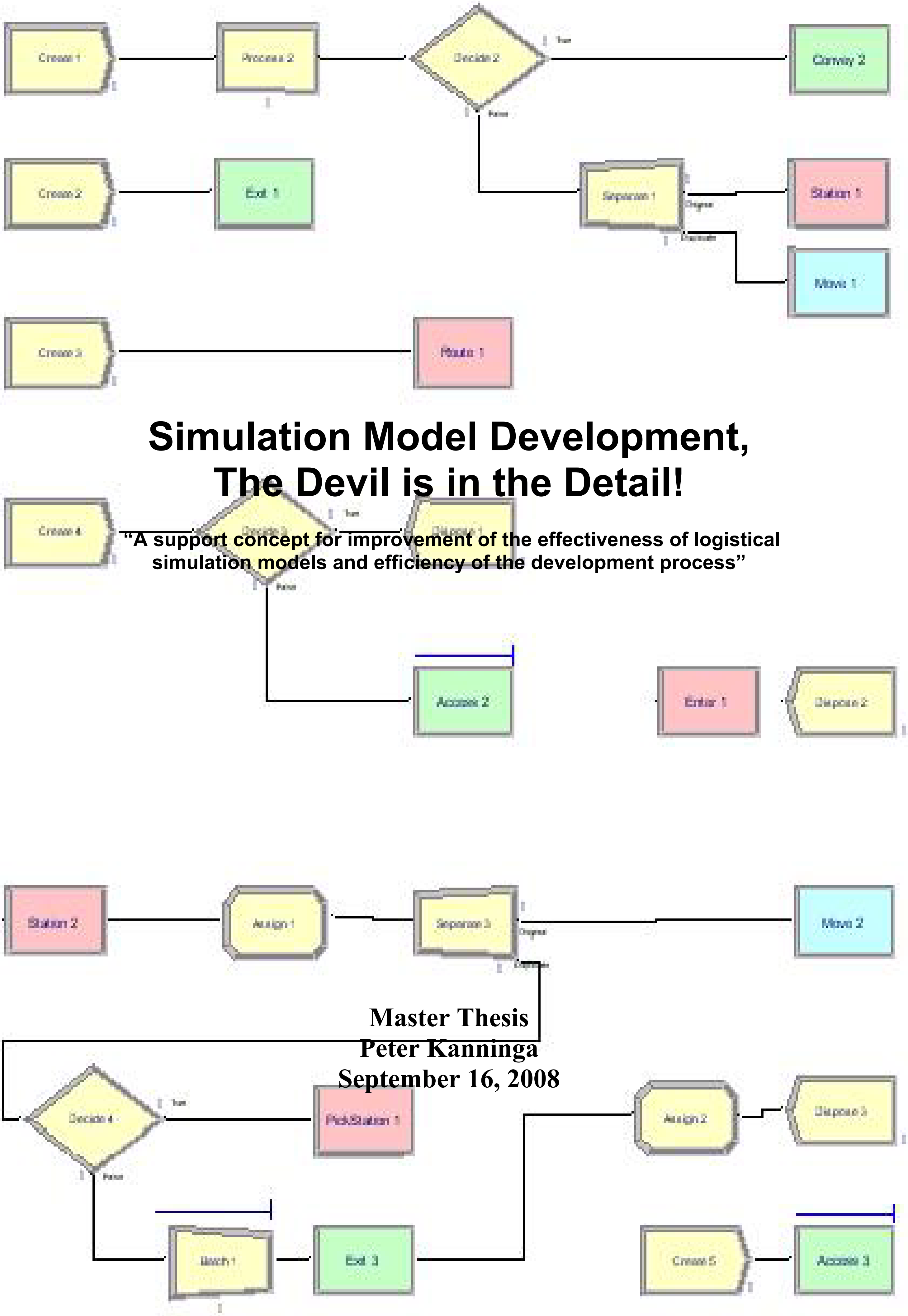


Simulation Model Development, The Devil is in the Detail!

"A support concept for improvement of the effectiveness of logistical simulation models and efficiency of the development process"

Master Thesis
Peter Kanninga
September 16, 2008

Simulation Model Development, The Devil is in the Detail!

"A support concept for the improvement of the effectiveness of logistical simulation models and efficiency of the development process"

Master Thesis
Peter Kanninga
September 16, 2008

Delft University of Technology
Faculty of Technology, Policy and Management
Section Systems Engineering

Author	P. Kanninga
Student number	1198882
Professor TU Delft	A. Verbraeck
1st Supervisor TU Delft	G. Kolfschoten
2nd Supervisor TU Delft	P. Herder

Tebodin Consultants and Engineers
Section logistical consultancy

Supervisor Tebodin	A.J. Vreeburg

Preface

This master thesis is the final product of my master Systems Engineering, Policy Analysis and management at the faculty of Technology, Policy and Management that is part of Delft University of Technology. This report describes the research process of the development and evaluation of a support concept for the simulation model development process for the department logistical consultancy of Tebodin Consultants & Engineers. The main objective of the support concept is to improve the efficiency of the simulation model development process and to improve the effectiveness of simulation models. I would like to quote John Crookes statement on methodologies for simulation model development that is, in my opinion, an encouraging one for all potential readers; *"I find reading about modeling methodologies very boring. Nevertheless, I continue to think that methodologies are quite important."* Readers that are mainly interested in the empirical research and conclusions of the problem analysis are directed to chapter 3. Readers who would like to be introduced into discrete-event simulation are directed to section 2.2

Acknowledgements

After having finished this research project, I would like to thank some people. First, I want to thank my first supervisor of the Delft University of Technology, Gwendolyn Kolfschoten, for all her useful support and advice during the whole research project. Furthermore, I would like to thank Pauline Herder and Alexander Verbraeck for their suggestions and discussions during official meetings. All these supportive activities have lead to quality improvements of the research and stimulated me to give my best. The research was done on behalf of Tebodin Consultants & Engineers, which provided me with all the necessary support and a nice working environment to execute this research project. I want the thank Leonie, Taco and Reinier for their corporation during the research phase of the project. My special thanks go out the Alexander Vreeburg who has helped me throughout the whole project as supervisor. Discussions with Alexander were constructive, informal and pleasant. Last but not least, I want to thank Ellen, who has always supported me during my entire study period including this research project.

Peter Kanninga,

Haarlem, 16 september 2008

Executive summary

Currently, a lot of problems occur during the development of simulation models. These problems lead to unwanted effects such as time delays and motivation problems of consultants for executing or joining simulation projects. Furthermore, nowadays clients are demanding shorter development times and high reliability of Tebodin which results in strict deadlines and tight planning of projects. Because of the continuous pressure of deadlines, the models are built with limitations such as low model flexibility. Because of this limited flexibility, effective use of simulation models is not possible. Momentarily, a structural approach to develop simulation models is missing. Simulation consultants have their own approach and personal way of modeling a problem situation. This personal approach is the result of the experience with simulation and the consultant's educational background. The absence of a structural development approach leads to these current problems which results in an inefficient development process and ineffective simulation models. So far, Tebodin has put in limited effort to analyse and reduce the current problems. The measures that were taken had limited effect and did not lead to the intended improvements. As a commercial organisation, Tebodin has the responsibility towards its shareholders to make profit and safeguard the continuity of the company. New and smarter ways to use and develop simulation models are needed to reduce the current problems and to cope with the changing needs of customers. Finding new efficient ways for the development of simulation models and effective ways of using simulation models allow Tebodin to stay competitive in the field of logistical consultancy.

Scientific literature recognizes a number of promising support concepts that can improve the efficiency of the development process and effectiveness of simulation models. The question rises whether these support concepts lead to the same effects if these support concepts are implemented within Tebodin. The effectiveness of support measures depends heavily on the organisation fit. Therefore, the effectiveness of several support concepts should be evaluated based on the specific problems and characteristics of Tebodin. Proposing a support concept does not automatically mean that this concept is actually being used. The rate of success heavily depends on the acceptance of the new support concepts among simulation consultants. Implementation should therefore be evaluated in order to assess if the proposed support concept is actually being used after implementation. The objective of this research project is to propose and evaluate a support concept that can be used in the development process of simulation models which can increase the effectiveness of simulation models and improve the efficiency of the simulation building process. The main research question is defined as the following;

How can simulation model development within Tebodin be supported and how can a support concept be implemented in order to increase the effectiveness of simulation models and improve the efficiency of the simulation model development process?

In order to answer this question, a series of research activities is carried out. The historic, current and future situations are assessed in order to discover potential improvements and analyze encountered problems in the simulation model development process. Analysis of the current situation is done by doing interviews with five simulation consultant. Analysis of the historic situation is done by analysis of seven finished simulation projects which have different project characteristics. Analysis of the future situation is done by interviewing the manager of the logistical consultancy department. The conclusion of analysis of the historic, current and desired situation are translated into a set of criteria which are used to select and compare suitable support concepts that can improve the problem situation. A literature study provides a number of suitable concepts for improving the effectiveness of simulation models and the efficiency of the development process.

After interviews with the simulation consultants it became clear that there were several aspects of the current development that require support. Support is required because of the following reasons;

- Important simulation knowledge is lost if consultants switch jobs
- Development delays due to unforeseen programming errors and problems adding together sub-models
- Lack of trust by simulation consultants in simulation (sub)models that are made by other consultants
- Poor attractiveness of simulation projects which leads to motivation problems with simulation consultants to execute or joint simulation projects current simulation model development process
- Poor extendibility of existing simulation models.
- Clients expectations are exceeded (quality and level of detail of finished simulation models)
- Communication problems during the actual development of simulation models between consultants
- Problematic reusability of simulation models

The bottlenecks in the current development process are located in the development phase and during experimenting with simulation models (running scenarios). Bottlenecks which occurred during historic simulation projects are the result of the following issues;

- Problematic reuse of existing simulation models
- The absence of a well-defined scope during development of models
- The use of tight and fast track-planning
- Insufficient experience of simulation consultants with developing simulation models

From the analysis of the desired future situation it became clear that new support concept should try to achieve the following aspects;

- Decrease the lead-time of simulation projects
- Increase the reliability of the section logistics towards clients
- Minimize the ascent of simulation consultants
- Reduce the complexity of simulation model development in order to reduce the effort needed to learn to develop simulation models for simulation novices.

Scientific literature provided several potential concepts for improving the effectiveness of simulation models and the efficiency of the development process. The following support concepts are recognized;

- *Conceptualisation techniques*
- *Design patterns*
- *Component based development*
- *Collaborative learning*

By means of a workshop, simulation consultants have been made familiar with each support concept. During the workshop, the effectiveness each concept is analyzed, considering the series of pre-defined criteria. Based on the discussions and results of the workshop, conclusions are drawn about the perceived effectiveness of each support concept. Based on these conclusions, a support concept is proposed. Research showed that the effectiveness of the support concepts made clear that each support concept can improve a limited number of problem areas of the problem situation, because every concept has advantages and disadvantages that limit the overall effectiveness of each individual concept. The proposed support concept is therefore a hybrid concept which includes all concepts in order to maximize the effectiveness of the support concept on each problem area. These concepts should be translated into design patterns.

Until now, scientific research focused on specific techniques that aim on solving specific problems of simulation model development and therefore solving only parts of the whole problem situation. The proposed support concept combines different techniques that have proven to be effective on certain problem areas into one integral solution in order to solve a whole range of different problems. The proposed support concept (figure S.1) provides support during the entire simulation development process by introducing a series of design pattern that can be used by consultants during the development process of simulation models. These solutions vary from how certain tasks should be executed to how the design process should look like given the function of a simulation model in a project. A list of design patterns that should be developed is proposed. The content of the design patterns should be worked out in detail in a further stage.

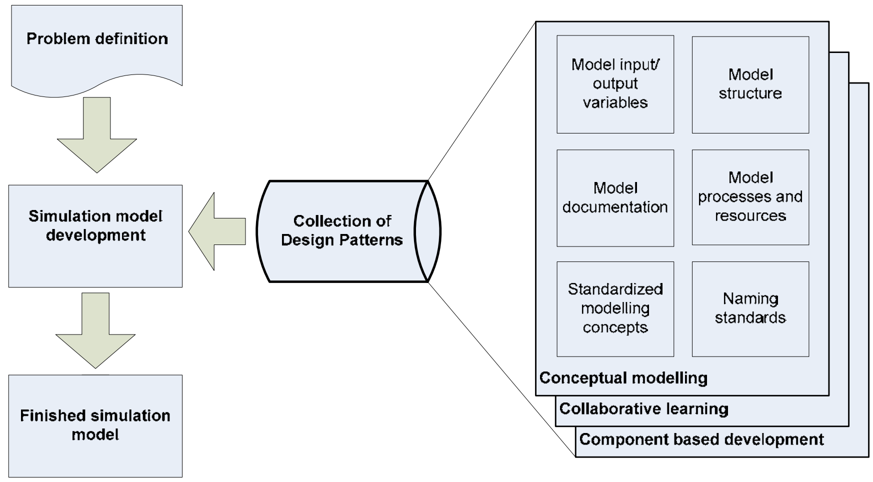


Figure S.1: Support concept

For the evaluation of implementation of the support concept within Tebodin, the Value Frequency Model was used. The Value Frequency Model determines whether or not change-of-practices occur. Input data for this model is gathered during the workshop. Based on the results of the Value Frequency Model that was used for the evaluation of the implementation, it can be concluded that the implementation of the support concept in the logistics department will not be problematic. Nevertheless, there is a risk that the actual effectiveness is limited because the effectiveness of the support concept is perceived by consultants average rather than high. The implementation strategy for the proposed support concept consists of two parts; the actual implementation phase and the post implementation phase. During the development of the design patterns, there should be tried to reduce the number of elements of the patterns as much as possible in order to minimize the implementation effort and to maximize the usability of the pattern. During the implementation, it is advised to pay specific attention to the following activities:

- Provide additional education in order to improve the conceptual modelling skills of consultants
- Construct an appropriate index or classification system for the set of design patterns
- Provide incentives to stimulate experts to transfer information and knowledge.
- Determine the feasibility of the use of templates
- Provide additional education , if every simulation consultant should be able to develop and/or use templates

The effectiveness of the design patterns heavily depends on the maintenance of design patterns. Design patterns should evolve over time. Therefore, the content of the patterns should be changed and elements should be added when necessary. Advised is to add problem symptoms, best practices and pitfalls/opportunities in the design patterns to improve the effectiveness of the patterns. It is advised to periodically evaluate the completeness of the series of design patterns and need for adjustments. It is important that simulation consultants are stimulated to actually improve the content and use of the design patterns. Apart from the recommendation to implement the proposed support concept within Tebodin, additional recommendations are made for Tebodin as well as for further scientific research.

Table of Contents

1. Introduction

Tebodin is a Consultancy and Engineering firm that operates worldwide with roughly 3000 employees in 50 offices. Annual turnover is about 220 million Euros a year. Tebodin is an operating company of Royal BAM Group, which is one of the largest construction companies in Europe with about 30.000 employees. A small part of the organisation is dedicated to consultancy. The logistical department, which is the biggest section in the consultancy department, is using computer simulation as one of the available tools to analyze problems. Simulation models are mainly used for the analysis of ports all over the world. Typical clients are port authorities and port related industries. Future developments such as economic growth trigger the demand for new investments in infrastructure that are needed to challenge these developments. Simulation models are used for the analysis of existing assets and resources or for the analysis of the impact of new investments on predefined performance indicators. Examples of performance indicators are land-use, vessel movements and storage capacity. The outcomes of simulation models are used to draw useful conclusions about current and future problem situations.

1.2 Research motive

A common view is that simulation models are becoming increasingly large and complex (Oses 2004). The growing demand for higher reliability, shorter development times and more specialized models demand new and smarter ways to use and develop simulation models. Finding new efficient ways for the development of simulation models and effective ways of using simulation models allow Tebodin to stay competitive in the field of logistical consultancy. Briggs (2005) provides that if an organization can find ways to improve its work practices, it can gain competitive advantage. The demand for short development times results in strict deadlines and tight planning of projects. Because of the continuous pressure of deadlines, the models are built with limitations such as low model flexibility. Because of this limited flexibility, effective use of simulation models is not possible.

Momentarily, a structural approach to develop simulation models is missing. Simulation consultants have their own approach and personal way of modeling a problem situation. This personal approach is the result of the experience with simulation and the consultant's educational background. Some consultants are simulation experts, while others are simulation novices without any experience with simulation at all. The absence of a structural development approach leads to an inefficient development process with unwanted effects such as unpredictable development times and development processes that are difficult to control. So far, Tebodin has put in limited effort to analyse and reduce the current problems. The measures that were taken had limited effect and did not lead to the intended improvements.

As a commercial organisation, Tebodin has the responsibility towards its shareholders to make profit and safeguard the continuity of the company. In order to achieve these objectives each individual part of the organisation is financially driven and has to work as efficient and effective as possible. The main objective of the department logistical consultancy is to be as competitive as possible regarding simulation. To achieve a competitive position, the development process must be efficient and the resulting simulation models must be effective. This research project should provide a solution to improve the effectiveness of simulation models and the efficiency of the development process.

1.3 Research objectives

The main objective of this research project is to propose and evaluate a support concept that can be used in the development process of simulation models for the logistical consultancy department of Tebodin which can increase the effectiveness of simulation models and improve the efficiency of the simulation building process. Unfortunately, the nature of scientific inquiry implies that it is impossible to eliminate pitfalls in simulation development entirely (Kleijnen, 1995). Furthermore, it is important to evaluate how the support concept can be implemented, because the effectiveness of the support concept depends heavily on the way it is implemented. The main research question is therefore formulated as the following;

How can simulation model development within Tebodin be supported and how can a support concept be implemented in order to increase the effectiveness of simulation models and improve the efficiency of the simulation model development process?

To answer this main question, a set of researchable questions is needed. The main research question is therefore divided into four sub research questions to enable different research methods and deliverables. The next section will elaborate on the different deliverables that are the result of this research project. Section 2.3 elaborates on the research questions in more detail.

1.4 Deliverables

This research project resulted in a number of deliverables. The type of deliverable depends on the function and user of that deliverable. This section will elaborate on the deliverables that are generated in this research project.

- *A support concept for simulation model development*
  A support concept is proposed and evaluated that can increase the effectiveness of simulation models and improve the efficiency of the simulation model development process. Research showed that, when this support concept is implemented by the logistical consultancy department of Tebodin, simulation projects can be executed more efficient and simulation models can be used more effective.

- *Report with recommendations*
  This final report is the main deliverable that includes conclusions and recommendations about a support concept for the improvement of the development process of simulation models for the logistical consultancy department. This report provides clear understanding of problems and bottlenecks in the current simulation model development process. Conclusions and recommendation about the implementation of the proposed support concept are also part of this thesis.

- *Scientific paper*
  The subject of the scientific paper is the quality assessment of simulation in different application areas. Because of the difference characteristics of each application area, the definition of quality should be different as well. This paper tries to provide a critical reflection, based on a literature review, on the current definitions of simulation quality

1.5 Report structure

The structure of the report is related with the research steps that are carried out during this research project. Figure 1.1 provides an overview of the research framework that was used in this project. The corresponding sections in which the individual research questions are answered and details can be found are included in figure 1.1 as well. This figure will be used as a guideline throughout the entire report and is presented in the beginning of each chapter. Each chapter starts furthermore with the description of the goal and structure of the chapter and summarizes with research question are addressed in the chapter. Each chapter ends with sub-conclusions which provide the answers to the research questions and other relevant conclusions.

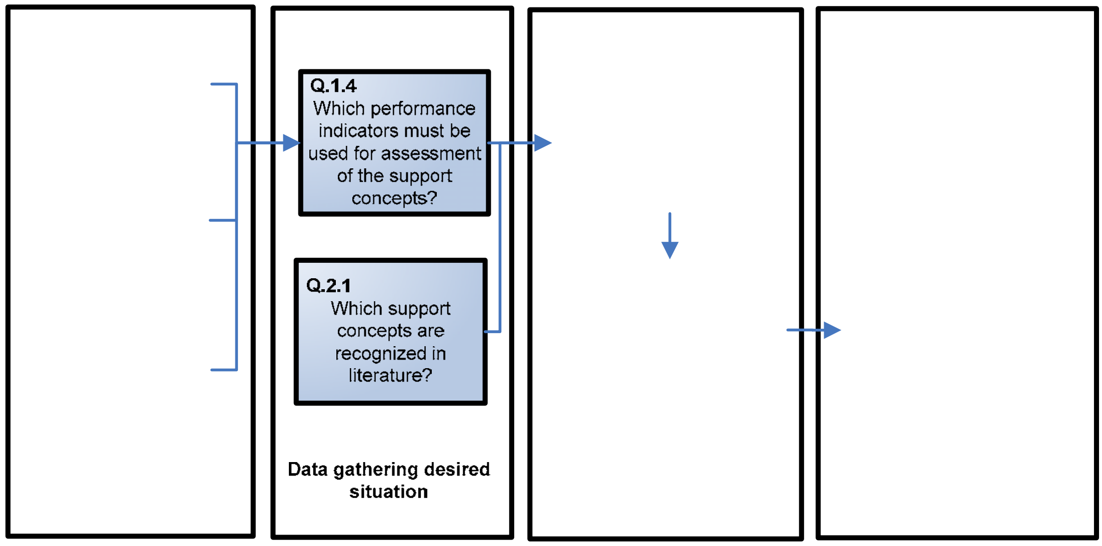


Figure 1.1: Research Framework

After the introduction, chapter two will focus on the problem analysis. In this chapter, the transition process from the initial problem towards the research question is described including the delineation and the research approach used in this research project. Chapter three elaborates on the empirical research done at Tebodin. The main goal of this chapter is to gather data about the current situation (section 3.1), historic situation (section 3.2) and the desired future situation (section 3.3). Chapter three ends with a list of performance indicators (section 3.4), which are the result from the previous analysis. Chapter four introduces potential support concepts that are recognized in scientific literature. Chapter five describes the selection of the most effective support concept. By means of a workshop (section 5.1) the concepts were evaluated. The best concept is described in section 5.2. Chapter six elaborates on the proposed support concept and the implementation of this support concept. Section 6.1 introduces the support concept. Furthermore, the implementation of the support concept (section 6.2) is discussed as well as the implementation strategy (section 6.3). This report will end with all relevant conclusions and recommendations.

2. Problem Analysis

This chapter describes the translation process of the initial problem description into manageable research questions. The problem description is the result of discussions with simulation consultants and project managers and observations during project meetings. These insights together with important notions that are derived from scientific literature result in a multi-perspective view on the problem situation. The first section describes the initial problem situation. The next section provides theoretical background on the most important problem issues. Section 2.3 elaborates on the delineation of the problem area. Section 2.4 provides an overview of the research questions. Finally, section 2.5 describes the research approach that is used to execute this research project.

2.1 Initial problem description

In the current way of executing simulation projects consultants encounter a lot of problems. These problems lead to unwanted effects such as time delays and motivation problems of consultants for executing or joining simulation projects. There are two main problem areas; an inefficient process of developing simulation models and simulation models that are ineffective.

Inefficient development process
All the necessary steps for the execution of simulation projects are provide and specified in general by Tebodin, but the actual process of developing a simulation model is not provided. Because of the absence of a prescribed approach for the development of simulation models, simulation consultants have their own approach and personal way of modeling a problem situation. The model structure, function and documentation of developed simulation models therefore vary quite a lot. This variation leads to fluctuations in the quality of simulation models and unpredictable problems during the development process. Especially these unpredictable problems make it difficult to safeguard the project planning and meet all deadlines. Extra time was always planned for contingencies. In practice, the extra time was always used.

Ineffective simulation models
Simulation models are momentarily built with limited flexibility because of tight project planning. Limited flexibility means that the simulation model can only provide specific answers under certain conditions. Because of this limited flexibility, any (small) scope change leads to significant time delays. For time and quality reasons, often successful simulation models are reused in different simulation projects. Because of the lack of flexibility and poor documentation, reuse of simulation models does currently not lead to the intended time saving and quality improvements. Furthermore, there is a trend that simulation models are used multiple times for the same client. A simulation model is build once for a particular assignment and new assignments result in extensions or changes to that particular simulation model. Poor model documentation and complex model structures result in the fact that making changes or extensions is a difficult and time consuming operation.

Ineffective simulation model development processes and ineffective simulation models lead to unpredictable development times and development processes that are difficult to control. These problems reduce the reliability of Tebodin towards clients and the competitive position of Tebodin. The next section provides a theoretical background on the most important aspects of the problem situation.

2.2 Theoretical background on aspects of the problem situation

This section provides a theoretical background on the most important aspects of the problem situation. The first section elaborates on discrete event simulation in general including functions and application areas of simulation. Section 2.2.2 provides information about quality of simulation. Conceptual models are used to design and specify a simulation model before they are actually being built. Section 2.2.3 provides some background information about conceptual models. Section 2.2.4 elaborates on simulation model reuse. Section 2.2.5 provides background information about simulation software. The last section elaborates on the organisation characteristics of Tebodin.

2.2.1 Discrete Event Simulation

Simulation is used in many different areas and has therefore different meanings in each context. A broad definition of the term simulation is provided by Moore et al. (2007); “To imitate conditions or behaviour of a situation or process by means of a model”. There are different types of simulation such as continuous or discrete simulation. In this research project, simulation refers to so called *discrete event simulation*. Robinson (2004) provides a definition for discrete event simulation;

The operation of a system is represented as a chronological sequence of events. Each event occurs at an instant of time and marks a change of state in the systems.

“Discrete event simulation often used to model systems where complex-often logistic-processes are combined with a limited infrastructure capacity” (Verbraeck et al, 2002, p. 1199). The terms *Simulation* and *simulation models* are often used in the same context. Robinson et al. (2004) provide a definition for a simulation model as “a device on which dynamic experiments can be conducted”. Experiments are often representing (future) scenarios. “Simulation is commonly used in problem systems where static calculations using spreadsheets or queuing theory are insufficient. These problem systems can be characterized by a mixture of process steps that interact and use common resources. Due to the interaction standards queuing theory or spreadsheet calculations cannot be applied to define a linear solution” (Valentin, 2008) Discrete event simulation is not new, but emerged in the late 1950s and steadily became more popular and is now to be recognized as the most frequently used of the classical operational research techniques across a range of industries (Hollocks, 2006).

Simulation models can have different functions in simulation projects. Robinson (2001) provides two extremes; simulation as software engineering and simulation as a process of so called social change. Figure 2.1 illustrates these two extremes. “Within the software engineering arena there is a tendency to think in terms of the user of decision-maker being the beneficiary of the work, whereas within the social change context it is more common to think in terms of the client or customer.” (Robinson, 2001, p.105)

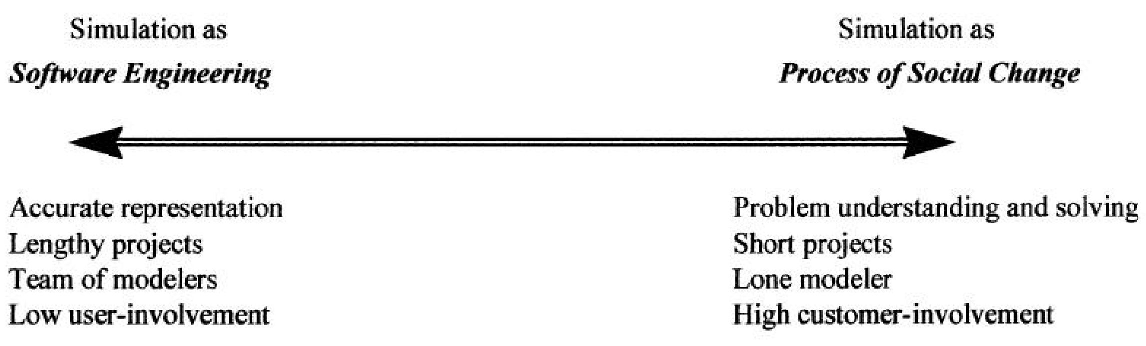


Figure 2.1: Software engineering vs. process of social change (Robinson, 2001)

Robinson (2001) provides that "in simulation studies that are a process of social change, the role of the modeller is as an agent of change, whose task it is to help the user. The prime motivation for such projects is problem understanding and problem solving. The modeller works with the customer to help him/her better understand the nature of the problems and to identify actions that lead to probable improvement. These projects tend to be short, typically a few weeks, are performed by a lone modeller and require high levels of customer involvement." Furthermore, Robinson (2001) provides that in other sectors like military and public policy, the dominant view is the one of simulation as software engineering. The most probable reason for that is that there is a need for large and complex models in this sector. Gregor et al. (1998) provide that the most effective application areas for simulation are the first project phases because of lower costs and many free decision degrees. Figure 2.2 provides an overview of the application areas of simulation.

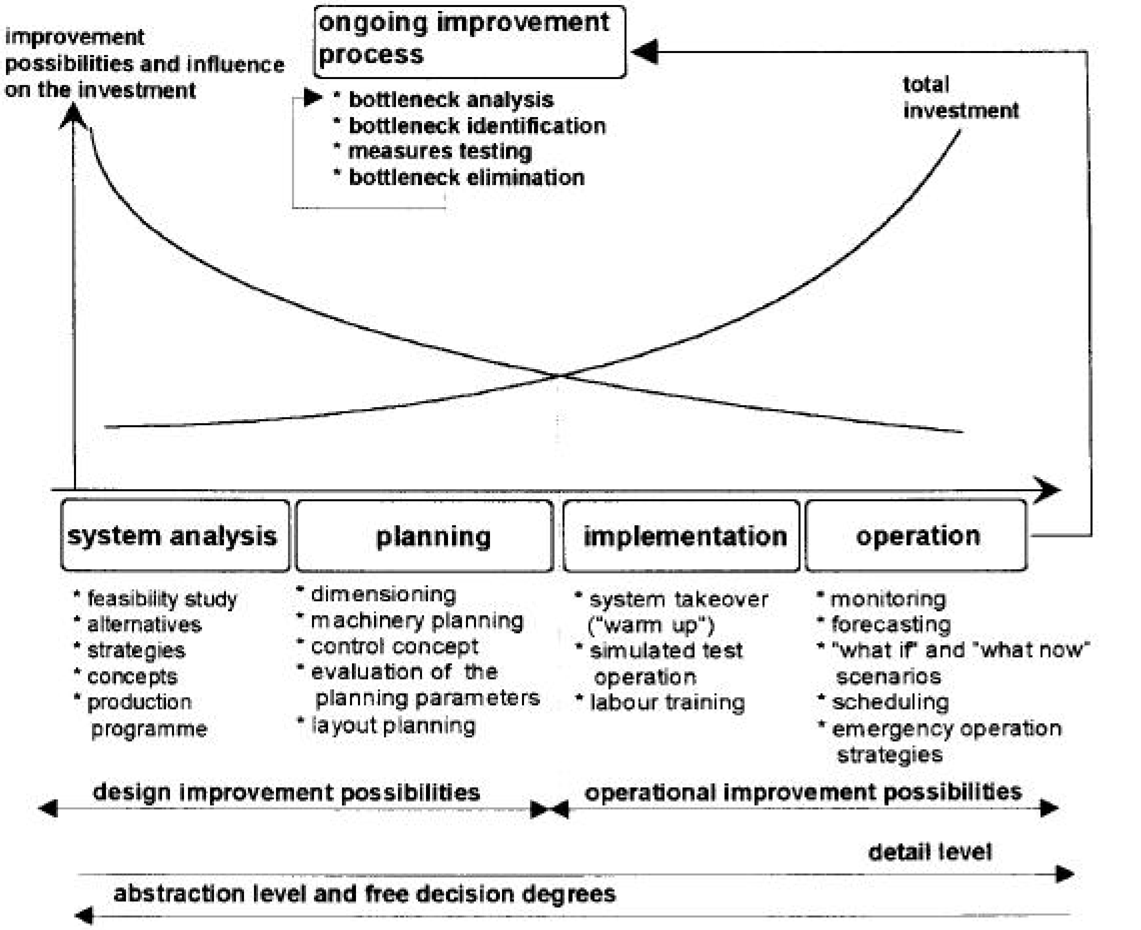


Figure 2.2: Application areas simulation (Gregor et al., 1998)

Simulation should not be seen as a holy grail to solve all logistical problems. "The possibilities of simulation are overestimated or other simpler and much cheaper methods are overlooked in many cases" (Gregor et al 1998). Furthermore Keller et al (1991) provide a number of pitfalls of failed simulation;

- Low salesmanship of the simulation expert to the problem owner, i.e. the problem owner does not understand what the simulation expert wants or is trying to do
- Low skills on behalf of the simulation expert, mainly regarding specific domain knowledge and statistical background

- Lack of time to complete the study, so the study is abandoned before all the necessary experiments and statistical tests have been performed.

Robinson (1999) also describes a set of pitfalls specific to simulation studies. These pitfalls cannot be solved using a clear process for simulation model development. These problems result from the structure of a simulation model. Robinson lists reasons for these pitfalls;

- The simulation model development is started from scratch, reuse is not applied
- The implemented simulation model does not fit with the conceptual model
- The simulation environment leads to unstructured complex models
- The simulation model is too inflexible and has a limited set of options for experimentation

The result of these problems is that it takes too long to construct a simulation model and the models are difficult to use for experiments. When a simulation model is used for experiments to evaluate different scenarios, the simulation model often needs to be extended or adjusted and a rigid structure makes it difficult to change the model to incorporate the needed extensions. Another problem that is observed is that the problem owner has difficulties understanding the structure of the model and relating the structure to the real world system. (Robinson 1999) Furthermore, Valentin (2008) provides that decisions made by the developer regarding the selection of building blocks can result in unforeseen limitations when instantiating a model of a solution. A minor change to the problem systems may require much work. Gregor et al. (1998) state that experiences learned that modelling approaches may have some limitations

- A simulation models itself can still be seen as a black box hiding the dynamics of the problem situation. It is difficult to investigate the modelled processes only by comparing a large set of exogenous and endogenous variables.
- For the model builder it is often hard to notice and localize modelling errors that cause unexpected, unintended behaviour by looking at the simulation code or static numerical output, like tables or end-values of endogenous variables. These problems have in common that they all concern communicating and interpreting a model of a problem situation. In order to understand why these problems occur and how they can be solved, we will take a closer look at the modelling and communication processes that take place in a dynamic modelling study. Every communicable model, be it expressed in natural language or in highly formalized diagrams, is a translation of a model builder's mental model of a problem situation.

2.2.2 Quality of Discrete event simulation

As a professional consultancy firm in a competitive market, Tebodin should always strive for high quality services. As a starting point in the discussion about quality of simulation, there should always remember that models never can be “good” in any absolute sense, but such measures will always be relative to particular users and their purposes (Kreutzer et al, 1998). Figure 2.3 represents the structure of human-computer relation

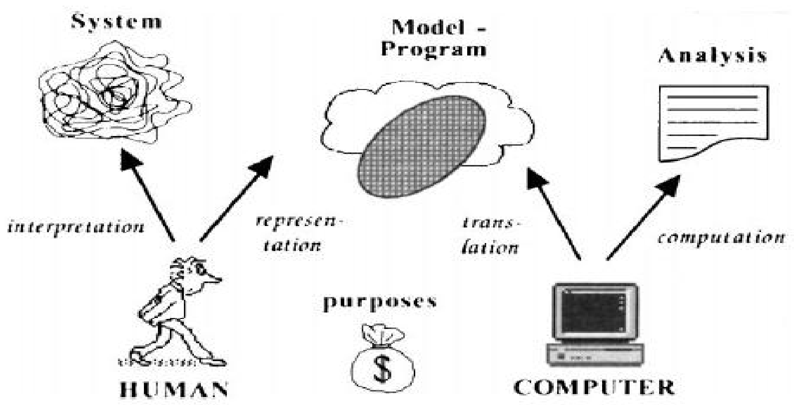


Figure 2.3: Human-computer relation (Kreutzer et al., 1998)

Discrete-event simulation quality is still a little understood concept. Most work in this field is restricted to the verification, validation and accreditation of simulation models. In literature, simulation quality is often described in terms of three attributes (Robinson, 2001);

- *Validity of simulation model*
  The key theme in the validity of simulation models is accuracy of the model and its intended use. "A model can only be valid for the purpose for which it is build; it is not possible to think is terms of universal validity" (Robinson, 2001, p.105).
- *Credibility of simulation models*
  Robinson (2001) provides that credibility is the confidence or belief someone is willing to place in a model and its results. Often this reflects in a person's willingness to make decisions based on what is learned from a simulation study. Another view is that credibility is "the confidence that should be placed in a model and its results, thereby making credibility an attribute of the model and the simulation study." (Balci in Robinson, 2001). However, if this view is dominant, the distinction between model validity and model credibility becomes blurred.
- *Acceptability of simulation models*
  According to Robinson (2001) acceptability is often described in terms of its attributes. "Acceptability involves the credibility, cost-effectiveness, timeliness and comprehensibility of the simulation study" (Oren, 1981 in Robinson, 2001). An other definition is that acceptability is 'an attribute of the decision-maker and so it is distinct from the definition of credibility" (Balci in Robinson, 2001)

The meaning of validity is generally agreed upon but there is less agreement over the meaning of credibility and acceptability. Especially the acceptability has been explored very little (Robinson, 2001). Quality of simulation models can not be regarded without the type of function of a simulation model and therefore it needs to be placed in the context of the specific function of a simulation model. Robinson (2001) introduced much more usable definitions for simulation model quality. Figure 2.4 provides an overview of these definitions and there connection with each other. Robinson recognizes three types of quality;

- *Quality of Content*
  This type of quality refers to content of the technical work within the modelling process conforms to the requirements of the study. The technical work includes the specification of the problem, the development of the conceptual model, the coding of the computer model, the experimentation and the analysis and reporting of the results.
- *Quality of Process*
  This type of quality is not concerned with the quality of the technical work, but with the way in which the work is performed and the extend to which it conforms to the expectations of clients. the process includes aspects such as the relationship between modeller and client, level of communication, timeliness of work and the confidence of the client in the modeller.
- *Quality of Outcome*
  This type of quality depends on the extend to which the simulation study is useful within the wider context for which it was intended. In the short term, the quality of outcome is the willingness of clients to act upon the results of the study. In the long term, the quality of outcome is the extend whether better decisions were made as a result of the simulation study. Difficulty with long term quality of outcome is that the real world is likely to change since the model was build. This makes comparisons problematic.

