway sector: A theoretical approach. *International Journal of System of Systems Engineering*, 8(4):330–345.

Bekius, F., Meijer, S., and De Bruijn, H. (2018a). Collaboration patterns in the Dutch railway sector: Using game concepts to compare different outcomes in a unique development case. *Research in Transportation Economics*, 69:360–368.

Bekius, F., Roungas, B., and Meijer, S. (2018b). A Game Theoretical Characterization of Design Processes in Complex Adaptive Systems. Poster presentation. CESUN conference Council of Engineering Systems Universities.

Bekius, F. A. and Meijer, S. A. (2018b). Selecting the right game concept for social simulation of real-world systems. In *14th Social Simulation Conference*, Stockholm, Sweden. Springer Verlag.

Bennett, P. G. (1987). Beyond game theory - where? In Bennett, P. G., editor, *Analysing Conflict and its Resolution: Some Mathematical Contributions*, chapter 3, pages 43–70. Clarendon Press, Oxford.

Bikhchandani, S., Hirshlleifer, D., and Welch, I. (1992). A theory of fads, fashion, custom, and cultural change as informational cascades. *Journal of Political Economy*, 100(2):992–1026.

Binmore, K. (2007). *Game Theory, A Very Short Introduction.* Oxford University Press.

Binmore, K. G. (1987). Why game theory "doesn't work". In Bennett, P. G., editor, *Analysing Conflict and its Resolution: Some Mathematical Contributions*, chapter 2, pages 23–42. Clarendon Press, Oxford.

Bloom, B. S., Engelhart, M. B., Furst, E. J., Hill, W. H., and Krathwohl, D. R. (1956). *Taxonomy of educational objectives. The classification of educational goals. Handbook 1: Cognitive domain.* Longmans Green, New York.

Bočková, K. H., Sláviková, G., and Gabrhel, J. (2015). Game theory as a tool of project management. *Procedia - Social and Behavioral Sciences*, 213:709–715. 20th International Scientific Conference Economics and Management 2015 (ICEM-2015).

Boeije, H. (2010). *Analysis in Qualitative Research*. Sage Publications, London.

Bolton, G. E. (2002). Game theory's role in role-playing. *International Journal of Forecasting*, 18(3):353–358.

Bornstein, G. (2003). Intergroup conflict: Individual, group, and collective interests. *Personality and Social Psychology Review*, 7(2):129–145.

Bornstein, G. (2008). A classification of games by player type. In Biel, A., Eek, D., Gärling, T., and Gustafsson, M., editors, *New Issues and Paradigms in Research on Social Dilemmas*, pages 27–42. Springer US, Boston, MA.

Bots, P. W., Van Twist, M. J., and Van Duin, R. (1999). Designing a power tool for policy analysts: Dynamic actor network analysis. In *Proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences, HICSS-32*, pages 10–20. IEEE.

Boutilier, C., Brafman, R., Domshlak, C., Hoos, H., and Poole, D. (2004). CP-nets: A tool for representing and reasoning with conditional ceteris paribus preference statements. *Journal of Artificial Intelligence Research*, 21:135–191.

Boyer, K. K. and McDermott, C. (1999). Strategic consensus in operations strategy. *Journal of Operations Management*, 17(3):289–305.

Brams, S. J. (1993). Theory of Moves. *American Scientist*, 81(6):562–570.

Brandenburger, A. M. and Nalebuff, B. J. (1995). *The Right Game: Use Game Theory to Shape Strategy*. Harvard Business Review, Chicago.

Brandt, F., Conitzer, V., Endriss, U., Lang, J., and Procaccia, A. D. (2016). *Handbook of Computational Social Choice*. Cambridge University Press, New York, NY, USA, 1st edition.

Braun, D. and Guston, D. (2003). Principal-agent theory and research policy: An introduction. *Science and Public Policy*, 30(5):302–308.

Brisbois, M. C. (2019). Powershifts: A framework for assessing the growing impact of decentralized ownership of energy transitions on political decision-making. *Energy Research & Social Science*, 50:151–161.

Brous, P., Janssen, M., and Herder, P. (2019). Next Generation Data Infrastructures: Towards an extendable model of the asset management data infrastructure as complex adaptive system. *Complexity*, 2019:1–17.

Brusoni, S. and Prencipe, A. (2006). Making design rules: A multidomain perspective. *Organization Science*, 17(2):179–189.

Bryson, J. M. (2004). What to do when stakeholders matter. *Public Management Review*, 6(1):21–53.

Bueren, E. M., Klijn, E. H., and Koppenjan, J. F. M. (2003). Dealing with wicked problems in networks: Analyzing and environmental debate from a network perspective. *Journal of Public Administration Research and Theory*, 13(2):193–212.

Burke, L. A. and Miller, M. K. (1999). Taking the mystery out of intuitive decision making. *Academy of Management Perspectives*, 13(4):91–99.

Burns, T. R. and Gomoliñska, A. (2001). Socio-cognitive mechanisms of belief change: Applications of generalized game theory to belief revision, social fabrication, and self-fulfilling prophesy. *Cognitive Systems Research*, 2(1):39–54.

Camerer, C. (2003). *Behavioral Game Theory: Experiments in Strategic Interaction*. Princeton University Press.

Camerer, C. F. (1997). Progress in behavioral game theory. *Journal of Economic Perspectives*, 11(4):167–188.

Cantarelli, C. C., Chorus, C. G., and Cunningham, S. W. (2013). Explaining cost overruns of large-scale transportation infrastructure projects using a signalling game. *Transportmetrica A: Transport Science*, 9(3):239–258.

CBS (2018). Meer Internationaal Goederentransport per Spoor. Accessed: 2019-05-21.

Chambers, G. J. (1985). What is a systems engineer? *IEEE Transactions on Systems, Man, and Cybernetics*, 15(4):517–521.

Checkland, P. (1981). *Systems Thinking, Systems Practice*. Wiley, Chichester.

Chen, T.-C., Lin, Y.-C., and Wang, L.-C. (2012). The analysis of BOT strategies based on game theory - case study on Taiwan's high speed railway project. *Journal of Civil Engineering and Management*, 18(5):662–674.

Chevaleyre, Y., Dunne, P. E., Endriss, U., Lang, J., Lemaître, M., Maudet, N., Padget, J., Phelps, S., Rodríguez-Aguilar, J. A., and Sousa, P. (2006). Issues in multiagent resource allocation. *Informatica*, 30:3–31.

Churchman, C. (1967). Wicked problems. *Management Science*, 14(4):141–142.

Cohen, N. (2015). Bargaining and informal interactions in the national budget: A game theory analysis of the Israeli case. *International Review of Administrative Sciences*, 81(1):58–78.

Cole, S., Izmalkov, S., and Sjo, E. (2014). Games in the Arctic: Applying game theory insights to Arctic challenges. *Polar Research*, 33(1):1–13.

Collis, L., Schmid, F., and Tobias, A. (2014). Managing incidents in a complex system: A railway case study. *Cognition, Technology & Work*, 16(2):171–185.

Conradie, Fritella, Palmigiano, Tzimoulis, and Wijnberg (2015). The impact of informational cascades on competitive processes in creative industries.

Creswell, J. W. and Cresswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* Sage Publications Ltd., Los Angeles, 5th edition.

Crozier, M. and Friedberg, E. (1980). *Actors and Systems: The Politics of Collective Action.* University of Chicago Press, Chicago.

Cunningham, S., Hermans, L., and Slinger, J. (2014). A review and participatory extension of game structuring methods. *EURO Journal Decision Process*, 2(3):173–193.

Cuppen, E., Bosch-Rekveldt, M. G., Pikaar, E., and Mehos, D. C. (2016). Stakeholder engagement in large-scale energy infrastructure projects: Revealing perspectives using Q methodology. *International Journal of Project Management*, 34(7):1347–1359.

Da Costa, E., Bottura, C., Boaventura, J., and Fischmann, A. (2009). The game to play: Expanding the co-opetition proposal through the strategic games matrix. *International Journal of Conflict Management*, 20(2):132–157.

De Bruijn, H. and Herder, P. M. (2009). System and actor perspectives on sociotechnical systems. *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans*, 39(5):981–992.

De Bruijn, H. and Leijten, M. (2007). Megaprojects and contested information. *Transportation Planning and Technology*, 30(1):49–69.

De Bruijn, H. and Ten Heuvelhof, E. (2000). *Networks and Decision Making.* Lemma Publishers, Utrecht.

De Bruijn, H. and Ten Heuvelhof, E. (2002). Policy analysis and decision making in a network: How to improve the quality of analysis and the impact on decision making. *Impact Assessment and Project Appraisal*, 20(4):232–242.

De Bruijn, H. and Ten Heuvelhof, E. (2018). *Management in Networks: On Multi-Actor Decision Making.* Routledge, London, UK.

De Bruijn, H., Ten Heuvelhof, E., and in 't Veld, R. (2010). *Process Management, Why Project Management Fails in Complex Decision Making Processes.* Springer-Verlag; Berlin Heidelberg.

De Gooyert, V. (2016). *Stakeholder Dynamics in the Dutch Energy Transition; Towards a Shared Frame of Reference.* PhD thesis, Radboud University Nijmegen, the Netherlands.

De Gooyert, V., Rouwette, E., Kranenburg, H., and Freeman, R. (2017). Reviewing the role of stakeholders in Operational Research: A stakeholder theory perspective. *European Journal of Operational Research*, 262(2):402–410.

De Kwaasteniet, V. (2018). Decision making is complex until the person understands the science – Een onderzoek naar het effect van zelforganisatie en co-evolutie in complexe besluitvorming binnen de Nederlandse spoorwegensector. Master's thesis, Erasmus University Rotterdam.

DeLaurentis, D. A. (2005). Understanding transportation as system-of-systems design problem. In *43rd AIAA Aerospace Sciences Meeting and Exhibit*, pages 1–14.

Demitz, J., Hubschen, C., and Albrecht, C. (2004). Timetable stability – Using simulation to ensure quality in a regular interval timetable. *WIT Transactions on State of the Art in Science and Engineering*, 40:549 – 562.

Deng, X., Zheng, X., Su, X., Chan, F. T., Hu, Y., Sadiq, R., and Deng, Y. (2014). An evidential game theory framework in multi-criteria decision making process. *Applied Mathematics and Computation*, 244:783–793.

DeWalt, K. M. and DeWalt, B. R. (2002). *Participant Observation: A Guide for Fieldworkers.* Walnut Creek, California: Altamirra.

Diekmann, A. (1985). Volunteer's dilemma. *Journal of Conflict Resolution*, 29(4):605–610.

Dodgson, J., Spackman, M., Pearman, A., and Phillips, L. (2009). *Multi-Criteria Analysis: A Manual.* Department for Communities and Local Government, London.

Dollevoet, T., Huisman, D., Schmidt, M., and Schöbel, A. (2018). Delay Propagation and Delay Management in Transportation Networks. In Borndörfer, R., Klug, T., Lamorgese, L., Mannino, C., Reuther, M., and Schlechte, T., editors, *Handbook of Optimization in the Railway Industry*, International Series in Operations Research & Management Science, pages 285–317. Springer, Chambridge.