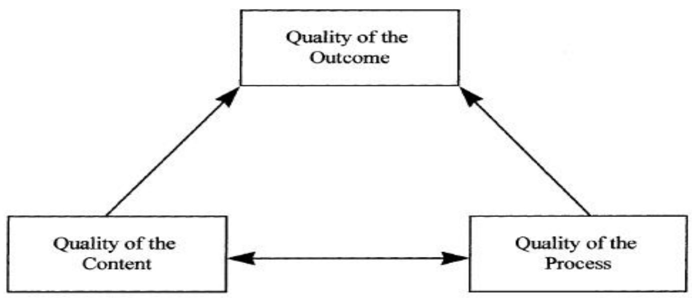


Figure 2.4: Simulation quality (Robinson, 2001)

The quality of the process affects the quality of the content and visa versa. The better the communication (process quality) in a simulation project, the better the information is likely to be, which leads to higher content quality. In addition, improvement of the content quality of a project can lead to improvement of the clients' perception of the process quality. Note that clients are willing to act upon the results of a simulation project if they perceive the process and content quality as sufficient. This is defined as the quality of outcome. Outcome quality is always important and its importance depends upon the risk involved in the decision and the cost of the simulation study. (Robinson, 2001) Unfortunately, there are more factors then only outcome quality that influence the clients' willingness to act on the results of simulation studies such as opportunity windows and availability of funds.

Taken into account the type of approach of simulation modelling (see figure 2.1), when simulation is carried out as a process of social change, the process quality may be the overriding judge of quality from the customers' perspective. In these two extremes, only the content or the process quality can be important (Robinson, 2001). Robinson (2001) furthermore provides that when a simulation model is used for facilitation, the accuracy of the model and the results may be almost irrelevant, as long as the process of modelling has provided a discussion which lead to better understanding of the real world. When simulation models are used as software engineering approach, the process quality has little effect on the quality of outcome. Therefore, in this approach, the quality of outcome almost totally depends on the quality of content.

2.2.3 Conceptual modeling

Chwif et al (2006) assert that "simplification is the essence of simulation" and that the core problem of model reduction is to find a simpler conceptual model that is still valid, with respect to the initial requirements and objectives. Figure 2.5 provides a function between outcomes and level of detail.

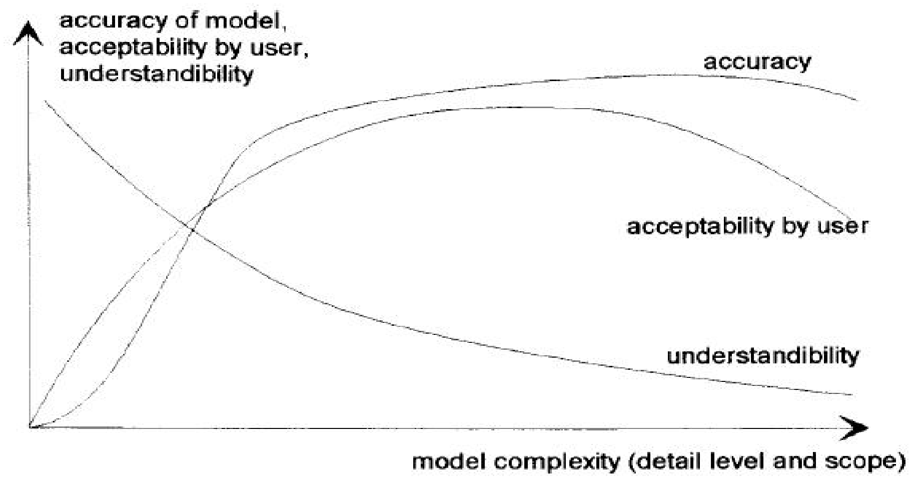


Figure 2.5: model complexity vs. user s understandability/acceptability/accuracy (Chwif et al. 2006)

Chwif et al. (2006) recognized two approaches for simplification;

- *Evolutive/Reductionist approach*: The initial model is more complex and we attempt to simplify it
- *Evolutive/Expansionist approach:* Produce an initially over-simplified model and then start adding necessary details

To apply simplification or reduction at the conceptual stage, the simulation model should be represented into a suitable conceptual modeling technique. Apart from simplification, conceptual models are used to determine the scope of a simulation model and to discover potential dilemmas in an early stage. Building discrete event simulation models is not an easy task. Therefore, the need for conceptual model design prior to program development is even more significant than in many other areas of computer modelling (Paul, 1992). Although this conclusion was drawn sixteen years ago, in a early stage of the evolution of the personal computer, this conclusion can still be applied because the fact that personal computers have evolved tremendously does not automatically mean that conceptual models have no proper function. Chwif et al. (2006, pp. 930) draw the conclusion that “discrete event simulation is an important system analysis technique. But for today‘s demand for speed, the time to complete a simulation study is considered to be long, even with the current developments in hardware and simulation software. In this scenario, simplification methods for simulation models could play a key role.” Empirical studies show that more than half of the errors which occur during systems development are the result of inaccurate or incomplete requirements. Requirements errors are also the most common reason for failure of systems development projects. This suggests that more effort should be spent to assure the quality of conceptual models, in order to catch requirements defects as soon as they occur, or to prevent them from occurring altogether (moody et al., 2002). Figure 2.6 provides an example of a conceptual model.

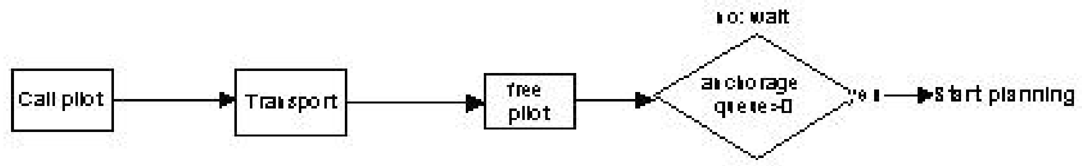


Figure 2.6: conceptual diagram

Valentin (2008) provides that in a conceptual model, the structure, concepts and boundaries of the systems are modelled. The conceptual model contains systems boundaries that are defined to limit the simulation study. The result will be an overview of elements and sub-systems of the problem system that will be included in the simulation model to be developed. This overview uses the terminology of the domain to enable the problem owner to understand the way the model developer interprets the system. In the next phase, the instantiation of the simulation model should be a straight forward process, because all the thinking and defining activities have been performed for the development of the conceptual models.

According to de Vreede et al. (2003), conceptual models define the structure of the problem and contain no or very little empirical data. Empirical models add data from the problem domain, which allows users to analyze and diagnose various versions of the models. Robinson et al. (2004) define a conceptual model as a software independent description of the model that is to be constructed. Chwif et al. (2006) argues that a conceptual model is intended to capture the essential features of the system and is usually represented as flow diagrams, as a textual description or both. By contrast, the computer model is the translation of the conceptual model into computer code. Gregor et al. (1998) conclude that a simulation model should be easier to manage if it can be decomposed into a set of smaller parts that can be considered separately. This does not mean that any first-time simulation user will, by some magic, be able to build extremely complicated models by using a component-based approach. It does mean, though, that appropriately trained, experienced and skilled consultant should find it easier to develop appropriate models.

Not all scientists are positive about the use of conceptual models. El Haouzi et al. (2008) conclude that existing modelling methodologies (such as IDEF1X) are focusing on knowledge formalisation and they enable the modelling of industrial systems with a point of view that is not easily translatable to simulation models. Furthermore, a problem is that one of the skills commonly found to be lacking in model developers is dealing with conceptual modeling (Sadowski and Grabau in Valentin, 2008). Conceptual modeling is difficult for model developers who are not an expert in the problem system. Setting boundaries to the systems requires insight and experience in the problem system (Valentin, 2008). Gregor et al. (1998) state that developing a model of a problem situation is not a goal in itself. Its main purpose is to communicate knowledge about the relevant aspects of a problem situation to others. Furthermore, the authors conclude that conceptual modelling approaches may have some limitations:

- Diagramming techniques to model the problem situation such as entity-relation diagrams or data flow diagrams are unfit to model the dynamics of the problem situation. Even when modelling dynamic aspects with dedicated techniques, the resulting diagrams are static in itself. This makes it hard to thoroughly understand and analyze the dynamical characteristics of the modelled processes.
- Diagrams are often poorly communicable to problem owners. Problem owners usually lack experience in reading and understanding diagrams. In addition, diagrams seldom resemble the problem situation visually.

2.2.4 Simulation model reuse

This section provides a theoretical background on simulation model reuse. Most of the reuse literature is related to software engineering. Simulation software engineering has much accordance with software development because in both situations there is a clear hierarchical structure with attributes and variables and reoccurring part of logic that can be recognized. Balci (1994) provides the following differences between software engineering and simulation software engineering;

- Simulation studies require the application of the “art of modelling”.
- Simulation models are usually validated be comparison with real world rather than against a requirements specification.
- The results of simulation experiments require careful analysis.
- Simulation projects are based on experimentation and involve replication runs of a model.

Modularity and reuse seem to be connected. “In the area of system modelling, modularity is used to facilitate the reuse of standardised components. The concept of modularity in software development refers to the encapsulation of key subsystems, objects and components behind well-defined and relatively stable interfaces. This facilitates the integration of these components with multiple applications, as well as the evolution or possible re-implementation of these components with minimal impact on the applications using them. Nowadays, the concept of modularity has been introduced as a logical choice in the complex systems organisation (El Haouzi et al., 2008). El Haouzi et al. (2008) state that it is obvious that the time savings in simulation model design can be obtained if it is possible to reuse some simulation model modules to construct new models. Robinson et al. (2004) provide that the main idea behind reuse is that “Reusability in the area of simulation models capitalizes generic knowledge about simulation models of systems that have common properties, instead of studying every system and developing specific components”. They describe two types of simulation model reuse

- *Reuse of subsystem models*. The modeller has models of various generic parts that are previously developed or has access to through a model library that can be adapted and used with a new model.
- *Reuse of a similar model*. The modeller has previously developed a model that has similar features to the factory being studied. The model is adapted appropriately.

“With reuse of subsystem models, the modeller identifies part of the system that can be quickly modelled by reusing a previously developed subsystem component that comes from the modellers own library or from the library of the modelling package he or she is using. Either way, the subsystem model has to be tested to determine if it correctly models the subsystem and then modified appropriately. If this complex component has baggage, then these also have to be checked and understood. The implication of this is that unless a subsystem component is quite simple, a modeller will have to spend a great deal of time understanding how the component works. Additionally, one must ask what is the likelihood that the subsystem component will conveniently model the equivalent factory sub-system? Similar arguments can be made about reuse of a similar model where the thorough testing of the model will only take longer than testing a subsystem component. It is possible to see a similar model (with appropriate modifications) being reused as the system it represents evolves. However, it is never likely that a model will be capable of being used to model another similar system" (Robinson et al., 2004, p.483) Therefore, Robinson (2001) concludes that model assessment must be applied when a model is to be used under a new set of circumstances other than that originally intended.

El Haouzi et al. (2008) concludes that reusability leads to generalise particular models through reference models (see Figure 2.7), which provide generic or standardised representation for a given class of application. From this global vision we can extract a specific vision dedicated to simulation models for one system of this class. "Software reuse implies the existence of a software architecture that supports reuse. Developing and agreeing this costs both time and money." (Robinson et al., 2004, p.479). This statement can also be applied on simulation model reuse. Additionally, El Haouzi et al. (2008) provide that basic components can be reused, but only after testing has been performed and modification have been made or added. The basic component often evolves significantly beyond its original form.

Robinson et al (2004) conclude that apart from benefits of reuse that there are also several obstacles for reuse. The main problem of reuse is that there is little motivation for model developers to adopt procedures that would enable model reuse because it increases the cost of model development, while the benefits are gained by others. This implies that implementation of reuse concepts is difficult. The second problem is that there is the time and cost of familiarisation with the model structure of someone else, which may outweigh the time and cost benefits of reuse. (Robinson, 2004)This implies that implementation of reuse concepts is difficult. The second problem is that there is the time and cost of familiarization with the model structure of someone else, which may outweigh the time and cost benefits of reuse. This is the same problem which the consultants at Tebodin encounter.

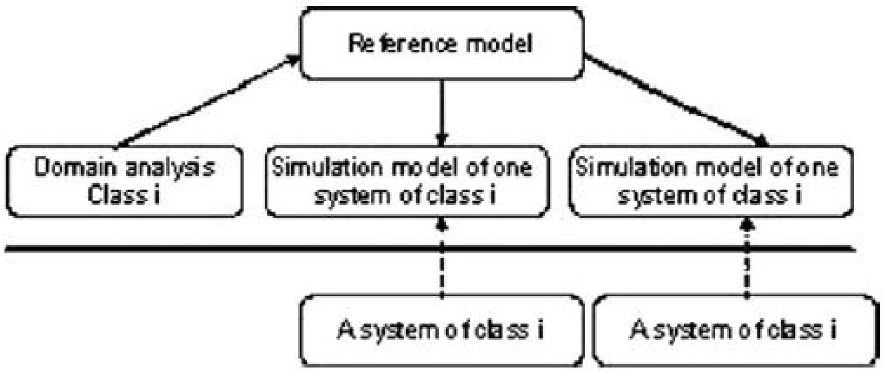


Figure 2.7: Reference model approach (El Haouzi et al., 2008)

Robinson et al. (2004) propose a financial model of the costs and benefits of reuse of software that can also be applied on reuse of simulation models. The authors define the average cost/use as;

$KN = (C + A(N-1))/N$

C = cost to develop the software for its first use
A = cost to adapt for reuse each time its is reused
N = number of times that the software is reused
KN = average cost/use

Reuse (N) is worthwhile if the average cost/use (KN) is lower than the cost to develop the software for its first use. This model can be an economic argument that advocates in favour of reuse. "This model is a simple representation which does not take into account the cost of adaptation and the cost of reuse includes many elements, including credibility re-assessment and software adaptation. It would also be sensible to apply a discount rate to future costs so as to allow for the time value of money." (Robinson et al. 2004, p. 485)

2.2.5 Simulation environment Arena

Simulation software is used as a tool to build simulation models and conduct experiments on the model. A broad range of high-quality simulation software has emerged on the market, with different characteristics and specific purposes. (Rincon et al., 2005) "Simulation approaches are certainly not exclusive to specific applications and visa versa." (Robinson, 2001 p.114) Tebodin uses simulation environment *Arena* that is developed by Rockwell Software. Basically, Arena provides its users a library of generic functional building blocks which can be used to develop different kinds of simulation models. These functional building blocks are clustered in so called templates. Arena provides a number of templates as standard functionality. Figure 2.8 provides a screenshot of the user-interface of Arena.

Because of these generic building blocks the model developer has large modeling freedom. In other words, the generic simulation environments offer a lot of options regarding how to simulate a system. Modeling a single system element is done using many generic building blocks. Decisions made by the developer regarding the selection of building blocks can result in unforeseen limitations when instantiating a model of a solution. A minor change to the problem systems may require remodelling several systems elements, using generic building blocks in an alternative way. If the simulation environment is less generic, model developers would have less modeling freedom. The generality of these simulation environments is seen as strength by advanced model developers (Robinson and Pidd in Valentin, 2008). Less experienced model developers have often difficulties with this large modeling freedom. Specific templates can be developed by advanced users or purchased from specialized commercial parties to reduce the modeling freedom. Tebodin is using a "flow processes" template. This template enables consultants to develop tank farm simulation models faster and easier.
Not all experiences with this template were positive. A lot of problems in the template itself caused many problems in simulation projects. Especially when less experienced simulation consultants were using the template. The problem then occurs that it is hard to trace if problems are caused by the template or by programming errors of the simulation consultant. Because of this situation, templates did not lead to the intended time savings.

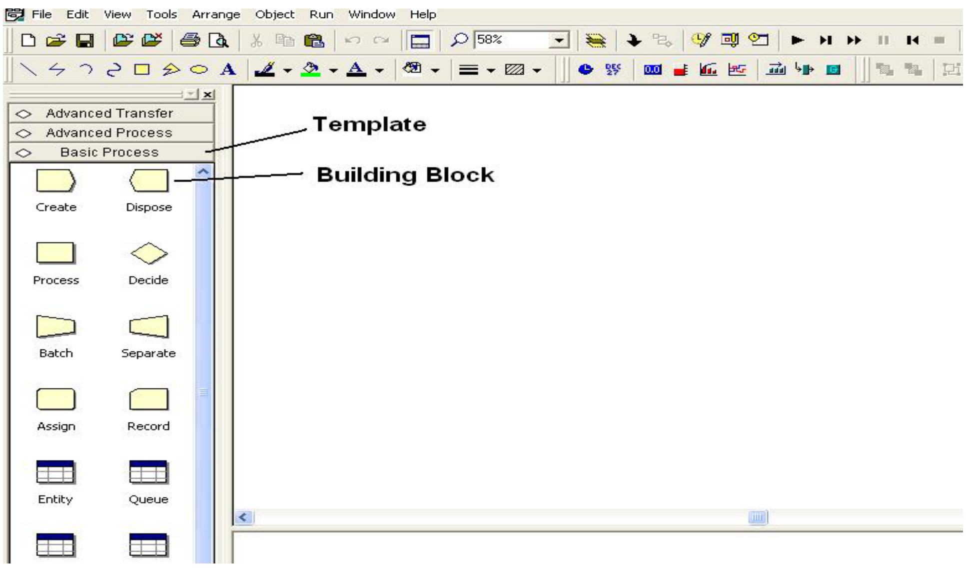


Figure 2.8: User interface Arena

Arena is a so called *Visual Interactive Modeling System* (VIMS). VIMS allow users to start building the model directly in the simulation environment. In this way, building the conceptual and computer models happens at the same time. VIMS allow a model to be visualized as a flow diagram while consultants built it and are designed to support a trial-and-error approach in which it is quite easy to make changes to the models. Since complexity is often best handled by starting with a simple representation that is successively refined, such an approach makes great sense (Oses et al., 2004). Rensburg (1995) provides a critical note for this approach; "Simulation products such as *Arena* provide user interfaces that allow significant reductions in programming time, but this intensifies the need for well-defined simulation model specifications". Oses et al. (2004) conclude that when using a VIMS, a clear separation of conceptual and computer modelling may be impossible.

2.2.6 Tebodin as professional bureaucracy

Tebodin Consultants & Engineers is an operating company of Royal BAM Group. Appendix A provides an overview of the organisation structure of Tebodin and the Royal BAM Group. All organisations are different and therefore not all types of improvements fit every organisation. The organisation fit of new support concept heavily depends on specific characteristics of Tebodin as an organisation. According to the organizational structure categorization of Mintzberg (2004), the logistics department of Tebodin can be described as a professional bureaucracy. Mintzberg is a well know author in the field of organizational structures and has made a categorization of different organizational structures. This section provides important characteristics of professional bureaucracies that are derived from Mintzberg work 'Organizational Structures'.

A professional bureaucracy can be recognized by a few specific characteristics. Employees are rather independent of other colleagues and have tight connections with customers. Operational work is rather stabile that makes that the behaviour of employees in the organisation rather predictable. The content of the operational work is complex and therefore the employees must have operational freedom to influence that work. To function properly, a professional bureaucracy is heavily dependent on the skills and knowledge of there professionals. Because of these characteristics, standardizing of skills and knowledge is the only suitable coordination mechanism. Work teams are often formed at an ad hoc basis and coordination generally is achieved through "mutual adjustment" (Leitko et al. 1991). Coordination between consultants works in a way that consultants expect the same behaviour and skills as they have themselves. Because of the complexity of the job, there must be enough space to fill in the work by there own judgment.

"The quality of an advice report can not be measured by a formula, so it can not be standardized." Standardization must therefore be applied for standardizing certain steps/approaches. Some authors talk about "cooking books" with the most important steps of, for example, an operation, but that leave enough freedom in the actual execution of the work To achieve this standardization of skills, training and indoctrination are important. By categorizing work in a professional bureaucracy, the operational tasks can be split up and allocated to individual rather autonomous professionals. In this so called *pigeon holing* the professional has two main tasks; Place a client in a certain category of with you can use a "standardized" approach/cooking book (diagnosis) and execute the actual task.

Diagnosis is a fundamental task in the professional bureaucracy. In the diagnosis the link between a standard program and problem situation is tried to be made. Within Tebodin, Project managers often do the diagnosis, while consultants execute the actual task. Sometimes execution of the task leads to additional assignments. In that case the diagnosis for the additional assignment is done by the consultant as well. Clients often make diagnosis an easy task. Most of the time clients contact Tebodin to execute a certain project such as a simulation project. Diagnosis is therefore done by the client in stead of Tebodin. In general, professional bureaucracies assume that categorization, diminishes uncertain factors.

2.3 Delineation

The previous sections provided an initial description of the problem situation. Delineation of the problem area is necessary in order to keep this research project focused. Scientific literature provides an overview of potential problems and possible solution for improving the efficient development processes and the effective simulation models. Empirical research should then verify in which degree these areas are problematic and solutions are suitable for the logistics department.

Mansar et al. (2005) conclude that many organisations favour business processes redesign because it is one of the most powerful ways to boost business performance and raise customer satisfaction. From the organisation analysis of the logistics department it can be concluded that the most effective control mechanism for professional bureaucracies is standardization of skills. This means that a consultant must be provided with a generic approach (cookbook) on how work should be executed on the one hand and with enough freedom to actually execute the work on the other hand. Furthermore, Briggs (2005) provides that if an organization can find ways to improve its work practices, it can gain competitive advantage. Therefore, this research project therefore focuses on the way simulation models are developed. The problem with the current process description is that, although at first sight it may seem like it, there is no cookbook provided on how to develop a simulation model. This can be an explanation for the wide variety of approaches that individual consultants use which. The goal of this research project is not to provide a cookbook with the title "how to develop a simulation model" but to provide a support concept that should be adopted by every simulation consultant in order to improve the development process of simulation models. By proposing a support concept for the development process of simulation models, the efficiency of the development process and the effectiveness of simulation models should improve. This research project will focus on the analysis, design and evaluation process of a suitable support concept rather than providing a worked-out support concept. The detailed content of the support concept should be determined during the actual implementation of the support concept and is therefore not part of this research project.

The main objective of the logistics department regarding this problem is to be as competitive as possible in simulation activities. The section logistics executes simulation projects that have different subjects. Nevertheless, most simulation projects are related to ports or port related industries. Furthermore, there is a clear trend within Tebodin towards the execution of port related simulation projects. Therefore, this research project will only take into account port related projects and simulation models. To achieve a competitive position, the development process must be efficient and the resulting simulation models must be effective. In the past, Tebodin has introduced several measures to reduce the encountered problems during the development of simulation models. These measures did not lead to the intended reduction of problems. The question rises why these measures did not lead to a reduction of problems?

Figure one represents a first global analysis of the objectives of the department logistical consultancy. Possible means derived from scientific literature that can achieve these objectives are also incorporated in figure 2.9. As discussed, this research project recognizes two problem areas; the efficiency of the simulation model development process and the effectiveness of simulation models. Scientific literature provided an overview of problem areas that result in inefficient development processes and ineffective simulation models. Therefore, the focus will particular be on those areas;

Efficiency of the development process

- Development time
- Ease of development
- Communication

Effectiveness of simulation models

- Transferability
- Quality
- Flexibility

The main problem with the mentioned issues is that some issues do not unite with each other. Trade-offs between for example development time and issues like complexity or quality shall always be made. A balance must be found between all issues in such a way that the problem situation will improve as a whole.

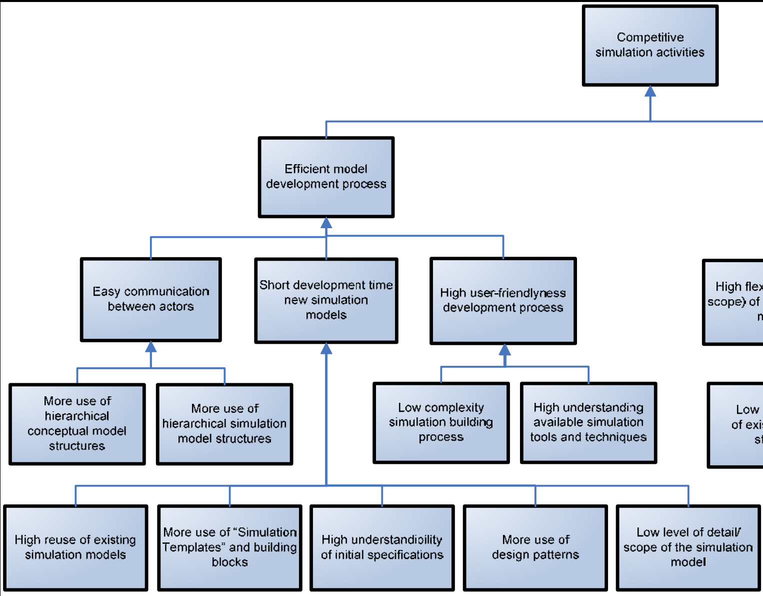


Figure 2.9: Objective tree department logistical consultancy

Both in developing new simulation models and adjusting existing simulation models, reuse of simulation models is done with the intention to reduce the development time and increase the quality of the simulation model. To sustain a desired level of quality, the policy is to reuse successful simulation models for different simulation projects. The lack of model structure and poor documentation of existing simulation models lead to unpredictable development times and insufficient quality when simulation model are reused. The tendency towards specialization into specific markets (harbour related simulation models) may justify the need for the reusability of simulation models. The main idea behind reuse is that reuse in the area of simulation models capitalizes generic knowledge about simulation models of systems that have common properties, instead of studying every system and developing specific components (Robinson et al, 2004). Reuse of simulation models should therefore be enhanced by the support concept.

Problems with the transferability of simulation model are mainly caused by complex model structures that developed simulation models have. Complex model structures are the result of an unstructured development process. Simulation software *Arena* makes it tempting for simulation consultants to just start building a simulation model by trial and error. At first sight a trial and error approach seems the most efficient one, especially when deadlines are tight. In literature this phenomena is also recognized; "Nowadays commercially available tools such as Visual Interactive Modelling Systems (VIMS), blur the line. VIMS users often start by building the model directly in the simulation environment. In a way, the conceptual and computer models are build at the same time.

Potential solutions
Conceptualization can play an important role in structuring the problem specification. If the model structures can be documented, the transfer of simulation models can become easier which leads to shorter execution times of simulation projects. "changing the existing models takes quite some time, so answering new questions takes usually more time than desirable" (Verbraeck, 2002) The problem is that once a simulation model is designed and constructed, the detailed levels of the simulation models are fixed or predefined and the fact that the effort required to construct models at different levels of detail is rather sensitive to the cost benefit effect (Verbraeck and Zhao, 2005). It was discovered that the use of conceptualisation techniques in simulation modelling activities, enhanced the quality of

simulation models and in turn reduced the time needed to build them. (Rensburg, 1995) Chwif et al. (2006) provide similar conclusions; reducing the complexity of a discrete event simulation model at the conceptual phase of simulation modelling can increase the speed of development of simulation models. Furthermore, Chwif et al. (2006) come to the conclusion that almost none of the many existing model representation techniques are suitable for conceptual modeling. El Haouzi et al. (2008) conclude that modelling techniques in general do not solve all problems related to simulation.

Pre-defined building blocks can also help to reduce development time and increase the quality of simulation models. Building blocks are pieces of simulation model logic that can be reused. Surprisingly, structured reuse of components is rarely seen (Verbraeck et al., 2002). Verbraeck and Valentin (2002) conclude that it is expected that faster modeling and easier maintenance will occur during day to day use of building blocks. The research showed that users of building blocks work faster and think that problem owners like the model better. The effectiveness of building blocks depends on the type of users. Simulation experts will only use building blocks when they “trust” them and know how they work. Simulation novices forget about the conceptual ideas of the problem situation and don’t want to understand the building blocks, but just use them to develop simulation models quickly. Given the fact that the level of experience of simulation consultants at Tebodin varies quite, it seems that implementation of building blocks can be difficult. The desired level of detail of simulation models vary between simulation projects. The level of detail needed depends on the specific function of simulation in projects. For some projects a rough analysis of the problem situation is needed, for other projects a detailed simulation model with many performance indicators. The problem is that once a simulation model is designed and constructed, the detailed levels of the simulation models are fixed and therefore the effort required to construct models at different levels of detail is rather sensitive to the cost benefit effect. (Verbraeck and Zhao, 2005)

Design patterns are widely used to reduce development time of new software. ”The objective of a design pattern is to identify parts that are repeated in several instances of similar projects and to classify them in a systematic way. So, when faced with solving a new problem, the designer can use a design pattern as a solution without having to rediscover it” (Souza et al. 2002). Ahmed et al. (2007) states that design patterns are usually presented as a vehicle to capture the best practices and facilitate their dissemination. The use of design patterns can be a desirable approach, especially considering the fact that simulation consultants in this way can indirectly use (tacit) knowledge of each other. Souza et al. (2002) introduce different types of design patterns for different domains and contexts. They claim that if reuse is done with design patterns in the analysis and design phase, considerable gains in time and cost can be acquired. This approach is much more effective than simply reusing component artefacts developed in implementation phase like libraries and templates. The effectiveness of reusing components is relatively low. Ahmed et al. (2007) conclude that design patterns in order to be an effective knowledge-capturing tool in model-based approaches, classification of patterns and support tools for developers to select a proper pattern are important. Again, implementation is critical as well for the effectiveness of the use of design patterns.

Scientific literature provides a lot of promising support concepts and describes expected effects of support concepts under certain conditions. The question rises if these concepts have the same effectiveness when these concepts are implemented within Tebodin. The effectiveness heavily depends on the organisation fit. Therefore, this research project tries to evaluate the effectiveness of several support concepts given the specific problems and characteristics of Tebodin. Furthermore, Briggs (2005) concludes that deliberate attempts to change the way people do business not always were successful. Sometimes people resist a new practice, even when evidence suggests that the new practice might benefit both the organization and the individuals involved. The success of implementation therefore heavily depends on the acceptance of new practices. There are several models for the evaluation of the acceptance of users of new technologies and change-of-practices. These models can be used in this research project to evaluate the rate of success of implementation before a support concepts is actually implemented within the logistics department. The next section provides the research questions that are used in this research project.

2.4 Research questions

The main research question is split up into four sub-questions. Most sub-questions are split-up even further to aggregate the sub-questions in such a way that research can be done in a structured way. After the introduction of the research questions the next section will elaborate on the research methods that will be used to find answers to the specified questions. The main research question of the research project is defined as the following;

How can simulation model development within Tebodin be supported and how can a support concept be implemented in order to increase the effectiveness of simulation models and improve the efficiency of the simulation model development process?

1. What is the current approach of the department logistical consultancy for the development of simulation models?

1.1 What does the current development process of simulation models look like and which aspects require support according to simulation consultants?
1.2 What are the problems and bottlenecks in historic simulation projects considering the effectiveness of simulation models and the efficiency of the development process?
1.3 Which factors influence current and future model development?
1.4 Which performance indicators must be used for the assessment of the performance and implementation of the support concept?

2. What are suitable solutions for the support of simulation model development at Tebodin?

2.1 Which potential support concepts are recognized for supporting simulation model development at Tebodin?
2.2 According to simulation consultants, which support concept is most effective, considering the performance indicators?

3. What does the new support concept for simulation model development look like?

4. How can the proposed support concept best be implemented?

4.1 Which evaluation methods from literature can be used to evaluate the implementation of the support concept at Tebodin?
4.2 What does the proposed implementation strategy look like?

2.5 Research approach

This section elaborates on the research approach that is used for this research project. In order to propose a suitable support concept, the current situation must be assessed in order to formulate the requirements for these measures. Den Hengst (2003) proposes three approaches to analyse problem situations within enterprises;

- Data approach (emphasizes on information flows between departments)
- Policy approach (emphasises on actors and there preferences)
- Process approach (emphasises on the processes that realize a product or service)

This research project will use a mixed approach that results from a process approach and a policy approach. There is emphasized on the process approach as well as on the policy approach which includes the preferences of simulation consultants. If consultants do not agree upon the proposed measures, implementation of these measures can be problematic. There are five phases in the research trajectory. Each phase consists of one or more sub-research questions. An explanation is given for each phase about what activities are done. Figure 2.10 provides a schematically representation of the research approach.

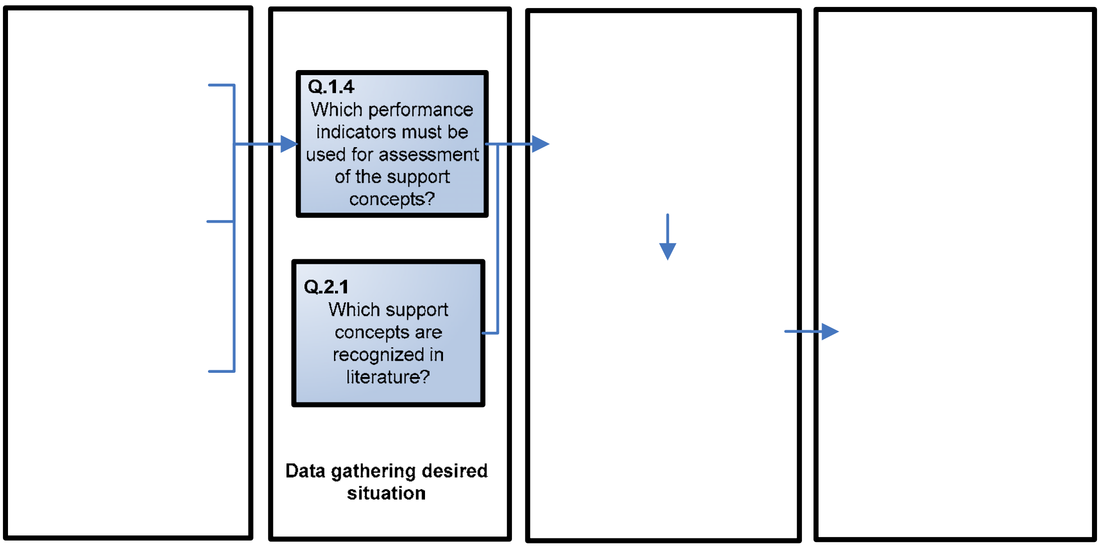


Figure 2.10: Research approach for research project

There is a clear distinction between the first two phases which have the primary function to gather all necessary information from different sources about the problem situation and possible solutions. The other two phases have the function to design and provide and implementation strategy for the support concept.

Data gathering current situation

The main purpose of this phase is to analyze the current situation and to identify the bottlenecks in the current simulation projects. A distinction is made between problems as they are perceived by consultants and bottlenecks in finished simulation projects. To analyse the problems as they are perceived by consultants interviews are used. Klofstad (2005) defines an interview as *a method of collecting data on a subject through some form of conversation between the researcher and respondent.* The interviews with simulation consultants are done in the form of one-to-one interviews with both open and closed questions. The questions used during the interview can be found in appendix B. Another option would have been a plenary interview session with all simulation consultants together. This approach was not used due to the fact that individuals are always influenced by group opinions. Lever (1981) concludes that one of the main advantages in one-to-one interview situations the presence of the tendency to produce more socially normative response is limited. All the respondents were asked the same questions and depending on their answers, additional questions were used to go into more detail. In this way, it was possible to provide simulation consultants an opportunity to explain why problems occur in the current situation and to give their opinion on how these problems should be resolved. Personal interviews have the tendency to be less structured than other types of interviews because the process is more spontaneous and open-ended (Klofstad, 2005). The need for a well prepared interview protocol is therefore necessary. There are several pitfalls when one-to-one interviews are used. The most important pitfall is that respondents could show strategic behaviour. Strategic behaviour is caused by respondents (hidden) agenda and preferences and leads to a situation where respondents give answers that are based on their own personal agenda and preferences and not on the actual situation. Klofstad (2005) provides that respondents tent to answer in a certain "socially desirable" way. This leads to inaccurate measurement.

Strategic behaviour and answering in a certain "socially desirable" way are not likely to occur in this situation because all simulation consultants have the same goal in this matter and all clearly indicated that they are in favour of improvement of the current situation. Apart from the respondent, the interviewer also has an important role in the interview. The way questions are asked and responses are interpreted have a significant effect on the quality of response during an interview. Klofstad (2005) concludes that maximizing response rate is vital to the success of any interview and that measurement errors occur because of traits or behaviour of the interviewer. An opportunity of doing one-to-one interviews with consultants which can give there opinion on certain support concepts is that the implementation of the new support concept should be easier. Acceptance for a new support concept becomes higher because consultants proposed measures themselves in an earlier stage of the design process. In this way, people have the feeling that the organisation accede and resolve issues raised by employees personally. Doing effective interviews and making use of the scares time of the respondents efficiently requires a well prepared interview protocol. The content of the interview and types of questions are the result of preliminary interviews, notions from scientific literature and experience gained during project meetings. These activities lead to increased quality of the interview and a broad perspective. Notions from scientific literature provided areas which did not logically follow from the current situation, but which are also important. In appendix C the list of used interview questions can be found. The selection of respondents included everyone that has done simulation projects and who is still working at Tebodin. Most of the respondents have done multiple simulation projects from start to finish and therefore have enough experience to draw conclusion on the current simulation model development approach. The next section will elaborate on the analysis of the outcomes of the interviews.

For the analysis of historic projects Yin's (2003) 'applications of case studies' was used as inspiration for this methodology. Case studies, according to all standards with responding requirements, were not executed. A more simplified approach was sufficient given the scope, intended quality and planned time for this part of the research. A schematic overview of the method is represented in Figure 2.11.

Figure 2.11: Methodology of analysis

The analysis of historic projects was split up into three phases. Each phase has several requirements that are derived from theory on explanatory case study analysis. There are several disadvantages of this type analysis. Yin (2003) provides that one of the main disadvantages of using explanatory cases is that "it can suggest important clues to cause-and-effect relationships, but not with the certainty of true experiments". "However, the goal of case studies may justifiably be to discover theory by directly observing a phenomenon in its raw form". The method of analysis will now be discussed in more detail.

Select projects
Certain selection criteria are used to make a selection of a set of projects that have to be analyzed. Discussions with consultants in combination with notions from scientific literature have lead to the following criteria for the selection of simulation projects;

- The "best" and "worst" simulation project must be assessed
- All different types of simulation models must be assessed at least once
- Projects are selected of which the related consultants are still working for Tebodin

From the results of interviews with consultants and project managers, it became clear that certain projects were successful and others less successful. It is therefore necessary and useful to discover a cause-and-effect relationship for the "rate of success" of simulation projects. Furthermore, the characteristics of different types of simulation projects can have an effect on the execution of simulation projects. It is therefore useful to asses which type of characteristics lead to problems and bottlenecks in simulation projects. To prevent inaccuracy in analysis, only projects are selected of which simulation consultants are still available for additional information. Multiple sources of data are essential for the quality of the assessment of simulation projects.

Analyze projects
The analysis tries to suggest important clues to cause-and-effect relationships in a descriptive way. Yin (2003) provides that one can not rely on a single data collection method, but will likely need to use multiple sources of evidence. Therefore, apart from analyzing project documents and simulation models, interviews with model developers were also used to collect data. In this way, evaluation of data was possible which leads to higher reliability and quality of data. Furthermore, personal insights and experience gained in supporting simulation model development for a running simulation project (which was executed by Tebodin during this research project) and attending most of the project and progress meetings were used to enrich the analysis and to collect data. The case descriptions can be found in appendix D.

Draw cross-project conclusions
According to Yin (2003), drawing conclusions is based on replication logic. By comparing the results of analysis of the different simulation projects, similarities in bottlenecks and encountered problems during simulation projects can be found. The cause of these problems and bottlenecks must be prevented by the new support concept and must therefore be taken into account by assessing potential measures.

Data gathering desired situation
The literature study provided potential support concept such as conceptualization techniques that could be used to resolve current problems. Furthermore, literature provides useful insights in opportunities and pitfalls of the different types of support concepts. These concepts are analyzed in a further stage against a set of performance indicators to see in which degree they are suitable for Tebodin. Furthermore, the research project should take into account future developments. This is done by doing an interview with the head of the logistical consultancy department on the desired future situation. In this way a balanced conclusion of possible changes with regards the use and function of simulation models can be drawn that can be translated into requirements for the new support concept.

Development of solutions
By evaluating potential concepts on a set of predefined performance indicators, a selection can be made for the most potential concept. By doing a modified version of a Delphi study, it can be determined how effective support concepts are. Furthermore, the study must create consensus among consultants about the most suitable concept. A Delphi study recognizes the opinion, experience and intuition of experts about a topic on which no consensus exists and uses this limited information when scientific knowledge is not available. In a Delphi study questions are formulated as hypotheses. Experts reply on these hypotheses and each round the results of the scores are discussed. Experts can

then, based on these discussions, change their opinion about their scores. Delphi studies have the following characteristics;

1. *Structured information flows*: in the beginning of the study expert opinions are gathered as responses on questions and comments on these questions.
2. *Continuous feedback:* Experts are able to provide comments on their own responses and responses of others. Furthermore, Experts can change their opinion during the study.
3. *Anonimity of experts:* In most Delphi studies, experts stay anonymous. In this way, experts can not influence other experts based on there personality, authority or reputation.

Experiences with Delphi studies are mixed and in many cases the results are not satisfactory. Critiques are focused on the use of Delphi studies rather than on the method itself. The main reason for this critique in that Delphi studies try to provide an exact prediction with high accuracy. This is in many cases impossible. Furthermore, outcomes of Delphi studies can strongly be influenced by the prejudices of experts (Wikipedia, 2008). Because of these limitations, a Delphi study is not used in this research project. In stead, a workshop expert session that has the same three characteristics of Delphi studies is used. In the workshop, the experts are simulation consultants within the logistics department. The hand-outs of presentation used during the workshop can be found in appendix F. The workshop is designed based on the specific characteristics of Delphi studies and concepts used in group support systems;

1. Structured information flows
After the introduction of the main problem each support concept is presented, examples are given. The consultants were given the opportunity to try out different concepts by using them. A positive side-effect of this approach is that implementation of the new support concept should become easier. Acceptance for a new support concept becomes higher because consultants tested the concept in an earlier stage and discovered the potential advantages themselves. Furthermore, the advantages and disadvantages are plenary discussed. After this plenary discussion, each consultant had to respond on a number of hypotheses on a scale of 1 to 7 and has to provide comments about the individual concepts. The hypotheses represent the performance indicators that were recognized earlier in the research project. By converting these performance indicators into hypothesises, these are made suitable to be used in the workshop. The assessment forms used during the workshop can be found in Appendix E.

2. Continuous feedback
After the gathering all responses of the simulation consultants for all support concepts, the results of the individual concepts are presented which include the average score, deviation and differences in response of simulation consultants. These results are discussed plenary again and each consultant had the opportunity to change their opinion about the most suitable concept along the process. The main goal of this discussion is to create consensus among consultants about the most suitable concept. This approach can also be found in so called ThinkLets that are used in group support systems. The so called “Moodring” ThinkLet has the function to enable participants to “register their opinion on a single topic, then begin an oral discussion. As they talk, if they hear something that changes their opinion in either direction, that change their vote” (Brigss et al, 2003)

3.Anonimity of experts
The chosen approach does not use the strength of anonymous of participants. Simulation consultants can therefore influence other consultants based on there personality, authority or reputation. This is not problematic because this approach focuses on plenary discussions that are started based on the personal results of responses on the series of hypothesises. The outcomes of the workshop can be influenced by the prejudices of simulation consultants as well, but this research projects strongly takes into account the opinion of consultants. If simulation consultants, because of prejudices, favour particular concepts, these concepts will be brought forward as most suitable concepts. After all, this choice is made after presentation of the advantages and disadvantages of concepts and plenary discussions with other consultants.

Evaluation of implementation

The fact that the proposed support concepts are the result of discussions and tests with simulation consultants does not automatically mean that the proposed support concepts can easily be implemented. It should be evaluated in which degree the implementation of the support concept is problematic. In scientific literature there are a many models that can be used for the evaluation of the acceptance of new technologies. Well known models are the technology acceptance model (TAM) and the technology transition model (TTM). These models focus on technological innovation rather then change-of-practice. These models are therefore not fully suitable to be used for change-of-practice. Briggs et al. (2007) formulated the Value Frequency Model. "VFM extends the Technology transition model (TTM) to explain change of work practices. VFM posits cognitive mechanisms that may have evolved among individuals who selected and pursued goals in ways that were more likely to lead to survival and reproduction." (Briggs, 2005 p.37) The Value Frequency Models is used to evaluate the implementation of the proposed support concept. The findings and outcomes of this model are used to draw conclusions on specific issues during the implementation of the support concept. These conclusions are used to define an implementation strategy for the proposed support concept.

3. Empirical research at Tebodin logistical consultancy

Introduction
The goal of this chapter is to provide clear understanding of the problems in the current situation at the logistical consultancy department regarding simulation model development. The historic, current and future situations are assessed in order to discover potential improvements and analyze encountered problems. Analysis of the historic and current situation is done by analysis of finished simulation projects, analysis of pending projects and by doing interviews with simulation consultants. Analysis of the future situation is done by interviewing the manager of the department logistical consultancy, who has insights in trends and the future goals of Tebodin regarding simulation model development. The outcomes of the individual analyses are translated to performance indicators which are being used for the selection (chapter 5) and evaluation of the most suitable support concept (chapter 6).

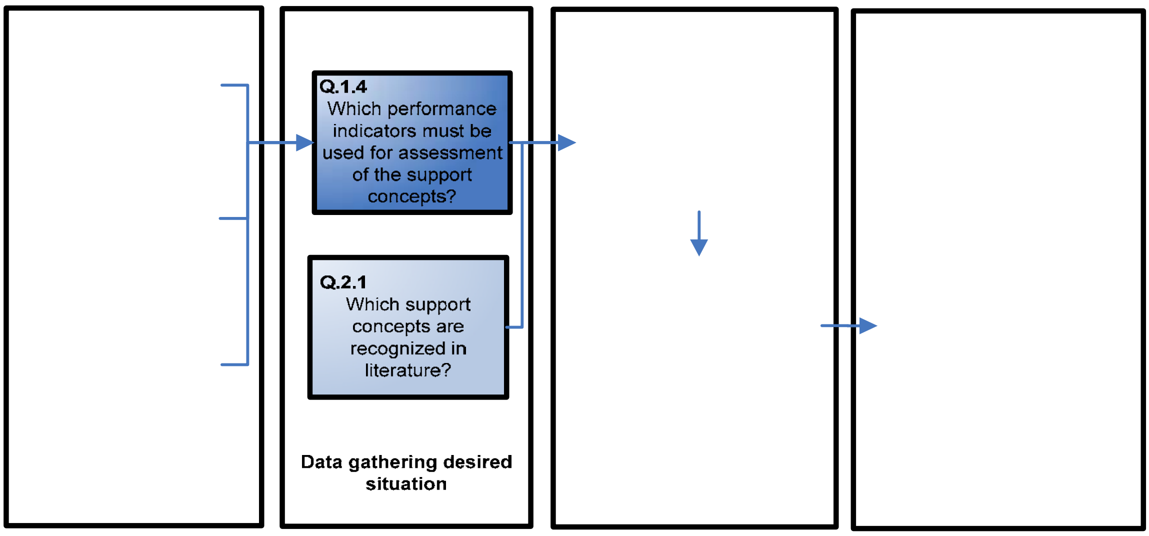


Figure 3.1: Research framework

Structure of the chapter
The first section elaborates on the current development process of simulation models. The next section provides information about the current situation as it is perceived by simulation consultants. Section 3.3 provides information about the bottlenecks in finished simulation projects. Section 3.4 provides information about the (future) trends and function of simulation models within Tebodin. Section 3.5 describes the transformation of the analysis results into performance indicators. This chapter will end with a summary of the most import conclusions and an overview of the performance indicators.

Sub-questions to be answered in this chapter

What is the current approach of the department logistical consultancy for the development of simulation models?

- *What does the current development process of simulation models look like and which aspects require support according to simulation consultants?*
- *What are the problems and bottlenecks in historic simulation projects considering effectiveness of simulation models and the efficiency of the development process?*
- *Which factors influence current and future model development?*
- *Which performance indicators must be used for the assessment of the performance and implementation of the support concept?*

3.1 Current simulation model development process

This section provides information about the current simulation model development approach as it is currently used by Tebodin. Tebodin is an ISO-certified company which has implications on the way work processes must be documented and executed. Figure 3.2 provides a schematic overview of the current simulation model development process. In the most ideal situation, these steps should be sequential steps. In practice these steps can have different order or can be executed parallel to each other. Gregor et al. (1998) conclude that simulation is not only the model building or experiments with the models as it is often presented. The right use of simulation has the following phases;

- Conceptual modeling and preparation
- Modeling and experimentation
- Evaluation of results and application

Proposal
A simulation project is as good as its preparation. (Gregor et al, 1998). A lot of new projects are in continuation of finished projects. During execution of a project, it becomes often clear to clients that additional research is necessary. Acquisition is therefore done by almost all members in the organisation. For all new projects, an initial proposal is made. The proposal includes the planning, budget and details of the projects. The proposal sometimes is adjusted couple of times before it is actually approved

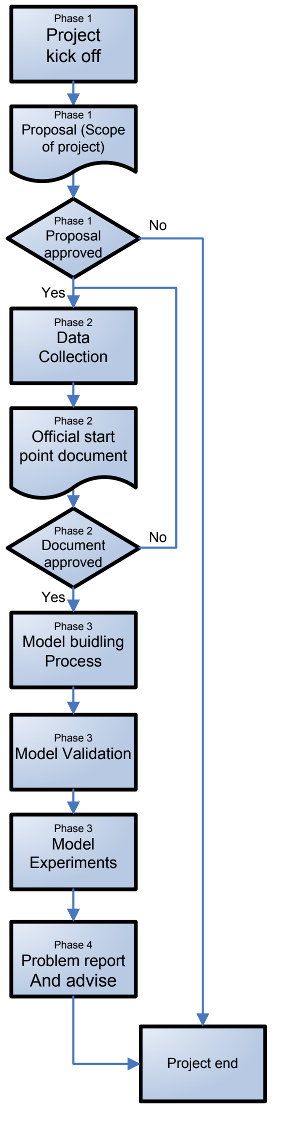


Figure 3.2: current approach

Data collection
Data collection and preparation belong to the most pretentious activities of a simulation project. A sufficient amount of input data must be available in a required quality and form. (Gregor et al ,1998). Data collection is most of the time done by clients and both by Tebodin. In the proposal and official start-point document, Tebodin usually includes that clients are responsible for the provision of all necessary data to Tebodin. If data collection is part of the project, this is usually done by standardized interviews in combination of analysis of client databases.

Start-point document
The start-point document is considered as contract in which all relevant details of the project are determined. Agreements about data gathering, scope of project are described at detailed level. This start-point document has to be officially approved by clients.

Gregor et al. (1998) conclude that a detailed situation analysis, exactly defined project objectives and good preparation of the simulation are crucial for the success of the simulation. According to the authors the following tasks must be solved in this project phase:

- The situation analysis: Identification of the bottlenecks, description of the recognized relationships.
- The objectives of the project
- The required and available resources for the project (time-scale, costs, human resources, knowledge and experience, simulation tools)
- The definition of the scope and the detail level of the simulation model (What elements should be included in the model? Which detail ?).
- The availability of the input data and the experimental framework determination. The detailed situation analysis and the exactly defined project objectives are crucial for the right scope and

detail level of the simulation model, time-scale of the project, required data as well as for the comparison and evaluation of the simulated alternatives.

Gregor et al. (1998) conclude that for the formulation of the project objectives are the following questions important:

- What should be achieved by using simulation? (System objectives, e.g., inventory reduction, throughput time reduction etc.)
- How much should be achieved? (Quantification of the objectives, e.g., throughput increase of about 30 percent etc.)
- How should the objectives be achieved? (Measures to achieve the defined objectives.) Experience confirms the estimation of the time and cost requirements for the simulation project

Model building process
Kleijnen (1995) provides that “it may be asserted that in all simulation studies the analysts should be guided by knowledge of theoretical models with known solutions, when study the real world systems. There are currently no guidelines on how this process should look like. Most of the time, (parts of) existing simulation models are reused in order to build new simulation models. Kleijnen (1995) suggests that good simulation building requires modularity. Then the modeller “devide and conquer”, that is, verify the simulation model module by module. Verification is also part of the model building process. Verification of intermediate simulation output can be calculated manually and compared with the outputs of the simulation model and is called *tracing* (Kleijnen, 1995).

Model Validation
To obtain a valid model, the analyst should try to measure the inputs and outputs of the real system. (Kleijnen, 1995). “Validation is the process of ensuring that a model reproduces the behaviour of the real system. Validation can be quite complicated – especially if the real system does not exit” (Son, 2003). Gregor et al (1998) believe that the main purpose of the validation phase is to determine if the model adequately resembles real system performance. Robinson (1999) argues that validation does not set out to prove the correctness of a model, but in fact to demonstrate that the model is incorrect. Model development and model validation go hand in hand in the interactive process of testing and modifying. The developed simulation models are currently validated with the use of outcomes of static calculations of performance indicators. Static calculations are made with historic data in a spreadsheet program. Model outcomes are compared with the static outcomes. Kleijnen (1995) provides that sometimes it is difficult or impossible to obtain relevant data. In such cases the analysis may try to show that the exact values of the input data are not critical. These problems will be further analyzed with a sensitivity analysis. If no data is available, currently benchmark or best practice data is used to validate model outcomes. Kleijnen (1995) states furthermore that “the further the analysts go back into the past, the more data they get and the more powerful the validation test will be, unless they go so far back that different laws governed the system”

Model experiments
Experiments with the model are done by calculating performance indicators of predefined scenarios. These scenarios are most of the time scenarios that are related to system changes such as future growth. Important for the quality of outcomes (content quality) of model experiments are the number of replications and warm-up period. Currently a fixed warm-up period is used and all scenarios are run with ten replications. The question rises if the warm-up period and the fixed number of replications is sufficient. Robinson (2007) concludes that the selection of a warm-up period for discrete event simulation continues to be problematic. According to Robinson, most methods are not sufficiently rigorous to give accurate results and therefore proposed a new method for determine the warm-up period (SPC Method). This research project will not take into account the process of determine the length of warm-up periods and number of replications because it does not improve the effectiveness of simulation models not the efficiency of the development process.

Report and advice
In the end, the model outcomes of scenarios are used to draw conclusions and provide useful answers to the initial problem description of the simulation project. Depending on the situation if actual handover of models are part of the assignments, user manuals are created that provide instructions for the use of the simulation model.

3.2 Current problems according to simulation consultants

The primary objective of the interviews was to find out what problems simulation consultants have experienced. In this way, conclusion can be drawn about what can be improved by the support concept. Five Simulation consultants were interviewed in order to answer the following research question.

- *What does the current development process of simulation models look like and which aspects require support according to simulation consultants?*

All interviews were held in the The Hague office. Due to the busy schedules of simulation consultants, interviews were held individually and on different moments in time. The next section will elaborate further on the interview methodology that was used for the interviews. During the interviews it became clear that simulation consultants did agree unanimous on certain issues, but also had different opinion on other issues. Overall, all simulation consultants indicated that the current situation should be improved. Table C.1 in Appendix C provides a matrix in which all addressed issues are compared for each individual simulation consultant. The conclusions from this comparison will now be discussed in detail.

Experience with discrete-event simulation
Almost every simulation consultant had experience with simulation before starting simulation projects at Tebodin. The experience was gained during academic education and is related to discrete-event simulation with Arena. One of the consultants had no experience with discrete-event simulation and indicated that the lack of experience lead to problems and that, after the project had finished, the consultant was still not able to develop a proper simulation model. It was mentioned that additional training has to be provided for consultants that have no initial experience with discrete-event simulation. Although most consultants had experience with simulation, all consultants needed help from more experienced colleagues to develop a proper simulation model. This was mainly because of limited experience with the possibilities of Arena (3x), excel interface which is used for input/output of model variables (3x), unclear model structures (2x) and the use of specific Arena templates. The complexity of the simulation models lies within the large number of applied building blocks, variables and attributes, especially when old models are reused and not developed by the consultant itself. Because of these differences in experience, most simulation projects are executed by the same few persons with the most experience. Less than half of the simulation consultants has done more than two simulation projects. This is an unwanted situation because, for simulation, Tebodin is heavily dependent on only these few individuals. This dependency leads to limited flexibility in resource utilization and low knowledge redundancy (because of concentrated tacit knowledge). The combination of low knowledge redundancy and the fact that the ascent of employees is relatively high within Tebodin, the risk of losing large amounts of important simulation knowledge is relatively high.

Communication in simulation projects
Consultants indicated that there were limited communication problems between clients and consultants. This has mainly to do with the extensive communication during the project. However, when more simulation consultants were working on the same project, communication problems between consultants did sometimes occur. Communication problems were related to practical issues like naming-standards in arena, how to split up the workload (sub models) and how to add together sub-models again. These communication issues lead to a less efficient development process.

Consultants indicated that in hardly any project, conceptual models were used for communication with clients. Conceptual models are an efficient tool to communicate about the scope of a simulation project. Not using conceptual models is surprising considering the fact that a few simulation consultants indicated that the risk of scope changes could be reduced during the project by defining the scope of projects in conceptual models. Mind that scope changes will never be avoided, but the risk on scope changes can be reduced. Section 1.5.3 provides more information about conceptual models. Overall, consultants indicated that they are satisfied with the current communication in simulation projects.

Development time of simulation models
Less than half of the simulation consultants have had experience with time overruns. These overruns were mainly due to programming problems and problems with the compilation of the final model from sub-models, that were made by individual consultants. Consultants indicated that in many projects, scope changes lead to a situation in which the planning was adjusted including the deadlines. The extra time planned was more than enough to include the new scope changes which resulted in extra time to finish the initial assignment. Without these scope changes, some consultants indicated that time overruns were more likely to happen in finished simulation projects. In general, most of the time overruns tend to occur in fast track planning projects. Hardly anyone uses conceptual models as a guideline for simulation model development. This is because in almost all projects, conceptual models are not made at all. In the few projects in which conceptual models were used, it was used because of a large complex project with multiple parties. The conceptual model was in these cases only used for communicational purposes. The conceptual modelling technique was applied incorrectly and did not comply with the requirements of the particular technique. There was no incentive to improve this situation because clients were satisfied with the conceptual models. For Tebodin, these conceptual models could not be used for other functions because they were not complete.

Not everybody used templates. A reason why templates are rarely used can be explained because many consultants indicated that they are not acquainted with the existence and possibilities of templates. Section 4.2.3 provides more information about templates. Consultants, who did use templates, indicated that the use of templates lead to a more efficient simulation model development process, which lead to several advantages such as time savings and improved user friendliness. Another important conclusion about the use of templates is that the more experienced simulation consultants are sceptic towards templates that are made by others. Before using a template, consultants indicated that there's no guarantee that templates work properly, so they want to understand what the template does. The most ideal situation is one in which the consultants that has made the template can explain how a particular template works. The problem is that most of the time, explanation can not be given because other consultants are to busy or do not work for Tebodin anymore. This conclusion is in line with findings of academic research to the use of templates (also know as pre-defined building blocks). Verbraeck and Valentin (2002) concluded that the effectiveness of building blocks depends on the type of users. Simulation experts will only use building blocks when they "trust" them en know how they work Given the fact that simulation consultants at Tebodin are mainly experts, it seems that implementation of building blocks can be difficult. Planning is an important part of a simulation project. It is therefore remarkable that not much effort is put in developing a project planning. For the proposal a simple excel planning is made, while other tools which provided much more functionalities and which are used in the industry are favoured.

Consultants indicated that they are not given the opportunity to determine the final lead times of simulation projects. This is surprising, given the fact that the consultants have clear insight in the content of the project. Only few consultants were involved in the planning/proposal of the project. If consultants were involved in the planning of projects, they indicated that the initially planned time was not the same as the lead time in the final proposal. In most cases, a few weeks of the total lead time was shaved of the initial planning by a couple of weeks. In general, there will always be healthy tension between a manager and an employee in lump-sump projects. An employee wants enough time to finish the job and a manager wants as less time as possible that is needed to finish the job to prevent gold plating and to make as much profit as possible. Gold plating occurs when to much time is spend on issues that are less important or are not part of the scope. It seems useful that people with the most experience with building simulation models are providing advice about the time necessary to execute the project and about pitfalls that can occur during a current simulation project.

User friendliness
All simulation consultants have indicated that the user-friendliness can be improved by implementing a new support concept. The main reason for this is that a lot of simulation consultants have indicated that they regret the fact that a structured approach to develop simulation models is missing. Structure leads to predictability and familiarity which leads to a higher user friendliness of the development approach. After having explained which possibilities there are to support simulation projects, all consultants indicated that they think that the user friendliness of the model development approach will increase after implementation. Worth mentioning is that some consultants indicated that it is important to keep simulation projects attractive to simulation consultants. If simulation projects are not attractive, motivation of consultants will be low which can affect the quality and execution speed of simulation projects in a negative way.

Flexibility of simulation models
Almost all consultants have indicated that certain parts of simulation models can be reused in different projects without any modifications. Most of the consultants mentioned the same sub-models that could be reused in every project. Examples of these sub-models are berth allocation, weather generator, ship arrivals and pilot availability. After a more detailed analysis of these sub-models, the conclusion can be drawn that these sub-models are relatively small and have low complexity in comparison to the simulation model as a whole. This indicates that most parts of simulation models are customized for each simulation project. At first sight, simulation models and assignments look very similar, but specific details of assignments obviously have major impact on the actual structure of the simulation model.

Furthermore, only a single consultant indicated that simulation models could easily be reused for similar projects. This reaction can be explained by the fact that consultants are reticent towards the term “similar”. Because of the impact of small details on the structure of simulation models, projects have to be “very” similar in stead of “more of less” similar in order to be easily reused in the future. The meaning of similar is different for every individual. There is another conclusion that can be drawn from the interviews that can possibly explain the reticence towards “reuse of similar models”. The limited number of consultants that indicated that simulation models could be reused for similar projects made the remark that this is only the case for simulation models that are made by themselves. Probably, in this way they can asses if similar projects are really similar projects. In literature, the same problem is recognized; “One must ask, what is the likelihood that the subsystem component will conveniently model the equivalent subsystem? (Robinson et al., 2004 p. 489).

Almost none of the simulation consultants indicated that simulation models can easily be extended for future assignments. Remarks were made that extensions could only be made when the model is set up rather flexible. This must therefore be one of the basic assumptions while building all simulation models. In the current situation this assumption is not given priority. This could be explained because of the limited development time that is planned for simulation models, which does not allow time to “build in” flexibility. Furthermore, making extension to simulation models made by others is difficult because of the lack of proper documentation. Therefore the limited number of consultants that indicated that simulation models could be extended made the remark that this is only the case for simulation models that are made by themselves. Robinson et al. (2004) may provide an explanation for this phenomenon; model reuse is essentially dependent on trust. If a modeller cannot trust a model then surely they cannot reuse it. Given the fact that almost nothing is documented about finished simulation models and conceptual models are not available, it is difficult to get clear insight in a simulation model that is build by others. Poor insight leads to low degree of trust in the simulation model.

Transferability of simulation models
Almost all simulation consultants have indicated that they used existing models as starting point for the development of new simulation models. The choice was made to reuse simulation models mainly due to the fact that planning did not allow starting from scratch. Reusing simulation models has lead to problems by everybody. In the few projects that problems with reuse did not occur, this was because of the fact that the initial model was made by the same person that reused that particular model. Not surprisingly, there was indicated that the main problem was to get clear understanding of the structure and function of the model used. Because of the lack of documentation and the fact that most of the time the former developer could not provide clarification makes this such a difficult task. Consultants indicated that, on average, they needed a week to understand what the other model actually does in general.

Because of tight project planning, most of the time not enough attention to the analysis of use and function of simulation models is given. In other words: people just start with converting the old model to the new situation without having clear understanding of the models initial purpose and model details. Lack of clear understanding leads to problems later in the process such as unpredictable programming and validation problems. These problems can have a large impact on missing deadlines and quality of simulation models because these problems occur near the end of the development process. Making changes later in the process has more impact and takes far more time and effort than making changes early in the process. For both consultants and project manager it is a frustrating experience that initial expectation of the model are not met so late in the process. This leads to a rather unpredictable development process which is a highly unwanted situation for everyone in the organisation. "The conclusion is that in most cases, reuse of subsystem models could be even more costly than developing it from scratch" (Robinson et al., 2004 p.489). This conclusion could be true for the situation within Tebodin. In almost every project, all planned time for contingencies is used for delays due to problems related to reusing simulation models. "So, asking the question "what use is model reuse?" Some use but with the caveat of careful planning and foresight!" (Robinson et al., 2004, p.490).

Quality of simulation models
A few of the simulation consultants indicated that some simulation models did not have the appropriate level of detail considering the problem situation. This was mainly caused by to many reductions and simplifications in simulation models. The reduction and simplifications were the result of planning issues. Insufficient development time was planned because assumptions were made that a "similar" simulation model could easily be reused for the problem area. The initial model turned out to be not fully appropriate for the new problem area which leads to necessary, but unwanted, simplifications in the new simulation model. Most of the simulation consultants did think that the simulation models provided the right conclusions, considering the problem description. Some made the remark that conclusions were sufficient but that conclusion could be better. Because of the intensive communication with clients during simulation projects and clearly defined goals and outcomes (performance indicators), this is a predictable conclusion. Final conclusions can be drawn relatively easily; the question is if the level of detail and outcomes of the model are reliable and detailed enough. Especially, considering that fact that relatively limited attention is given to the validation of simulation models.

After interviews with the simulation consultants it became clear that there were several aspects of the current development that require support. Support is required because of the following reasons;

- Important simulation knowledge is lost if consultants switch jobs
- Development delays due to unforeseen programming errors and problems adding together sub-models
- Lack of trust by simulation consultants in simulation (sub)models that are made by other consultants
- Poor attractiveness of simulation projects which leads to motivation problems with simulation consultants to execute or joint simulation projects current simulation model development process
- Poor extendibility of existing simulation models.
- Clients expectations are exceeded (quality and level of detail of finished simulation models)

- Communication problems during the actual development of simulation models between consultants
- Problematic reusability of simulation models

According to the simulation consultants these aspects lead to problems in the current development process. There are possible more problems that occurred in the past. Most of the current simulation consultants have not experienced these problems, so finished simulation projects should be analysed as well. The next section will elaborate on the bottlenecks in historic simulation projects.

3.3 Problems in historic simulation projects

The primary objective of this section is to elaborate on the problems and bottlenecks which occurred during historic simulation projects. In this way, conclusion can be drawn about what can potentially be improved by new support concept. Several simulation projects were assessed in order to answer the following research question.

- *What are the problems and bottlenecks in historic simulation projects considering the effectiveness of simulation models and the efficiency of the development process?*

Seven projects are assessed which were selected based on a set of predefined criteria which can be found in section 2.4. The assessed simulation projects had different size, different number of consultants working on them, level of complexity, subject and client satisfaction. The analysis focused on finding problems during each phase in the simulation development process (section 1.6.3) in each simulation project. Furthermore, there was tried to find cause-and-effect relationships for the encountered problems. By comparing the results of analysis of the different simulation projects, similarities in bottlenecks and encountered problems during simulation projects can be found. The cause of these problems and bottlenecks must be prevented by the new support concept and must therefore be taken into account be assessing potential measures. In appendix D, detailed description of the analysed projects can be found. Table 3.2 provides an overview the encountered problems in different project phases in each of the finished simulation projects.

Problem phase	A	B	C	D	E	F	G
Proposal/planning approval		√					
Data gathering							
Creating Start point document						√	√
Start point document approval							
Model building process	√	√	√		√	√	√
Interim discussions build process		√					
Validation process					√	√	
Experiments with simulation model			√		√	√	√
Presentation/discussion results				√			

Table 3.2: Overview problem phases of finished projects

Not all problems that occurred during simulation projects were significant. Some problems were the result of specific circumstances of the projects. Overall, the conclusion is that the bottlenecks in the current development process are located in the development phase and during experiments with simulation models (running scenarios). Bottlenecks in the current development process are the result of the specific issues;

- Problematic reuse of existing simulation models
- The absence of a well-defined scope during development of models
- The use of tight and fast track-planning
- Insufficient experience of simulation consultants with developing simulation models

Analysis has shown that the reuse of simulation models is most of the time problematic. If reductions and lack of details are problematic for clients, starting from scratch becomes more interesting. Starting from scratch is especially an interesting approach considering the experienced problems in most projects with the reuse of existing simulation models. Reuse of simulation models lead to time delays and arguable limitations in the model which can influence the model quality in a negative way.

Reuse of (parts of) simulation models has shown to be an effective approach in some simulation projects which had a very high rate of similarity. Analysis on similarity is therefore very important and should be done in the early phase of the development process. Analysis on similarity takes extra time in the development process, but can save much time later in the development process. This assessment is especially time consuming when documentation on the initial simulation model is poor and the former model developer is not available for questions. In general, people should be aware of the fact that minor changes in starting assumptions or performance indicators can have major implications for model structure. Underestimating the complexity of modern computer simulation can lead to misunderstanding about possibilities of existing simulation models and estimations of development time. The conclusion from Robinson et al. (2004) that in most cases, reuse of subsystem models could be even more costly than developing it from scratch can possibly be applied for Tebodin as well. The Client D model can be a good example. In this project, there were no significant delays, discussions about proposed planning and quality issues. Because of additional model extensions it was a successful project for Tebodin as well. Furthermore, the client was so pleased with the results that a letter of recommendation was provided. This is a result to which should be strived for in every project.

A clear project scope has shown to be important for a pliant simulation model development process. The reoccurring phenomenon that, because of "progressive insights", clients change there priorities and want to change issues or add scenarios during the simulation project caused a lot of problems. For some assignments, simulation is chosen as a tool to provide (detailed) outcomes while for other assignments simulation is chosen to support decision processes in general (also see section 1.5.1). Valentin (2008) provides that simulation models enable problem owners to gather insight into the aspects of their system. With this insight problem owners can then suggest alternative solutions and further improve their decision making process. Therefore, in projects where simulation is used to support decision processes in general, scope changes are more likely to happen. Currently, these scope changes are a threat because most of the simulation projects are based on fixed price contracts. This threat can be translated into an opportunity for Tebodin. Scope changes can be used as an opportunity when because they result in new fixed price projects. In this way, scope changes lead to extra work in a project. In fixed price contracts, the scope should determined a clear. In this type of projects, scope changes should lead to additional assignments such as simulation model extensions. Project A is a good example of a successful fixed price approach and can be used as "best practice".

3.4 Future simulation model development

To asses the future situation on simulation model development, the manager of the logistical consultancy department was asked about current and future trends and the future role of simulation within Tebodin. The primary objective of the interview was to find out which factors influence the future simulation model development. In this way, conclusion can be drawn about what performance indicators must used for the support concept. The manager was interviewed in order to answer the following research question.