Duke, R. D. (1974). *Gaming: The Future's Language.* Sage Publications, Inc.

Easley, D. and Kleinberg, J. (2010a). Games. In *Networks, Crowds, and Markets: Reasoning about a Highly Connected World*, chapter 6. Cambridge University Press.

Easley, D. and Kleinberg, J. (2010b). Information cascades. In *Networks, Crowds, and Markets: Reasoning about a Highly Connected World*, chapter 16. Cambridge University Press.

Eden, C. (1992). A framework for thinking about Group Decision Support Systems (GDSS). *Group Decision and Negotiation*, 1(3):199–218.

El-Akruti, K., Dwight, R., and Zhang, T. (2013). The strategic role of engineering asset management. *International Journal of Production Economics*, 146(1):227–239.

Elrod, J. K. and Fortenberry, J. L. (2017). The hub-and-spoke organization design: An avenue for serving patients well. *BMC Health Services Research*, 17(1).

Epstein, C. (2013). Theorizing agency in Hobbes's wake: The rational actor, the self, or the speaking subject? *International Organization*, 67(2):287–316.

Fang, L., Hipel, K. W., and Kilgour, D. M. (1993). *Interactive decision making: The graph model for conflict resolution.* John Wiley & Sons, New York.

Farr, J. V. and Brazil, D. M. (2009). Leadership skills development for engineers. *Engineering Management Journal*, 21(1):3–8.

Fatta, D., Naoum, D., and Loizidou, M. (2002). Integrated environmental monitoring and simulation system for use as a management decision support tool in urban areas. *Journal of environmental management*, 64(4):333–343.

Feld, S. L. (1997). Simulation games in theory development. *Sociological Forum*, 12(1):103–115.

Floyd, S. W. and Wooldridge, B. (1997). Middle management's strategic influence and organizational performance. *Journal of Management studies*, 34(3):465–485.

Flyvbjerg, B., Priemus, H., and van Wee, B. (2008). *Decision-Making on Mega-Projects: Cost-Benefit Analysis, Planning and Innovation.* Edward Elgar, Cheltenham, UK and Northampton, MA.

Forrester, J. (1958). Industrial dynamics: A major breakthrough for decision makers. *Harvard Business Review*, 36(4):37–66.

Franco, L. A. and Hämäläinen, R. P. (2016). Engaging with behavioral operational research: On methods, actors and praxis. In Kunc, M., Malpass, J., and White, L., editors, *Behavioral Operational Research: Theory, Methodology and Practice*, pages 3–25. Palgrave Macmillan UK, London.

Fraser, N. M. and Hipel, K. W. (1984). *Conflict Analysis: Models and Resolutions.* North-Holland, New York.

Fudenberg, D. and Tirole, J. (1984). The fat-cat effect, the puppy-dog ploy, and the lean and hungry look. *The American Economic Review*, 74(2):361–366.

Fuenfschilling, L. and Truffer, B. (2016). The interplay of institutions, actors and technologies in socio-technical systems – An analysis of transformations in the Australian urban water sector. *Technological Forecasting and Social Change*, 103:298–312.

Fullerton, T. (2014). *Game design workshop: A playcentric approach to creating innovative games.* Elsevier, 2nd edition.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6):897–920.

Geurts, J. L. and Joldersma, C. (2001). Methodology for participatory policy analysis. *European Journal of Operational Research*, 128(2):300–310.

Geyer, A. and Davies, A. (2000). Managing project – System interfaces: Case studies of railway projects in restructured UK and German markets. *Research in Engineering Design*, 29(7):991–1013.

Gilles, R. P. (2010). *The Cooperative Game Theory of Networks and Hierarchies*. Springer-Verlag Berlin Heidelberg.

Gintis, H. (2000). Bosses and workers, landlords and peasants, and other principal-agent models. In *Game Theory Evolving: A Problem-centered Introduction to Modeling Strategic Behavior*, chapter 14, pages 357–369. Princeton University Press.

Gneezy, U., Haruvy, E., and Yafe, H. (2004). The inefficiency of splitting the bill. *The Economic Journal*, 114:265–280.

Goeree, J. and Holt, C. (1999a). Games: Coordination. In *Encyclopedia of Cognitive Science*, pages 1–8. American Cancer Society.

Goeree, J. K. and Holt, C. A. (1999b). Stochastic game theory: For playing games, not just for doing theory. *Proceedings of the National Academy of Sciences*, 96(19):10564–10567.

Goeree, J. K. and Holt, C. A. (2000). An explanation of anomalous behaviour in binary-choice games: Entry, voting, public goods and the volunteers' dilemma. In *Virginia Economics Online Papers*. University of Virginia, Department of Economics.

Gomes, S. L., Hermans, L. M., Islam, K. F., Huda, S. N., Hossain, A. Z., and Thissen, W. A. H. (2018). Capacity building for water management in peri-urban communities, Bangladesh: A simulation-gaming approach. *Water*, 10(11).

Goverde, R. M. P. (2005). *Punctuality of Railway Operations and Timetable Stability Analysis*. PhD thesis, Delft University of Technology.

Goverde, R. M. P. (2007). Railway Timetable Stability Using Max-Plus System Theory. *Transportation Research Part B: Methodological*, 44(2):179–201.

Granello, D. H. (2000). Encouraging the cognitive development of supervisees: Using Bloom's taxonomy in supervision. *Counselor Education and Supervision*, 40(1):31–46.

Groenleer, M., Jiang, T., de Jong, M., and Bruijn, H. D. (2012). Applying western decision-making theory to the study of transport infrastructure development in China: The case of the Harbin metro. *Policy and Society*, 31(1):73–85.

Grogan, P. T. and Bayrak, A. E. (2018). Operational and strategic decisions in engineering design games. In *ASME International Design Engineering Technical Conferences & Computers and Information in Engineernig Conference*, Quebec City, Quebec, Canada.

Guardiola, E. and Natkin, S. (2005). Game theory and video game, a new approach of game theory to analyze and conceive game systems. In *CGAMES'05, International Conference on Computer Games*, pages 166–170, Angoulème, France.

Guth, W. D. and Macmillan, I. C. (1986). Strategy implementation versus middle management self-interest. *Strategic Management Journal*, 7(4):313–327.

Hansen, I. A. (2010). *Timetable Planning & Information Quality*. Southampton: WIT Press.

Hansen, I. A. and Pachl, J. (2008). *Railway Timetable & Traffic: Analysis, Modelling, Simulation*. Hamburg: Eurailpress.

Hansson, S. O. (1996). What is ceteris paribus preference? *Journal of Philosophical Logic*, 25(3):307–332.

Hardy, C., Lawrence, T. B., and Grant, D. (2005). Discourse and collaboration: The role of conversations and collective identity. *The Academy of Management Review*, 30(1):58–77.

Harsanyi, J. C. (1967). Games with incomplete information played by "bayesian" players. *Management Science*, 14(3):159–182.

Harteveld, C. (2011). *Triadic game design: Balancing reality, meaning and play*. Springer Science & Business Media, London.

Hatchuel, A. and Weil, B. (2009). C-K design theory: An advanced formulation. *Research in Engineering Design*, 19:181–192.

Helbing, D. (1994). A mathematical model for the behavior of individuals in a social field. *The Journal of Mathematical Sociology*, 19(3):189–219.

Helbing, D. and Balietti, S. (2011). From social simulation to integrative system design. *The European Physical Journal Special Topics*, 195(1):69–100.

Herder, P., Bouwmans, I., Dijkema, G., Stikkelman, R., and Weijnen, M. (2008). Designing infrastructures from a complex systems perspective. *Journal of Design Research*, 7(1):17–34.

Herder, P. and Verwater-Lukszo, Z. (2006). Towards next generation infrastructures: An introduction to the contributions in this issue. *International Journal of Critical Infrastructure Systems*, 2(2):113–120.

Hermans, F., van Apeldoorn, D., Stuiver, M., and Kok, K. (2013). Niches and networks: Explaining network evolution through niche formation processes. *Research Policy*, 42(3):613–623.

Hermans, L., Cunningham, S., and Slinger, J. (2014). The usefulness of game theory as a method for policy evaluation. *Evaluation*, 20(1):10–25.

Hermans, L. M. and Thissen, W. A. (2009). Actor analysis methods and their use for public policy analysts. *European Journal of Operational Research*, 196(2):808–818.

Holland, J. H. (1992). Complex adaptive systems. *Daedalus*, 121(1):17–30.

Holland, J. H. (1995). *Hidden Order: How Adaptation Builds Complexity*. Basic Books, New York, USA.

Holland, J. H. (2006). Studying complex adaptive systems. *Journal of System Science and Complexity*, 19(1):1–8.

Hollander, Y. and Prashker, J. N. (2006). The applicability of non-cooperative game theory in transport analysis. *Transportation*, 33(5):481–496.

Hopkins, W. E. (1991). Engineers as strategic managers: Performance assessment. *Journal of Management in Engineering*, 7(2):213–222.

Howard, N. (1971). *Paradoxes of Rationality: Theory of Meta-games and Political Behavior*. MIT press, Cambridge.

Howard, N., Bennet, P., Bryant, J., and Bradley, M. (1993). Manifesto for a theory of drama and irrational choice. *Journal of the Operational Research Society*, 44(1):99–103.

Hughes, T. (1987). The evolution of large technological systems. In Bijker, W., Hughes, T., and Pinch, T., editors, *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, pages 51–82. MIT Press, Cambridge.

Hui, E. C. M. and Bao, H. (2013). The logic behind conflicts in land acquisitions in contemporary China: A framework based upon game theory. *Land Use Policy*, 30(1):373–380.

Huisman, D., Kroon, L. G., Lentink, R. M., and Vromans, M. J. C. M. (2005). Operations Research in passenger railway transportation. *Statistica Neerlandica*, 59(4):467–497.

Idenburg, A. and Weijnen, M. (2018). Sturen op Sociale Waarde van Infrastructuur. Den Haag. Wetenschappelijke Raad voor het Regeringsbeleid.

Iida, K. (1993). When and how do domestic constraints matter? Two-level games with uncertainty. *The Journal of Conflict Resolution*, 37(3):403–426.

Ishizaka, A. and Nemery, P. (2013). *Multi-Criteria Decision Analysis: Methods and Software*. John Wiley & Sons, Chichester, UK.

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly*, 24(4):602–611.

Johnsson, M. (2018). Prisoner's dilemma as a workshop tool? In *The 2nd International GamiFIN Conference*.

Karras, D. A. and Papademetriou, R. C. (2018). A systematic review of analytical management techniques applied to competition analysis modeling towards a framework for integrating them with BPM. In Shishkov, B., editor, *Business Modeling and Software Design*, pages 166–185, Chambridge. Springer International Publishing.