- *Which factors influence current and future model development?*

The factors that influence current and future simulation model development can be split up into different areas. The following areas can be recognized;

- Trends in the market
- Current situation for simulation
- Desired future situation for simulation

Trends in the market
At this moment, there are a few trends in the market. The simulation market becomes more and more a compilation of small niche markets. This is the result of that fact that Tebodin and simulation consultancy firms in general are becoming more and more specialized. Experience and high reputation in certain niches reinforces this tendency towards specialization. Relationships with customers become stronger and more dedicated as well.

There is a clear trend that simulation models must be developed more quickly because of specific characteristics of the liquid bulk market and because of the increasing dynamics of markets in general. One of the specific characteristics of the liquid bulk market that causes the demand for speed is the long building process of facilities. The expansion of existing facilities and building new facilities is a time consuming process. Simulation studies are done in the early phases of making decisions on e.g. facility extensions. The faster simulation projects are finished, the faster decisions can be made and the actual building process can be started. Another characteristic of the liquid bulk market is that there is always a finite opportunity window. Clients lose momentum if the decision making process is slowed down. Considering these characteristics in combination with, in many cases, limited facility capacity and the increasing oil price, speed becomes even more important.

Apart from speed of development, there is a trend that reliability is becoming more and more important. Reliability does not only mean that deadlines are met, but also that the whole development process is predictable and controllable. Predictability of the development process is important because clients have a high degree of involvement in simulation projects and tend to want to have insight and control on the project as well. The overall conclusion is that clients demand that Tebodin does what is promised, transparent, fast and in time. There is a negative trend in the ascent of consultants. An increasing number of people come and go as consultant of Tebodin. Employees tend to change jobs more quickly. This is in line with the general trend of a flexible labor market which is in favour of employees. Because of this phenomenon, important knowledge comes and goes as well.

Current situation for simulation
In the current situation, there are several aspects of simulation projects that are notable or that can be improved. The size and complexity of simulation models varies quite a lot. This is the result of different clients. There are clear differences in size and structure of simulation models for oil related industries on the one hand and port authorities on the other hand. This means that the knowledge needed to execute a simulation study also differs.

Momentarily, there are more than enough consultants and skills available to execute simulation projects. There are, for example, consultants who have had experience with simulation long time ago with relatively simple simulation software that can also execute projects if necessary. It seems like it, that the logistical department can therefore cope with possible future growth of the number of simulation projects. The question rises if historic experience of consultants is sufficient in order to successfully employ the current, much more complex, simulation software. Because of the strong relationship with clients and the good reputation in the market, earnings and margins of simulation projects are not problematic. Discussions on proposed contract values are rarely seen. It seems like, that the market is willing to pay as long as Tebodin is committed to the desired reliability and speed.

According to the manager, an unwanted and recurrent situation is that in every simulation project, the extra time planned for contingencies was always needed. The conclusion is that the planned extra time was always needed in the development phase of the simulation model. Programming problems were the main cause of the need for extra time. Worth notifying is that project managers should always keep in mind that strategic behaviour of consultants can occur. The question should be asked if the delays are really caused due to unforeseen programming problems or if extra time is used to extend the consultants planning. Project managers have not enough insight in project details to assess actual progress themselves. Mintzberg (2004) concludes that in professional bureaucracies there is hardly any control on the job and no way to improve short comes that the professional themselves want to neglect.

Desired future situation for simulation

The desired future situation is a combination of future goals and anticipation on trends (need to haves) and aspects that are desirable (nice to haves). Turnover goals are set by the management of Tebodin, which are specified for each core competence of Tebodin. The turnover, generated by simulation projects, has to be improved. Goals are set, that in 2008, 40% more turn-over is generated by liquid bulk related simulation projects.

Tebodin should anticipate on future trends. This means that the current approach for simulation needs to be improved on certain areas. Simulation projects must be executed more quickly. Apart from increasing the speed of development, simulation projects must become more predictable and project planning must be more controllable to improve the reliability of Tebodin towards clients. Furthermore, the negative effects of the ascent of employees must be reduced is much as possible. The nice to have issues are related to the consultants of Tebodin. There was indicated that higher flexibility of consultants is desired. More people should be able to do different projects such as simulation projects. Furthermore, there should always be strived for improvement of the working environment for consultants. The companies mission statement, explicitly states that Tebodin wants "to be an attractive employer" for that reason. This section made clear that there are several future requirements regarding simulation models that should be taken into account when developing a suitable support concept. The following aspects are recognized that are needed to be achieved by the new support concept;

- Decrease the lead-time of simulation projects
- Increase the reliability of the section logistics towards clients
- Minimize the ascent of simulation consultants
- Reduce the complexity of simulation model development in order to reduce the effort needed to learn to develop simulation models for simulation novices.

The next section elaborates on the performance indicators that should be used to evaluate suitable support concepts in a further stage of this research project. These performance indicators follow from the results of the analysis of the historic, current and desired future situation regarding simulation model development.

3.5 Performance indicators for evaluating support concepts

The objective of this section is to provide a list of performance indicators for the assessment of potential support concept. These performance indicators follow from the analysis of the historic, current and future (desired) situation of simulation model development. The results of interviews with simulation consultants and the head of logistical consultancy combined with the results of the analysis of finished simulation projects lead to conclusions that were used to answer the following research question.

- *Which performance indicators must be used for the assessment of the performance and implementation of the support concept?*

Section 3.4.1 will elaborate on the translation process of the analysis results into usable performance indicators. Section 3.4.2 provides an overview of all performance indicators.

3.5.1 Abstraction of performance indicators

Previous sections have made clear what problems can be recognized in historic and current simulation model development process. Furthermore, it became clear how the future of simulation model development within Tebodin should look like. These findings are used as criteria that can be used for evaluating potential support concepts. The requirements should be translated into measurable performance indicators in order to evaluate in which degree the potential support concepts comply with these requirements. There are different approaches to measure performance indicators. Performance indicators can measure specific units of measurement such as hours if development time is discussed or can be measures on a certain scale without using a unit of measurement. The way performance indicators are used should fit the method that is used to evaluate or compare alternatives. In this research project, workshops are used to assess the perceived effectiveness by consultants about the effectiveness of each support concept for Tebodin. The effectiveness is measured with the use of performance indicators. Because the goal of the workshop is to assess the perceived effectiveness based on the perception of simulation consultants rather than on the effectiveness that is based on factual changes, assessment is done with performance indicators that use a scale from one to seven in stead of using units of measurement. Many of the performance indicators focus on assessing the effectiveness of something that is rather subjective. Therefore, the discussed approach seems to be the most suitable approach given the specific character of the problem situation. Wieringa (1996) provides a list of desirable properties for specification of requirements that the performance indicators should have;

- *Communicability*: The specification should serve as a channel of communication about the system among all stakeholders.
- *Validity*: The specification should present the requirements on the system accurately
- *Completeness*: Although it would be desirable that the specification describes all requirements, without omitting one, total completeness is not achievable and certainly not within a restricted time interval. Therefore, a certain degree of completeness can only be established by agreement.
- *Feasibility*: The specification should describe behaviour that is realizable in a system. The costs of implementing the system according to these descriptions has to be justified by its (future) benefits.
- *Verifiability*: It should be possible to observe whether a system satisfies its specification, which means that properties of the system should be specified in a measurable way.

With these desired properties in mind, the outcomes of the empirical research are translated into a set of performance indicators. Simulation consultants indicated which problems occurred in the current development process. Table 3.3 provides an overview of the current problems with corresponding performance indicators. Many authors (Kolfschoten et al, 2006;Chwif et al, 2006;Briggs et al., 2003) relate cognitive load reduction for model developers as the ease of use or ease of development of certain concepts. Cognitive load can be defined as the cognitive effort made by a person to understand and perform his task while using specific tools (Kolfschoten et al., 2006). It was concluded that consultants had problems using Arena when developing simulation models. The cognitive load of simulation consultants should therefore be taken into account.

The redundancy of knowledge within the logistics department should be increased. There is a risk that consultants change jobs which results in losing important knowledge. Therefore, the risk of lost knowledge should be taken into account. The quality of process is concerned with the way in which the work is performed. The process includes aspects such as the level of communication. Based on this definition, communication between consultants should be measured with level of quality of process. The quality of content refers to content of the technical work within the modelling process conforms to the requirements of the study. The technical work includes the specification of the problem, the development of the conceptual model, the experimentation and the analysis and reporting of the results. These aspects determine the quality of a simulation model and the level of detail of simulation models. Therefore, the level of detail and quality of the simulation model is measured as the level of quality of content.

The execution time of simulation projects and the number of delays during the development should be taken into account to asses in which degree delays in the development can be reduced. Robinson (2001) provides that credibility of simulation models is the confidence or beliefs someone is willing to place in a model and its results. During the interviews it became clear that simulation consultants were precarious about simulation models made by other simulation consultants. The credibility of simulation models can therefore be used as performance indicators to measure the level of trust consultants have in simulation models.

At the moment, simulation consultants find simulation projects not attractive. This situation is mainly caused by fact that simulation consultants have difficulties with determining how to develop a simulation model in general and how to develop a simulation model in Arena. To take into account this problem, the pragmatic quality should be assessed. Briggs et al. (2003) conclude that the perceptual load reflects the user friendliness of systems, that is the amount of mental effort required to find the features and functions that are required to accomplish a task.

Extending and reusing simulation models is currently problematic, because simulation consultants have difficulties with understanding the structure and logic of simulation models that should be extended or reused. This is caused by the fact that the developer of the initial model is not the same person as the one that should reuse or extend the simulation model. Rensburg (2005) defines the pragmatic quality of models as the degree in which models can be understood by relevant stakeholders. In this case, the relevant stakeholders are consultants that reuse simulation models or make extensions to a simulation model in the future.

Problems current process	Performance indicator:
Difficulties with model development using Arena	Cognitive load reduction
Poor knowledge redundancy	Risk of lost knowledge
Communication between consultants	Quality of process
Development delays	Execution time simulation projects
	Number of delays
Lack of trust in simulation (sub)models	Credibility of simulation models
Poor attractiveness/user friendliness current simulation model development process	Perceptual load reduction
Limited quality/level of detail simulation models	Quality of content
Problematic reusability and extendibility of simulation models	Pragmatic quality

Table 3.3: Current problems according to simulation consultants

Some of the above mentioned problems in the current development process were observed as problems in finished simulation projects as well. Analysis of finished simulation projects provided a number of bottlenecks in simulation projects. Bottlenecks should be reduced as much as possible, so these bottlenecks must be taken into account as performance indicators.

As discussed, the quality of process is concerned with the way in which the work is performed and the extend to which it conforms to the expectations of clients. The process includes aspects such as the relationship between modeller and client, level of communication, timeliness of work, to level to which the work performed conforms to the expectation of clients and the confidence of the client in the modeller. These factors determine the chance of scope changes and the degree in which a planning is realistic. If the quality of process is low, scope changes are more likely to happen because expectations are not managed sufficiently. Furthermore, if communication between clients and consultants or between consultants is poor, there is limited input of information for the definition of the expected lead time of simulation projects which leads to an unrealistic planning. If quality of process can be improved, information transfer will improve the accuracy of project planning.

Robinson (2001) provides that one of the dimensions of project quality is the competence of the modeller; the possession of the necessary skills and knowledge by the modeller (and his/her organisation to perform simulation projects). This dimension can be used as performance indicator for evaluating the required experience of simulation consultants. Table 3.4 provides an overview of the observed bottlenecks with the corresponding performance indicators.

Bottlenecks in the development process	Performance indicator:
Unrealistic planning	Quality of process
High chance on scope changes	
Limited simulation experience of consultants	Required competence of modellers

Table 3.4: Bottlenecks in simulation projects

Apart from problems that can be observed, requirements can be abstracted that take into account future trends and desirable future situations. In this way, the robustness of solutions is being increased. Table 3.5 provides an overview of the desired requirements for the future situation with corresponding performance indicators. The lead time of simulation projects should be reduced. Therefore, the support concept should be evaluated on there impact on the execution time of the entire simulation projects.

It has become clear that the quality of process includes aspects such as the timeliness of work, to level to which the work performed conforms to the expectation of clients. These factors determine the reliability of Tebodin towards customers. In the context of this research project, the only factor that could be improved to minimize the ascent of simulation consultants is the attractiveness of simulation projects in general. The current attractiveness is limited and should be improved. As stated before, cognitive load can be defined as the cognitive effort made by a person to understand and perform his task. (Kolfschoten et al., 2006) If the cognitive load for developing simulation models can be reduced, the non-experienced consultants should find it easier to learn and execute simulation projects.

Future requirements	Performance indicator:
Shorter lead time simulation project	Execution time simulation projects
Increase reliability of Tebodin towards clients	Quality of process
Minimal ascent of simulation consultants	Attractiveness of simulation projects
Reduce effort for novices to develop simulation models	Cognitive load reduction

Table 3.5: Future requirements for simulation model development

Briggs (2005) concludes that deliberate attempts to change the way people do business are not always successful. Sometimes people resist a new practice, even when evidence suggests that the new practice might benefit both the organization and the individuals involved. Therefore, successful implementation of new measures depends on the users' acceptance of these new measures. Section 6.1 elaborates on different models that can be used to evaluate the acceptance of new technologies by users. The outcomes of such models can be useful to find out how successful the implementation of the new support concept could be, before the actual implementation (based on users acceptance). Therefore, performance indicators related to implementation should be included as well. In this research project there is chosen to use Briggs (2005) Value Frequency Model for the evaluation of the acceptance of users. The Value Frequency Model recognizes a number of dimensions that determine the perceived magnitude of the net value that may be obtained after change-of-practices. These dimensions are therefore critical for the success of new measures and should be taken into account in the selection of suitable support concepts. Briggs et al. (2003) provide the definitions of the dimensions that determine the perceived magnitude of value;

- *Affective:* The extent to which the change-of-work-practice will invoke positive or negative emotional response in the user.
- *Economic:* The extent to which the change-of-work-practice will increase or decrease the user's cash etc.

- *Physical:* The extent to which the change-of-work-practice will increase or decrease the user's health or comfort.
- *Political:* The extent to which the change-of-work-practice will increase or decrease the user's power or influence within or across organizations.
- *Social:* The extent to which the change-of-work-practice will enhance or detract from the user's personal relationships with other people, such as colleagues, friends and family.
- *Cognitive:* The extent to which the change-of-work-practice will increase or decrease the user's amount of mental effort expended to complete tasks the technology supports.

Not all dimensions are useful for this research project because change-of-work-practices are more generic then the implementation of support concepts within Tebodin. The physical and economic dimensions are precluded because these dimensions are not applicable for the implementation of new support concept within the logistics department. Table 3.6 provides an overview of performance indicators that must be used for the evaluation of support concepts regarding implementation.

Implementation issue:	**Performance indicator:**
Emotional response of user because of a support concept	Affective magnitude
Personal gain of the user because of support concept	Political magnitude
Personal relationship change because of a support concept.	Social magnitude
Change of mental effort to complete simulation studies because of a support concept.	Cognitive magnitude

Table 3.6: Performance indicators implementation

After the definition process of performance indicators, the performance indicators should be validated. Requirements validation is according to Theodoulidis (1993) in Burg (2001) are subject to the following criteria;

- *external consistency*: agreement between what is stated in the requirements model and what is true in the problem domain
- *non-ambiguity:* a requirement cannot be interpreted in more than one way
- *completeness*: no omission of essential information about the problem domain

The external consistency and completeness are checked by discussing the problems and performance indicators with simulation consultants. The consultants agreed on the fact that the described problems actually occur and that the performance indicators address all relevant problems in the current situation. Without proper explanation, the performance indicators can be perceived as ambiguous. In this section, clear explanations are provided in order to avoid the problem that performance indicators could be perceived ambiguous. During the workshop, before assessing potential support concepts, all performance indicators are properly explained in order reduce the degree of ambiguity of the performance indicators as much as possible.

3.5.2 Overview of performance indicators

The performance indicators that are used to select and evaluate support concept are the result of the analysis of the historic, current and desired situation. The performance indicators are grouped into four main categories. A clear distinction can be made between development process related and simulation model related performance indicators. Development related indicators are used for the assessment of the actual development process of a simulation model while simulation model related indicators are used for the assessment of necessary characteristics that the actual model should have. Furthermore, there are consultant related performance indicators that are used for the assessment of more general issues. Finally there are performance indicators that are used for the evaluation of the acceptance of consultants that determine successful implementation. The following performance indicators for the selection and evaluation of support concept are defined;

Development process related performance indicators

- Execution time simulation projects
- Number of delays
- Process quality

Simulation model related performance indicators

- Credibility of simulation models
- Content quality
- Pragmatic quality

Consultant related performance indicators

- Risk of lost knowledge
- Attractiveness of simulation projects
- Required competence of modellers
- Perceptual load reduction
- Cognitive load reduction

Implementation related performance indicators

- Affective magnitude
- Political magnitude
- Social magnitude

3.6 Sub-conclusions

The main goal of this chapter is to provide insight in the problems that occur in the development of simulation models. The results of analysis of the historic, current and desired situation are translated into a set of performance indicators that are used to select and compare suitable support concept that can reduce these problems.

All simulation consultants unanimous indicated that the current situation has to be improved. Table 3.7 provides an overview of which areas need attention and additional support.

Aspect of development process	Current situation
Communication during simulation project	
Development time of simulation models	
User friendliness of development approach	
Flexibility of simulation models	
Transferability of simulation models	
Quality of simulation models	

Table 3.7: Current situation according to simulation consultants

Overall, simulation consultants are satisfied with communication during simulation projects. Communication between clients and consultants does not need improvement. Communication between consultants in joint-modeling projects is sometimes difficult. Most simulation consultants have had experiences with time overruns in simulation projects. The cause of these overruns was due to programming problems that were underestimated and not incorporated in the initial planning. Support is needed to have more control over the project execution and a more reliable planning. The user friendliness of the current simulation model development approach is very low and should be improved to keep simulation projects attractive to consultants. Simulation models lack flexibility, which results in simulation models that are difficult to extend and reuse in future projects. Support must be provided to “build in” flexibility. The transferability of simulation models should be supported as well. In the current situation it is not possible to properly reuse existing simulation models due to the lack of structure and documentation of the initial model. Measures must also be taken to improve the quality of simulation models. Some existing models did not have the intended level of detail considering the problem situation.

Not all problems that occurred during simulation projects were significant. Some problems were the result of specific circumstances of projects. Analysis has shown that the bottlenecks in the current development process are located in the development phase and when experimenting wit the model. In most projects, the reuse of existing simulation models was problematic. Reuse of simulation models leads to time delays and arguable limitations in the model which can influence the model quality and client satisfaction in a negative way. For model reuse in general, people should be aware of the fact that minor changes in starting assumptions or performance indicators can have major implications for new model structure. The lack of a clear project scope has shown to have a negative effect on the simulation model development process. Because of “progressive insights” by clients during the development process, priorities and scope changed which caused a lot of problems in the development of the actual simulation model. This problem can be translated into an opportunity under the condition that the scope of the project is clearly defined. For some assignments, simulation is chosen as a tool to provide (detailed) outcomes while for other assignments simulation is chosen to support decision processes in general. Especially in projects where simulation is used to support decision processes in general, scope changes are likely to happen. Furthermore, a fast-track project planning leads to time overruns during the development phase of simulation.

The desired future situation regarding simulation is the result of both anticipation on market trends as well as complying to turnover goals set by the management. The turnover, generated by simulation projects, has to be improved. Because of trends in the market, simulation projects must be executed more quickly, simulation projects must become more predictable and project planning must be more controllable in order to improve the reliability of Tebodin towards clients. Furthermore, the negative effects of the ascent of employees must be reduced as much as possible. Higher flexibility of consultants and improvement of the working environment of simulation consultants are desirable.

The performance indicators that are used to select and evaluate support concept are the result of the analysis of the historic, current and desired situation. The performance indicators are grouped into four main categories. The following performance indicators for the selection and evaluation of the support concepts are defined;

Development process related performance indicators
- Execution time simulation projects
- Number of delays
- Process quality

Simulation model related performance indicators
- Credibility of simulation models
- Content quality
- Pragmatic quality

Consultant related performance indicators
- Risk of lost knowledge
- Attractiveness of simulation projects
- Required competence of modellers
- Perceptual load reduction
- Cognitive load reduction

Implementation related performance indicators
- Affective magnitude
- Political magnitude
- Social magnitude

4. Literature research on support concepts for simulation model development

Introduction
The goal of this chapter is to provide an overview and theoretical background of suitable concepts for supporting simulation model development within Tebodin. In scientific literature, several concepts for improving the effectiveness of simulation models and the efficiency of the development process are recognized. Each concept has specific advantages and disadvantages. The advantages and disadvantages are being used for the evaluation of support concepts. Chapter five elaborates on the evaluation of the recognized support concepts and the evaluation of the most suitable concept.

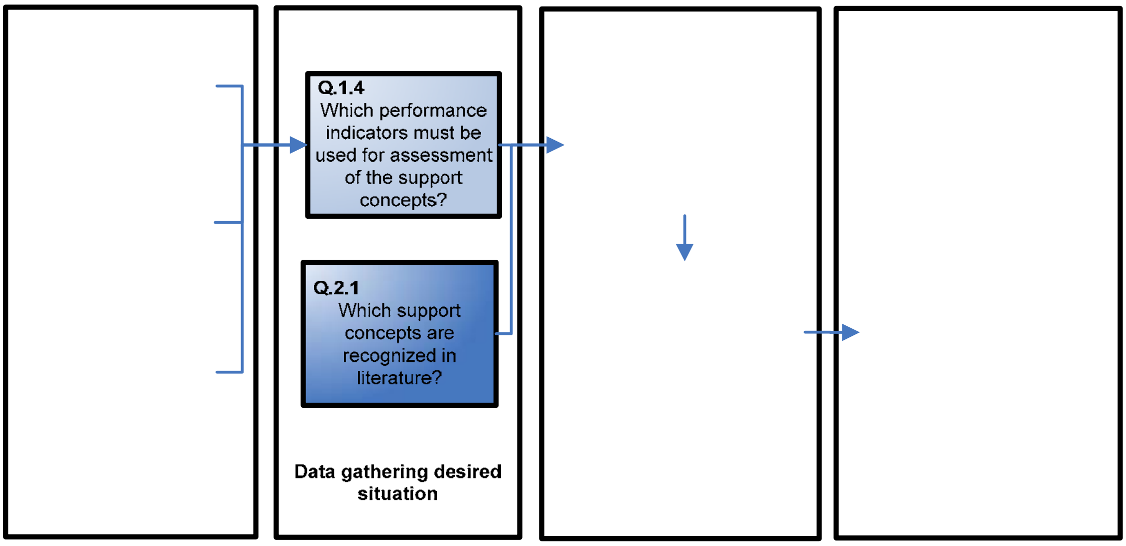


Figure 4.1: Research framework

Structure of the chapter
Section 4.1 elaborates on the selection of support concepts that are evaluated. Section 4.2 elaborates on the different support concepts including definitions, advantages and disadvantages of each concept. This chapter ends with the most important conclusions of the literature research.

Sub-question to be answered in this chapter

- *Which potential support methods are recognized for supporting simulation model development at Tebodin?*

4.1 The selection of support concepts

In the introduction and delineation of this research project it became clear that there were several support concepts that are suitable to improve the current situation. These concepts have different areas of application such as process conceptualisation, object conceptualization, standardization of development process or collaborative engineering.

The goal of the new support concept is to improve the effectiveness of simulation models and the efficiency of the development process order to improve the competitiveness in the field of simulation modelling for Tebodin. Briggs (2005) provides that if an organization can find ways to improve its work practices, it can gain competitive advantage. Suitable support concepts should therefore focus on the improvement of the actual work practices that are related to simulation model development. The following concepts are being evaluated;

- Design patterns
- Conceptualisation techniques
- Component based development (a.k.a. templates or pre-defined building blocks)
- Collaborative learning

The advantages and disadvantages of different concepts should make clear in which way certain concepts can to improve the current situation. A trade-off should always be made between the practical usability of a concept that improves the efficiency of the development process and the conceptual usability of a concept to improve the effectiveness of simulation models. This trade-off is illustrated in figure 4.2.

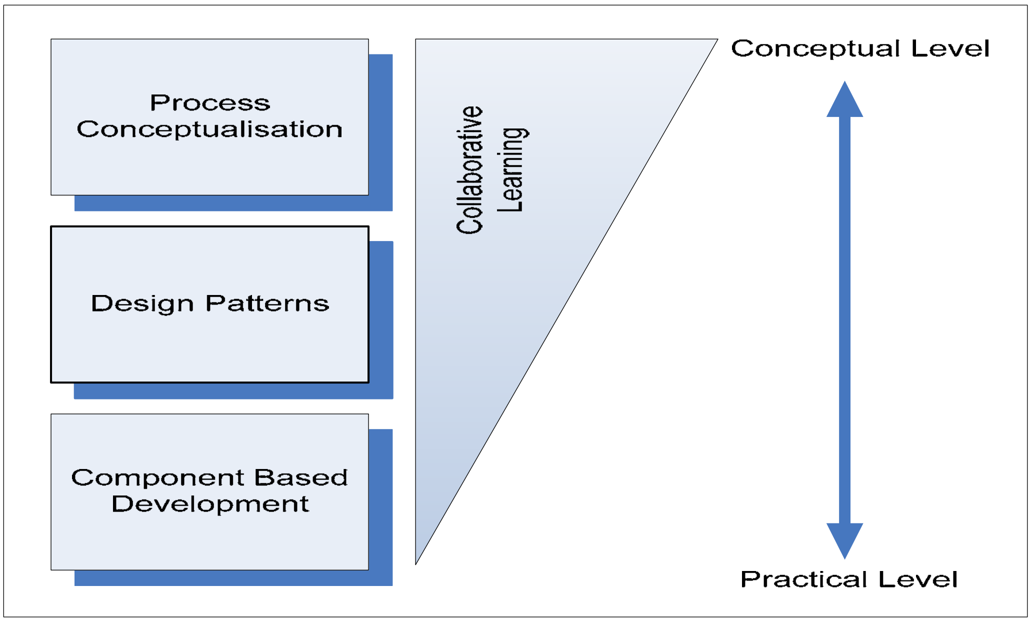


Figure 4.2: Conceptual vs. Practical usability

The workshop with simulation consultants that has the function to introduce potential concepts to simulation consultants and to discuss opinions about the effectiveness considering the defined performance indicators should make clear how this trade of should look like based on the expectations and preferences of the simulation consultants.

4.2 The content of support concepts

This section provides an overview of the most important concepts (methodologies) that can be used as support concepts. If methodologies are not (fully) thought through or wrongly applied, the process and results of simulation model development will not be optimal. Therefore, all concepts should be critically evaluated in order to achieve the desired effects of the concepts.

4.2.1 Conceptualization methods

As discussed earlier, conceptual models are used for the specification of simulation models. Paterno (2000) states that the conceptual model-based approach was introduced to support the specification and design of interactive systems at a semantic, conceptual and abstract level as an alternative to dealing with low-level implementation issues earlier on in the development lifecycle. Ahmed et al. (2007) add that by using conceptual models, designers can concentrate on important conceptual properties instead of being distracted by the technical and implementation details. Rensburg (1995, p.467) concludes that "current Business Engineering projects use techniques such as IDEF0 and IDEF3 to enhance human-to-human communication in drawing up business models, It was discovered that the use of these techniques in simulation modelling activities, enhanced the quality of simulation models and in turn reduced the time needed to build them." There are different types of conceptualization methods. Ceric et al. (1992) classify modelling representation methods in three groups;

- *Simulation neutral methods*. These methods do not belong to any of the simulation types, nor to any specific simulation language. Examples are Petri Nets and Activity Cycle Diagrams (ACD)
- *Simulation oriented methods.* These methods are oriented towards specific simulation type, but not to any specific simulation language. An example is the use of event graphs.
- *Simulation Language oriented methods.* These methods often use a kind of flowchart of dynamic system entities flowing through the blocks to represent system actions. An example is the use of SADT (IDEF) Diagrams.

For a complete analysis, methods from all categories should be taken into account in this research project. Literature provides the most popular and most used techniques from all categories. The following techniques are recognized;

- Petri Nets
- Activity Cycle Diagrams
- Event graphs
- IDEF0 graphs

Appendix J provides additional information on each conceptualisation technique. These techniques have a different characteristic which implies that every technique has advantages and disadvantages and is applicable effectively in certain situations. Table 4.1 provides an overview of the comparison of the different conceptualization techniques. Literature provides several assessment criteria that can be used to compare conceptualisation techniques. According to Gregor et al. (1998), conceptual models are needed for the following purposes;

- To save knowledge of a problem situation for later use.
- To record knowledge because the problem situation is too complex to consider as a whole.
- To get a better understanding of the problem situation by studying it from different perspectives.

Godwin et al. (1988) provide that we can expect a good assessment technique to have:
- A well understood set of objects to which it can be applied;
- A well understood range of possible results. The assessment techniques we are considering could be applicable to very complex objects that have broad functions. In such cases it is desirable that the assessment technique can be adapted in response to experience in its use. We thus allow there to be a

variation in the assessment process carried out as the application of an assessment technique. In fact it is essential for some cases that the assessment technique can be modified to suit a particular evaluation environment.
- A good assessment technique will have an appropriate capability for evolutionary change.

Rensburg (2005) represents a framework for evaluation of the quality of conceptual models of all types. There are three levels of quality recognized;
- Syntactic quality; whether conforms to the grammar rules of the modelling language being used
- Semantic quality; Whether the model accurately represents user requirements
- Pragmatic quality; whether the model can be understood by all relevant stakeholders

Assessment Criteria	Petri Nets	Activity Cycle Diagrams	Event Graphs	IDEFO Graphs
Safe knowledge for later use	√	√	√	√
Record knowledge with high complexity	√	√	√	√
Better understanding a of problem situation from different perspectives	√	√	√	√
Well understood set of objects	√	√	√	√
Well understood range of possible results	√	√	√	√
The model accurately represents user requirements				
The model can be understood by all relevant stakeholders			√	√

Table 4.1: Comparison of conceptualisation techniques

In general, the problem is that the effects and "precise comparison of the different diagrammatic methods is almost impossible because of the qualitative nature of such criteria and because of the bias introduced by researcher's own experience. The influence of previous experience and the time needed to master a new method produces a tendency to favour the method being used." (Ceric et al., 1992) Therefore, a workshop should be used for assessing most suitable technique for Tebodin.

Furthermore, Gustavson et al (2005) provide that "while it's important to understand the attributes of a conceptual model during the capture process, the more elusive activity is in seeking and discovering common themes within a domain space. Solutions for these themes can be represented (described) as reusable design patterns. A pattern identifies a set of activities used to accomplish a common need, capability, or purpose. In other words, a defined pattern reflects what activities take place and with what resources are needed to carry out an objective." The next section will elaborate on design patterns.

4.2.2 Design Patterns

Design patterns are widely used to reduce development time of new software. Modern Software Design Patterns allow the design and the development of reusable software architecture. This is an excellent way to reduce development costs of remote sensing data processing systems and to provide reliable software. (Herrmann et al., 2000) Souza et al. (2002) claim that if reuse is done with design patterns in the analysis and design phase, considerable gains in time and cost can be acquired.

These conclusions can also be applied for the design and development of reusable simulation model architecture because its purpose is to identify generic reoccurring solutions. Souza et al. (2002) provide that the objective of a design pattern is to identify parts that are repeated in several instances of similar projects and to classify them in a systematic way. When faced with solving a new problem, the designer can use a design pattern as a solution without having to rediscover it. Design patterns are flexible because it uncouples its participants in such a way that each can easily be understood, reused and personalized. The most influential authors in the area of pattern design patterns and pattern languages is Gamma et al. (1995). They belief the rationales behind design patterns are;

- Discuss the trade-offs that are related to a specific design decision
- Provide designers with a shared vocabulary to discuss and comment on design alternatives
- Provide designers with micro architecture building blocks that they can compose to generate more complex architectures
- Ease learning of frameworks by referring to design patterns in the frameworks description

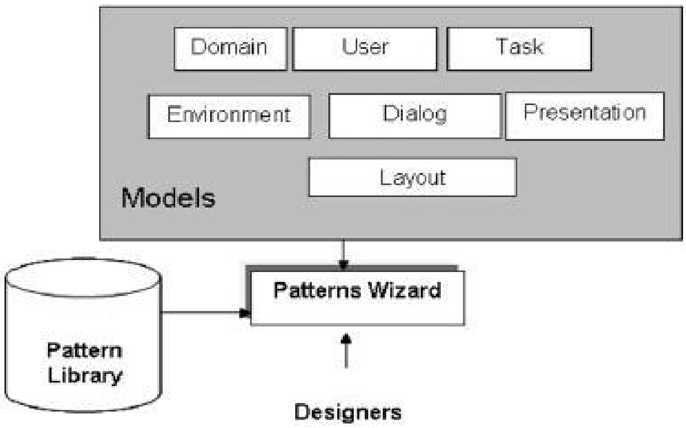


Figure 4.3: Use of design patterns (Ahmed et al., 2007)

Cheung (2005) provides that design patterns have been put forth as 'cookbook' solutions to accommodate software changes. Each pattern provides a structure to facilitate program extension along a design concern. A design concern is a set of program requirements with common implementations. A program fulfils a subset of the requirements in a concern. Furthermore, Ahmed et al. (2007) provide that design patterns are usually presented as a vehicle to capture the best practices and facilitate their dissemination. According to Souza et al (2002) the description of a pattern should contain at least four elements;

- *Name:* The name is used to briefly describe the problem that the pattern aims to solve
- *Problem:* The problem describes when to apply the pattern and indicates the constrains to its use.
- *Solution:* The solution describes the elements that compose the pattern, usually by the use of object oriented diagrams that explicit their relationships etc.
- *Consequences:* The consequences describe the results and trade-offs of applying the pattern

There are two main types of design patterns; behaviour oriented and structure oriented. These types are no being discussed

Behaviour oriented (rule based) patterns
Souza et al (2002) state that "the objective of rule based pattern is to provide a generic reusable and customizable architecture for constructing rule based systems, in such a way that its components can be understood and easily reused. The construction of rule-based systems is usually accomplished with the use of ready-to-use shells or some convenient programming language. Creation of classes and objects, oriented to the application that has the same characteristics of the generic classes and objects can be found in the pattern. These classes and objects are handled with mechanisms such as composition, inheritance and delegation. These tools are a good choice for knowledge systems whose components will present similar structure and behaviour." Unfortunately, many of the examples

related to behavioural-oriented patterns that are found in the design pattern literature may not seem as applicable for distributed simulation (Gustavson et al., 2005)

Structure oriented design patterns
Gustavson et al (2005) discusses recognizable design patterns that are applicable to simulation. The most common applications of design patterns to software systems are to the structure of the software itself. According to Gustavson et al (2005), the following structure-oriented design patterns are might be expected to see in a simulation system.;

- *The Adapter pattern* matches an existing object beyond your control to a particular interface. A system has the right data and behaviour but the wrong interface.
- *The Composite pattern* is used to form a collection of objects. Composition is used to formulate the model representation for a federation, or an aggregation of elements or object classes.
- *The Flyweight pattern* can be used to help manage large numbers of class instances (i.e. entities) within a simulation. By identifying the common attributes of the classes representing the entities within a simulation, a common class can be defined and, where there are any differences in attributes among the various classes, these can be maintained as extrinsic data passed in as arguments

It can be difficult to define patterns. Gustavson et al. (2005) concludes that patterns are discovered rather than invented. The best way to discover a pattern is to perform a conceptual analysis on the problem space. Ahmed et al. (2007) conclude that design patterns in order to be an effective knowledge-capturing tool in model-based approaches, classification of patterns and support tools for developers to select a proper pattern are important (see figure 4.3). Souza et al. (2002) provide that "reuse with design patterns begins with the identification in patterns catalogue of a pattern that aids in the solution of a specific problem. After finding a convenient pattern, it is necessary to make its adaptation to the needs of the problem that it is being solved, because a pattern represents a generic solution to the problem." Figure 4.3 represents this approach for the use of design patterns.

This section made clear that applying design patterns in the design phase leads to considerable gains in time. This is much more effective than simply reusing components artefacts developed in implementation phase like libraries and templates (Souza et al., 2002) The effectiveness of reusing components is relatively low because relatively limited time is spend and saved in the actual coding of the model (Jacobson et al. in Souza et al., 2002). The next section discusses component based developments such as the use of libraries and templates.

4.2.3 Component based development

The application of component based simulation development (also known as pre-defined building blocks, component libraries or templates) is thoroughly discussed in scientific literature. Valentin et al, 2003) define the concept of building blocks as:

A building block is a self-contained, interoperable, reusable and replaceable unit that encapsulates its internal structure and provides useful services to its environment through precisely defined interfaces
Using reusable blocks to form a simulation model – when designed well –can represent an element of the system in the way the problem owner expects, both in structure and in behaviour. The concept of building blocks encompasses the idea of decomposing a prototypical system within a domain and implementing the observed domain elements in a standard simulation environment. (Valentin et al, 2002).The Arena simulation environment, used by Tebodin allows a modeller to develop a library of building blocks and to construct a simulation model from these predefined building blocks. The complexity of the building blocks ranges from simple statements of the simulation language to very complex constructs such as servers, conveyor belts and automatically guided vehicles. The building blocks are presented as *modules* in a template. A simulation model is then constructed by dragging the modules from the template into the modeling screen, connecting them and entering the right data in

the user interface of the module. The notion of predefined modules also conforms to the distinction between object class (i.e., an “empty” module consisting of logic and “empty” attributes) and object instance (i.e., a copy of a module containing specific data as attribute values). With the Arena professional edition, it is possible to define templates and to create specific modules that can be seen as specific object classes that can be instantiated in a model. This user-defined template can be used in conjunction with other predefined templates because the templates function as a kind of “macro” that converts the template. (de Vreede et al., 2003). Figure 4.4 provides a graphical representation of the use of simulation development with pre-defined libraries

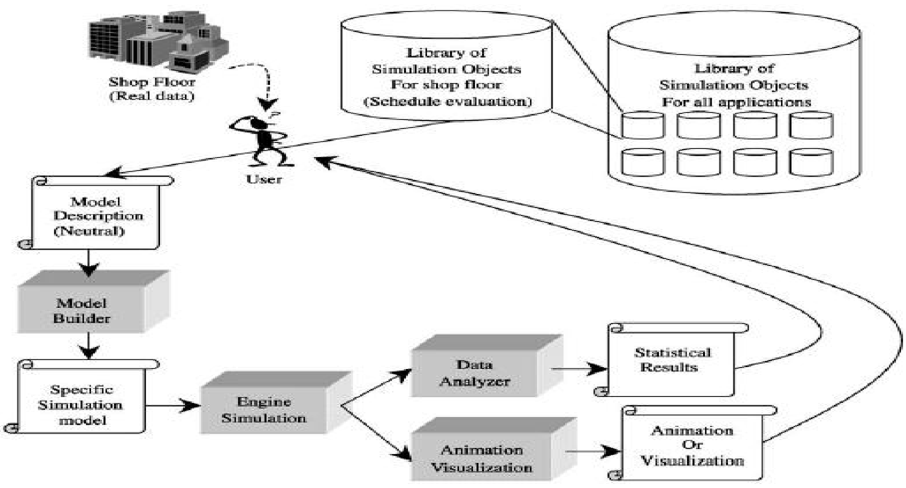


Figure 4.4: Library/component oriented model development (Son et al., 2003)

Valentin et al. (2002) propose four types of building blocks for airport modelling that can also be applied on modelling harbours;

- Infrastructure building blocks (harbours: lay-out harbour , anchorage queues, berths)
- Passenger of group building blocks (harbours: vessel or vessel classes)
- Passenger behaviour building blocks (harbours: vessel characteristics such as speed and loading times)
- Control building blocks (determining optimal berth, claiming pilots and tugboats)

According to Oses et al. (2004), potential benefits are cost reduction and reduction of development time arising from reuse of components, as well as easier model adaptation due to the features of extensibility and evolvability. If these are to be realised, then organisations must develop ways to ensure that costs and benefits are shared and should ensure that suitable libraries and component distribution frameworks are available. In a simulation context it is also crucial to ensure that the issue of model credibility and validity is addressed even if the components are thought valid. According to Valentin et al. (2003) the expected benefits of simulation building blocks are a higher reconcilability of simulation models, easier construction and adjusting of simulation models and an ability to transfer a simulation model to an environment where there is less experience in simulation and experimentation. These benefits should result in a better support for problem owners, because they will receive more insight into their system in less time.

There are several pitfalls for component based reuse as well. Oses et al. (2004) conclude that though components provide for rapid development this does not imply that any software developer will, by using components, find that the development process is a lot easier and faster, for the system developer needs expertise in component based software development. Oses et al. (2004) provide furthermore that the used of component based development does not mean that first-time simulation users will be able to build extremely complicated models. This implies mastery of the architecture being used and significant knowledge of the components in the available libraries. If these requirements are not met the promise of faster development will not be fulfilled through component reuse. Proper training and specialised knowledge are needed, as ever, to achieve full potential. Furthermore, Oses et al. (2004) conclude that if components are to be reused in-house, then the budget that bears the cost of initial development may not receive the benefits of later, lower costs. Since projects often have tight budgets and time schedules this means that without a properly managed reuse program, it may not be worthwhile to build components.

Son et al. (2003) show that component based simulation modeling from neutral component libraries can be effective under specific assumptions. Because of these assumptions the effectiveness of this type of modeling is limited. An example is a simulation model that operates in a push environment. Changing these assumptions to a pull would require major modifications to the approach (Son, 2003). Valentin et al. (2003) provide that from the literature on software engineering research we learned that expert and novice software developers use software components in a different way. The experts are more hesitant to use components and prefer to construct models or components themselves, because they are not sure whether they can trust a component made by others. Novices are glad the components are available and see them as their best option. The effectiveness of component based development depends on the degree of experience of simulation consultants. Kolfschoten et al (2006) provide that the use of building blocks reduces the cognitive load of model developers. The authors provide that developing models requires understanding of the following things in relation with cognitive load;

- Elements and relations (intrinsic cognitive load)
- Designs are represented in coding such as modeling language (extraneous cognitive load)
- Building initial schema of concepts (germane cognitive load)
- Creativity of designer (additional germane cognitive load)

A major pitfall is recognized by Kolfschoten et al. (2006). The authors describe the expertise reversal effect; methods to reduce cognitive load for novices can increase cognitive load for experts and thus design support and modelling support should be different for experts and novices. Valentin (2008) provides a number of potential pitfalls of using domain specific extensions in simulation studies.

- Use of model constructs that are not suitable for representation of system elements.
- Lack of trust resulting in no motivation to use domain specific extensions
- Model developers do not understand models constructs
- Model developers do not know how to parameterize model constructs
- Difficulties with composing simulation models by person other than developer(s) domain specific extension
- Model developers know something is wrong, but cannot identify what to do about it
- Model constructs do not provide performance indicators problem owner desired
- Model developers are limited by parameters and model constructs

4.2.4 Collaborative learning

Theories of collaborative learning tended to focus on how individuals functions in a group. More recently the group itself has become the unit of emphasis and the focus has shifted to more emergent socially constructed properties of the interaction. Tasks that have been typically used in collaborative learning include skill acquisition, joint planning and categorisation. There are many other approaches to collaborative learning (GDRC, 2008);

- Learning is an active process whereby learners assimilate the information and relate this new knowledge to a framework of prior knowledge.
- Learning requires a challenge that opens the door for the learner to actively engage his/her peers and to process and synthesize information rather than simply memorize and regurgitate it.
- Learners benefit when exposed to diverse viewpoints from people with varied backgrounds.
- In the collaborative learning environment, the learners are challenged both socially and emotionally as they listen to different perspectives and are required to articulate and defend their ideas. In doing so, the learners begin to create their own unique conceptual frameworks and will not rely solely on an expert's or a text's framework

Collaboration is viewed as the process of building and maintaining a shared conception of a problem. Collaboration is not simply a treatment which has positive effects on participants. Collaboration is a social structure in which people interact and some types of interaction occur that have a positive effect. Collaboration is in itself neither efficient nor inefficient. Collaboration works under some conditions. Efficient collaboration depends on the following conditions (Dillenbourg et al., 1996):

- *Group heterogeneity and size*
  Group heterogeneity is important, if differences are to small it may fail to trigger interactions. The size of groups also determines the efficiently of collaboration. Pairs are more effective than larger groups. Groups of three are less effective because they tend to be competitive, while pairs tend to be more corporative
- *Development level of individuals*
  It seems that collaboration does not benefit an individual if he or she is below a certain development level (considering the absolute level rather then the level relative to other group members) Some results show that certain skills in understanding other people' mental state are required for collaboration.
- *Task features*
  The nature of tasks influences the results: Some tasks are less shareable than others. Solving an equation is a less shareable task then building a brick wall. Therefore the nature of a task determines the suitableness for collaboration.
- *Level of expertise*
  Collaboration depends on the individuals specific level of expertise. The interaction between novices and experts can be characterised by tutoring and guidance by the expert. If both individuals are experts, the interaction involves more collaboration and joint construction

"Attaining shared understanding is a necessary condition for collaborative learning (one cannot be said to be "really" collaborating, or agreed, if one doesn't understand what one is collaborating or agreed about)" (Dillenbourg et al., 1996, p. 20) Knowledge transfer is an essential part of collaborative learning. "The ease with which knowledge can be transferred is a characteristic of that knowledge, which depends on its nature". (Molina, 2004, p. 345) Furthermore, research showed that implementation of a Total Quality System (TQS) does not significantly affect knowledge transferability, but increases the transfers. Research also showed that the certification of activities using the ISO 9000 standard was shown to have an influence on knowledge transferability. This is due to the fact it is, in itself, a process that is orientated towards the documentation of the firms different processes. (Moody et al, 2002) There are tools that can be used to enhance collaborative learning. Collaboration engineering is an approach to design collaborative work practices for high-value recurring tasks and transferring them to practioners to execute for themselves without the on-going intervention of professional facilitators. (Briggs et al, 2007) Many industries such as the aeronautic and car manufactures have experienced substantial improvements and reduce design rework, reporting cost savings and reduction in development time as a result of the use of collaboration engineering technologies. Several systems have been developed to support specific activities in product life cycles such as conceptual design. (Mejia et al. 2006) Briggs et al. (2003) describe three requirements that must be met to execute collaboration engineering efforts with the use of Group Support Systems (GSS) successfully;

- GSS related facilitation skills must be packaged in such a way that the conceptual load for practioners is reduced significantly.
- GSS related facilitation skills must be packaged in such a way that different practioners using the same packaging will get similar, predictable results from their groups
- GSS related facilitation skills in such should be reused to enable short development times for new processes.

Unfortunately, it is rare that for any one work unit to encounter sufficient challenges to justify the expenses of group support systems. Furthermore, when a budget crunch comes (and they always come eventually) Group support systems are disbanded because no work unit is likely to need the group support system facility frequently. (Briggs et al, 2003) Because of the large investments and the limited number simulation studies, the use of groups support systems is not feasible for Tebodin.

4.3 Sub-conclusions

The goal of this section is to provide an overview and theoretical background of suitable concepts for supporting simulation model development within Tebodin. This section has tried to answer the following research question

- *Which potential support methods are recognized in for supporting simulation model development at Tebodin?*

Scientific literature provided several potential concepts for improving the effectiveness of simulation models and the efficiency of the development process. The following support concepts were recognized;

- Conceptualisation techniques
- Design patterns
- Component based development
- Collaborative learning

The following conceptualisation techniques are recognized; Petri Nets, Activity Cycle diagrams, Event graphs and IDEF0 diagrams. Unfortunately, precise comparison of the different diagrammatic methods is almost impossible because of the qualitative nature of such criteria and because of the bias introduced by researcher's own experience. The influence of previous experience and the time needed to master a new method produces a tendency to favour the method being used." (Ceric et al., 1992). Therefore a workshop should evaluate and comparing the "best" method. Gustavson et al (2005) provided that "while it's important to understand the attributes of a conceptual model during the capture process, the more elusive activity is in seeking and discovering common themes within a domain space. Solution for these themes can be represented (described) as reusable design patterns.

A pattern identifies a set of activities used to accomplish a common need, capability, or purpose. In other words, a defined pattern reflects what activities take place and with what resources are needed to carry out an objective. (Gustavson et al., 2005) Component based development seems a suitable approach for supporting simulation model development. Potential time savings and cognitive load reduction are mentioned as advantages of component based development. Critical issues for the effectiveness of this concept are trust and the degree of experience of simulation consultants. Collaborative learning can be suitable for supporting simulation model development. Especially the frequency of use and the type of tasks make up for the effectiveness of this concept.

5. Selection of most the effective support concept

Introduction
This chapter elaborates on the selection of the most effective support concept. The previous chapter made clear which potential support concepts are recognized for reducing current problems in the logistics section. None of the support concepts seems to be effective on all parts of the problem. Furthermore, not every aspect of the problem situation has the same level of importance. Therefore, a workshop was held with all relevant simulation consultants in which they were made familiar with suitable support concepts including the advantages and disadvantages. Consultants were given the opportunity as well to discuss and try out support concepts. Based on there perception of the support concepts, the consultants were asked to give there opinion about the effectiveness of each concepts with the use of predefined performance indicators (chapter 3). The results of the workshop are used to draw conclusions about the best support concept.

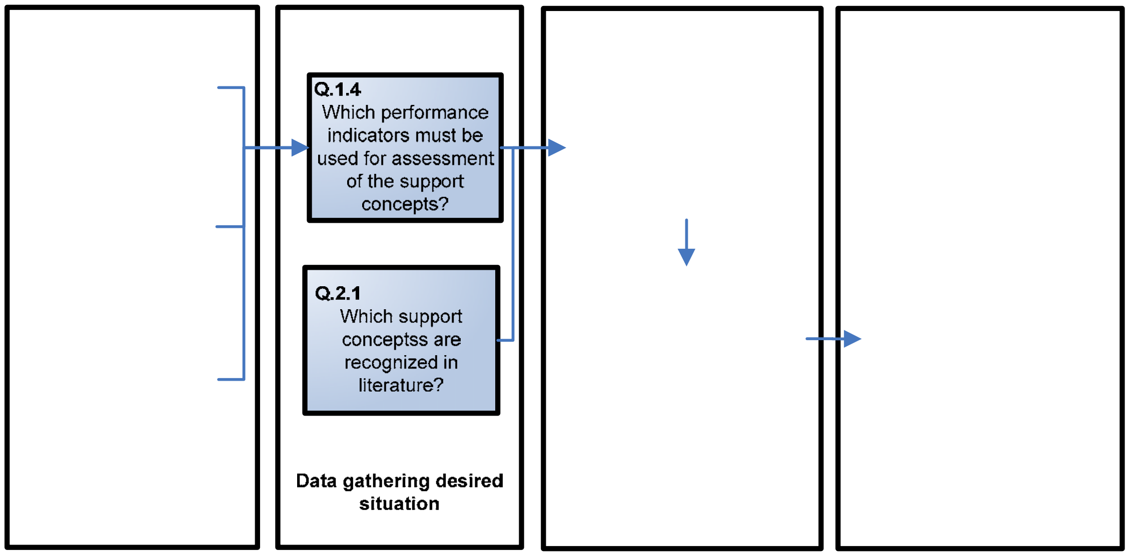


Figure 5.1: Research framework

Structure of the chapter
The first section will elaborate on the outcomes of the workshop with simulation consultants. In this section, the effectiveness of each support concept is discussed individually. Section 5.2 provides information about the selection process of the best support concept for Tebodin. The last section provides all relevant outcomes and conclusions of this section.

Sub-questions to be answered in this chapter

What are suitable solutions for the support of simulation model development at Tebodin?

- *According to simulation consultants, which support concept is most effective, considering the performance indicators?*

5.1 The effectiveness of support concepts

This section provides an overview of the outcomes of the workshop with simulation consultants. Appendix G provides an overview of the scores of the support concepts provided by the individual consultant. The outcomes of each individual concept will now be discussed in detail.

5.5.1 Conceptualisation techniques

The first impression of simulation consultants about the effectiveness of conceptualisation techniques was that the effectiveness heavily depends on the function of simulation in a simulation project (more information about the function of simulation can be found in section 1.5.1). For optimalization studies (Software Engineering) it can be used for communication between client and consultant to determine the scope of the project. Conceptual models should also be used for internal use to define the structure of simulation models.

It has become clear that one of the advantages is that conceptual models provide clarity and structure for the simulation model. Furthermore, apart from reusability, someone indicated that using conceptual models makes it easier for other consultants to get involved half way in a simulation project. Furthermore, conceptual models will mainly improve the effectiveness of the development process because communication becomes more easy and clear. The effectiveness of simulation models could also increase, because models can be transferred and reused more easily, but this can only be achieved by detailed conceptual models. One of the major advantages of using conceptual models is that structural problems can be avoided early in the project life-cycle. None of the consultants thought that problems in the actual development phase could be avoided by using conceptual models as model specification. Using conceptual models will not reduce the cognitive load and therefore making it easier to develop simulation models. The use of conceptual models only influences the reusability and transferability of simulation models. The main reason for this view is that the conceptual model (with or without a tremendous amount of detail) still has to be translated to an Arena model. One of the consultants provided that “hard and time consuming problems only occur in Arena and those problems conceptual models do not catch”.

Specific simulation techniques for conceptual modelling such as Event Graphs and Activity Cycle Diagrams were perceived as “absolutely useless” for communication as well as for specification. “It is an utopia that problems with development and understandability of simulation models can be solved by these types of complex models”. Furthermore, client will get very confused be these types of chaotic models. “Even this simple example looks chaotic and complex; imagine the conceptual model of a harbour”. Conceptual models must be used as generic, simple diagram that can easily be understand by clients. “It is unacceptable for clients that they first need intensive explanation how to interpret and understand model, they should be self-explaining”. Furthermore, model techniques are only accepted if they are already be in used or are well-known in industries and clients. All consultants agreed on the fact that the IDEF (SADT) modelling is the only technique that can cope with both communication as well as detailed specification of models and therefore is favoured.

Figure 5.2 provides an overview of the average scores of conceptualization techniques on the set of performance indicators. On average, this concept scores 3.9 with an deviation of 1.4. This indicates that this concept is perceived by every consultant as neutral effective to resolve current problems (a mean of 3,5 indicates that consultants are neutral because they do not agree and they do not disagree on the effect either). It can be concluded from the results that the use of conceptualization techniques leads to a lower risk for Tebodin of losing important simulation related knowledge. Furthermore, it seems that conceptual models make it easier to develop simulation models. As said, this is caused mostly by easier transferability and easier reuse of simulation models rather than easier development of new models from scratch. The fact that simulation models can be developed more easily does not mean that the execution time of simulation projects decreases as well. Figure 5.2 is showing clearly that conceptual models will not reduce the number of problem in the actual model building phase. In most projects the scope is not fixed and can not be fixed because of the function of simulation, so using conceptual models does therefore not lead to decreasing execution times. Figure 5.2 is also showing clearly that the required competence of simulation consultants does not change by using conceptual models.

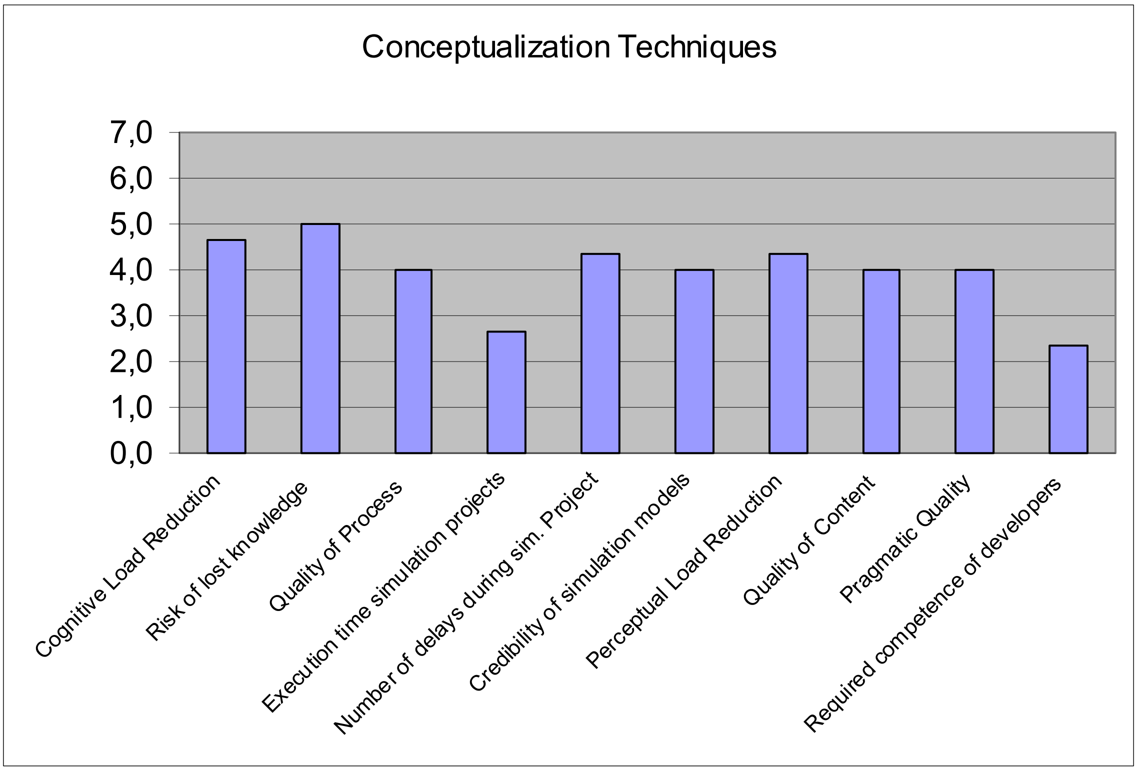


Figure 5.2: Average scores conceptualisation techniques

The implementation of conceptual models does not seem very problematic. Only the time for building these conceptual models is seen as a potential barrier for implementation. Consultants indicated that extra time should be invested, without having the guaranty that the invested time will pay off. One of the consultants mentioned that "because of the limited number of simulation projects, it is probably not feasible to invest in solution that takes more time" Furthermore, clients should not pay for the extra work, so extra costs must be covered by Tebodin alone. In the end there was agreement about the fact that high level conceptual models are used for proposal and communication with client and low level conceptual models for model specification that improves the reuse and transferability of simulation models. It was mentioned that this way of working is important because in this way, "before the actual client approval for the project, the logic of model is not given away to clients"

5.1.2 Design Patterns

The first impression of simulation consultants about the use of design patterns is that the idea behind design patterns is promising, but that the actual content of a pattern is too extensive and formalized for Tebodin. A consultant's first impression of design patterns was that it is "rubbish, although I like the idea". Another consultant stated; "I like the idea but the amount of information that is provided in design patterns is useless, nobody reads thick manuals!" Furthermore, all consultants think that the work required to define design patterns seems extremely high. Most consultants therefore thought that design patterns are probably not feasible and hard to implement. The first impression of the effectiveness of design patterns was also different between consultants. One thought that "It will probably only be used if problems occur during a project rather then before actually start a simulation projects, so the effectiveness will be limited" while another consultant mentioned that the strength of this idea lies in the effectiveness of design patterns; "with simple patterns, a lot of problems can be solved". The Level of detail that is addressed in design patterns is important and it seems that only design patterns with a low level of detail have potential for implementation. Figure 5.3 provides an overview of the average scores of conceptualization techniques on the set of performance indicators. On average, this concept scores 3.4 with an deviation of 1.7. This indicates that this concept is perceived as neutral effective to resolve current problems. As discussed, there are differences of opinion between consultants considering the effectiveness of design patterns. All consultants liked the general idea, but some rated this concept lower because they did not like the high level of detail in which design patterns are worked out.

Figure 5.3 is showing that the use of design patterns reduces the risk of losing important simulation related knowledge. This can be explained because design patterns contain most knowledge that is needed to perform tasks. Furthermore, figure 5.3 is showing that the use of design patterns improves the credibility of simulation models and the pragmatic quality. This can be explained because the use of design patterns leads to a more standardized way in which models are build. This leads to a higher degree of trust in simulation models and the fact that standardized models can more easily be transferred and reused. Figure 5.3 is also showing clearly that the quality of content will not improve by the use of design patterns. This can be explained because of the fact that most design patterns are providing guidelines for the approach of solving problem situations, which does not automatically lead to improved quality of the actual simulation models. Furthermore, providing guidelines and generic approaches does not lead to a n actual reduction of the number and types of problems during a simulation project but probably only to solving these problems faster.

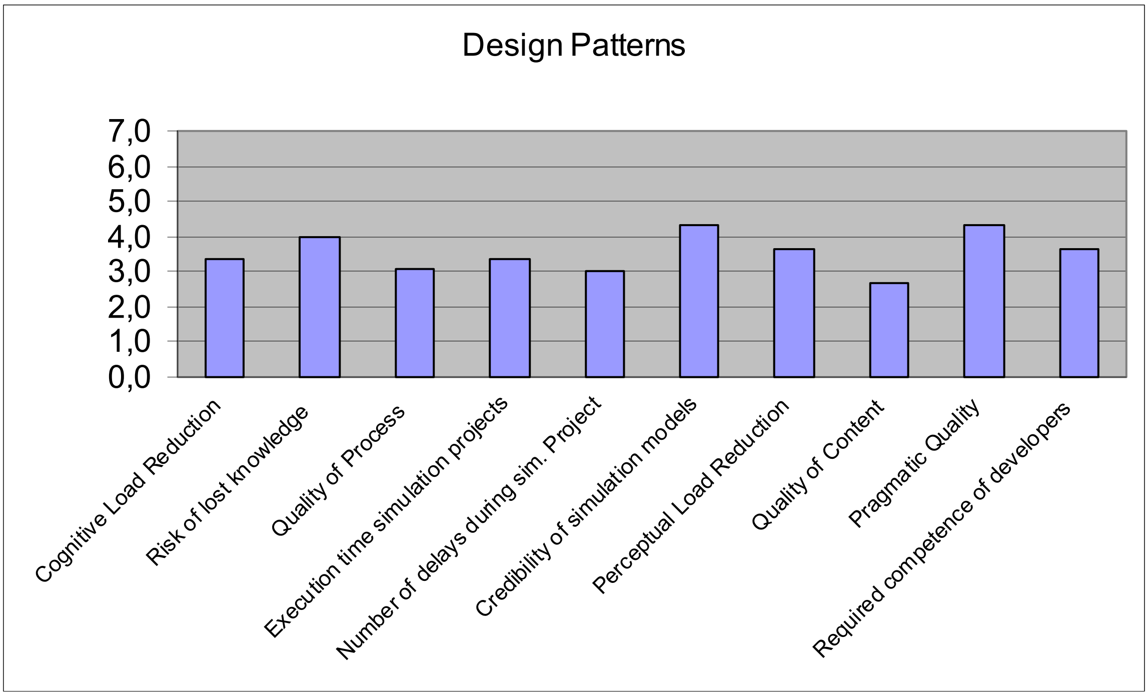


Figure 5.3: Average scores design patterns

5.1.3. Component Based Development

The first impression of simulation consultants about the effectiveness of this concept for Tebodin was that the effectiveness of the use of templates or libraries is limited. Most of the consultants have experience with the use of templates and experienced the limitation and know specific pitfalls. A big disadvantage is the lack of flexibility when using libraries/templates. The fixed structure of a template does not always fit the requirements that the model should have according to clients. Consultants indicate that they "do not think that by using templates, complete models can be compiled" and that "compiling complete models with templates is impossible." Furthermore, consultants are still depending on the template developer because problems are likely to occur at one point. Proper documentation will not completely resolve these problems. An advantage is that the output of models becomes standardized and predictable. "The use of templates reduces the chance of making annoying errors in programming the Arena model. Templates provide the guaranty that values and names of variables/attributes are correct." One of the consultants indicated that there are two different approaches for the use of templates; using templates as sub-models in complex models and reusing templates for multiple simulation models. Consultants should "build templates during a simulation project to reduce the number of problems and improve the speed of development. If they are lucky, the templates can be used in other projects." Figure 5.4 provides an overview of the average scores of conceptualization techniques on the set of performance indicators. On average, this concept scores 3.6 with an deviation of 1.5. This indicates that this concept is perceived as neutral effective to resolve current problems. The deviation indicates that there is some difference of opinion about the effectiveness of component based development. This difference can be explained because of the difference in experience with templates. Some of the consultants are experts while others consultants are novices. Experts were less positive about the effectiveness of templates in comparison to novices. "Templates sound promising in the beginning until while using then you discover it almost generates more problems than that they solve".

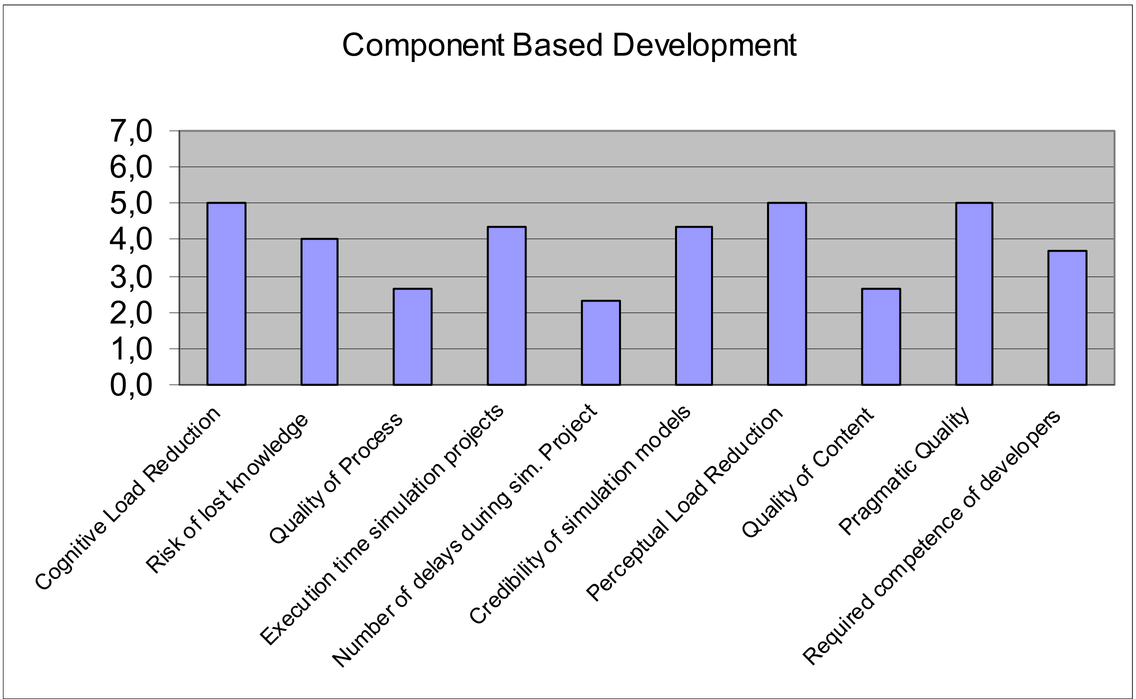


Figure 5.4: Average scores component based development

Figure 5.4 is showing that the use of templates or component libraries will reduce the cognitive load for consultants when developing simulation models. Furthermore, if templates work well, the execution time of simulation models will decrease. As discussed, templates allow standardized mode input and output. This standardization probably explains why the credibility and the pragmatic quality of simulation models will improve when using templates. Furthermore, using templates leads to perceptual load reduction. Because the cognitive and perceptual load reduction, the attractiveness of simulation projects will improve. Because of the limitation of templates such as the reduced flexibility, the use of templates does not lead to improvement of the quality of process and quality of content. The level of detail of the model is fixed and can not be influenced. The quality of content therefore heavily depends on the structure of the template and the requirements and scope of the simulation project. The quality of process will not improve because the use of templates does not affect problems with communication or project planning. Furthermore, the use of templates will decrease the number of arena related problems but will not decrease the number of other problems during a simulation project like interface problems between simulation and database software. Therefore, the total number of delays during simulation projects will not significantly reduce. Implementation seems problematic according to the consultants. It was mentioned that the development of templates and libraries is very time consuming. “Especially the fine-tuning process of the template and resolving small implementation issues is time consuming”. One consultant concluded that “rather then using templates, I suggest that reuse of sub-models is applied because sub-models allow consultants to make small modifications in order to meet the different requirements in every simulation project.”

5.1.4 Collaborative learning

The first impression of simulation consultants about the effectiveness of collaborative learning for Tebodin was that it is an easy and effective way to reduce a number of the current development problems. The effectiveness of simulation models is hardly improved by using collaborative learning techniques. One of the main advantages perceived by the consultants is that this approach enables knowledge transfer. The effectiveness depends heavily on the level of experience of consultants and in which phase/which tasks collaborative learning is applied. Consultants concluded that “problems and questions are earlier recognized in the development process.” Furthermore, is “Collaborative learning is only efficient if the right persons are frequently coming together” Another consultant claimed that “collaborative learning only effective for novices”, because knowledge is transfer from expert to novice and not visa versa. Collaborative learning is the only concept which takes into account the fact that the department within Tebodin also work together. “Collaborative learning would be specifically useful and effective when other departments are also involved in simulation projects” For instance, the input and output variables in the model comply with the variables that are needed and used in other departments that calculate costs and tank volumes. At the moment, the information interfaces between departments are not covered.

Figure 5.5 provides an overview of the average scores of conceptualization techniques on the set of performance indicators. On average, this concept scores 4.0 with a deviation of 1.4. This indicates that this concept is perceived by every consultant as neutral effective to resolve current problems.

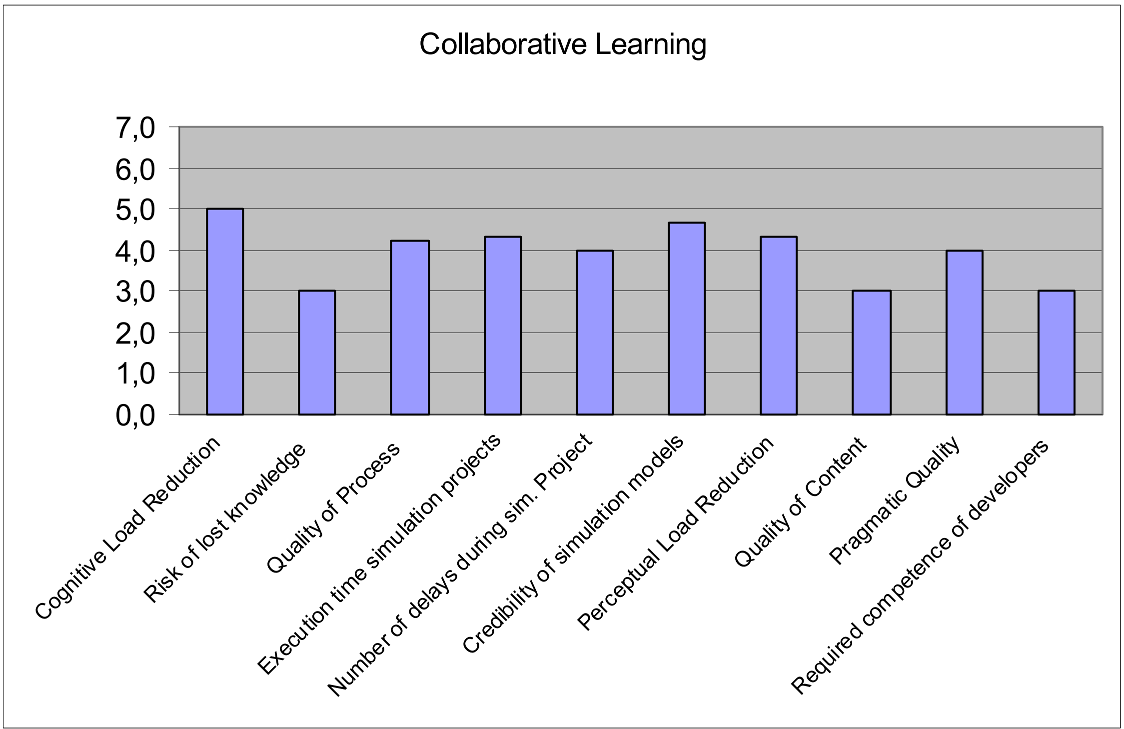


Figure 5.5: Average scores Collaborative Learning

The quality of content will not increase by applying collaborative learning because it seems not suitable for improvement of model quality and outcomes. One consultant mentioned that “methods for learning that allow sitting around a computer monitor will not work.” The risk of lost knowledge will not be reduced by applying collaborative learning. It seems that consultants do not think that collaborative learning leads to the knowledge transfer of important skills and knowledge needed to develop simulation models. Consultants think that more generic knowledge is transferred rather than more detailed knowledge needed to actually develop simulation models. Because of this perception, it seems that the required competence needed to develop simulation models will not change.