Kenis, P. and Schneider, V. (1991). Policy networks and policy analysis: Scrutinizing a new analytical toolbox. In Marin, B. and Mayntz, R., editors, *Policy networks: Empirical evidence and theoretical considerations*, pages 25–59. Campus Verlag, Frankfurt am Main, Germany.

Kickert, W. J. M., Klijn, E. H., and Koppenjan, J. F. M. (1997). *Managing Complex Networks*. SAGE Publications Ltd, London, UK.

Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P., and Linkov, I. (2005). Application of multicriteria decision analysis in environmental decision making. *Integrated Environmental Assessment and Management*, 1(2):95–108.

Kimbrough, S. O., Wu, D., and Zhong, F. (2002). Computers play the beer game: Can artificial agents manage supply chains? *Decision Support Systems*, 33(3):323–333.

Klabbers, J. H. G. (2018). On the Architecture of Game Science. *Simulation & Gaming*, 49(3):207–245.

Klijn, E. H. and Teisman, G. R. (1997). Strategies and games in networks. In Kickert, W., Klijn, E. H., and Koppenjan, J., editors, *Managing Complex Networks*, chapter 6, pages 98–118. SAGE Publications Ltd.

Knoke, D. (1990). Networks of political action: Toward theory construction. *Social Forces*, 68(4):1041–1063.

Koppenjan, J. and Klijn, E. H. (2004). *Managing Uncertainties in Networks.* Taylor & Amp; Francis Ltd, London.

Laffont, J.-J. and Martimort, D. (2002). *The Theory of Incentives: The Principal-Agent Model.* Princeton University Press, Princeton and Oxford.

Lavertu, S. and Moynihan, D. P. (2012). The empirical implications of theoretical models: A description of the method and an application to the study of performance management implementation. *Journal of Public Administration Research and Theory*, 23(2):333–360.

Leech, N. and J. Onwuegbuzie, A. (2007). An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly*, 22(12):557–584.

Leijten, M., Koppenjan, J., ten Heuvelhof, E., Veeneman, W., and van der Voort, H. (2010). Dealing with competing project management values under uncertainty: The case of Randstadrail. *European Journal of Transport and Infrastructure Research*, 10(1):63–76.

Leyton-Brown, K. and Shoham, Y. (2008). *Essentials of Game Theory: A Concise, Multidisciplinary Introduction.* Synthesis Lectures on Artificial Intelligence and Machine Learning. Morgan & Claypool Publishers, Oregon State University.

Ligtvoet, A. (2013). *Images of Cooperation – A Methodological Exploration in Energy Networks.* PhD thesis, Delft University of Technology.

Lindblom, C. E. (1959). The science of muddling through. *Public Administration Review*, 9(2):79–88.

Lo, J., Van den Hoogen, J., and Meijer, S. (2013). Using gaming simulation experiments to test railway innovations: Implications for validity. In Pasupathy, R., Kim, S.-H., Tolk, A., Hill, R., and Kuhl, M. E., editors, *Proceedings of the 2013 Winter Simulation Conference*, pages 1766–1777, Washington, D.C., USA. IEEE Press.

Lo, J. C. and Meijer, S. (2014). Gaming simulation design for individual and team situation awareness. In *Frontiers in Gaming Simulation*, pages 121–128. Springer International Publishing, New York, USA.

Lo, J. C., Van den Hoogen, J., and Meijer, S. A. (2014). Testing changes in the railway system through gaming simulation: How different types of innovations affect operators' mental models. *Advances in Human Aspects of Transportation: Part III*, 9:291–302.

Lynam, T., De Jong, W., Sheil, D., Kusumanto, T., and Evans, K. (2007). A review of tools for incorporating community knowledge, preferences, and values into decision making in natural resources management. *Ecology and Society*, 12(1).

MacArthur, J. (1997). Stakeholder analysis in project planning: Origins, applications and refinements of the method. *Project Appraisal*, 12(4):251–265.

Mader, S., Natkin, S., and Levieux, G. (2012). How to analyse therapeutic games: The player/game/therapy model. In *International Conference on Entertainment Computing*, pages 193–206, Bremen, Germany. Springer Berlin Heidelberg.

Mannaerts, A., Van Daalen, C., Van Luipen, J., and Meijer, S. (2013). Supporting policy analysis in the Dutch rail sector using System Dynamics. In *Proceedings of the 31st International Conference of the System Dynamics Society, Cambridge, Massachusetts, USA, 21-25 July 2013*. System Dynamics Society.

March, J. G. (1978). Bounded rationality, ambiguity, and the engineering of choice. *The Bell Journal of Economics*, 9(2):587–608.

Marin, B. and Mayntz, R. (1991). *Policy Networks: Empirical Evidence and Theoretical Considerations*. Campus Verlag, Frankfurt am Main.

Marks, P. K. and Gerrits, L. M. (2017). Association between decisions: Experiments with coupled two-person games. *Public Management Review*, 20(7):960–979.

Markusen, A. (1996). Sticky places in slippery space: A typology of industrial districts. *Economic Geography*, 72(3):293–313.

Matsubayashi, N., Umezawa, M., Masuda, Y., and Nishino, H. (2005). A cost allocation problem arising in hub-spoke network systems. *European Journal of Operational Research*, 160(3):821–838.

Mayer, I. and De Jong, M. (2004). Combining GDSS and gaming for decision support. *Group Decision and Negotiation*, 13(3):223–241.

Mayer, I. S., Daalen, C. E. V., and Bots, P. W. (2004). Perspectives on policy analyses: A framework for understanding and design. *International Journal of Technology, Policy and Management*, 4(2):169.

Mayer, I. S., van Bueren, E. M., Bots, P. W. G., van der Voort, H., and Seijdel, R. (2005). Collaborative decision-making for sustainable urban renewal projects: A simulation gaming approach. *Environment and Planning B: Planning and Design*, 32(3):403–423.

McCardle-Keurentjes, M. H., Rouwette, E. A., and Vennix, J. A. (2008). Effectiveness of group model building in discovering hidden profiles in strategic decision-making. Athens: System Dynamics Conference.

McEvoy, S., van de Ven, F. H., Blind, M. W., and Slinger, J. H. (2018). Planning support tools and their effects in participatory urban adaptation workshops. *Journal of Environmental Management*, 207:319–333.

Meijer, S. (2012a). Gaming simulations for railways: Lessons learned from modeling six games for the Dutch infrastructure management. In Perpinya, X., editor, *Infrastructure Design, Signaling and Security in Railway*, chapter 11, pages 275–294. InTech.

Meijer, S. (2012b). Introducing gaming simulation in the Dutch railways. *Procedia - Social and Behavioral Sciences*, 48:41–51.

Meijer, S. (2015). The power of sponges: Comparing high-tech and low-tech gaming for innovation. *Simulation & Gaming*, 46(5):512–535.

Meijer, S., Reich, Y., and Subrahmanian, E. (2014). The future of gaming for designing complex systems. In Duke, R. and Kriz, W., editors, *Back to the Future of Gaming*, pages 154–167.

Meng, R., Ye, Y., and Xie, N.-g. (2010). Multi-objective optimization design methods based on game theory. In *8th World Congress on Intelligent Control and Automation (WCICA)*, pages 2220–2227, Jinan, China. IEEE.

Merrick, K., Hardhienata, M., Shafi, K., and Hu, J. (2016). A survey of game theoretic approaches to modelling decision-making in information warfare scenarios. *Future Internet*, 8(3):1–29.

Michael, D. R. and Chen, S. L. (2005). *Serious Games: Games that Educate, Train, and Inform.* Thomson Course Technology PTR.

Middelkoop, D., Meijer, S., Steneker, J., Sehic, E., and Mazzarello, M. (2012). Simulation backbone for gaming simulation in railways: A case study. In Laroque, C., Himmelspach, J., Pasupathy, R., Rose, O., and Uhrmacher, A., editors, *Proceedings of the 44th Conference on Winter Simulation*, pages 3262–3274, Berlin. IEEE.

Miller, J. H. and Page, S. E. (2007). *Complex Adaptive Systems: An Introduction to Computational Models of Social Life.* Princeton University Press.

Mingers, J. and Rosenhead, J. (2001). *Rational Analysis for a Problematic World Revisited.* John Wiley and Sons Ltd, Chichester, UK.

Mingers, J. and Rosenhead, J. (2004). Problem structuring methods in action. *European Journal of Operational Research*, 152(3):530–554.

Morecroft, J. D. (1988). System dynamics and microworlds for policymakers. *European Journal of Operational Research*, 35(3):301–320.

Morrow, J. D. (1994). *Game Theory for Political Scientists.* Princeton University Press, Princeton, New Jersey.

Moss, S. (2001). Game theory: Limitations and an alternative. *Journal of Artificial Societies and Social Simulation*, 4(2).

Muthoo, A. (1996). A bargaining model based on the commitment tactic. *Journal of Economic Theory*, 152(41):134–152.

Myerson, R. B. (1997). *Game Theory: Analysis of Conflict.* Harvard University Press.

Nair, I. (1997). Decision making in the engineering classroom. *Journal of Engineering Education*, 86(4):349–356.

Nash, C. A., Smith, A. S., van de Velde, D., Mizutani, F., and Uranishi, S. (2014). Structural reforms in the railways: Incentive misalignment and cost implications. *Research in Transportation Economics*, 48:16–23.

Nikas, A., Doukas, H., and López, L. M. (2018). A group decision making tool for assessing climate policy risks against multiple criteria. *Heliyon*, 4(3):1–38.

Nikolic, I., Dijkema, G., and van Dam, K. (2009). Understanding and shaping the evolution of sustainable large-scale socio-technical systems. In Ruth, M. and Davidsdottir, B., editors, *The Dynamics of Regions and Networks in Industrial Ecosystems*, pages 156–178. Edward Elgar Publishing, Incorporated, Cheltenham, UK, Northampton, USA.

Nilsson, F. and Darley, V. (2006). On complex adaptive systems and agent-based modelling for improving decision-making in manufacturing and logistics settings: Experiences from a packaging company. *International Journal of Operations & Production Management*, 26(12):1351–1373.

O'Donovan, J., Jones, R. E. T., Marusich, L. R., Teng, Y., Gonzalez, C., and Tobias, H. (2013). A model-based evaluation of trust and situation awareness in the diner's dilemma game. In *22nd Behaviour Representation in Modeling & Simulation (BRIMS) Conference*, pages 11–14.

O'Neill, B. (1994). Game theory models of peace and war. volume 2 of *Handbook of Game Theory with Economic Applications*, pages 995–1053. Elsevier, Amsterdam.

Oruc, S. (2014). *Strategic Behavior in Liberalized Electricity Sectors: Game Theoretical Formal Modeling in Policy Analysis.* PhD thesis, Delft University of Technology.

Oruç, S. and Cunningham, S. W. (2014). Game-like characteristic of engineering design. *Infranomics*, 24:257–266.

Osborne, M. (2003). *An Introduction to Game Theory.* Oxford University Press, USA.

Osborne, M. J. and Rubinstein, A. (1994). *A Course in Game Theory.* The MIT Press, Cambridge, Massachusetts.