The use of collaborative learning will lead to cognitive load reduction. The ease in which simulation models are developed will improve because a lot of important and difficult aspects of developing simulation models are solved because of collaborative learning. The quality of process will improve and execution time will be reduced because of the intensified information transfer and knowledge sharing between employees. The credibility of simulation models will improve because the use of shared knowledge as well. If knowledge is shared it becomes familiar knowledge. If everybody agrees about certain knowledge, the credibility of simulation models build using that knowledge will improve. Because of these improvements, the attractiveness of simulation will also improve.

The next section will elaborate on the discussion about the most suitable support. It seems that there is not one support concept that solves all current problems. Every consultant had its own perception of the most suitable concept. Figure G.1 in appendix G shows the graphs that visualize the opinion of the individual consultants. During the workshop, after having filled in all the assessment forms, a plenary discussion about the results leads to a discussion which has the goal to create consensus about the best support concept. In the end, consensus about the best concept was achieved among all simulation consultants.

5.2 The best support concept

It has become clear that there is no "best" support concept, because every concept has advantages and disadvantages that limit the overall effectiveness of each concept. The previous section made clear that each support concept scores higher and lower on different performance indicators (also see appendix G). As a result, there is hardly any difference in the average score of each concept. Analysis of the results of the workshop show that the average score of each concept varied between 3.4 and 4.0 with a deviation between 1.4 and 1.7. The deviation in the score of each performance indicator question varied in 80% of the indicators between 0 and 1.5 and varied in 20 % of the performance indicators between 1.5 and 2.5. These deviation figures are rather low, especially considering the limited number of respondents which may indicate that the hypotheses (based on translation of the performance indicators) were unambiguous. It can therefore be concluded that the effectiveness of support concepts on the almost all aspects of the problem situation are perceived similar by all simulation consultants. The problem areas of which the effectiveness is perceived differently among consultants will be discussed later in this section.

Given the fact that each support concept can only reduce parts of the current problem situation, a smart mix of elements of these support concepts should be determined in order to develop a hybrid support concept that covers the whole problem situation. Figure 5.6 provides an overview of the average scores of each support concept for each performance indicator. During the workshops it became clear that the basic idea of design patterns is very promising. The implementation of design patterns, as used in software development industry, did not seem suitable because of the high level of detail and the time needed to develop all necessary design patterns. Furthermore, design patterns do not reduce actual problems, but provide "standardized" approaches for parts of simulation model development. Because of these reasons, the effectiveness of design patterns on the individual performance indicators was rather low. After the plenary discussion about the best concept, consensus was reached about the decision made to use the main concept of design patterns as a basis for the support concept.

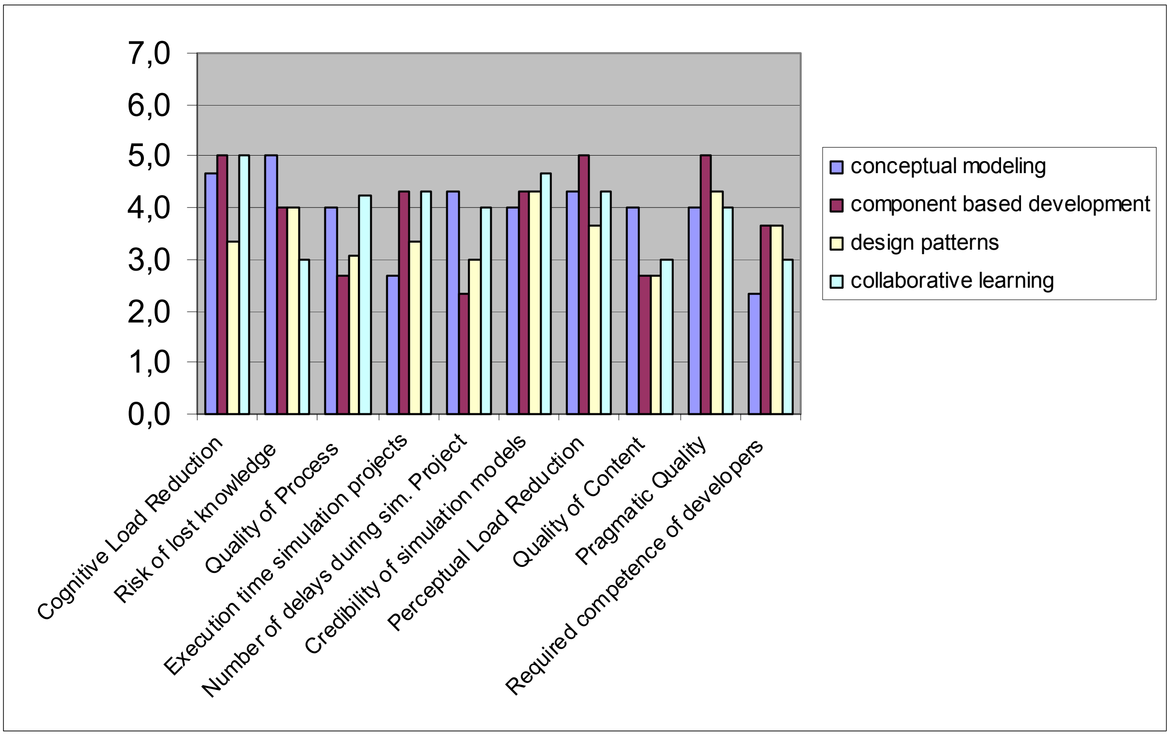


Figure 5.6: Average scores support concepts compared

By selecting the support concept that is most effective for each problem area, the result will be a solution that is most effective on all problem areas. In this way, the overall effectiveness of the support concept is maximized. Table 5.1 provides the most effective support concept for each problem area.

Performance indicator: (problem area)	Most effective support concept:
Development process related performance indicator	
Execution time simulation projects	Collaborative Learning
Number of delays	Conceptual Modelling
Process quality	Collaborative Learning
Simulation model related performance indicators	
Credibility of simulation models	Collaborative Learning
Content quality	Conceptual Modelling
Pragmatic quality	Component Based Development
Consultant related performance indicators	
Risk of lost knowledge	Conceptual Modelling
Required competence of modellers	Component Based Development
Perceptual load reduction	Component Based Development
Cognitive load reduction	Collaborative Learning

Table 5.1: Most effective support concept for each problem area

There are a few problem areas where two concepts have the same highest score. The required competence of developers can best be reduced by both component based development as well as design patterns. Given the fact that design patterns used as basis and therefore apply on all problems areas, component based development is the most effective concept. To reduce the cognitive load for consultants, both collaborative learning as well as component based development seems to be the most effective concepts. Selecting the most suitable concept is done by comparing the individual scores of consultants for both concepts. The variation between scores for component based development is relatively high. The effectiveness was rated low by the most experienced consultant and high by least experienced consultant. This can explained because of the risk of the "expertise reversal effect" (Kolfschoten et al., 2006) when using predefined building blocks. The expertise reversal effect is the effect that the cognitive load reduction for novices improves while the cognitive load reduction for experts increases by using pre-defined building blocks. The individual scores of collaborative learning techniques were stable, so this concept should be favoured.

To reduce the execution time of simulation projects, again both collaborative learning as well as component based development seems the most effective concepts. The same patterns in scores as for cognitive load reduction are found. Because of the expertise reversal effect, the experts conclude that the use of pre-defined building blocks does not reduce the execution time of simulation projects. Furthermore, from the previous section it became clear that there was discussion about the limited usability of pre-defined building blocks. Because of the fixed structure of pre-defined building blocks, the overall usability is low. The individual scores of collaborative learning techniques did not vary much so, for this problem area as well, this concept should be favoured.

It can be concluded that the best support concept is a mixed set of concepts for each problem area, made available for consultants as design patterns. A few remarks to this conclusion should be added. In general, the average scores of all support concepts are not very high. This suggests that the effectiveness of all support concepts is not very high. Furthermore, for some problem areas, the average score of all concepts are almost the same. This indicates that, in these problem areas, all support concepts have similar effectiveness. The conclusion about the best concept does not take this remark into account.

5.3 Sub-conclusions

The goal of this chapter is to assess which support concept is the most suitable for reducing the current problems with simulation model development. Therefore, this chapter tried to answer the following research question;

- *According to simulation consultants, which type of support concept is most effective, considering the performance indicators?*

By means of a workshop, simulation consultants have been made familiar with the possible support concepts. Simulation consultants were given the opportunity to discuss and try out all suitable support concepts. After these activities, consultants filled in assessment forms for the evaluation of the effectiveness of each concept, considering pre-defined performance indicators. Based on the discussions and results of the workshop, conclusions are drawn about the best support concept.

It has become clear that there is no best support concept, because every concept has advantages and disadvantages that limit the overall effectiveness of each concept. It can be concluded that the best support concept is therefore a mixed set of concepts for each problem area, made available for consultants as design patterns. By using different support concepts for specific problem areas, the overall effectiveness of the support concept is maximized. Table 5.2 provides the most effective support concept for each problem area.

Performance indicator: (problem area)	Most effective support concept:
Development process related performance indicator	
Execution time simulation projects	Collaborative Learning
Number of delays	Conceptual Modelling
Process quality	Collaborative Learning
Simulation model related performance indicators	
Credibility of simulation models	Collaborative Learning
Content quality	Conceptual Modelling
Pragmatic quality	Component Based Development
Consultant related performance indicators	
Risk of lost knowledge	Conceptual Modelling
Required competence of modellers	Component Based Development
Perceptual load reduction	Component Based Development
Cognitive load reduction	Collaborative Learning

Table 5.2: Most effective support concept for each problem area

A few remarks to this conclusion should be added. In general, the average scores of all support concepts are not very high. This suggests that the effectiveness of all support concepts is not very high. Furthermore, for some problem areas, the average score of all concepts are almost the same. This indicates that, in these problem areas, all support concepts have similar effectiveness. The conclusion about the best concept does not take this remark into account.

6. A support concept for simulation model development

Introduction

The goal of this chapter is to propose a support concept that is the result of the analysis of different support measures. Briggs (2005) concludes that, deliberate attempts to change the way people do business are not always successful. The rate of success heavily depends on the acceptance of the new support concepts among simulation consultants. Therefore, this chapter elaborates on the evaluation of the success of implementation of the support concept. Partly based on the outcomes of the evaluation of the implementation, an implementation strategy for the support concept is proposed.

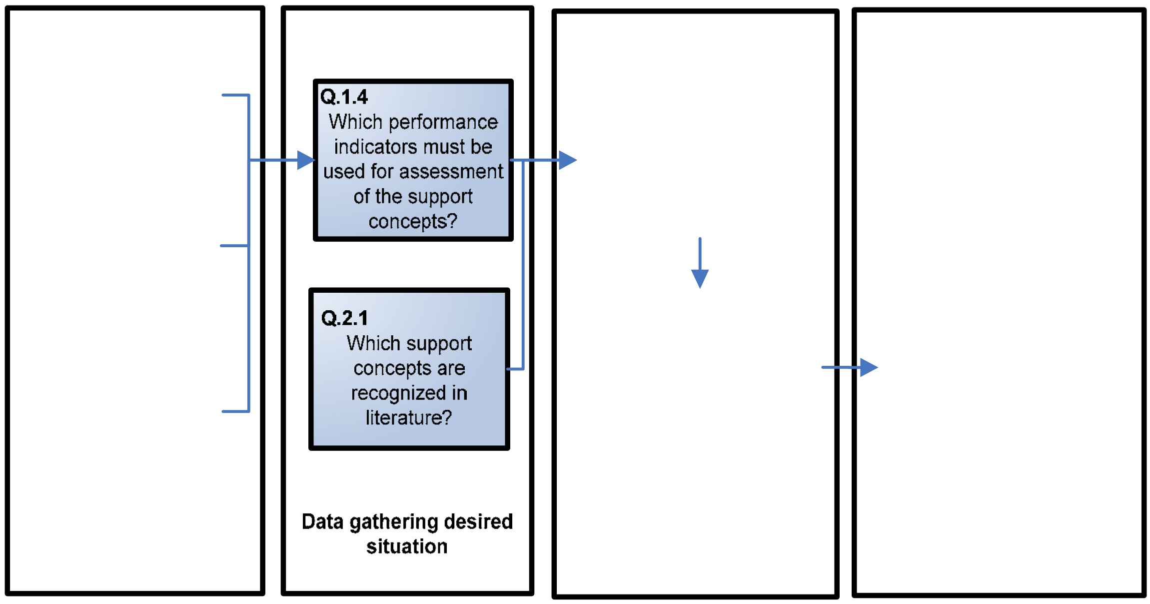


Figure 6.1: Research framework

Structure of the chapter

The first section will present the proposed support concept. Section 6.2 introduces a model that is used to evaluate whether consultants actually will use the support concept after it is implemented. The outcomes of the model are discussed in this section as well. Section 6.3 will propose the implementation strategy. This chapter will end with a set of conclusions.

Sub-questions to be answered in this chapter

What does the new support concept for simulation model development look like?

How can the proposed support concept best be implemented?

- *Which evaluation methods from literature can be used to evaluate the implementation of the support concept at Tebodin?*
- *What does the proposed implementation strategy look like?*

6.1 Proposed support concept

This section introduces the proposed support concept. Furthermore, a list of all design patterns that should be defined is introduced. The exact definition of the content of design patterns is not part of the scope of this research project and should be done based on the recommendation of this report. Section 6.3 provides an implementation strategy which includes a process description for the actual tasks that have to be performed to define the content of these design patterns. Figure 6.2 visualizes the proposed support concept. Before the actual start of the simulation project, there is an initial problem definition. This problem definition is translated into a finished simulation models during all phases of the development process. The concept is that during the whole simulation development process, specific design patterns are used that provide solutions for specific topics. These solutions vary from how certain tasks should be executed to how the design process should look like, given the function of a simulation model in a project. The content of these solutions are based on the principles of the support concepts. For example, given a specific function of a simulation model, design patterns can provide standardized conceptual models for specific functionality in the model. This design pattern should be used by a simulation consultant in the development phase of the model. In this way, the design pattern provides information which reduces the time, knowledge and effort needed to develop a conceptual model.

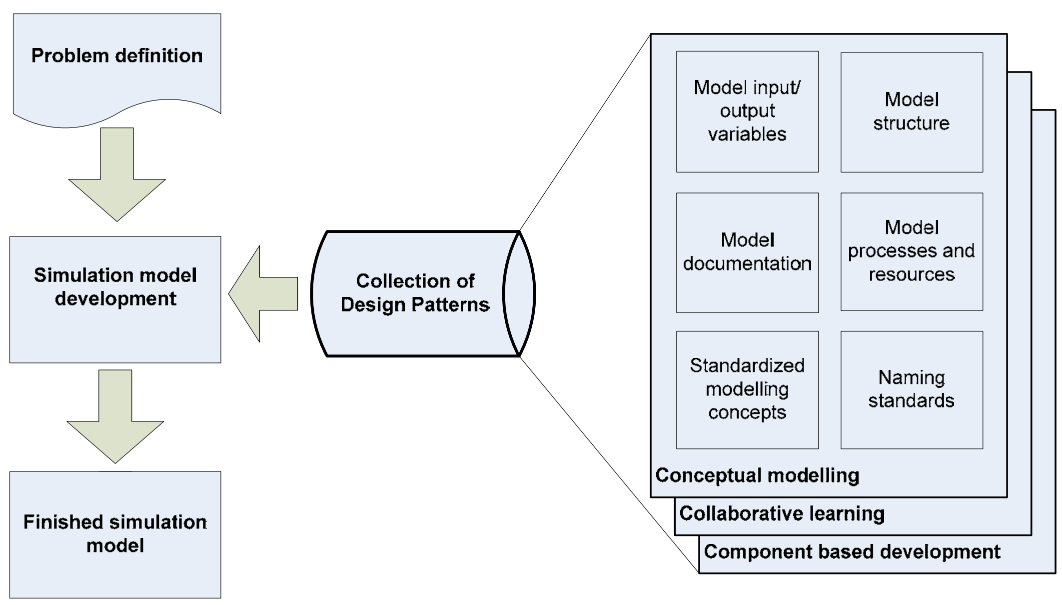


Figure 6.2: proposed support concept

After the support concept is discussed in general, the concept should be worked out into more detail. Based on the current simulation model development process (see section 1.6.3) all relevant design patterns that can reduce problems during different phases should be discovered. The best way to discover a pattern is to perform a conceptual analysis on the problem space (Gustavson et al., 2005). During a brainstorm session with simulation consultants, potential design patterns were discovered by structurally analysing each development phase. Based on this session, a series of design patterns is proposed for each different phase in a simulation project.

The application of support concepts in specific phases of the development process differ. Figure 4.2 illustrates that certain concepts are more suitable at conceptual level and others at a more practical level. Collaborative learning and conceptual modelling related design patterns are used in the earlier phases of the development process while component based development related design patterns are used in stages further on in the development process. Most design patterns are focused on structuring a problem and translating the problem into a proposal and start-point document. The current approach is more focused on the actual development of the simulation model and solving problems related to that development process. The proposed change in focus is in line with conclusions from Valentin (2008), who concludes that the instantiation of the simulation model should be a straight forward process if all the thinking and defining activities have been performed before the actual instantiation (with the use of for example conceptual models). Each design patterns that should be developed for each phase of the development process is discussed. For each design pattern, between brackets the support concept which should be used in the pattern is provided. Design patterns no fully based on one particular concept are indicated with (O).

Proposal

Design patterns that are related to the proposal are probably the most important design patterns because these patterns should provide an approach that results in a proposal that satisfies a client on the one hand and that leaves enough flexibility for Tebodin to make changes when translating the proposal into a more detailed start-point document. Because of the importance and required experienced needed to compose a proposal, relatively many collaborative learning (CL) related design patterns are proposed.

Model function (CL)

This design pattern provides an approach on how the function of a simulation model should be determined considering an initial problem description which is the basis for the simulation project. This pattern should include which consultants should be involved in determining the model function.

Model structure proposal (CM)

In this design pattern an approach on how a (high level) model representation of the model input, output and control variables as well as resources should be defined should be described. This function should presented with the use of IDEF0 diagrams.

Model approach (CL)

This design pattern provides an approach how it should be determined if model reuse should be applied and if so, how model reuse should be applied considering the initial problem description in the simulation project.

Project planning (CL)

In this design pattern an approach on how to determine a feasible project planning considering the function of a simulation model should be provided.

Project approach (O)

This design pattern provides an approach how a project should be structured. This pattern should describe which phases a simulation project should contain considering a specific function.

Proposal design (CM)

In this design pattern it should be described which elements should be included in a proposal as well as the way the proposed activities are formulated in order to build-in flexibility in a proposal to allow easy translation to a start-point document for Tebodin.

Data Collection

Design patterns related to data collection are important because these patterns should provide the link between the structure/function of the simulation model and data that is required for these simulation models. It is advised to add this design pattern to the proposed design patterns in the proposal phase.

Data requirements (CM)

This design pattern provides an approach how to determine which data is required regarding the structure and function of a simulation model. Furthermore, this pattern should describe which characteristics the data should have and how it should be abstracted from a client.

Start-point document

Design patterns that are related to the start-point document are important design patterns because these patterns provide approaches to determine all important aspects of a simulation study. In the start-point document, aspects such as project planning, project scope and variables in the simulation model are defined and these aspects are approved by clients. The aspects that are defined in the proposal should be used in the start point document and worked out into more detail. The start-point document is a document for approval for a client and, when approved, is therefore leading in all phases of a simulation study. Because of the legal character of the document, conceptual modelling (CM) related design patterns are used to define the content of the simulation model.

Conceptual scope of simulation model (CM)
This design pattern provides an approach how to define a detailed conceptual model representation of the actual simulation model including all relevant variables and attributes as well as resources. This function should presented with the use of IDEF0 diagrams. These conceptual models are not provide towards clients but are for internal use only. These conceptual models should be developed in this stage of the project because insights gathered during the development of the conceptual models which can be used to check the proposed project scope or other important aspects of the start-point document. Furthermore, these conceptual models can be used as basis for the model documentation that is required after finishing a simulation project.
Scope of project (O)
In this design pattern an approach how to translate the data requirements into a textual description of the project scope should be provided.
Start-point document design (O)
This design pattern provides which elements should be included in a start-point document as well as the way the elements in the proposal should be worked out into more detail.

Model building process
Design patterns that are related to the model building process focus on standardizing the simulation models as well as on standardizing the development process. Based on the function of simulation and specific characteristics of a simulation project, the building process varies.

Model documentation (CM)
This design pattern provides an approach on how simulation models should be documented. The pattern should describe who is responsible for documentation and which aspects should be documented (variables, attributes, resources, relations etc). Model documentation should be presented with the use of IDEF0 diagrams.
Building templates (CBD)
In this design pattern it should be provided how sub-models should be translated into templates. Furthermore, this pattern should provide criteria for determining when simulation (sub-) models should be translated into templates. For example, simulation models should be secured for clients who are not allowed to make changes to the structure of delivered simulation models.
Build process design (O)
This design pattern provides which process steps should be executed during the model building process given the model function. Furthermore, the patterns should describe how formal project communication, client milestones and milestones for Tebodin should look like.
Model appearance (O)
In this design pattern the conventions that should be used during the development process are specified. These conventions should lead to simulation models that have a high rate of standardization with regard to model appearance. This pattern should provide a standardized lay-out structure, naming conventions for attributes/variables/resources and standardized colours for sub-models.
Project Communication (CL)
This design pattern provides an approach for determining the communication activities during simulation models. Based on specific characteristics such as the experience of the responsible modeller or if simulation projects are single or joint modelling projects, the number of progress meetings, help sessions and model reviews should be determined.
Templates use (CBD)
In this design pattern an approach to determine which templates can be used when developing a simulation model should be provided. This pattern should help to determine and select which templates can be used for specific functions in a particular simulation model.

Model validation
This project phase is important because it assesses the model quality. The way models are validated depends on the data that is available and function that the model function has in a simulation project.

Validation approach (O)
This design pattern provides an approach how to determine the validation method based on available data and function of the simulation model. Furthermore, it provides how validation should be executed in these different functions. Validation requires a sensitivity analysis or requires a more detailed comparison of models outcomes with the available data depending on the available data during the simulation project.

Model experiments
This project phase is currently not structured and currently there is some confusion about the approach of running experiments. The desired approach of running scenarios varies between projects whith different functions.

Experiments approach (CM)
This design pattern provides an approach how interactions between consultants and clients during this project phase should look like given a specific function of the simulation model. By using this design patterns the interaction between clients and consultants is structured and formalized. A flow chart should be used to visualize the interactive experiments process.
Experiments design (O)
In this design pattern an approach how to determine the warm-up period, number of replication and replication length of the experiments (scenario's) that are used during the simulation project should be provided. Currently these aspects are fixed in every simulation project, while these aspects should vary depending on the characteristics of the simulation model.

Report and Advice
This project phase is currently relatively unstructured. Most of the time, an old report is used as basis for a new advice report. Consultants should be provided with a standardized approach to report the results and conclusion that follow from simulation models.

Report design (O)
In this design pattern, it should be provided which elements should be included in a simulation report, given a particular function of the simulation model. This pattern should include a checklist to determine if the report contains all necessary elements.
Review process (CM)
This design pattern provides an approach how to review a simulation advice report. Apart from the formal control responsibilities that are currently addressed in the Total Quality System, specific aspects such as content related review criteria should be provided to structurally review an report before it is send to a client. A flow chart should be used to visualize the review process.

Evaluation
This project phase is added to the current simulation development process. Each project should be evaluated after the finish of the project. In this evaluation, all relevant gathered knowledge in the simulation project should be distributed among others.

Knowledge sharing (CL)
This design pattern provides an approach how to share new knowledge. In this pattern, the procedure for a wrap-up meeting is provided which includes who must attend the meeting and which aspects are discussed, such as lesions learned, pitfalls and success stories. Furthermore, this pattern should describe how this evaluation should be documented and who is responsible for the documentation of the evaluation.

The question rises how effective this support concept will be after the actual implementation? The effectiveness heavily depends on the actual use of the support concept. The concept should be used in order to generate the intended effects. Therefore, the next section provides understanding about which factors influence the actual use of the support concept by simulation consultants.

6.2 Reflection on support concept

Until now, scientific research focused on specific techniques that aim on solving specific problems of simulation model development and therefore solving only parts of the whole problem situation. The proposed support concept combines different techniques that have proven to be effective on certain problem areas into one integral solution. The result is a support concept that can improve all relevant problems areas in a practical manner rather. The series of design patterns is designed based on the specific problems and characteristics of Tebodin. During the development of the support concept the organisation fit played a key role which resulted in a maximization of the effectiveness of the design patterns for Tebodin. Therefore, implementing this support concept in other organisation will probably not lead to the same level of effectiveness. The character of design patterns allows sharing of particular patterns with certain topics.

Scientific literature provides a series of common problems during the development of simulation models. Some of these problems were found within Tebodin. It is likely that other organisations, who use discrete event simulation, will encounter a number of these problems as well. Individual design patterns solve small particular problems which are addressed in literature. Certain design patterns could therefore be used by other organisation. It is advised, before design patterns are used in other organisation to evaluate the organisation fit of these design patterns based on the specific problems and characteristics of the organisation.

6.3 Evaluating the implementation of the new support concept

Briggs (2005) concludes that, “if an organization can find ways to improve its work practices, it can gain competitive advantage. However, deliberate attempts to change the way people do business are not always successful. Sometimes people resist a new practice, even when evidence suggests that the new practice might benefit both the organization and the individuals involved”. Theories on implementation are helpful to predict the rate of success for implementation. There are several models for organisational change or specific aspects of organisation change. “The strength of process theories and models is that they offer detailed and structured descriptions or prescriptions of the myriad of important details to which an organization must attend to accomplish a transition to a technological innovation.” (Briggs et al., 2003) This section provides a model from scientific literature that is used to evaluate the effectiveness of the proposed support concept.

As said, there are a many models that can be used for the evaluation of the acceptance of new technologies. Well known models are the technology acceptance model (TAM) and the technology transition model (TTM). TAM “posits a causal relationship between a set of factors that lead to system use. Its purpose is to predict usage patterns among users several weeks after an initial one-hour exposure. TAM posits that people will develop an intention to use and therefore will use a new technology to the extend that it is perceived useful, to the extend that it is easy to use.” (Briggs et al., 2003, p.36). In contrast of TTM, TAM focuses on individual rather then on groups of users. “TTM is a casual model to predict and explain technology transitions. TTM seeks to explain the existence of communities of users for technologies. Limitations of the TTM are that we used as the foundation for our argument has been substantiated by a still relatively limited number of field cases and observations.“ (Briggs et al., 2003, p.54). Both models posit a so called “system of use”, but TAM and TTM focus on technological innovation rather then change-of-practice. Both models are therefore not fully suitable to be used for change-of-practice. “Given the costs and risk of changes of practice, it may be useful to have a general theory to explain the stability of work practices and the technologies to support them” (Briggs, 2005 p.37). “Although TTM was proposed to explain technology transition, its propositions may apply equally to other kinds of transitions of practice. While TTM has received some support, it is incomplete, in that its propositions have not yet been rigorously derived from a set of underlying axioms; the assumptions underlying its propositions have not yet be articulated. VFM therefore extends TTM by articulating a set of assumptions from which its propositions could be derived and by adapting its constructs and propositions to explain the more general construct, changes of practice." (Briggs, 2005 p.36)

Briggs et al. (2007) formulated the Value Frequency Model. "VFM extends the Technology transition model (TTM) to explain change of work practices. VFM is a causal theory in the logical positivist tradition to explain changes of practice. VFM posits cognitive mechanisms that may have evolved among individuals who selected and pursued goals in ways that were more likely to lead to survival and reproduction." (Briggs, 2005 p.37). Briggs (2003) concludes that changes of practice appear to be consistent with an explained by the logic of VFM and that the field study provides evidence that the theory may be useful. In line with this conclusion, Briggs et al. (2005) conclude that it may be a useful basis for detecting in advance whether people are likely to transition to or resist an innovative work practice. This model is therefore used to predict the effectiveness of implementation of the new measures. The value frequency model is now being discussed in more detail.

6.3.1 The Value Frequency Model

This section provides an introduction of the Value Frequency Model and elaborates on the elements which are recognized in the model. "VFM extends the Technology Transition Model (TTM) to explain change of work practice. Figure 6.3 illustrates the propositions of VFM. It proposes change-of-practice as a multiplicative function of the *perceived-magnitude-of-value* (V) for a proposed change and *perceived-frequency-of-value* (F). Perceived-magnitude-of-value is defined as an overall sense of the degree to which a proposed change of work practice would be good or bad for the individual.

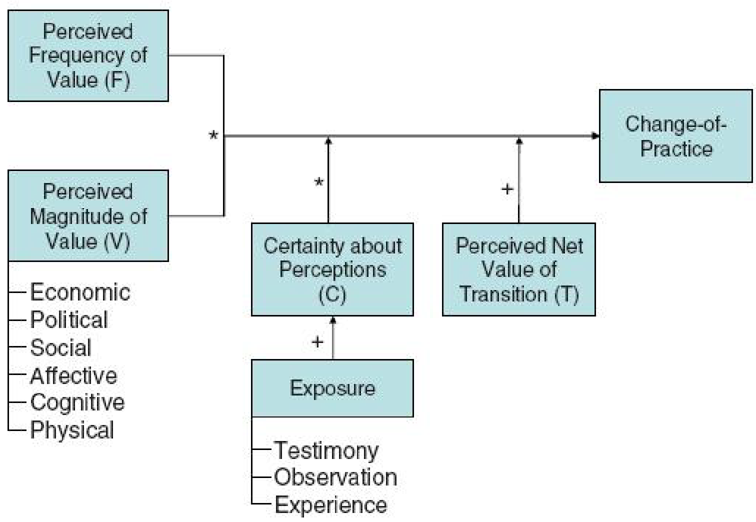


Figure 6.3: Value Frequency Model for Change-of-practice (Briggs, 2005)

Perceived-frequency of value (or *frequency*) is defined as an overall sense of how often such value would be realized. Taken together, the multiplicative relationship between value and frequency is labelled as *the value-frequency judgment*. VFM posits that the causal relationship between the value-frequency judgment and change-of-practice is moderated certainty-about-perceptions (C) and perceived-value-of-transition (T). *Certainty-about-perceptions* (or *certainty)* is a subconscious assessment of the likelihood that value-frequency judgments are accurate. *Perceived Net Value of Transition* (T) (or *Transition Value*) is defined as an overall sense of the positive or negative value that would derive from the change process itself." (Briggs, 2005, p. 131).The next section will use this model for the evaluation of the implementation of the proposed support concept within the logistics department. Each element of the model will be discussed in detail. Based on the outcomes of each element, conclusions can be drawn on whether change of practice will be realized.

6.3.2 Evaluation of the implementation of the proposed support concept

Whether or not individuals will change practice depends on four major variables (see figure 6.3). During the workshop, simulation consultants were asked about their opinion about the value of these variables for each support concept. In this way, data about the value of these variables became available. Based on this data, the value frequency model is filled in to draw conclusions on whether the actual use of the set of support methods by simulation consultant is likely to happen. This section will elaborate on the values of the variables and ends with the conclusions about the change-of-practice.

Perceived Magnitude of Value

As discussed earlier in this report, not all dimensions (see section of figure 3.4.1) that determine the magnitude of value are useful for this research project because change-of-work-practices are more generic then the implementation of specific support concepts within the logistics department of Tebodin. The physical and economic dimensions are not used because these dimensions are not applicable for the implementation of new support concept within the logistics department. The data used to draw conclusions about the perceived magnitude of value follows from discussions and the opinions of the consultants (assessment forms) during the workshop.

The affective magnitude after implementation of all support concepts is low to average. Some of the concepts were seen as attractive and useful while most were perceived less attractive and useful. Conceptual modelling was perceived as not very useful because of the mixed feelings among consultants which was the result of the limited effectiveness of this concept. Component based development is also not seen as very attractive because of the limited effectiveness and usefulness. This feeling is caused because no simulation consultant believes that all simulation models can be compiled from templates or libraries alone. The fixed content and structure decrease the flexibility of this approach and therefore the effectiveness. Collaborative learning was perceived as very useful and attractive mainly because of the ease of implementation combined with the high effectiveness. The main idea behind design patterns was perceived as an effective and attractive concept. The overall political magnitude after implementation of the support concept is limited. For most concepts, there is no political magnitude. In general, the results of the research show that the support concepts have no political magnitude because of the following reasons;

- Position of simulation consultants within Tebodin does not change
- Not all problems can still be solved by consultants by using a support concept
- Knowledge of simulation and experience is still needed

The use of component based development can lead to negative political magnitude, because more (inexperienced) colleagues are able to build simulation models as well. Using collaborative learning techniques can lead to a positive political magnitude because using collaborative learning techniques can improve the contact and knowledge transfer between the logistics department and other departments in cross-department projects. Therefore, consultants (the logistics department as a whole) can acquire more influence within Tebodin. The social magnitude after implementation of the support concept is average. By using collaborative learning techniques, the communication between consultants or between consultants and clients will improve. Furthermore, the relationship between consultants becomes more equal because of improved knowledge transfer and interaction. The use of component based development and design patterns can lead to a negative social magnitude. Because of the formalisation and standardization of the simulation development process, the social interaction will be reduced when applying these concepts. The cognitive magnitude after implementation of all support concepts is high. In general, every support concept will reduce the cognitive load of consultants when developing simulation models in some way. After the discussion of all dimension that make up for the perceived magnitude of value, it has become clear that the perceived magnitude of value is average. This is not surprising, considering the conclusions of the effectiveness of each concept. The scores on performance indicators provided by the consultants were also average.

Perceived Frequency of Value

The overall perception about the frequency of value is high. During interviews in the beginning of the research project, it became clear that every consultant agreed on the fact that it is important to implement a support concept to resolve the current problems. By implementing a support concept that can be used by simulation consultants, the frequency of value is hundred percent if they are actually used. The chance that simulation consultants will not use the support concept is low because the need for change is clear to them. Briggs et al. (2003) provide Applegate's (1991) conclusion that the role of stimulators in technology transfer is important. Applegate uses the example of the "level of frustration of end users with the current processes" as a strong stimulator for transitions of innovation. Briggs et al. (2003) conclude that there are no obvious arguments that this principle can not be applied on the change-of-practice in stead of technological innovation as well.

Certainty about perceptions

The certainty about perceptions among simulation consultants is high. The certainty about perceptions reflects the accuracy of the consultants' assessment of his/her perceived magnitude and frequency of value judgments for the support concept. Briggs et al. (2007) conclude that the more exposure someone has to a new systems, the more certain one feels about ones perceptions of that system. The certainty about perceptions can be influenced by the rate of exposure. Briggs (2005) provides that the rate of exposure is influenced by the experiences and observations of the system of someone or by providing testimonials of others. Therefore, during the entire research project, the simulation consultants were involved as much as possible. With the use of interviews and workshops, consultants have become aware of the effectiveness of the support concept on simulation model development. Furthermore, the consultants were given the opportunity to try-out support concepts and to provide their opinion about the best concept and best way of implementing the support concept.

Perceived Net Value of Transition

Change-of-practices will be stimulated even more if the implementation process itself would lead to positive values for simulation consultants. At first sight, there seems to be no obvious reasons why the implementation process of the support concept itself would benefit consultants. There is one good reason why the perceived value of transition should be improved. The fact that the proposed support concept has to be worked-out in more detail during the implementation phase provides the opportunity for consultants to place there mark on the actual content of the support concept. During the implementation continuous choices have to be made. Individual preferences of simulation consultants can be included during implementation, which results in an increasing perceived value of transition.

Change-of-Practice

Whether or not the implementation of the support concept is going to be successful depends on the variables that are previously discussed in this section. It has become clear that the implementation of the support concepts in the logistics department will not be problematic. Apart from the magnitude of value which is average, the perceived frequency of value, certainty about perceptions and perceived value of transition seem very positive. Based on these findings, it can be concluded that the change-of-practice is likely to happen which results in successful implementation of the support concept. Nevertheless, the variable with the most influence on the actual change-of-practice is the magnitude-of-value. Nevertheless, there is a risk that the actual effectiveness is limited because the effectiveness of the support concept is perceived by consultants average rather than high.The magnitude-of-value that resulted from this research project is determined based perceptions of simulation consultants who his/her perception is based on limited examples and basic principles of support concepts. The actual magnitude-of-value depends on the eventual content of the support concept. Because of the fact that during implementation, the support concept is worked out in detail, the actual magnitude of value can be different than it is suggested at this moment. It is expected that the actual effectiveness of the support concept (magnitude of value) becomes higher because of the effort and experience put into the implementation process to customize the support concepts for the situation within Tebodin. Obviously, during this customization process there is tried to maximize the effectiveness of each individual support measure. The next section proposes an implementation strategy for the support concept. The strategy can be used as a guideline during the actual implementation.

6.4 Implementation Strategy

Section 6.1 introduced a list of design patterns that should be implemented. Furthermore, the previous section evaluated the actual change-of-practice after implementation of the new support concept. It seems like that there are no barriers for implementation. Discussions about the use and function of the total quality system (TQS) of Tebodin are continuously held. During this research project, within the logistics department discussions are held about the absence of a simulation project related quality system. Therefore, a clear opportunity window for the implementation of the support concept has appeared.

This opportunity window has opened further along with the progression of this research project. In the beginning of this research project, all simulation consultants agreed on the fact that it is important to come up with measures in order to resolve problems in the current situation. Almost everybody thought implementation of the support concept should not be problematic. This perception is caused by the fact that current problems are proven to be reduced, implementation is a logical consequence. Furthermore, this perception has become stronger during the research project, because the simulation consultants were involved in the design process. The manager of the logistics department also indicated in an interview that there are no major barriers for implementation. If small investments are needed to, for example, make models more flexible which should lead to time savings in a later stage, implementation should be favoured. Generally speaking, it seems like the commitment is high for changing the current situation by means of implementation of the support concept.

To actually implement the support concept, a clear implementation strategy is needed. There should be made a clear separation between the actual implementation phase and the post implementation phase. This section elaborates on the implementation strategy for the proposed set of design patterns. The most important aspects that should be taken into account during and after implementation of the support concept are discussed. Furthermore, the pitfalls and opportunities regarding implementation are also discussed in this section.

6.4.1 Implementation phase

Den Hengst (2003) concludes that for implementation of work processes it is important to clearly define tasks and responsibilities. It is therefore advised to make a particular consultant in the department responsible for the implementation of the support concept. Furthermore, this consultant should be able to define tasks that are necessary to define and implement the set of design patterns.

During the development of the design patterns, it should be tried to reduce the number of elements of the patterns as much as possible in order to minimize the implementation effort and to maximize the usability of the pattern. From the results of the workshop it became clear that the usability of design patterns heavily depends on the number of elements addressed in a design pattern. It is advised to use four elements, which are based on the conclusion Souza et al. (2002) who conclude that design patterns contain at least the following four elements;

- *Name:* The name is used to briefly describes the problem that the pattern aims to solve
- *Problem:* The problem describes when to apply the pattern and indicates constrains to its use.
- *Solution:* The solution describes the elements that compose the pattern,
- *Consequences:* The consequences describe the results and trade-offs of applying the pattern

Figure H.1 in appendix H provides an example of how these elements should be used in a design pattern. The design pattern shown in figure H.1 includes an extra element; additional information. If additional information should be added extra elements could be included in the design pattern. The next section will go into more detail on additional elements in design patterns.

Apart from having to construct all design patterns during the implementation phase, an appropriate catalogue or classification system for the set of design patterns should be constructed. Ahmed et al. (2007) conclude that for design patterns, in order to be an effective knowledge-capturing tool, classification of patterns and support tools for developers must be available to select a suitable design pattern (see figure 4.3). Souza et al. (2002) provide that using design patterns begins with the identification of a pattern in a catalogue of a pattern that aids in the solution of a specific problem. The following aspects considering the classification of design patterns are advised to use;

- Unique number for each design pattern
- Representation of the content of the design pattern with an sensitizing picture
- Overview of all design patterns
- Search function to find appropriate design patterns
- Physical distinction between patterns that are used in different phases of the development process.

Advised is to use a simple tools such as excel, that is available for every simulation consultant, to develop a search function and index for the set of design patterns. In this way, both the ease of development as well as the ease of use are improved. Furthermore, it is advised that design patterns are not only provided to simulation consultants digitally but also hard-copy at a central location. Using hard-copy documents is most of the time more convenient than using digital documents. When the number of design patterns increases in the future, the effectiveness of the use of design patterns depends heavily on ease in which appropriate design patterns can be found.

Design patterns based on collaborative learning need extra attention during the implementation as well as after implementation. During the workshop it became clear that the effectiveness of collaborative learning is different for simulation novices and simulation experts. The main problem is that experts have no incentive to share knowledge and share experiences with novices, because the information flow is only one-way (see left situation in figure 6.4). Experts have to put in time and effort without getting hardly anything in return for this effort (even a negative reduction in occupancy rate). The most ideal situation is that all consultants are experts and can every consultant can gain useful information for other experts (see right situation in figure 6.4). Therefore, advised is to provide incentives in order to stimulate experts to transfer information and knowledge in some way. The easiest way of stimulation is to provide enough time for experts to share knowledge and information. Periodically meetings or a required wrap-off meeting after each finished simulation project could be sufficient.

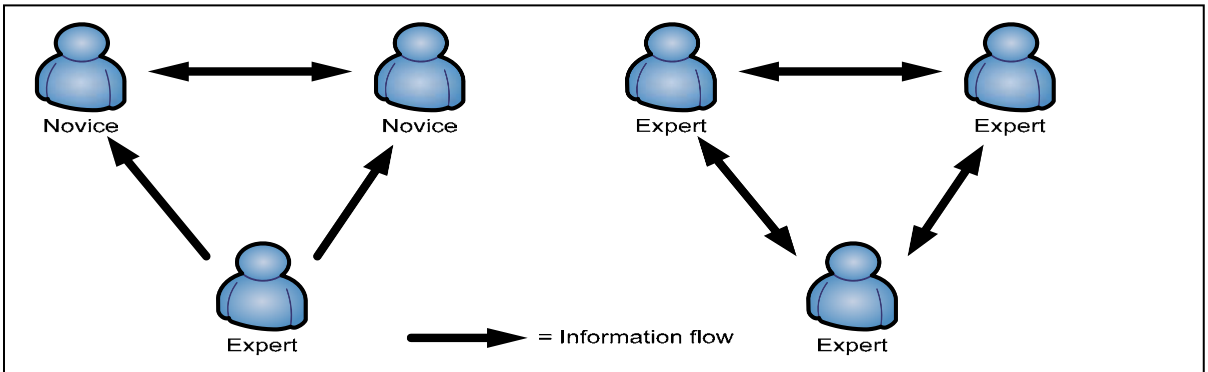


Figure 6.4: Communication between experts and novices

In order to use conceptual modelling based design patterns effectively, conceptual models should be defined properly and consistently. Simulation consultants should have the necessary skills and experience to develop such conceptual models. A problem is that one of the skills commonly found to be lacking in model developers is dealing with conceptual modeling (Valentin, 2008). Within Tebodin, the conceptual modelling skills of consultants are limited. Therefore, additional education is needed in order to improve the conceptual modelling skills of the simulation consultants.

Sub-models can be reused by translating them to generic templates. The effectiveness of these templates depends on the main assumptions of the model logic in the template. These assumptions limit the effectiveness of templates. An example is a simulation model that operates in a push environment. Changing these assumptions to a pull would require major modifications to the approach (Son, 2003). Figure 6.5 provides that the usability of pre-defined building blocks depends on the generality of the building block. The more generic a template is, the higher the usability in different simulation project shall be. Therefore, when generic templates are developed, the focus should be on selecting the right content of the template. It should be determined which abstraction level, level of detail and types of variables should be included in the template. During development a trade-off should be made between the usability of the template and the generality of the template. Furthermore, it is advised to execute a simple financial analysis on each template (see section 1.5.6) to determine the feasibility of each template.

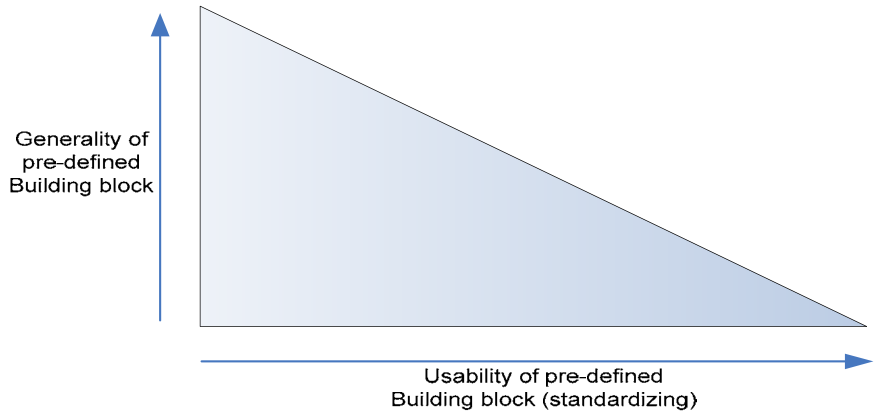


Figure 6.5: Usability vs. generality of pre-defined building blocks

Development of pre-defined building blocks is not an easy task. Furthermore, using templates also requires a certain level of skills. Oses et al. (2004) conclude that using components leads to more rapid development, but this does not imply that any software developer will, by using components, find that the development process is a lot easier and faster. The system developer still needs expertise in component based software development. Furthermore, Oses et al. (2004) provides that the used of component based development does not mean that first-time simulation users will be able to build extremely complicated models. It is advised to provide additional education, if every simulation consultant should be able to develop and/or use (simple) templates. Apart from the actual implementation in which the design patterns are developed, the post implementation phase also has an important function. The next section will elaborate on the post implementation phase.

6.4.2 Post implementation

Implementation is not the same as actual use. Therefore, after implementation effort should be put in stimulating consultants to use design patterns. This means that consultants should be granted extra time when necessary to use design patterns. Simulation consultants should be instructed on how to use the design patterns during simulation projects and the use of design patterns should become a work standard. It is expected that stimulating consultants to use design patterns is not necessary because consultants are aware of the advantages of using design patterns.

Gustavson et al. (2005) concludes that patterns are discovered rather than invented. Therefore the post implementation phase has an important role. Design patterns that are not defined yet, could be spontaneously discovered during day to day activities. Furthermore, the effectiveness of the design patterns heavily depends on the maintenance of design patterns. Design patterns should evolve over time. The content of the patterns should be changed and elements should added when necessary. Advised is to add the following elements after implementation:

- Problem symptoms
- Best practices
- Pitfalls/Opportunities

It is advised to periodically evaluate the completeness of the series of design patterns and the need for adjustments. This evaluation should be incorporated in the agenda of the monthly department meetings. In this meeting, it should be discussed which adoptions should be made or additional new patterns should be defined. This implies that extra information is needed such as including a version number and a date of change in order to track changes. In contrast to the responsibilities during the actual implementation, after implementation each consultant should be responsible for the adaptation of the design patterns. Please note that consultants should be able and stimulated to actually improve the content and use of the design patterns. It is advised to provide sufficient time for these activities.

6.5 Sub-conclusions

The goal of this chapter was to propose a support concept and to propose an implementation strategy for this support concept. Therefore, this chapter tried to answer the following research question;

- *What does the new support concept for simulation model development look like?*
- *Which evaluation methods from literature can be used to evaluate the implementation of the support concept at Tebodin?*
- *What does the proposed implementation strategy look like?*

Until now, scientific research focused on specific techniques that aim on solving specific problems of simulation model development and therefore solving only parts of the whole problem situation. The proposed support concept combines different techniques that have proven to be effective on certain problem areas into one integral solution in order to solve a whole range of different problems.

The proposed support concept provides that during the whole simulation development process, a series of specific design patterns is used that provides solutions for specialized topics. These solutions vary from how certain tasks should be executed to how the design process should look like given the function of a simulation model in a project. Figure 6.6 visualizes the proposed support concept.

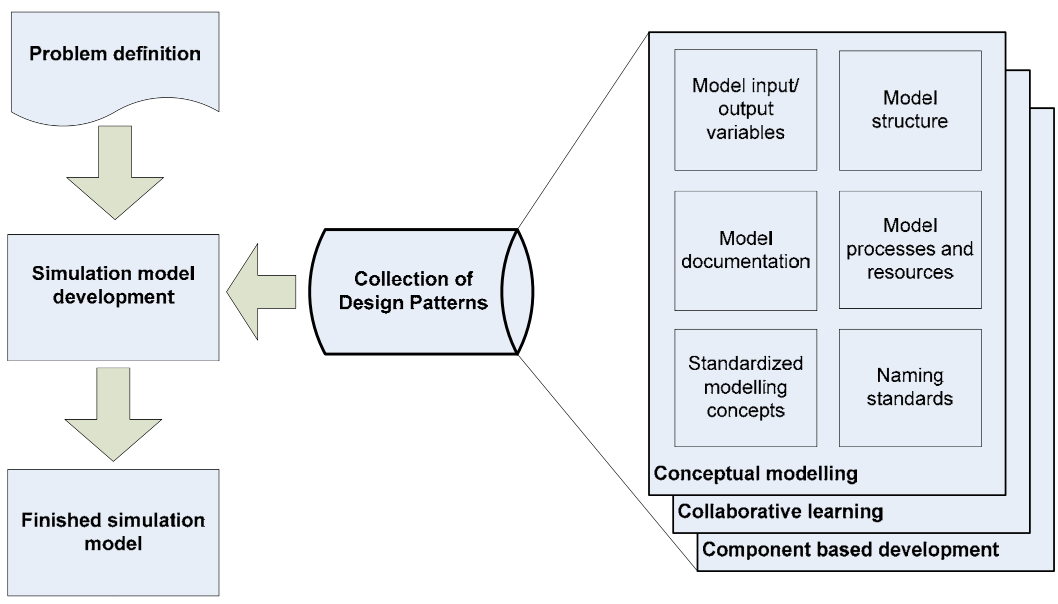


Figure 6.6: Support concept

Briggs (2005) concludes that, “if an organization can find ways to improve its work practices, it can gain competitive advantage. However, deliberate attempts to change the way people do business are not always successful. Sometimes people resist a new practice, even when evidence suggests that the new practice might benefit both the organization and the individuals involved”. Theories on implementation are helpful to predict the rate of success for implementation. For the evaluation of implementation of the support concept the Value Frequency Model was used. The Value Frequency Model determines whether or not change-of-practices will occur. Change-of-practice is a function of multiple variables. During the workshops, simulation consultants provided data about these variables. This data was used to fill in the model in order to draw conclusion about the rate of success of the implementation. It has become clear that the implementation of the support concept in the logistics department will not be problematic. Nevertheless, there is a risk that the actual effectiveness is limited because the effectiveness of the support concept is perceived by consultants average rather than high.

The implementation strategy consists of two parts; the actual implementation phase and the post implementation phase. A single individual should be responsible for the whole implementation phase. Responsibility after implementation lies by all simulation consultants. During the development of the design patterns, the number of elements of the patterns should be tried to be reduced as much as possible in order to minimize the implementation effort and to maximize the usability of the pattern. It is advised to minimally include the following elements in a design pattern;

- *Name:* The name is used to briefly describes the problem that the pattern aims to solve
- *Problem:* The problem describes when to apply the pattern and indicates constrains to its use.
- *Solution:* The solution describes the elements that compose the pattern,
- *Consequences:* The consequences describe the results and trade-offs of applying the pattern

Figure H.1 in appendix H provides an example of how these elements should be used in a design pattern. During the implementation it is advised to pay specific attention to the following activities:

- Provide additional education in order to improve the conceptual modelling skills of consultants
- Construct an appropriate index or classification system for the set of design patterns
- Provide incentives to stimulate experts to transfer information and knowledge.
- Determine the feasibility of the use of templates
- Provide additional education , if every simulation consultant should be able to develop and/or use templates

The effectiveness of the design patterns depends heavily on the maintenance of design patterns. Design patterns should evolve over time. Therefore, the content of the patterns should be changed and elements should be added when necessary. It is advised to periodically evaluate the completeness of the series of design patterns and need for adjustments. Furthermore, consultants should be able and stimulated to actually improve the content and use of the design patterns. It is advised to provide consultants sufficient time for these activities. Advised in to add the following elements in design pattern after implementation when needed:

- Problem symptoms
- Best practices
- Pitfalls/Opportunities

7. Conclusions and recommendations

This final chapter elaborates on the conclusions of this research project. In this chapter the main research question is answered. Furthermore, recommendations are made for Tebodin as well as for further research. This chapter ends with a personal reflection on the research project.

7.1 Conclusions

This section provides all relevant conclusions of this research project and answers the main research question. The main research question is defined as the following;

How can simulation model development within Tebodin be supported and how can a support concept be implemented in order to increase the effectiveness of simulation models and improve the efficiency of the simulation model development process?

The historic, current and future situations are assessed in order to discover which aspects of the current simulation model development process need support. After interviews with the simulation consultants it became clear that there were several aspects of the current development process that require support. Support is required because of the following reasons;

- Important simulation knowledge is lost if consultants switch jobs
- Development delays due to unforeseen programming errors and problems adding together sub-models
- Lack of trust by simulation consultants in simulation (sub)models that are made by other consultants
- Poor attractiveness of simulation projects which leads to motivation problems with simulation consultants to execute or joint simulation projects current simulation model development process
- Poor extendibility of existing simulation models.
- Clients expectations are exceeded (quality and level of detail of finished simulation models)
- Communication problems during the actual development of simulation models between consultants
- Problematic reusability of simulation models

Analysis of the historic situation is done by analysis of finished simulation projects. The bottlenecks in the current development process are located in the development phase and during experiments with simulation models (running scenarios). The Bottlenecks which occurred during historic simulation projects are the result of the following specific issues;

- Problematic reuse of existing simulation models
- The absence of a well-defined scope during development of models
- The use of tight and fast track-planning
- Insufficient experience of simulation consultants with developing simulation models

Analysis of the future situation is done by interviewing the manager of the logistical consultancy department. During this interview, questions are asked about current and future trends and the future role of simulation within Tebodin. The following aspects are recognized that are needed to be achieved by the new support concept;

- Decrease the lead-time of simulation projects
- Increase the reliability of the section logistics towards clients
- Minimize the ascent of simulation consultants
- Reduce the complexity of simulation model development in order to reduce the effort needed to learn to develop simulation models for simulation novices.

The results of analysis of the historic, current and desired situation are translated into a set of performance indicators that are used to select and compare suitable support concepts that can improve the problem situation. Scientific literature provided several potential concepts for improving the effectiveness of simulation models and the efficiency of the development process. The following support concepts are recognized;

- *Conceptualisation techniques*
- *Design patterns*
- *Component based development*
- *Collaborative learning*

By means of a workshop, simulation consultants have been made familiar with the possible support concepts. Simulation consultants were given the opportunity to discuss and try out all suitable support concepts. After these activities, consultants filled in assessment forms for the evaluation of the effectiveness of each concept, considering the list of pre-defined performance indicators. Based on the discussions and results of the workshop, conclusions are drawn about the best support concept. Research showed that it is impossible to select one best support concept because each support concept has advantages and disadvantages and it therefore effective in a limited area. From the research it became clear that the best support concept is therefore a mixed set of concepts for each problem area, made available for consultants as design patterns. By using different support concepts for specific problem areas, the overall effectiveness of the support concept is maximized. In general, the average scores of all support concepts are not very high. This suggests that the perceived effectiveness of each support concept is not very high. Furthermore, for some problem areas, the average score of all concepts are almost the same. This indicates that, in these problem areas, all support concepts have similar effectiveness. Based on the conclusions about the perceived effectiveness of the support concepts that follow from the workshop, the actual support concept is proposed.

Until now, scientific research focused on developing specific techniques that aim on solving specific problems of simulation model development and therefore solving only parts of this problem situation. The proposed support concept combines different techniques that have proven to be effective on certain problem areas into one integral solution in order to solve a whole range of different problems. The proposed support concept provides that during the whole simulation development process, specific design pattern are used that provide solutions for specific topics (figure 7.1). These solutions vary from how certain tasks should be executed, to how the design process should look like given the function of a simulation model in a project. A list of design patterns that should be developed is composed. The content of these design patterns is based on the principles of the support concepts and should be worked out in detail in a further stage. Because the organisational fit of the support concept has played a leading role the development process of the design concept, this concept can not be used in this particular form in other organisations. Several design patterns could probably be beneficial for other organisation as well who develop discrete-event models. Before actual implementing these patterns in other organisations it is advised to assess the organisation fit based on the characteristics and encountered problems of these organisations.

Scientific literature made clear that deliberate attempts to change the way people do business are not always successful. Sometimes people resist a new practice, even when evidence suggests that might benefit both the organization and the individuals involved. The rate of success heavily depends on the acceptance of the new support concepts among simulation consultants. Theories on implementation are helpful to predict the rate of success for implementation. For the evaluation of implementation of the support concept the Value Frequency Model was used. The Value Frequency Model determines whether or not change-of-practices will occur. Change-of-practice is a function of multiple variables. During the workshop, simulation consultants provided data about these variables. This data was used to fill in the model in order to draw conclusions about the rate of success of the implementation

.

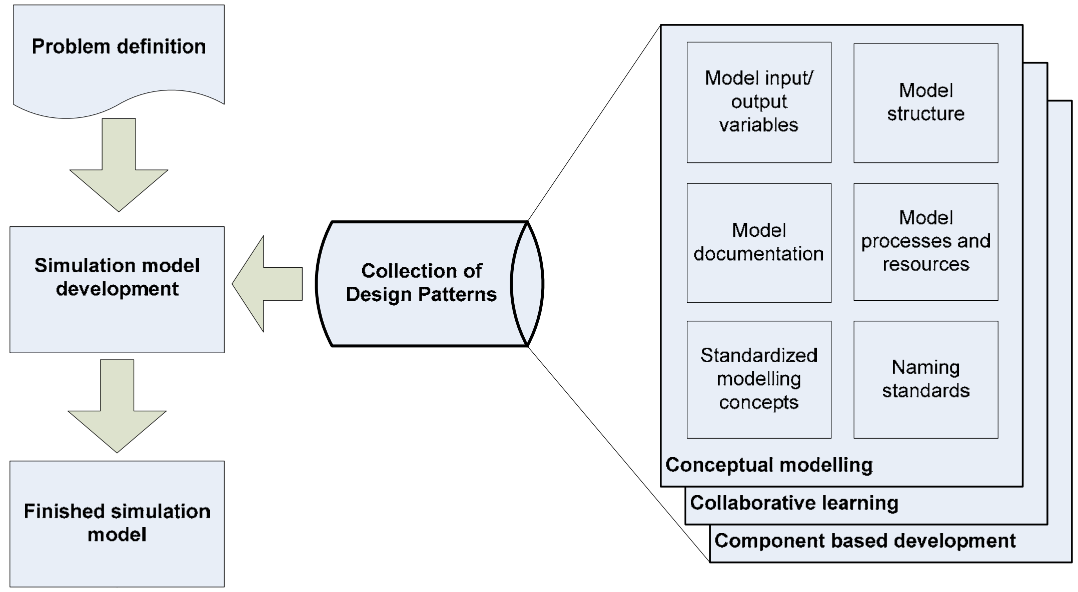


Figure 7.1: Support concept

Based on the results of the evaluation, it can be concluded that the implementation of the support concept in the logistics department will not be problematic. Nevertheless, there is a risk that the actual effectiveness is limited because the effectiveness of the support concept is perceived by consultants average rather than high. For the implementation of the support concept an implementation strategy is defined. The implementation strategy consists of two parts; the actual implementation phase and the post implementation phase. During the development of the design patterns, the number of elements of the patterns should be tried to be reduced as much as possible in order to minimize the implementation effort and to maximize the usability of the pattern. Figure H.1 in appendix H provides an example of how these elements should be used in a design pattern. During the implementation, it is advised to pay specific attention to the following activities:

- Provide additional education in order to improve the conceptual modelling skills of consultants
- Construct an appropriate index or classification system for the set of design patterns
- Provide incentives to stimulate experts to transfer information and knowledge.
- Determine the feasibility of the use of templates
- Provide additional education, if every simulation consultant should be able to develop and/or use templates

Design patterns should evolve over time. Therefore, the content of the patterns should be changed and elements should be added when necessary. The effectiveness of the design patterns heavily depends on the maintenance of design patterns. It is advised to periodically evaluate the completeness of the series of design patterns and need for adjustments. Furthermore, consultants should be able and be stimulated to actually improve the content and use of the design patterns. It is advised to provide consultants sufficient time for these activities. Advised is to add problem symptoms, best practices and pitfalls/opportunities in design pattern after implementation when needed.

7.2 Recommendations

This section elaborates on the recommendation for Tebodin as well as for further scientific research. Eight useful recommendations for Tebodin and two recommendations for further research are specified.

7.2.1 Recommendations for Tebodin

- **Implement the proposed support concept;** This research project made clear that the proposed support concept can improve the current situation in a positive way. During the actual implementation, the provided implementation strategy should be used to reduce potential problems during implementation and to maximize the effectiveness of the support concept. After successful implementation, simulation models can be used more effective and the simulation model development process is more efficient.

- **Determine the feasibility of simulation model reuse;** The proposed support concept includes simulation model reuse. This research project made clear that simulation model reuse can be beneficial. To fully benefit from reuse, sub-models should be translated into templates that can be applied in every simulation project. Developing these templates takes a significant amount of time. Therefore, before developing these templates, the feasibility of the use of templates should be assessed by using the economic model introduced in section 1.5.6.

- **Improve skills of simulation consultants;** This research project made clear that implementing the support concept will improve the current situation. Providing consultants a series of design patterns does not automatically mean that the minimal required skills of simulation consultants will decrease. Using the support concept requires even more skills, which results in improvements of the current problems. It is advised to provide additional training to improve conceptual modelling skills of simulation consultants and additional training for template development, if every simulation consultant should be able to develop and/or use templates. Furthermore, this research project made clear that the minimum level of training required, before start executing simulation studies for novices, was considered to low. Therefore, newbie simulation consultants should be provided with additional training in developing simulation models.

- **Improve project planning development;** This research project made clear that project planning plays a key role in problems during simulation projects. It is advised to involve simulation consultants in development of a project planning as much as possible. In this way, consultants can provide better understanding about potential problems which results in a more realistic planning. It is advised not to use a fast-track planning as proposed by clients because these tend to be unrealistic because of a clients lack of insight. Currently, a project planning is presented as a simple excel planning while other more specialized planning tools are available.

- **Improve the availability of software;** Apart from implementing the proposed support concept, the current situation can be improved by providing consultants with useful software. It is advised to provide simulation consultants with Microsoft Projects, which is an industry standard for project planning. Communication between clients and consultants about project planning and project progress will improve as a result and consultants can better assess the risks and impact of project delays. Based on these assessments, consultants can react better on project delays. Furthermore, it is advised to upgrade the current Arena version to Arena version 12 which includes new useful features such as search and replace functions. Simulation consultants indicated that considerable development time can be gained by using such features.

- **Improve the quality assurance of simulation models;** The purpose and function of simulation models depend on the project budget. The quality of a simulation project should not be determined by the budget. Currently, certain aspects of the development process such as, in some cases, limited validation and structural aspects such as not determining a warm-up period and using a fixed number of ten replications for every simulation model can affect the quality of a simulation model negatively. It is advised to improve these aspects in order to assure the quality of each simulation model and project. By introducing a quality standard, a certain level of quality can be suggested.

- **Secure simulation related knowledge;** Currently, Tebodin heavily depends on simulation related knowledge of only a few simulation consultants. This dependency leads to limited flexibility in resource utilization and low knowledge redundancy. In combination with today's high ascent of employees in general, the risk of losing large amounts of important simulation related knowledge can be seen as a threat. The proposed support concept reduces this risk substantially, but if the support concept is not implemented, all relevant knowledge should be secured as soon as possible in an appropriate way.

7.2.2 Recommendations for further research

During this research project, several knowledge gaps were recognized. This section provides recommendations for further scientific research which should focus on gathering knowledge that close these knowledge gaps.

- **Further research on quality of simulation models**; the quality of simulation depends on the function of simulation models. Therefore, the assessment of quality should be different for each function. The quality of simulation models that are used as software engineering is clearly defined. Unfortunately, the quality of simulation models that are used as process of social change are limited. Further research is necessary in order to provide a quality framework for these types of simulation models. The research paper which is part of this research project elaborates on this topic and proposes further research.

- **Research opportunities for an open source pattern community;** the effectiveness of the proposed support concept for Tebodin is high because of the fact that during the development of the support concept the organisation fit played a key role. Therefore, the proposed support concept can probably not easily achieve the same effectiveness in other organisations. In order make the proposed support concept useful and effective for other organisations it is advised to do research to the opportunities for an open source pattern community on the internet where different organisations can post and find design patterns related to simulation model development. In this way, each organisation can determine for themselves which available patterns can be used in their simulation model development process based on the characteristics of their organisation and problems that are encountered.

- **Design new conceptual modeling technique;** current conceptualisation techniques seem to be suitable only for communication between clients and consultants or for detailed specification of simulation models and not for both functions. IDEFO technique does recognize different levels of detail but is less effective for specifying structure and logic of the actual simulation model. Technique like Activity Cycle Diagrams, Petri Nets or Event graphs are very useful for specifying simulation models in detail. A new conceptual modeling technique should be developed which allow different levels of detail as in IDEFO diagrams as well as effectively specify the structure and logic of simulation models. The result will be a conceptual modeling technique which can successfully be used to specify both a simulation model as well as for communication purposes.

7.3 Personal reflection

This section elaborates on the personal reflection of this research project. After having finished the research project, there are several things I have learned and things that I should attack different when I face a similar project again in the future.

One of the most important things I have learned is that, when facing organisation problems and suggesting changes, one should involve the most important actors (managers and employees) as much as possible. Being involved takes a certain amount of effort. To stimulate people to put in enough effort, the researcher should always be enthusiastic and informative, which is hard when not everybody is willing to provide input or agrees on the importance of the problem. This research project focused on the preferences of the employees and managers but because of factors like the busy schedules, this focus alone was not enough to stimulate all actors. I've learned to persevere and try to be as enthusiastic as possible in order to get people motivated to get involved. Luckily this strategy has worked out well. Furthermore, people do not like to be confronted with things that go wrong in organisations. Trying to analyse what caused these problems was difficult because every consultant had an own opinion about these causes. I've learned to cope with this problem by being as interactive as possible when formulating problems and causes of problems. By continuously confronting and discussing opinions of consultants, in the end everybody was happy with the formulated problems and causes. All consultants felt that their opinions were writen down on paper and taken into account in the research.

Although the research went relatively smooth and fast without major problems, if I faced the challenge to execute a similar research project again I would do certain things differently. The most challenging problem was to comply with the expectations of the faculty of TPM, Tebodin and myself. It is challenging to continuously take this situation into account, especially when working in the Tebodin office all week long. Managing expectations overcomes this challenge, but next time I would try to reduce the time working at a company substantially. It is better to have certain formal moments and limited research periods that makes it input of both the company as well as the faculty more balanced. In the end, the research is part of a master thesis rather than an assignment for a commercial company.

List of References

- Ahmed S., Ashraf G. (2007) *Model-based user interface engineering with design patterns*. The Journal of Systems and Software (Vol. 80, pp. 1408–1422)
- Argyris C., Putnam R., mcLain Smith D. (1982) *Action science – Concepts, methods and skills for research and intervention,* Jossey-Bass, San Francisco
- Barjis J. (2008) *The importance of business process modeling in software systems design,* Science of Computer Programming (Vol. 71, pp. 73-87)
- Briggs R.O., Davis A.J., Murphy J.D., Steinhauser L., Carlisle T.F. (2007) *Transferring a Collaborative Work Practice to Practitioners: A Field Study of the Value Frequency Model for Change-of-Practice,* Springer-Verlag, Berlin Heidelberg.
- Briggs R.O. (2005) *The Value Frequency Model: Towards a Theoretical understanding of Organizational Change.* Journal of management information systems (Vol. 22. No. 6, pp. 124-137)
- Briggs R.O., de Vreede G., Nunamaker jr. J.F. (2003) *Collaboration Engineering with ThinkLets to pursue sustained success with Group Support Systems,* Journal of management information systems (Vol. 19, No. 4, pp. 31-64)
- Burg J.F.M.H. (2001) *Business modeling and requirements engineering,* Ordina
- Ceric V., Paul R.J (1992) *diagrammatic representations of the conceptual simulation model for discrete event systems,* Mathematics and Computers in Simulation (Vol. 34, pp.317-324)
- Cheung S.C. (2005) *Enhancing class commutability in the deployment of design patterns,* Information and Software Technology (Vol. 47, pp. 797–804)
- Chwif L., Paul J.P., Pereira Barretto M.R. (2006) *Discrete event simulation model reduction, A causal approach,* Simulation modelling Practice and Theory (Vol. 14, pp. 930-944)
- Den Hengst. (2003) *Analyse van bedrijfssystemen,* faculteit techniek, bestuur en management, Delft
- Dillenbourg P., Baker M., Blaye A., O'Malley C. (1996) The evolution of research in collaborative learning in E. Spada & P. Reiman *Learning in Humans and Machine: Towards an interdisciplinary learning science*, (pp. 189-211). Oxford: Elsevier
- El Haouzi H., Thomas A., Petin J.F.(2008) *Contribution to reusability and modularity of manufacturing systems simulation models: Application to distributed control simulation within DFT context,* Int. J. Production Economics (Vol. 112, pp. 48–61)
- Gamma E., Helm R., Johnson R., Vlissides J. (1995) *Design Pattern; Elements of reusable Object-oriented Software,* Addison-Wesley
- Global Development Research Center (GDRC) (2008), *Collaborative learning,* http://www.gdrc.or/kmgmt/c-learn/index.html (6-6-2008)
- Godwin A.N., Gleeson J.W., Gwillian D. (1989) *An Assessment of the IDEF Notations as descriptive Tools*, lnformation Systems (Vol. 14. No. I, pp. 13-28)
- Gregor M., Kosturiak J. (1998) *FMS simulation: Some experience and recommendations,* Simulation Practice and Theory (Vol. 6, pp. 423–442)
- Gustavson P., Morse K.L., Lutz R., Reichenthal S.W. (2005) *Applying design patterns for enabling simulation interoperability*.
- Herrmann A., Schoning T. (2000) A*n object oriented approach using Software Design Patterns,* Aerosp. Sci. Technol (Vol. 4, pp. 289–297)
- Hollocks B.W. (2006) *Forty years of discrete-event simulation: a personal reflection,* The journal of the Operational Research Society (Vol. 57, pp. 1383-1399)

- Klofstad C.A. (2005) *Interviews,* encyclopaedia of Social Measurement. (Vol. 2, pp. 359-363)
- Kolfschoten G.L, Valentin E., de Vreede G., Verbraeck A. (2006) *Cognitive load reduction through the use of building blocks in the design of decision support systems,* Proceedings of the twelfth Americas Conference on support systems.
- Kreutzer W., Osterbye K. (1998) *BetaSIM, a framework for discrete event modelling and simulation,* Simulation Practice and theory (Vol. 6, pp.573-599)
- Leitko T.A., Szczerbacki D. (1991) *Why Traditional OD Strategies fail in Professional Bureaucracies.*
- Lever J. (1981) *Multiple methods of data collection: a note on divergence,* Urban life (Vol 10, pp. 199-213)
- Mansar S.L., Reijers H.A. (2005) *Best practices in business process redesign: validation of a redesign framework,* Computers in Industry (Vol. 556, pp. 457-471)
- Mejia R., Lopez A., Molina A. (2006) *Experiences in developing collaborative engineering environments: An action research approach,* Computers in Industry. (Vol. 58, pp.329-346)
- Mintzberg, H. (2004) *Organisatie structuren*, Academic service, Den Haag
- Molina L.M., Montes J.L., Del Mar Fuentes Fuentes M. (2004) *TQM and ISO 9000 Effects on Knowledge Transferability and Knowledge Transfer*, Total quality management (Vol. 15, No.7, pp. 1001-1015)
- Moody L.D., Sindre G., Brasethvik T., Solvberg A. (2002) *Evaluating the quality of Process Models*: Emperical Testing of a Quality Framework, Springer-Verlag, Berlin
- Moore A.D., Holzworth D.P., Herrmann N.I., Huth N.I., Robertson M.J. (2007) *The Common Modeling Protocol: A hierarchical framework for simulation of agricultural and environmental systems,* Agricultural Systems (Vol. 95, pp. 37–48)
- Nance R.E. (1994) *The Conical Methodology and the evolution of simulation model development.* Annals of Operational research (Vol. 53, pp. 1-45)
- Oses N., Pidd M., Brooks R.J. (2004) *Critical issues in the development of component-based discrete simulation*, Simulation Modeling Practice and Theory (Vol.12, pp. 495–514)
- Rensburg A., Zwemstra N. (1995) *Implementing IDEF Techniques as Simulation Modeling Specifications,* Computers ind. Engng (Vol. 29, No. 1--4, pp. 467-471)
- Rincon G.,Alvarez M., Perez M., Hernandez S. (2005) *A discrete-event simulation and continuous software evaluation on a systemic quality model: An oil industry case,* Information & Management (Vol. 42, pp. 1051–1066)
- Robinson S. (2001) *General concepts of quality for discrete-event simulation,* European Journal of Operational Research (Vol. 138, pp. 103-117)
- Robinson S. (2004) *Simulation – The practice of model development and use,* Wiley& Sons.
- Robinson S. (2007) *A statistical process control approach to selecting a warm-up period for a discrete-event simulation,* European Journal of Operational Research (Vol. 176, pp. 332-346)
- Robinson S, Nance R.E, Paul R.J., Pidd P., Taylor S.J.E. (2004) *Simulation model reuse: defenitions, benefits and obstacles,* Simulation Modelling Practice and Theory (Vol. 12, pp. 479–494)
- Son Y. J., Jones A.T., Wysk R.A. (2003) *Component based simulation modeling from neutral component libraries,* Computers & Industrial Engineering (Vol. 45, pp. 141–165)
- Tebodin (2008), *Company information,* http://www.tebodin.nl. (17-03-2008)

- Valentin E.C. (2008) *Draft doctoral dissertation pre-defined building blocks in simulation,* (ch.1, ch.5).
- Valentin E.C., Verbraeck A., Sol H.G. (2003) *Advantages and disadvantages of building blocks in simulation studies: A laboratory experiment with simulation experts,* Proceedings 15th European Simulation Symposium.
- Valentin E.C., Verbraeck A. (2002) *Simulation building blocks for airport terminal modeling,* Proceedings of the 2002 Winter Simulation Conference.
- Verbraeck A., Zhao W. (2005) *A framework for configurable hierarchical simulation in a multiple–user decision support environment,* Proceedings of the 2005 Winter Simulation Conference.
- Vlatko C., Ray J.P. (1992) *Diagrammatic representations of the conceptual simulation model* for *discrete event systems,* Mathematics and Computers in Simulation (Vol. 34 pp. 317-324)
- de Vreede G.J, Verbraeck A.(1996) *Animating organizational processes Insight eases change,* Simulation Practice and Theory (Vol. 4, pp. 245-263)
- de Vreede G.J, Verbraeck A., van Eijk D.T.T. (2003) A *Integrating the Conceptualization and Simulation of Business Processes: A Modeling Method and Arena Template,* Simulation, *(* Vol. 79, Issue 1, pp. 43-55)
- Wieringa, R.J. (1996) *Requirements Engineering: frameworks for understanding*, John Wiley &Sons
- Wikipedia (2008) *Delphi-studie,* http://nl.wikipedia.org/wiki/Delphi-studie (6-7-2008)
- Yin R.K. (1994) *Case study research: design and methods,*Sage publishing, Thousand Oaks

Definitions and acronyms

VIMS	*Visual Interactive Modeling System*
OSTT	*Open Sea Tank Terminal*
ARENA	*Simulation environment for the development of Simulation models*
IDEF0	*Integration DEFinition for Function Modeling. Also known as SADT*
SADT	*Structured Analysis and Design Technique*
ISO	*International Standardization Organisation*
TAM	*Technology Acceptance Model*
TTM	*Technology Transition Model*
VFM	*Value Frequency Model*

Table of Appendixes

Appendix A: Organizational structures Tebodin and Royal BAM Group

Tebodin Consultants & Engineers is an operating company of Royal BAM Group. Royal BAM Group is one of Europe largest construction companies with a worldwide turnover EUR 7.4 billion. BAM employs about 30.000 people and is listed on the Amsterdam Stock Exchange (Tebodin, 2008). Apart from Consultancy and Engineering, there are five other major departments within Royal BAM Group. Figure A.1 provides an overview of the organisation structure of Royal BAM Group.