Osman, H. and Nikbakht, M. (2014). A game-theoretic model for roadway performance management: A socio-technical approach. *Built Environment Project and Asset Management*, 4(1):40–54.

Ottens, M., Franssen, M., Kroes, P., and Poel, I. (2006). Modelling infrastructures as socio-technical systems. *International Journal of Critical Infrastructure Systems*, 2(2):133–145.

Owen, G. (1982). *Game Theory*. Academin Press, Inc., New York.

Priemus, H. (2010). Decision-making on mega-projects: Drifting on political discontinuity and market dynamics. *European Journal of Transport and Infrastructure Research*, 10(1):19–29.

ProRail (2014). Informatiedocument Programma Hoogfrequent Spoorvervoer Amsterdam Centraal. Technical report, Utrecht.

ProRail (2017). PHS Nijmegen, nota voorkeursalternatief. Technical report, Utrecht.

ProRail (2018a). Jaarverslag ProRail 2018. Accessed: 2019-05-21.

ProRail (2018b). Programma Hoogfrequent Spoor.

Putnam, R. D. (1988). Diplomacy and domestic politics: The logic of two-level games. *International Organization*, 42(3):427–460.

Ragin, C. C. and Becker, H. S. (1992). *What is a Case? Exploring the Foundations of Social Inquiry*. Camebridge University Press, New York.

Ramesh, R. and Whinston, A. B. (1994). Claims, arguments, and secisions: Formalisms for representation, gaming, and coordination. *Information Systems Research*, 5(3):294–325.

Rapoport, A. (1970). *N-person Game Theory: Concepts and Applications*. Ann Arbor science library. University of Michigan Press.

Rasmusen, E. (2007). *Games and Information: An Introduction to Game Theory*. MA: Blackwell Publishing, Malden.

Reich, Y. (1995). A critical review of general design theory. *Research in Engineering Design*, 7(1):1–8.

Reich, Y., Konda, S. L., Monarch, I. A., Levy, S. N., and Subrahmanian, E. (1996). Varieties and issues of participation and design. *Design Studies*, 17(2):165–180.

Rhodes, R. A. W. and Marsh, D. (1992). New directions in the study of policy networks. *European Journal of Political Research*, 21(1):181–205.

Rittel, H. and Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2):155–169.

Ritterfeld, U., Cody, M., and Vorderer, P. (2009). *Serious Games: Mechanisms and Effects*. Routledge, New York.

Rizzo and Whitman (2003). The camel's nose is in the tent: Rules, theories and slippery slopes. *UCLA Law Review*, 51(2):539–592.

Rosenthal, R. W. (1973). A class of games possessing pure-strategy Nash equilibria. *International Journal of Game Theory*, 2(1):65–67.

Rossi, F., Venable, K. B., and Walsh, T. (2004). mCP nets: Representing and reasoning with preferences of multiple agents. In *AAAI*, volume 4, pages 729–734.

Roth, A. E. and Sotomayor, M. (1992). Two-sided matching. Handbook of Game Theory with Economic Applications, pages 485–541. Elsevier.

Rottmann, C., Sacks, R., and Reeve, D. (2015). Engineering leadership: Grounding leadership theory in engineers' professional identities. *Leadership*, 11(3):351–373.

Roungas, B., Bekius, F., and Meijer, S. (2019). The game between game theory and gaming simulations: Design choices. *Simulation & Gaming*, 50(2):180–201.

Roungas, B. and Dalpiaz, F. (2016). A model-driven framework for educational game design. In De Gloria, A. and Veltkamp, R., editors, *GALA 2015 Revised Selected Papers of the 4th International Conference on Games and Learning Alliance*, volume 9599, Rome, Italy. Springer International Publishing.

Roungas, B., De Wijse, M., Meijer, S., and Verbraeck, A. (2018a). Pitfalls for debriefing games and simulation: Theory and practice. In Naweed, A., Wardaszko, M., Leigh, E., and Meijer, S., editors, *Intersections in Simulation and Gaming*, pages 101–115. Springer, Cham, Switzerland.

Roungas, B., Lo, J. C., Angeletti, R., Meijer, S. A., and Verbraeck, A. (2018b). Eliciting requirements of a knowledge management system for gaming in an organization: The role of tacit knowledge. In *49th International Conference of International Simulation and Gaming Association*, Bangkok, Thailand.

Roungas, B., Meijer, S., and Verbraeck, A. (2018c). Knowledge management of games for decision making. In Lukosch, H., Bekebrede, G., and Kortmann, R., editors, *Simulation Gaming. Applications for Sustainable Cities and Smart Infrastructures. ISAGA 2017. Lecture Notes in Computer Science, vol 10825*, Cham, Switzerland. Springer.

Roungas, B., Meijer, S., and Verbraeck, A. (2018d). Validity of railway microscopic simulations under the microscope: Two case studies. *International Journal of System of Systems Engineering*, 8(4):346–364.

Roungas, B., Meijer, S. A., and Verbraeck, A. (2018e). The future of contextual knowledge in gaming simulations: A research agenda. In Rabe, M., Juan, A. A., Mustafee, N., Skoogh, A., Jain, S., and Johansson, B., editors, *Proceedings of the 2018 Winter Simulation Conference*, Gothenburg, Sweden. IEEE.

Rouwette, E. A. and Vennix, J. A. (2006). System dynamics and organizational interventions. *Systems Research and Behavioral Science: The Official Journal of the International Federation for Systems Research*, 23(4):451–466.

Rouwette, E. A., Vennix, J. A., and Felling, A. J. (2009). On evaluating the performance of problem structuring methods: An attempt at formulating a conceptual model. *Group Decision and Negotiation*, 18(6):567–587.

Rouwette, E. A., Vennix, J. A., and Thijssen, C. M. (2000). Group model building: A decision room approach. *Simulation & Gaming*, 31(3):359–379.

Rudnianski, M. and Bestougeff, H. (2010). *Bridging games and diplomacy*. Springer, Berlin Heidelberg.

Sage, A. P. and Cuppan, C. D. (2001). On the Systems Engineering and Management of Systems of Systems and Federations of Systems. *Information Knowledge System Management*, 2(4):325–345.

Salen, K. and Zimmerman, E. (2004). *Rules of Play: Game Design Fundamentals*. MIT press, Cambridge.

Salonen, H. and Wiberg, M. (1987). Reputation pays: Game theory as a tool for analyzing political profit from credibility. *Scandinavian Political Studies*, 10(2):151–170.

San Cristóbal, J. R. (2015). The use of game theory to solve conflicts in the project management and construction industry. *International Journal of Information Systems and Project Management*, 3(2):43–58.

Schaffer, J., O'Donovan, J., Marusich, L., Yu, M., Gonzalez, C., and Höllerer, T. (2018). A study of dynamic information display and decision-making in abstract trust games. *International Journal of Human-Computer Studies*, 113:1–14.

Scharff, J. (2013). *Dynamic Contracting in Infrastructures*. PhD thesis, Delft University of Technology.

Scharpf, F. W. (1997). *Games Real Actors Play, Actor-Centered Institutionalism in Policy Research*. Westview Press, Oxford.

Schelling, T. (1960). *The Strategy of Conflict*. Harvard University Press, Cambridge.

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., Janssen, M. A., McAllister, R. R., Müller, B., Orach, K., Schwarz, N., and Wijermans, N. (2017). A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological Economics*, 131:21–35.

Schoppa, L. J. (1993). Two-level games and bargaining outcomes: Why gaiatsu succeeds in Japan in some cases but not others. *International Organization*, 47(3):353–386.

Schubert, S. and Gupta, J. (2013). Comparing global coordination mechanisms on energy, environment, and water. *Ecology and Society*, 18(2).

Schuitemaker, K., van Spaandonk, H., Kuijsten, M., and Rajabalinejad, M. (2018). Evaluating key factors influencing ERTMS risk assessment: A reference model. *International Journal On Advances in Systems and Measurements*, 11(1):22–35.

Scott, J. (2000). *Social Network Analysis. A Handbook.* Sage, London, 2nd edition.

Sebenius, J. K. (1983). Negotiation arithmetic: Adding and subtracting issues and parties. *International Organization*, 37(2):281–316.

Sen, A. (1985). Well-being, agency and freedom: The Dewey lectures 1984. *The Journal of Philosophy*, 82(4):169–221.

Senge, P., Roberts, C., and Ross, R. (1994). *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization.* Doubleday, Garden City.

Shepherd, S. and Balijepalli, C. (2015). A game of two cities: A toll setting game with experimental results. *Transport Policy*, 38:95–109.

Shoham, Y. and Leyton-brown, K. (2008). *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations.* Cambridge University Press.

Shubik, M. (1981). Game theory models and methods in political economy. *Handbook of Mathematical Economics*, 1(7):285–330.

Simon, H. A. (1972). Theories of bounded rationality. In McGuire, C. B. and Radner, R., editors, *Decision and Organization*, chapter 8, pages 161–176. North-Holland Publishing Company, Amsterdam, The Netherlands.

Simon, H. A. (1973). The structure of ill structured problems. *Artificial Intelligence*, 4(3):181–201.

Skardi, M. J. E., Afshar, A., and Solis, S. S. (2013). Simulation-optimization model for non-point source pollution management in watersheds: Application of cooperative game theory. *KSCE Journal of Civil Engineering*, 17(6):1232–1240.

Slinger, J. H., Cunningham, S. W., Hermans, L. M., Linnane, S. M., and Palmer, C. G. (2014). A game-structuring approach applied to estuary management in South Africa. *EURO Journal on Decision Processes*, 2(3):341–363.

Stauvermann, P. J. (2004). Application of principal-agent models in science policy. In *Comparative Perspectives on Scientific Expertise for Public Policy*, pages 1–13.

Steenhuisen, B. (2009). *Competing Public Values - Coping Strategies in Heavily Regulated Utility Industries.* PhD thesis, Delft University of Technology.

Sterman, J. (2000). *Business Dynamics, System Thinking and Modeling for a Complex World.* Irwin Professional, London.

Sterman, J. D. (1989). Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Science*, 35(3):321–339.

Straffin, P. D. (1993). *Game Theory and Strategy.* Mathematical Association of America.

Subrahmanian, E., Reich, Y., Smulders, F., and Meijer, S. (2011a). Design as a synthesis of spaces. In *Proceedings of the The International Association of Societies of Design Research (IASDR2011)*, pages 1–8.

Subrahmanian, E., Reich, Y., Smulders, F., and Meijer, S. (2011b). Designing: Insights from weaving theories of cognition and design theories. In *International Conference on Engineering Design (ICED11)*, pages 1–14.

Takai, S. (2010). A game-theoretic model of collaboration in engineering design. *Journal of Mechanical Design*, 132(5):1–10.

Takebayashi, M. (2015). Multiple hub network and high-speed railway: Connectivity, gateway, and airport leakage. *Transportation Research Part A: Policy and Practice*, 79:55–64.

Teisman, G. (2000). Models for research into decision-making processes: On phases, streams and decision-making rounds. *Public Administration*, 78(4):937–956.

Teisman, G. R. and Klijn, E.-H. (2008). Complexity theory and public management. *Public Management Review*, 10(3):287–297.

Teng, Y., Jones, R., Marusich, L., O'Donovan, J., Gonzalez, C., and Höllerer, T. (2013). Trust and situation awareness in a 3-player diner's dilemma game. *2013 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, CogSIMA 2013*, pages 9–15.

Thissen, W. A. and Twaalfhoven, P. G. (2001). Towards a conceptual structure for evaluating policy analytic activities. *European Journal of Operational Research*, 129(3):627–649.

Thissen, W. A. H. and Walker, W. E. (2013). *Public Policy Analysis: New Developments*. Springer US, Boston, MA.

Thompson, K. M. and Badizadegan, N. D. (2015). Valuing information in complex systems: An integrated analytical approach to achieve optimal performance in the beer distribution game. *IEEE Access*, 3:2677–2686.

Trist, E. L. (1981). *The evolution of socio-technical systems: A conceptual framework and an action research program.* Ontario Quality of Working Life Centre, Toronto.

Trist, E. L. and Bamforth, K. W. (1951). Some social and psychological consequences of the Longwall method of coal-getting. *Human Relations*, 4(1):3–38.

Tsebelis, G. (1988). Nested games: The cohesion of french electoral coalitions. *British Journal of Political Science*, 18(2):145–170.

Tversky, A. and Kahneman, D. (1986). Rational choice and the framing of decisions. *The Journal of Business*, 59(4):251–278.

Tweede Kamer der Staten-Generaal (2015a). Letter from department of infrastructure and environment to Parliament. Technical report.

Tweede Kamer der Staten-Generaal (2015b). Rapport Parlementaire enquêtecomissie Fyra. Technical report.

Tyran, C. K. (2010). Designing the spreadsheet-based decision support systems course: An application of Bloom's taxonomy. *Journal of business Research*, 63(2):207–216.

Van Benthem, J. (2014). *Logic in Games*. MIT Press.

Van de Velde, D., Jacobs, J., and Stefanski, M. (2009). Development of railway contracting for the national passenger rail services in the Netherlands. International Conference on Competition and Ownership in Landpassenger Transport - Thredbo 11. University of Sydney.

Van den Hoogen, J. (2019). *The Gaming of Systemic Innovations: Innovating in the Railway Sector using Gaming Simulations*. PhD thesis, Delft University of Technology.

Van den Hoogen, J. and Meijer, S. (2012). Deciding on innovation at a railway network operator: A grounded theory approach. In *CESUN 2012: 3rd International Engineering Systems Symposium*, Delft University of Technology, The Netherlands.

Van den Hoogen, J. and Meijer, S. (2015). Designing gaming simulations for convergence and divergence in volatile innovation journeys. In *Proceedings of the 2015 Winter Simulation Conference*.

Van den Top, J. and Sierts, A. C. F. (2009). ERTMS in Nederland. *Op de Rails*, 3:133–140.

Van den Top, J. and Steenhuisen, B. (2009). Understanding ambiguously structured rail traffic control practices. *International Journal Technology, Policy and Management*, 9(2):148–161.

Van der Lei, T., Bekebrede, G., and Nikolic, I. (2010). Critical infrastructures: A review from a complex adaptive systems perspective. *International Journal of Critical Infrastructure Systems*, 6(4):380–401.

Van der Lugt, L., Dooms, M., and Parola, F. (2013). Strategy making by hybrid organizations: The case of the port authority. *Research in Transportation Business & Management*, 8:103 – 113.

Van Dulken, J. (2018). Analysing decision-making processes within ProRail – With regard to strategic and administrative decision-making. Master's thesis, University of Groningen.

Van Lankveld, G., Sehic, E., Lo, J. C., and Meijer, S. A. (2017). Assessing gaming simulation validity for training traffic controllers. *Simulation & Gaming*, 48(2):219–235.

Van Luipen, J. and Meijer, S. A. (2012). Uploading to the MATRICS: Combining simulation and serious gaming in railway simulators. In Wilson, J. R., Mills, A., Clarke, T., Rajan, J., and Dadashi, N., editors, *Rail Human Factors around the World: Impacts on and of People for Successful Rail Operations*, page 165. CRC Press.

Veeke, H. P., Ottjes, J. A., and Lodewijks, G. (2008). *The Delft Systems Approach: Analysis and Design of Industrial Systems*. Springer London.

Veeneman, W. (2016). Public transport governance in the Netherlands: More recent developments. *Research in Transportation Economics*, 59:116–122.

Vennix, J. A. (1999). Group model-building: Tackling messy problems. *System Dynamics Review: The Journal of the System Dynamics Society*, 15(4):379–401.

Voinov, A. and Bousquet, F. (2010). Modelling with stakeholders. *Environmental Modelling & Software*, 25(11):1268–1281.

Vollmer, H. (2013). What kind of game is everyday interaction? *Rationality and Society*, 25(3):370–404.

Volokh, E. (2003). The mechanisms of the slippery slope source. *Harvard Law Review*, 116(4):1026–1137.

Von Neumann, J. and Morgenstern, O. (1944). *Theory of Games and Economic Behaviour*. Princeton University Press.

Von Neumann, J. and Morgenstern, O. (1953). *Theory of Games and Economic Behavior*. John Wiley & Sons Inc, Princeton.

Wang, J., Wei, W., Ding, L., and Li, J. (2017). Method for analyzing the knowledge collaboration effect of R&D project teams based on Bloom's taxonomy. *Computers & Industrial Engineering*, 103:158–167.

Webster, T. (2009). *Introduction to Game Theory in Business and Economics*. M.E. Sharpe, Inc., New York, USA.

Weijnen, M. and Bouwmans, I. (2006). Innovation in networked infrastructures: Coping with complexity. *International Journal of Critical Infrastructure Systems*, 2(2):121–132.

Weiss, R. S. (1994). *Learning from Strangers: The Art and Method of Qualitative Interview Studies*. The Free Press, New York.

West, D. B. (2000). *Introduction to Graph Theory*. Prentice Hall, 2nd edition.

White, L. (2009). Understanding problem structuring methods interventions. *European Journal of Operational Research*, 199(3):823–833.

Williamson, Ó. (2000). The new institutional economics: Take stock, looking ahead. *Journal of Economic Literature*, 38(3):595–613.

Winter, E. (1997). Negotiations in multi-issue committees. *Journal of Public Economics*, 65(3):323–342.

Wooldridge, B. and Floyd, S. W. (1990). The strategy process, middle management involvement, and organizational performance. *Strategic Management Journal*, 11(3):231–241.

Xiao, A., Zeng, S., Allen, J. K., Rosen, D. W., and Mistree, F. (2005). Collaborative multidisciplinary decision making using game theory and design capability indices. *Research in Engineering Design*, 16(1):57–72.

Yin, R. K. (2009). *Case Study Research: Design and Methods.* Sage Publications, London.

Zahedi, F. (1986). The analytic hierarchy process - A survey of the method and its applications. *INFORMS Journal on Applied Analytics*, 16(4):96–108.

Zajac, E. J. and Bazerman, M. H. (1991). Blind spots in industry and competitor analysis: Implications of interfirm (mis)perceptions for strategic decisions. *Academy of Management Review*, 16(1):37–56.

Zhu-Gang, J., Wen-Jia, C., and Can, W. (2014). Simulation of climate negotiation strategies between China and the US based on game theory. *Advances in Climate Change Research*, 5(1):34–40.

Zürn, M. (1993). Problematic social situations and international institutions: On the use of game theory in international politics. In *International Relations and Pan-Europe: Theoretical Approaches and Empirical Findings*, pages 63–84, Münster; Hamburg. LIT Verlag.

Zyda, M. (2005). From visual simulation to virtual reality to games. *Computer*, 38(9):25–32.

SUMMARY

This thesis investigated complex decision-making processes on large infrastructure systems by bringing together two traditions: empirical decision-making processes and game concepts. The application area of this dissertation is the Dutch railway sector which we considered a Complex Adaptive System. The overall aim of the thesis is:

Understanding and supporting complex decision-making processes by using game concepts.

THEORETICAL PERSPECTIVE

In Chapter 2, we introduced the theoretical perspective of the thesis: the game concepts. Game concepts describe the behavior of and interaction between actors who have to make a decision. The game concept approach is positioned in the field of decision support methods, such as formal (game theoretical) modeling and gaming simulation, and is unique in two aspects: (i) it addresses the actors' *agency*, meaning who is responsible for what, in a structured way, and (ii) it represents the *dynamics* of the actor relations and thus the dynamics of the process. We composed a list of game concepts that originate from different fields - ranging from formal mathematics to public administration - and this list is categorized in a taxonomy. The taxonomy is based on characteristics like the number of actors and the type of relations between actors. Based on the taxonomy we selected a limited number of game concepts that together cover a variety of different decision-making situations and that do justice to the complexity of such processes. These concepts can explain the essence of a decision-making process. The final product of this chapter is a selection of seven game concepts: Multi-Issue game (M-I), Principal-Agent game (P-A), Cascade Game (CG), Hub-Spoke game (H-S), Volunteers Dilemma (VD), Diners Dilemma (DD), and Battle of the Sexes (BS).

EMPIRICAL OBSERVATIONS

In Chapter 3, we described six case studies, i.e., decision-making processes on large infrastructure projects of the Dutch railway sector. The case studies were classified into three different families: rebuilding emplacements, frequency increase, and safety transition. The case descriptions consist of an explanation of the technical, actor, and context complexity, as well as the essence of the decision-making process. The case descriptions are used to identify the game concepts in the next chapter.

In Chapter 4, we characterized the case studies by using the game concepts and the case descriptions. We applied different methods for identification of the game concepts and used at least two different identification methods. These methods involved multiple researchers and experts for each case study to cross-check the identification of the game concepts. The chapter discussed which of the seven game concepts were present in the

case studies and outlined their main characteristics. Moreover, for each case study and each game concept, we summarized its explanatory power. From this we concluded that the game concepts are able to explain a large part of the essence of the decision-making process. The characterization of the decision-making processes using the game concepts led to the following observations: (i) some game concepts (M-I, P-A) are *always* present while other game concepts (VD, DD, BS) only appear *incidentally*; (ii) some game concepts (M-I, P-A, CG) exists at *multiple* decision levels while other game concepts (VD, DD, BS) only exist at a *single* decision level; and (iii) game concepts *interact* and the activation of a game concept can impact other game concepts both constructively and destructively.

In Chapter 5, based on the six case studies, we presented a follow-up analysis and searched for generic patterns of the presence of game concepts in empirical decision-making processes. Based on the observations in Chapter 4, we discussed three perspectives: (i) the presence of game concepts over *time*, (ii) the existence of game concepts at *multiple levels*, and (iii) the *interactions* between game concepts. For each perspective we addressed the appearance of game concepts (the "what" question), how the games are played (the "why" question), and their impact on the decision-making process. This resulted in a classification of the game concepts:

- *Dominant* game concepts (M-I and P-A) are continuously present at multiple decision levels.
- *Design* game concepts (CG and H-S) are present at some decision levels for a fixed period of time (these game concepts are called 'design' since one can choose to structure (part of) the process as such).
- Incidental game concepts (VD, DD, and BS) usually pop-up late in the process at a single decision level.

These patterns of game concepts' appearances structure empirical observations of the game play and dynamics of decision-making in the Dutch railway sector and provide guidelines for decision makers.

Up to Chapter 5, we used the game concepts to *describe* empirical decision-making processes (researchers who use the game concepts to describe the decision-making process). From Chapter 6 onward, we studied the *prescriptive* nature of the game concepts (decision makers who use the game concepts to potentially steer the process).

Applications

In Chapter 6, we designed and evaluated an instrument to identify the game concepts. It should enable potential users without knowledge of the game concepts to identify game concepts in a process of decision-making. The tool uses a decision tree based on the game concept characteristics that allows users to follow a path of (observable) characteristics leading to a game concept. Iterating the design and testing phases led to a final design we evaluated with a group of students. The evaluation showed that, for most game concepts, a majority of the participants could identify the right game concept. Taking into account the explanations of incorrect results, we concluded that the game concept identification tool has the potential to support real-world decision-making processes.

In Chapter 7, we applied the game concepts to improve the modeling of gaming simulations to support decision-making. First, the decision-making process is characterized by using the game concept identification tool. Second, we linked game concept elements (actors, strategies, issues, etc.) and decisions regarding the gaming simulation components (scenarios, goals, etc.). The resulting framework helps in filtering out less relevant gaming simulation decisions, accelerates the modeling and prototyping of gaming simulations, and makes the design decisions for such games more rigorous. The framework therefore allows for game design by less experienced game designers. Additionally, the framework identified the purpose of the game, worst-case scenarios, and problematic areas in three case studies. Furthermore, it predicted possible outcomes and showed how game concepts can evolve over time. Given these advantages, and the game design recommendations in particular, we concluded that meaningful games (for the cases in this chapter) can be designed based on the proposed framework.

In Chapter 8, the game concepts were applied by decision makers of the Dutch railway sector. We assessed how decision makers use the game concepts and aimed to understand the potential consequences of its use for the decision-making process. In workshop sessions, each addressing a different decision, the decision makers identified game concepts individually and discussed as a group which game concepts apply and what the consequences of the identification are for the process. The sessions enabled discussions on content and context of the decision-making process, and on behavior and perspectives of actors involved in the process after identification of game concepts. Additionally, participants evaluated the current situation and defined next steps in the process or identified improvements based on the discussions after the game concept identification. We found a difference in the use of game concepts between the more technically focused and the more actor focused participants. Decision makers who initially had a more technical focus on the decision-making process shifted to a more actor focus at the end of the session. Moreover, they express that the session provided them with a new or different insight into the process of decision-making.

Formalization

In Chapter 9, we formalized the Multi-Issue game. This game is one of the most frequently identified game concepts in this thesis. Formalization of not-yet formalized game concepts is a first step towards modeling and simulating real-world decision making processes. The formalization is based on the *ceteris paribus* interpretation of preference statements and uses CP-nets as structures to represent this interpretation. Based on the single-actor CP-net, we defined a multi-actor extension of the theory of CP-nets, a Multi-Issue game model, and different notions of consensus. Furthermore, we developed an algorithm that computes the smallest k for which k-optimal consensus exists. The formalization provides insight into which type of consensus exists. It has the potential to analyze non-consensus situations by defining an *issue set* for each actor on which the actor (dis)agrees. Moreover, it can assist in selecting the issues for the Multi-Issue game agenda. Finally, this chapter gave an informal account on how to address the dynamics of the Multi-Issue game and proposed directions for future research.

Conclusion

This thesis has shown that the game concepts improved our understanding of complex decision-making processes by addressing the agency of actors, its dynamics, and the dynamics of the process. Moreover, the game concepts were able to explain a large part of the essence of the decision-making process. In particular, the dynamics of the process were characterized by the game concepts and they revealed the compositional nature - over time and at decision levels - of complex decision-making processes.

Additionally, the game concepts had value for game designers and decision makers and supported the decision-making process. Game concepts assisted game designers in designing a gaming simulation that addresses the problem at hand and that involves the right actors at the appropriate moment in time. Furthermore, game concepts helped decision makers with a technical focus to understand the broader context and actor complexity of the decision-making process. Last but not least, they enabled decision makers to define next steps in the process.

Samenvatting

In dit proefschrift onderzoeken we complexe besluitvormingsprocessen over grote infrastructurele systemen. Wij hebben de besluitvorming in kaart gebracht door gebruik te maken van twee perspectieven: empirische besluitvormingsprocessen en spelpatronen. Het toepassingsgebied is de Nederlandse spoorwegsector die we zien als een Complex Adaptief Systeem. Het overkoepelende doel van het proefschrift is:

> *Complexe besluitvormingsprocessen begrijpen en ondersteunen door gebruik te maken van spelpatronen.*

Theoretisch kader

Hoofdstuk 2 introduceert het theoretisch kader van dit proefschrift: de spelpatronen. Spelpatronen beschrijven het gedrag van en interactie tussen actoren die een beslissing moeten nemen. Deze benadering valt binnen het gebied van beslissingsondersteunende methoden, zoals formele (speltheoretische) modellering en spelsimulaties. De benadering is uniek op twee belangrijke aspecten: (i) het adresseert de *vertegenwoordiging* van actoren, dit betekent op een gestructureerde manier aangeven wie verantwoordelijk is voor wat, en (ii) het beschrijft de *dynamiek* van de relaties tussen de actoren en daarmee de dynamiek van het proces. We hebben een lijst met spelpatronen samengesteld die hun oorsprong vinden in verschillende gebieden - van formele wiskunde tot bestuurskunde - en deze lijst is gecategoriseerd in een taxonomie. De taxonomie is gebaseerd op kenmerken zoals het aantal actoren en het soort relaties tussen actoren. Op basis van de taxonomie hebben we een beperkt aantal spelpatronen geselecteerd die samen een verscheidenheid aan verschillende besluitvormingssituaties beschrijven. Zij doen ook recht aan de complexiteit van een dergelijk proces door de essentie van het proces te verklaren. Het resultaat van dit hoofdstuk is een selectie van zeven spelpatronen: Multi-Issue game (M-I), Principal-Agent game (P-A), Cascade Game (CG), Hub-Spoke game (H-S), Volunteers Dilemma (VD), Diners Dilemma (DD), en Battle of the Sexes (BS).

Empirische observaties

In hoofdstuk 3 beschrijven we zes casussen van besluitvormingsprocessen over grote infrastructurele projecten in de Nederlandse spoorwegsector. Deze casussen zijn ingedeeld in drie soorten: verbouwing van grote emplacementen, frequentieverhoging en veiligheidstransitie. De casusbeschrijvingen geven de technische, actor- en contextcomplexiteit en de essentie van het proces weer. De casusbeschrijvingen worden in het volgende hoofdstuk gebruikt om de spelpatronen te identificeren.

In hoofdstuk 4 hebben we de zes besluitvormingsprocessen gekarakteriseerd aan de hand van de spelpatronen en de casusbeschrijvingen. We hebben voor elke casus ten minste twee verschillende methoden toegepast voor het identificeren van spelpatronen.

Meerdere onderzoekers en experts hebben de identificatie van spelpatronen gecontroleerd. Voor elke casus zijn de aanwezige spelpatronen samen met hun belangrijkste kenmerken weergegeven. Bovendien hebben we voor ieder spelpatroon de verklarende kracht samengevat. Hieruit concluderen we dat de essentie van de besluitvormingsprocessen grotendeels verklaard kan worden met de spelpatronen. De karakterisering van de besluitvormingsprocessen met behulp van de spelpatronen heeft tot een aantal observaties geleid: (i) sommige spelpatronen (M-I, P-A) zijn altijd aanwezig terwijl andere spelpatronen (VD, DD, BS) slechts incidenteel verschijnen; (ii) sommige spelpatronen (M-I, P-A, CG) bestaan op meerdere besluitvormingsniveaus, terwijl andere spelpatronen (VD, DD, BS) alleen bestaan op een enkel besluitvormingsniveau; en (iii) spelpatronen interacteren en de activering van een spelpatroon kan andere spelpatronen zowel constructief als destructief beïnvloeden.

In hoofdstuk 5 presenteren we een vervolganalyse waarbij we zochten naar generieke patronen van spelpatronen in empirische besluitvormingsprocessen. Op basis van de observaties van hoofdstuk 4 hebben we drie dimensies gekozen: (i) de aanwezigheid van spelpatronen over tijd, (ii) het bestaan van spelpatronen op besluitvormingsniveaus, en (iii) de interacties tussen spelpatronen. Voor elke dimensie onderzochten we het voorkomen van spelpatronen (de 'wat' vraag), hoe de spellen zijn gespeeld (de 'waarom' vraag) en hun impact op het besluitvormingsproces. Dit leverde de volgende classificatie van spelpatronen op:

- *Dominante* spelpatronen (M-I and P-A) welke continu aanwezig zijn op meerdere besluitvormingsniveaus.
- *Ontwerp* spelpatronen (CG and H-S) zijn gedurende een bepaalde periode aanwezig op de meeste of slechts enkele besluitvormingsniveaus (deze spelpatronen worden 'ontwerp' genoemd omdat men kan kiezen (een deel van) het proces als zodanig te structureren).
- *Incidentele* spelpatronen (VD, DD en BS) verschijnen meestal laat in het proces op één besluitvormingsniveau.

Deze generieke patronen structureren empirisch observaties van het gespeelde spel en de dynamiek in besluitvormingsprocessen in de Nederlandse spoorwegsector. Daarnaast geven ze ook richtlijnen voor besluitvormers.

Tot en met hoofdstuk 5 zijn de spelpatronen gebruikt om empirische besluitvormingsprocessen te beschrijven (onderzoekers karakteriseren besluitvorming met behulp van spelpatronen). Vanaf hoofdstuk 6 bestuderen we de prescriptieve aard van de spelpatronen (besluitvormers gebruiken de spelpatronen om het proces mogelijk te sturen).

Applications

In hoofdstuk 6 ontwerpen en evalueren we een instrument dat gebruikt kan worden om spelpatronen te identificeren in een besluitvormingsproces. De identificatie vindt plaats door potentiële gebruikers (o.a. besluitvormers en spelontwerpers) die geen kennis van de spelpatronen hebben. De spelpatroon identificatie tool gebruikt een beslisboom gebaseerd op de kenmerken van de spelpatronen. Dit stelt de gebruiker in staat om een pad van (observeerbare) kenmerken te volgen welke leidt naar een spelpatroon. Een iteratieve ontwerp- en testfase van dit instrument heeft geleid tot een definitief ontwerp dat is geëvalueerd met een groep studenten. Deze evaluatie toonde aan dat voor de meeste spelpatronen een meerderheid van de deelnemers in staat was om het juiste spelpatroon te identificeren. Op basis hiervan hebben we geconcludeerd dat, de uitleg van incorrecte resultaten meenemend, het instrument de potentie heeft om de besluitvormingsprocessen in de "echte" wereld te ondersteunen.

In hoofdstuk 7 hebben we de spelpatronen toegepast om de modellering van spelsimulaties ter ondersteuning van besluitvorming te verbeteren. Eerst hebben we het besluitvormingsproces gekarakteriseerd met de spelpatroon identificatie tool. Vervolgens hebben we de elementen van spelpatronen (actoren, strategieën, besluiten, enz.) verbonden met de beslissingen van de spelsimulatiecomponenten (scenario's, doelen, enz.). Het resulterende framework helpt bij het uitfilteren van minder relevante spelsimulatiebeslissingen, het versnelt het modelleren en prototypen van spelsimulaties en vereenvoudigt de ontwerpbeslissingen voor een dergelijk spel. Het framework kan daardoor ook worden toegepast door minder ervaren spelontwerpers. Het is daarnaast in staat om het doel van de game, worst case-scenario's en probleemgebieden te identificeren in drie casussen, i.e., ontworpen games voor de Nederlandse spoorsector. Verder voorspelde het framework mogelijke uitkomsten van het spelpatroon en liet zien hoe spelpatronen mogelijk kunnen evolueren in de tijd. We concluderen we dat voor de casussen die in dit hoofdstuk zijn geanalyseerd, een zinvol spel kan worden ontworpen op basis van het voorgestelde framework.

In hoofdstuk 8 beschrijven we hoe de spelpatronen zijn toegepast door besluitvormers in de Nederlandse spoorwegsector. Het doel was om te ontdekken hoe besluitvormers de spelpatronen gebruiken en te begrijpen wat de waarde van het gebruik zou kunnen zijn voor het besluitvormingsproces. In workshops identificeerden de besluitvormers spelpatronen. Daarna besprak de groep welke spelpatronen van toepassing zijn en wat de gevolgen van de spelpatroon identificatie zijn voor het proces. De workshops droegen bij aan discussies over de inhoud en de context van het besluitvormingsproces, en over het gedrag en de perspectieven van betrokken actoren. Deelnemers evalueerden de huidige situatie en identificeerden volgende stappen of verbeteringen in het besluitvormingsproces. We vonden een verschil in het gebruik van spelpatronen tussen meer technisch gefocuste en meer actor gefocuste deelnemers. Besluitvormers die aan het begin van de workshop een meer technische focus hadden verschoven hun focus naar actoren aan het einde van de workshop. Bovendien gaven vooral deze besluitvormers aan dat ze door de workshop een nieuw inzicht of ander perspectief op het besluitvormingsproces kregen.

Formalisatie

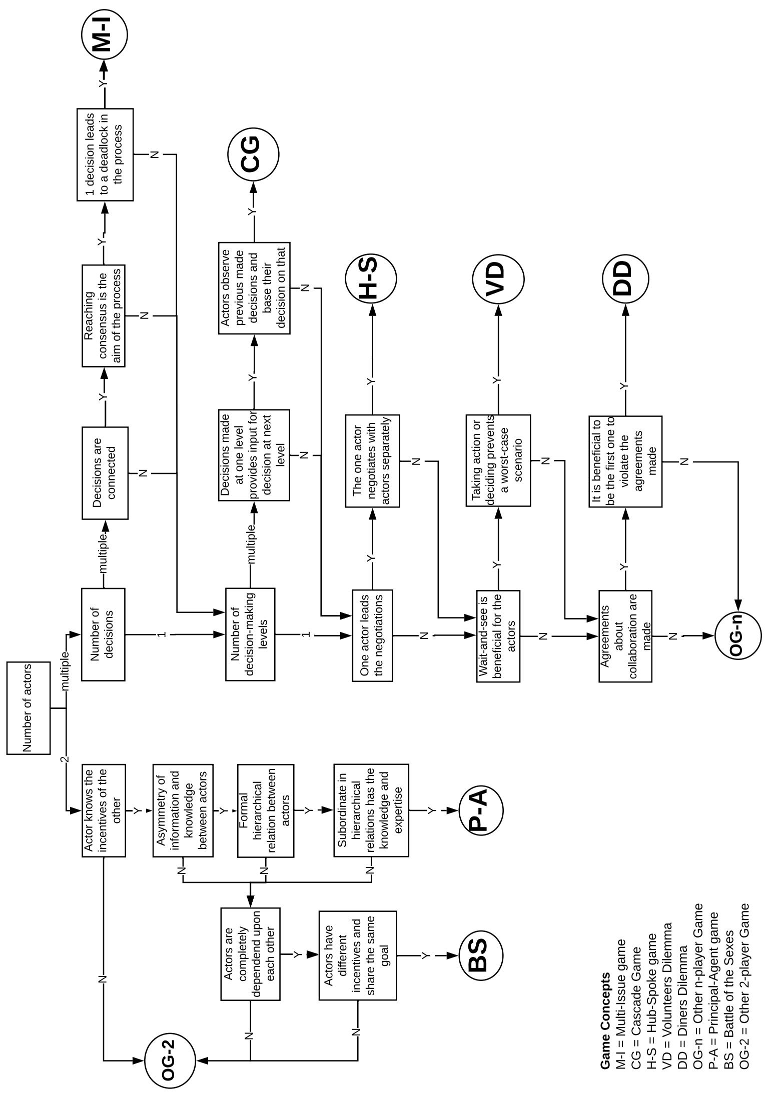
In hoofdstuk 9 hebben we de Multi-Issue game, één van de meest geïdentificeerde spelpatronen van dit proefschrift, geformaliseerd. Formalisatie van nog niet geformaliseerde spelpatronen is een eerste stap op weg naar het modelleren en simuleren van besluitvormingsprocessen. De formalisatie is gebaseerd op de *ceteris paribus*-interpretatie om voorkeuren weer te geven en maakt gebruik van Conditional Preference (CP) structuren om deze interpretatie te representeren. We hebben een multi-actor uitbreiding gedefinieerd op basis van een CP-structuur voor één actor. Daarnaast hebben we een M-I-game model en verschillende noties van consensus gedefinieerd. De formalisatie geeft inzicht in het type consensus en we hebben een algoritme ontwikkeld dat de kleinste k vindt waarvoor k-optimale consensus bestaat. Bovendien maakt de formalisatie het mogelijk om niet-consensus situaties te analyseren door middel van het definiëren van de *issue set* voor elke actor. Deze issue set bevat de issues waarover de actor het niet eens is, gegeven de voorgestelde (optimale) uitkomst. De formalisatie kan helpen bij het selecteren van de issues voor de M-I game agenda. Ten slotte geven we in dit hoofdstuk een idee hoe de dynamiek van de M-I game verder zou kunnen worden geformaliseerd samen met een aantal andere richtingen voor verder onderzoek.

Conclusie

Dit proefschrift toont aan dat spelpatronen inzicht geven in complexe besluitvormingsprocessen over grote infrastructurele projecten in de Nederlandse spoorsector. We zijn in staat om een groot deel van de essentie van het besluitvormingsproces te verklaren met de geselecteerde spelpatronen. Met name de vertegenwoordiging van actoren en hun onderlinge samenspel wordt gekarakteriseerd. Verder structureerden de spelpatronen de dynamiek van het besluitvormingsproces zelf en ze onthulden de samengestelde aard, zowel over tijd als op besluitvormingsniveaus, van complexe besluitvormingsprocessen.

De spelpatronen hebben hun waarde bewezen voor ontwerpen van spelsimulaties en ondersteunen van besluitvormingsprocessen. Spelpatronen helpen spelontwerpers bij het modelleren van een spelsimulatie door het probleem te adresseren en de juiste actoren op het juiste moment te betrekken. Spelpatronen helpen besluitvormers om vervolgstappen of verbeterpunten in het proces te identificeren. Ook stellen spelpatronen besluitvormers met een technische focus in staat om inzicht te krijgen in de bredere context en actorcomplexiteit in het besluitvormingsproces.

APPENDIX A: GAME CONCEPT IDENTIFICATION TOOL



Appendix B: Scenarios

Non-Automatically Operated Level Crossings

ProRail would like to reduce the number of non-automatic operated level crossings. They cause unsafe situations and recently several accidents happened on those level crossings. ProRail would prefer the municipalities to replace them with a tunnel. Building tunnels, however, costs a municipality a lot of money. Additionally, those level crossings are often on a dead-end road. Therefore, only few people would use the tunnel, hence this is not in the interests of the municipalities.

The situation in which one would talk about one decision regarding one level crossing brings the decision-making process into a deadlock. One way to solve this is to make a traffic plan for all non-automatic operated level crossings in the region. A proposal can be to remove half of the level crossings and to make the other half automated, or to construct a parallel road alongside the track instead of a tunnel.

This way several actors are involved, such as local residents, the province and owner of the land where the parallel road has to be placed. By discussing several decisions, which are connected to each other, room for negotiations is created. Hopefully, the end result is that the actors reach a consensus.

ERTMS

ERTMS (European Rail Traffic Management System) is a security system for trains. It has many advantages, such as trains driving closer to each other and the safety system being the same across Europe. The decision to be made is, are we going to introduce ERTMS in the Netherlands, yes or no?

A decision like this includes multiple actors and multiple levels of decision-making. This means that the decision is taken over by an organization, or part of an organization, at each next stage of the decision-making process. The decision-making process in the Netherlands started with a parliamentary research committee, who advised the government to implement ERTMS. This advice was based on an analysis concluding that ERTMS offers short follow-up times for trains and provide in the need for more capacity in the future. Then, the government took over the advice of the parliamentary committee. Subsequently, the decision to implement ERTMS nationwide was taken over by the Ministry of Infrastructure and Watermanagement (I&W). This resulted in a distribution of budgets and a plan for implementation that is carried out by ProRail and operating companies. The decision of ProRail and the operating companies to introduce ERTMS is based on the outcomes of the same decision made by the government and I&W.

Frequency increase

In the process of deciding on the increase of the number of trains per hour on the busiest corridor in the Netherlands, decision makers from different departments of the infrastructure manager (ProRail), the main operating company (NS), and the Ministry of Infrastructure and Watermanagement (I&W) are involved. There is a great desire to implement this because trains are already running in their full capacity and more passengers are expected in the future. However, the introduction of more trains must not lead to more disruptions and stranded passengers.

This situation is concerned with the decision-making that took place between the operational directors, i.e., at the operational level of the organization. Each operational director is responsible for part of the system, such as the trains, infrastructure, timetable, etc. Every part of the system must improve in order to avoid disruptions. The decision makers make an individual assessment of the extent to which their part of the system contributes and what are the risks associated with it. For an individual, it is beneficial to wait and see until someone else gets up and says that we cannot raise the frequency since that person will most probably be blamed for that. If nobody rises, there is a chance that major problems will occur on the railway system which will affect everyone, this is the so-called: worst-case scenario.

High speed line (HSL)

The HSL line is a rail connection between Schiphol and the Belgian border, via Rotterdam. In order for operating companies to drive their trains on this track, they must pay a fee to the Ministry of Infrastructure and Watermanagement (I&W). This leads to a hierarchical relation between the operating company and the Ministry.

The main operating company of the Netherlands (NS) initially offers a high bid and gets the right to drive its trains on the HSL line, provided that NS achieves a certain performance level on this track. For example, a fix number of seats must be available for passengers and trains may not delay too often.

The last two years NS was not able to meet these performance requirements. As a result, the Ministry is not happy with this and fines NS. On the other hand, the Ministry does not have the expertise and knowledge to drive the trains themselves, hence they are dependent on the expertise and knowledge of NS. Currently, the Ministry warned NS that, if they do not meet the performance requirements for the third year, the right to drive on the high speed rail will be revoked.

Rebuilding Utrecht Central Station

ProRail made a design for the new infra layout of Utrecht Central Station with the aim to increase the number of trains per hour in the railway system. A department of ProRail has fully worked out the design of the layout and at this moment they want to convince the other departments within ProRail, the operating companies, municipalities and the Ministry of Infrastructure and Watermanagement (I&W).

ProRail negotiates with the other actors separately. They never invited all actors involved together at same the table. Each negotiation is about the same decision: do you agree with the design for the infra layout of Utrecht Central Station? The decisions taken in the different negotiations do not provide input for the next negotiation. Explicit agreements on cooperation between the actors have not been made. The operating companies and the Ministry can make arguments against the design, but ProRail wants to stick to their design thus leaving little room for changes. Therefore, performing wait-and-see behavior is not beneficial for the actors.

New infra layout

ProRail made a design for the new infra layout of Utrecht Central Station with the aim to increase the number of trains per hour in the railway system. A department of ProRail has fully worked out the design of the layout and at this moment they want to convince the other departments within ProRail, the operating companies, municipalities and the Ministry of Infrastructure and Watermanagement (I&W).

ProRail negotiates with all actors together. The negotiation is about the same decision: do you agree with the design for the infra layout of Utrecht Central Station? The decisions taken during the negotiations do not provide input for the next negotiation. Explicit agreements on cooperation between the actors have not been made. The operating companies and the Ministry can make arguments against the design, but ProRail wants to stick to their design thus leaving little room for changes. Therefore, performing wait-and-see behavior is not beneficial for the actors.

New infrastructure

The construction of new infrastructure, i.e., building new tracks in the railway system, can be expensive depending on the chosen options. ProRail, the Ministry of Infrastructure and Watermanagement (I&W), the operating companies and the municipalities made an agreement to go for a low-cost option of 200 million: design A was chosen.

This situation describes the development phase of design A for the to-be-constructed infrastructure. In this phase it is very attractive to fulfill some extra wishes, meaning have additional request included in the design. For example, the fire department wants extra access to the new track due to an evacuation requirement stated in the law. Additional wishes regarding maintenance are put on the table such that the track cannot be used for some time. During these negotiations, all actors sit together at the table. Moreover, the development phase takes place within one decision-making level.

Despite the agreement (and decision) to develop the low-cost option, the actors try to fulfill as many wishes as possible. It is an advantage to be the first one to violate the agreement by trying to fulfill your wishes and not perform wait-and-see behavior. However, if everyone wants to fulfill their wishes, the result is an expensive, rather than the agreed low-cost, design option.

Switches around Utrecht Central Station

ProRail and NS have the common goal to increase capacity on the railways. In order to achieve this, they will have to work together. The desired capacity increase can be achieved by driving more trains per hour through Utrecht Central Station.

ProRail proposes to remove switches around Utrecht Central Station. Fewer switches ensure that trains can enter the station at higher speeds and it reduces maintenance costs for ProRail. This is not in the interest of NS and thus NS does not agree with the proposal. Removing switches means reducing the flexibility: trains can no longer stop at all platforms and the stabling area is less accessible. Without an agreement on the removal of switches, the renovation of Utrecht Central Station cannot start. Each actor considers the question: do I stick to my own interests, or do I agree with the common goal?

More trains

ProRail and NS work together in order to have more trains running in the Netherlands. Both want more trains but with a different goal in mind: ProRail wants to have more capacity for freight trains whereas NS wants to be able to transport more passengers.

ProRail proposes to remove switches around Utrecht Central Station. Fewer switches ensure that trains can enter the station at higher speeds and it reduces maintenance costs for ProRail. This is not in the interest of NS and thus NS does not agree with the proposal. Removing switches means reducing the flexibility: trains can no longer stop at all platforms and the stabling area is less accessible. Without an agreement on the removal of switches, the renovation of Utrecht Central Station cannot start.

Appendix C: Scoring scheme Use Type levels

	Tijd video	Participant
UT level 1: Inzichten in inhoud en context van het besluitvormingsproces		
Wat is het te nemen besluit		
De uitkomsten van het besluit		
Het optimale besluit		
De context van het besluit (politiek, media, andere projecten/besluiten)		
Missende informatie		
Problemen en/of risico's van het besluit		
Bekende aspecten van de besluitvorming		
Nieuwe aspecten van de besluitvorming		
UT level 2: Bewustwording van positie en perspectieven andere betrokken actoren		
Begrijpen van de interactie tussen en gedrag van actoren		
Inzicht in strategisch actor gedrag		
Inzicht in belangen, perspectieven actoren		
Verschillende interpretatie van/taalgebruik in het besluitvormingsproces		
UT level 3: Ontwerpen van vervolgstappen in de besluitvorming		
Het proces van besluitvorming sturen		
Evalueren van de huidige situatie in het proces		
Specificeren van vervolgstappen		
Oplossingen voor problemen/risico's aandragen		
Spelen van een ander spel (of hetzelfde spel op een andere manier)		
UT level 4: Op een andere manier naar de besluitvorming kijken		
Meer structuur zien in het proces		
Gezamenlijk blik op het proces, ze zijn het eens over		
Verhelderend, out-of-the-box denken		
Overig		
Gebruik van map		
Gebruik van beschrijving		
Gebruik van template		
Checkvraag(en) nodig / focus op inhoud ipv game concepten		
Game concept elementen in discussie		

APPENDIX D: STATEMENTS PRE-TEST AND POST-TEST

STATEMENTS PRE-TEST

1. Ik ben tevreden over het proces.
2. Ik verwacht een goede uitkomst.
3. Het besluitvormingsproces verloopt volgens planning.
4. De financiële middelen zijn beschikbaar.
5. De verwachte uitkomst is technisch correct.
6. Ik verwacht dat andere actoren tevreden zijn met de uitkomst.
7. Ik verwacht na afloop goede relaties tussen de actoren.
8. Alle relevante actoren zijn betrokken.
9. De actoren hebben invloed op het besluit.
10. Er is vertrouwen tussen actoren.
11. Belangen van actoren worden beschermd.
12. Er is een goede samenwerking tussen actoren.
13. Er zijn conflicten tussen actoren.
14. Er is sprake van powerplay tussen actoren.
15. Er worden overduidelijk spelletjes gespeeld (zoals kaarten voor de borst houden, afwachtend gedrag, etc.).
16. Context (politiek, media, andere projecten) zijn van invloed op dit proces.
17. Technische onzekerheden zijn bekend.
18. Er zijn actoren die minder informatie hebben dan andere actoren en hierdoor belangrijke informatie missen.
19. Risico's van uitkomsten van het besluit zijn bekend.
20. Invloed van het besluit op de technische systemen is bekend.

21. Nieuwe actoren met andere belangen zijn betrokken gedurende het proces.
22. Er is veel wisseling van actoren.
23. Er zijn veel technische ontwikkelingen/innovaties.
24. Context (politiek, media, andere projecten) van besluit is voortdurend in beweging.

Open questions

1. Kunt u de voor u drie belangrijkste aspecten voor dit besluit hieronder weergeven en de nummers ordenen van meest (1.) naar minst (3.) belangrijk?
2. Welke aspecten van de besluitvorming mist u in bovenstaande stellingen?

Statements post-test

1. Mijn eigen kennis over de casus was voldoende om de analyse te doen.
2. De geïdentificeerde game concepten helpen mij de casus beter begrijpen door middel van gedrag van en interactie tussen actoren.
3. De geïdentificeerde game concepten helpen mij meer structuur in de casus te zien.
4. De geïdentificeerde game concepten helpen mij de casus op een andere manier te bekijken.
5. Door het identificeren van game concepten is het duidelijk geworden dat ik informatie mis.
6. De geïdentificeerde game concepten beschrijven de casus volledig.
7. Er zijn voor mij nieuwe aspecten van het proces aan de orde gekomen in de discussies.
8. Er zijn voor mij bekende aspecten van het proces verduidelijkt in de discussies.
9. Door de discussie is het voor mij duidelijk geworden dat ik informatie mis.
10. De mogelijke uitkomsten van de game(s) sluiten aan bij de uitkomsten van het besluit.
11. De vervolgstappen besproken in de discussie zijn volgens mij nog niet eerder besproken.
12. De vervolgstappen zijn tijdens deze discussie voor mij concreet geworden.
13. De discussie gaf een goede weergave van de problemen/risico's van de casus.
14. Ik had voldoende kennis van de casus om game concepten schema in te vullen.
15. Het was makkelijk om een keus te maken tussen de twee mogelijke antwoorden bij de vragen.

16. De beschrijving van de game concepten op de kaartjes was duidelijk.
17. Het was makkelijk om met de groep tot consensus te komen over de gekozen game concepten.
18. Deze tool/sessie heeft mij inzicht gegeven in: strategisch actor gedrag.
19. Deze tool/sessie heeft mij inzicht gegeven in: context van het besluit.
20. Deze tool/sessie heeft mij inzicht gegeven in: mogelijke risico's/problemen.
21. Deze tool/sessie heeft mij inzicht gegeven in: uitkomsten van het besluit.
22. Deze tool/sessie heeft mij inzicht gegeven in: het optimale besluit.
23. Ik pas de tool/sessie graag toe in toekomstige besluitvormingsprocessen.
24. Door deze tool/sessie ben ik in staat beter te sturen op het proces van de besluitvorming.
25. Door deze tool/sessie kijk ik op een andere manier naar het besluitvormingsproces.
26. Door deze tool/sessie hebben we gezamenlijk de huidige situatie van het proces geëvalueerd.
27. Ik raad anderen aan om deze tool/sessie te gebruiken.

Open questions

1. Er waren vragen over aspecten waaraan ik nog niet eerder had gedacht met betrekking tot de casus? Zo ja, welke?
2. Heeft u inzichten verkregen tijdens deze workshop die niet of onvoldoende zijn bevraagd in de voorgaande stellingen?
3. Kunt u de voor u drie belangrijkste aspecten voor dit besluit hieronder weergeven en de nummers ordenen van meest (1.) naar minst (3.) belangrijk?