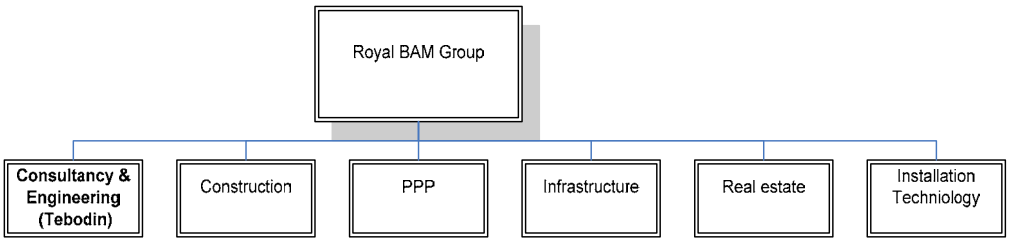


Figure A.1: Organisation structure Royal BAM Group

Tebodin is an independent and international consultancy and Engineering company that is specialized in strategic and technical advice in a wide variety of sectors. On the one hand, Tebodin supports Royal BAM Group with its engineering services and on the other hand Tebodin executes projects for third parties. Consultancy projects are mainly done for third parties. Tebodin has approximately 3,000 employees worldwide in circa 50 offices. Annual turnover is circa 200 million. Figure A.2 provides an overview of the organizational structure of Tebodin.

Tebodin executes all types of multi- and mono-disciplinary projects for clients such as petrol-chemical industries, pharmaceutical industries, food processing industries, car manufacturers and governmental organizations. The majority of the organisation of Tebodin is dedicated to engineering. Consultancy is only a small part of the organisation that employs circa 80 consultants. The consultancy department is spilt up into six sub-departments. Each sub-department has its own specific competences and uses specific tools such as simulation to execute projects. The biggest sub-department of the consultancy branch is logistics. Projects that are executed by the logistics department are related to the following areas;

- Operations Audits
- Capacity Optimization
- Business Layouts
- Investment Planning
- Handling and Packaging
- Lean Manufacturing

Simulation projects are one of the available tools to execute projects. Simulation is mainly used for operation audits, capacity optimalization and investment planning. Typical clients are Port Authorities and Oil related industries.

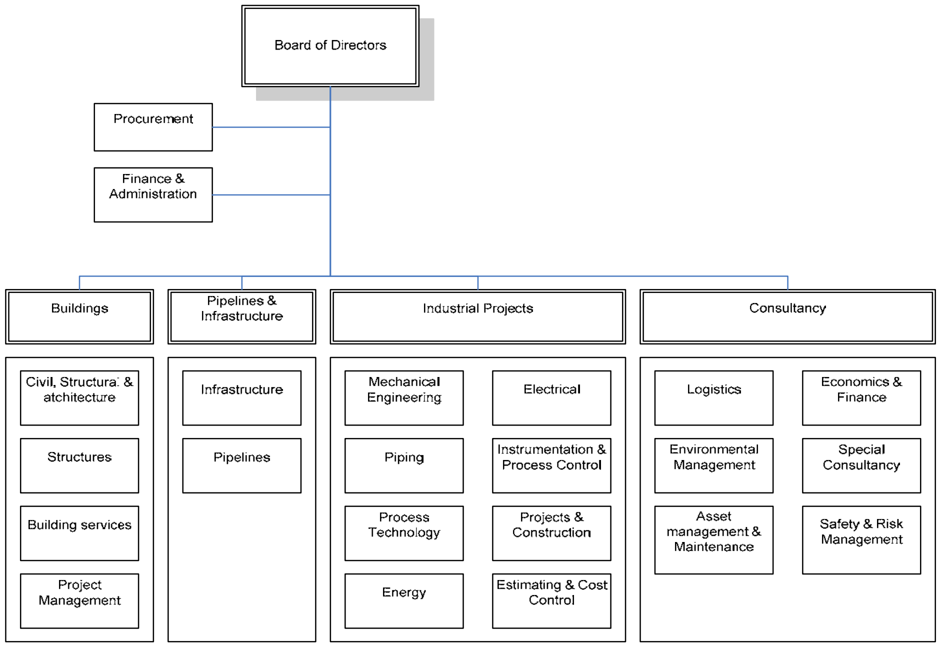


Figure A.2: Organisation structure Tebodin

Appendix B: Interview Questions

This appendix provides an overview of the questions that were used for the interviews with simulation consultants for the analysis of the current situation.

1. Personal experience with simulation and simulation models

- How many simulation projects have you done or worked on (for Tebodin)?
- Did you have experience with discrete simulation before you started simulation projects for Tebodin?
- If yes, what past experience did you have with discrete simulation?
- If no, how long did it take before you could build a useful simulation model yourself while working at Tebodin?
- Did you need help of (more experienced) colleagues to develop a simulation model.
- If yes, were these questions related to working with arena or to other things?

2. General questions about current situation

- Did you encounter problems while building simulation models?
- If yes, which problems did you encounter and how could these problems be avoided or reduced in the future?
- According to your own perception, how important is it to improve the current simulation model development process and why?

3. Communication in the simulation model development process

- Did you build the whole simulation model yourself or did you share the workload with other simulation consultants?
- If you shared the workload, were there communicational problems between you and the simulation consultants?
- If you shared the workload, how many times a week/month was there communication about the simulation model and why in that frequency?
- Was a conceptual model used for communication with clients?
- In the end, did the structure of the conceptual model look like the structure of the simulation model?
- Did the simulation model visualize animations or performance indicators?
- Was a simulation model handed over to customers which could be used for experiments by these customers or was only a report written based on simulation results or both?
- Were clients satisfied with communication during the project and why?
- Were you satisfied with the communication during the project and why?

4. Development time of simulation models

- If you shared the workload, did everybody build a part of the simulation model?
- If yes, did the compilation of the final model based on the sub-models lead to time overruns and why?
- Did you use a conceptual model of the simulation model as a guideline for the development of the actual model?
- Were you involved in the offering/planning phase of the simulation project?
- How was the planning determined/ development time estimated?

- Was the estimated development time of the simulation model similar in comparison to planned development time in the contract?
- If no, in percentages how much time was cut in the final planning/contract?
- Did you use specific tools for developing the simulation model (like templates)?
- Was the use of these tools useful and did it lead to time savings?
- Did you need more time for building the simulation model than planned?
- If yes, in percentages how much more time did you need?
- What was the cause of this time overrun?

5. User friendliness current simulation model development approach

- Is the current way of developing simulation models efficient and why?
- How can the user friendliness of the development process be improved?
- Do you think that additional tools such as templates could increase the user friendliness of the development process and why?

6. Flexibility of simulation models

- In general, which parts of simulation models can be easily reused and which parts can not be easily reused and why?
- Can the developed simulation models be reused in the future without major modifications for new projects that have many similarities and why?
- Can the developed simulation models, in the future, easily be extended without major modifications and why?

7. Transferability of simulation models

- Did you ever used existing models as starting point for new simulation models?
- If yes, was the model structure of the existing model clear and structured?
- How much time did it take to understand and adapt the model in such a way that it could be used for the new situation?
- Was a conceptual model of the existing simulation model available?
- If yes, did you use the conceptual model to clarify the simulation model?
- If yes, did the model structure look like the structure of the conceptual model?
- Did you encounter problems while building the simulation model?
- If yes, which problems did you encounter and why?

8. Quality of simulation models

- Did the simulation model have the appropriate level of detail?
- According to your own perception, was the quality of the simulation model sufficient to provide the right conclusions for the project?
- Were clients satisfied with the model outcomes and complied the simulation model with their expectations?

9. Implementation of new support concept

- Do you think that it is important to implement a support concept ? Why?
- Do you think implementation of a new support concept would be difficult or easy in the section logistics? Why?

Appendix C: Interview Results

This appendix provides an overview of the answers given by simulation consultants.

Experience	Experience with discrete event simulation before starting at Tebodin	√	√	√		√
	Expert simulation consultant (> 3 large projects)	√		√		
Communication in simulation projects	Experienced communication problems between consultants in joint modelling simulation projects	√		√		√
	Experienced communication problems with clients in simulation projects					
	Used a conceptual model for communication with client	√ **1**		√		
	Overall satisfied with communication in projects	√		√	√	**7**
Development time of simulation models	Has experience with time overruns	√				
	Used a conceptual model as a guideline for simulation model development	√				
	Was involved in offering/planning phase of the simulation project	√	√			
	Used additional tools for development such as templates in simulation projects	√				√
	Additional tools are useful and lead to time savings	√				√
User friendliness of current approach	Thinks current simulation model development approach is efficient			√		
	Thinks that new support concept will increase the user friendliness	√ **2**		√	√	√
Flexibility of simulation models	Thinks that parts of simulation models can be easily reused in different simulation projects	√		√	√	√
	Thinks that the simulation models they developed can be reused for similar projects in the future without major modifications	√ **3**		√	√ **6**	
	Thinks that the simulation models they developed can be easily be extended in the future without major modifications	√ **3**			√ **3**	
Transferability of simulation models	Has used existing models as a starting point for new simulation models	√ **4**		√		√
	Thinks that model structures of existing simulation models are clear and structured	√				
	Thinks that the conceptual model did help to clarify the existing model and structure					√
	Encountered problems with converting the existing model structure to a new simulation model structure			√		√
Quality of simulation models	Thinks that simulation models did have the appropriate level of detail, considering the problem description	√		√	√	
	Thinks that simulation models did provide the right conclusions, considering the problem description	√		√		√ **8**
Implementation of a new support concept	Thinks that it is important to implement a support concept to resolve current problems	√	√	√	√	√
	Thinks that implementation of the new support concept would be difficult	√ **5**	√ **5**		**9**	

Table C.1: Answer matrix of interviews

1 Only once used for communication
2 Only for "standard", non-complex models
3 If properly programmed
4 Only models programmed by myself
5 Templates and such, no time available next to consultancy work
6 All port show similarities
7 Project not yet finished
8 Sufficient, but could better
9 If it is proven to be working, it should be no problem

Appendix D: Case Descriptions

This appendix provides a description of problems and bottlenecks that were encountered during simulation projects. The projects were selected based on a set of predefined criteria. The following simulation projects were analyzed;

- Project A
- Project B
- Project C
- Project D
- Project E
- Project F
- Project G

A general introduction of the main assignment of each project is given as well as a description of encountered problems and bottlenecks and possible causes of these problems.

Project A

Project A is one of the largest oil terminals in the world that is located on the Maasvlakte in the port of Rotterdam. Client A is a joint venture of all the major oil companies. CLient A has had a request from Client X for the expansion of three 120.000 m3 tanks. Client A appointed Tebodin to investigate the effects on port operations of the increased volumes that has to be handled. Tebodin has built a simulation model in which future operations can be simulated. The key performance indicators that were important are berth occupancies and ship waiting and turnaround times. This assignment followed from a simulation assignment that Tebodin executed for client A in the past.

The assignment had clear boundaries from the beginning. These boundaries were provided by Client A. This resulted in a clear scope and a number of fixed answers. Because of these clear boundaries, new insights that were gained by client A during the project resulted in three extensions on the initial assignment. This was only possible because the first model was build flexible by the simulation consultant, who had already in mind that other extensions were necessary and would follow. For this assignment the Client D model was used as a starting point. This was done because of the fact that the assignments of Client D and Client A had major similarities.

Because of the proven success of the Client D model, no major problems during the building of the simulation model did occur. The only problems there were had to do with the interpretation of the results. As an objective consultancy firm, Tebodin has to stay unbiased. The responsible manager of Client X wanted to use different interpretation of the result because of strategic reasons. This gave some discussions but the objectivity prevailed. Overall, because of the clear scope and absence of problems during the project, Client A and Tebodin were pleased with the results and process of the simulation project.

Project B

This Simulation project was executed for the Client B in the United Arab Emirates in corporation with Tebodin Middle East. The reason for the simulation study was the limited capacity of the Oil terminal Berth (OTB). This OTB is used by many actors who indicated to want to expand storage capacity of liquid products. The Client B was therefore planning an expansion of the port with an open sea tanker terminal (OSTT) which leads to 17 berthing places on a deep water jetty. The objective of the simulation study was to investigate the optimum throughput capacity of OTB as well as OSTT in order to determine the ability to expand by other actors in Port X. The simulation model had given insights in required capacity and throughput and identifies bottlenecks in current infrastructure. Important performance indicators were berth occupancies, optimum number of berths and optimum product allocation on berths.

Data gathering and communication were not a problem because of the corporation with Tebodin Middle East who was responsible for delivering all necessary data and direct communication with the client. The flow process template was introduced in this project to be used for the first time. This flow process template was introduced to decrease programming time and to make simulation of tank farms easier. Simulation consultants had no experience with the use of templates till that moment. Due to problems in the actual template, the building process of the simulation model was delayed. After the template related issues were solved, model development could continue.

The phenomenon, that occurs in many projects, that because of “progressive insights”, clients change there priorities and want to change issues or add scenarios during the simulation project occurred in this project. The changing scopes lead in this case to time delays. The final result included an operational simulation model which was handed over. Validation was actually not possible, because of the fact that historic data was not available. Based on benchmark figures of harbour throughput, total turnaround times and berth occupancies validation of the simulation model was executed. In the end, clients were satisfied with the overall result.

Project C

This simulation project was executed in cooperation with Client C. Client C is a large international consultancy and engineering firm that operates in the gas and oil industry. There were plans for the building of a new refinery complex in Al Jubail, Saudi Arabia. The simulation model was build to perform a logistic optimalization study for the planned Refinery X. The objectives of the simulation study was to asses and verify the design of the overall refinery. Important performance indicators of the simulation model were Tank sizes of the raw, intermediate and final products including blending operations.

Because of the size of this simulation project, the planned development time was relatively long. The proposed planning was rejected by the client, which resulted in a fast track planning. By assigning multiple consultants to work on this project it was possible to work according to this changed planning. The complexity of the simulation project was comprehended and therefore the decision was made to use conceptual models (SADT) for communication between consultants and client. Because of use of these conceptual models, there were no scope changes during execution of the project. There were some problems which were solved by management of expectations. Client could not understand why certain concepts could not be modelled a particular way. During interim discussions, this lack of understanding disappeared. The communication between consultants was fine and there was agreed upon naming standards in Arena and the sub-model structure of the simulation model.

Because of intense contact between consultants during the model building process, a lot of problems were avoided. Unfortunately, all people do make mistakes. In this case, small mistakes like typing errors occurred because many sub-models were copied and renamed. These small errors stayed unnoticed till late in the development process. Especially with older versions of Arena, these types of errors are hard to trace. The reason for this is the limited search function of all Arena versions, except for the latest version 12. To reduce typing errors and such, a template was build and used for standardizing the pumping functionality of berths. The use of this template has saved quite some time but in the end, not surprisingly, the project did have time overruns due to the shaved-off planning and unforeseen problems late in the development process.

Project D

Client D had plans to expand there site with a finger pier with four extra berths. Objective of the model is to provide a tool that will help in determining the optimum for berth occupancy, the used capacity of discharge/loading facilities and the effects on port operation. First, the maximum capacity of the current port situation had to be determined. Secondly, the maximum capacity of the future situation with the new finger pier had to be determined.

As one of the only simulation projects, there was chosen not to reuse an old simulation model. Instead the decision was made to start from scratch, because the potential simulation model for reuse was unstructured and not understandable because of the absence of documentation. There must be noticed that there was no clue if the time available was enough to build the simulation model, which made the decision probably easier. In the start-point document, the scope was clearly determined which lead to no problems during the building phase. This clear scope was the result of management of expectations. With the use of many interim reports and discussions it was possible to determine what was actually possible with the simulation model (assumptions) and what not. In this project templates were used in the end of the development process. The primary reason to make use of templates was because of strategic reasons. If simulation models are translated to templates, the model does not unveil the model logic and structure (the model was handed over) to clients.

The limited experience with Arena of assigned simulation consultant resulted in some delays. During the project 3 extension were made (Scope changes) that resulted in a situation in which the planning was adjusted, which on its turn resulted in a situation in which the delays that originated in the simulation model development were captured. These extensions lead to almost twice as much work as initially planned. Without these extensions, the project should have had time delays. In the end, client was very satisfied with the quality and outcomes of the simulation model and provided a letter of recommendation. This client satisfaction can possibly be explained because the simulation model included limited reductions in comparison to reality due to the fact that the model was build from scratch. Unwanted limitation in a simulation model can influence client satisfaction in a negative way. Because of the success of this model, it is currently often used as starting point for new simulation models.

Project E

The project was executed together with Client Z and had the goal to analyze the existing Client E operations and facilities at Port X in Saudi Arabia. Based on scenarios for imported quantities of Iron Ore and for the vessels used, a selection of five expansion alternatives have been identified. The simulation model had the goal to gain insight in the bottlenecks that influence the future port performance. As a result, the simulation model will determine if the future growth can be handled by its present operations based on maximum waiting/turnaround times and berth occupancies.

The main problem during this project was that not all important and related operational decisions were made by the client yet and therefore this process ran parallel to the simulation model development process. New insights or decisions lead to a situation in which the model had to be adjusted. For example, the initial number of products that had to be simulated in the simulation study increased from two till ten. To people who are not familiar with simulation, this might seems as a minor change. In practice, the complexity of the simulation model can dramatically, increase by these changes. Validation was difficult due to lack of initial data. Validation was done with general key performance indicators such as total throughput. Due to the changing scope, the development process had time delays which eventually lead to an extra assignment for necessary extension of the model. The client was satisfied with outcomes of the simulation model.

Project F

This simulation project was executed for an assignment for Client F, which is a joint venture of S (international petrochemical company) and P (petrochemical storage company) which are located in location Q in Saudi Arabia. The port authorities of location Q had already reclaimed new land for future port expansion purposes. The port authorities wanted to know how to make use of the new reclaimed land in the most efficient and effective way based on future supply forecasts. Subjects of the study were berth occupancy, berth product allocation, tank capacity and ship waiting times.

Without proper consideration, an existing simulation model was chosen as a starting point for the new simulation model. Valuable time was lost, because later in the process it became clear that the simulation model was not suitable for the assignment. Another simulation model was selected as starting point that was more suitable. Due to the tight planning and the lost time, starting from scratch was not an issue in this project. As a result, the simulation model that was used had some limitations. Creative and smart thinking lead to data transformation concepts that resolved most of the limitations of the new simulation model. Given the function of the simulation model, the remaining limitations did not lead to much discussion and explanation towards the main client. In the building process some problems occurred, but that had more to do with the limited experienced of one of the simulation consultants than with actual development problems. This could be expected because the new simulation model was almost an exact copy of the old model. Most problems occurred during the validation of the simulation model. Most of the development time was used for changing the model in such a way that expected outcomes were actually generated by the simulation model.

Project G

Client G in Qatar has made an expansion plan to increase the port capacity on available berths, storage capacity and pipeline infrastructure. As a result, the vessel activity in the port will increase as well. The goal of this simulation project was to obtain more information about the performance of the proposed expansion plan. A simulation model was used to analyze tank capacities, berth occupancies, ship waiting times, pipeline capacity, spiking of products and availability of sailing routes.
The simulation consultant appointed to the project had no experience with simulation what so ever. An existing simulation model, used for a previous assignment for client G, was used and extended to make it suitable for this project. One of the strange situations that occurred during the project was that the scope of the project was not agreed on until late in the process. Luckily for Tebodin, no major scope changes did occur during the project. Not having an approved start-point document (which includes the scope) before start developing a simulation models is not advisable and can cause serious problems. As a result, parallel to the formulation of the start-point document the actual simulation model was developed.

Because of unstructured simulation model and lack of proper documentation, extensions were made on a kind of trial-and error basis. The model was adjusted over and over again. This resulted in an even more chaotic model structure which could be described as spaghetti (which is a well known phenomenon under simulation model developers). Validation and running experiment was therefore problematic because of this chaotic model structure and was done by trial-and-error as well. This approach is time consuming in comparison to a predefined development approach. Outside the power of Tebodin, software related issues did also cause problems which has lead to tremendous delays. Overall, the simulation project was not a very successful project for Tebodin.

Appendix E: Assessment form for support concepts

This appendix provides the assessment form that was used for the assessment of the individual support concepts during the workshop.

TEBODIN
Consultants & Engineers

Please rate the following statements on a scale from 1 till 7 that corresponds with 1 is I do not agree at all…………..… and 7 is I do fully agree. There are also a few open questions on the next page.

After implementation of this support concept, it will become easier (reduced cognitive effort) for simulation consultants to develop simulation models	1 2 3 4 5 6 7
This support concept will decrease the dependency on individuals and risk of losing important knowledge that is essential for the development of simulation models	1 2 3 4 5 6 7
This support concept will improve the communication between consultants during the entire development process	1 2 3 4 5 6 7
This support concept will decrease the total execution time of an entire simulation project	1 2 3 4 5 6 7
This support concept will decrease the number of delays during the entire simulation project	1 2 3 4 5 6 7
This support concept will improve the amount of trust I have in developed (sub) models and templates build by others	1 2 3 4 5 6 7
This support concept will improve the attractiveness of simulation projects for simulation consultants	1 2 3 4 5 6 7
This support concept will improve the quality of conclusions and level of detail that are the result of the simulation project	1 2 3 4 5 6 7
In the future, the reusability and extendibility of existing simulation models that are build by using this support concept will improve	1 2 3 4 5 6 7
This support concept will improve the insights needed to develop a realistic planning	1 2 3 4 5 6 7
This support concept will decrease the number of scope changes during the entire simulation project	1 2 3 4 5 6 7
This support concept will decrease the amount of skills and experience needed to build simulation models	1 2 3 4 5 6 7
This support concept will improve the reliability of Tebodin towards clients	1 2 3 4 5 6 7

What is your first impression of the effectiveness/suitableness of this support concept?

Do you think that it becomes easier (mental effort) to complete a simulation project after implementation of this support concept and why?

Do you think that your power/influence within Tebodin will change because of the implementation of this support concept and why?

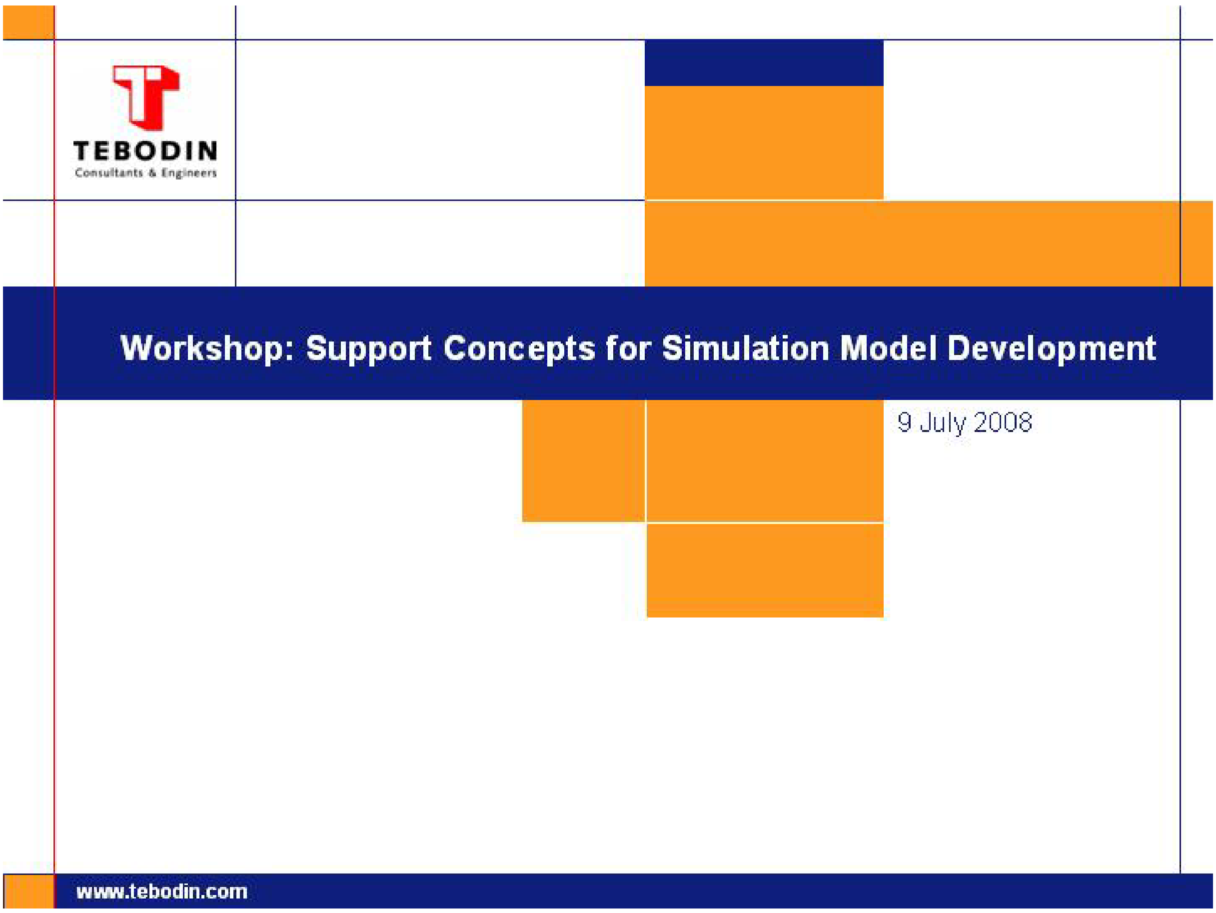
Do you think relations between colleagues or between you and colleagues will change because of the implementation of this support concept and why?

Do you think this support concept has negative aspects/side effects as well and why?

Do you think the implementation of this support concept will difficult and why? And what about implementation costs?

Appendix F: Workshop content

This appendix provides the hand-outs of the presentation that was used for the workshop that was held on July 9th, 2008. Unfortunately, these hand-outs are static which makes it impossible to represent the dynamic character of the presentation and workshop because aspects such as animations and side discussions. But in general, these hand-out provide an initial overview about the set up of the workshop and the issues that were addressed. The workshop had duration of four hours and was attended by Consultant A, Consultant b and Consultant C. These three simulation consultants together have by far the most experience with developing simulation models.



TEBODIN
Consultants & Engineers

Today's Planning

- 13:00 – 13:30 **Workshop introduction**
- 13:30 – 14:15 **Conceptualization Techniques**
- 14:15 – 14:30 **Break**
- 14:30 – 15:00 **Component Based Development**
- 15:00 – 15:30 **Design Patterns**
- 15:30 – 15:45 **Break**
- 15:45 – 16:15 **Collaborative learning**
- 16:15 – 17:00 **Discussion**

www.tebodin.com

TEBODIN
Consultants & Engineers

Workshop Introduction (1)

- The goal of the workshop is:

- To generate shared understanding about the effectiveness of potential solutions.
- To create consensus about the most suitable support concept that should be implemented.
- To eveluate the effort needed for implementation

www.tebodin.com

Workshop Introduction (2)

Efficiency of the development process

- Development time
- Ease of development
- Communication

Effectiveness of simulation models

- Transferability
- Quality
- Flexibility (Reusability)

www.tebodin.com

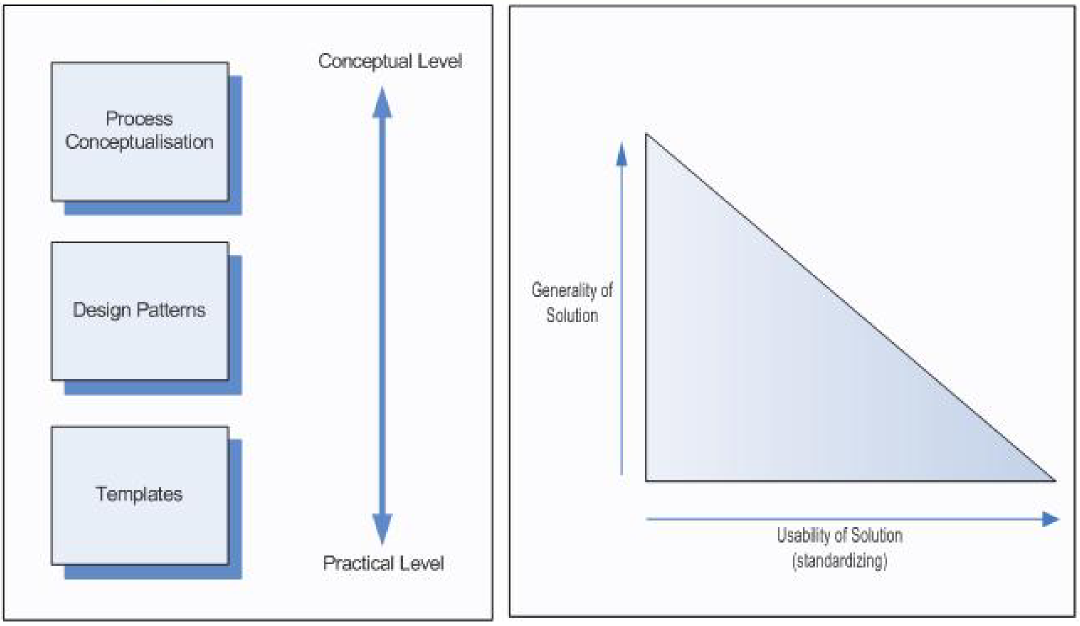
Workshop Introduction (3)

- Support Concepts that we will evaluate today are:
  - Conceptualization Techniques
  - Design Patterns
  - Component Based Development
  - Collaborative Learning

- Which concept is most suitable depends on many things…………

www.tebodin.com

Pratical vs. Conceptual Approach



www.tebodin.com

Workshop Introduction (4)

Assessment Criteria:

- Speed of development
- Number of delays
- Process quality
- Credibility of simulation models
- Content quality
- Pragmatic quality (understandibility for all stakeholders)
- Risk of lost knowledge
- Attractiveness of simulation projects
- Required competence of modellers
- Perceptual load reduction (user friendliness of development method)
- Cognitive load reduction (effort to understand how perform tasks
- Implementation costs
- Affective magnitude (emotional feeling with concepts)
- Political magnitude (personals gains because of concepts)
- Social magnitude (internal relationship changes because of concepts)

www.tebodin.com

TEBODIN
Consultants & Engineers

Conceptualization Techniques

- **Simplification is the essence of simulation**. The goal of model reduction is to find a simpler conceptual model that is still valid, with respect to the initial requirements and objectives.
- In the building phase, the instantiation of the simulation model should be a straight forward process, because all the thinking and defining activities have been performed for the development of the conceptual models.
- Conceptual models are needed for the following purposes;

-To save knowledge of a problem situation for later use.

-To record knowledge because the problem situation is too complex to consider as a whole.

-To get a better understanding of the problem situation by studying it from different perspectives.

-To define systems boundaries to limit the simulation study

www.tebodin.com

TEBODIN
Consultants & Engineers

Conceptualization: Advantages and Disadvantages

- Advantages, what do you think?

- By specifying interactive systems at a semantic, conceptual and abstract level, there is dealt with low-level implementation issues in an earlier phase in the simulation project.
- By using conceptual models, designers can concentrate on important conceptual properties instead of being distracted by the technical and implementation details.
- Conceptualization techniques enhance human-to-human communication in drawing up conceptual models, the use of these techniques in simulation modelling enhanced the quality of simulation models and reduced the time needed to build them.

www.tebodin.com

Conceptualization: Advantages and Disadvantages

- Disadvantages, what do you think?

- Conceptual modelling techniques focus on knowledge formalisation and they enable the modelling with a point of view that is not easily translatable to simulation models.
- The skills commonly found to be lacking in model developers is dealing with conceptual modelling.
- Conceptual modelling is difficult for model developers who are not an expert in the problem system. Setting boundaries to the systems requires insight and experience in the problem system.
- Diagramming techniques to model the problem situation are unfit to model the dynamics of the problem situation. The resulting diagrams are static in itself, therefore making it hard to thoroughly understand and analyze the dynamical characteristics of the modelled system.
- Diagrams are often poorly communicable to problem owners. Problem owners usually lack experience in reading and understanding diagrams. In addition, diagrams seldom resemble the problem situation visually.

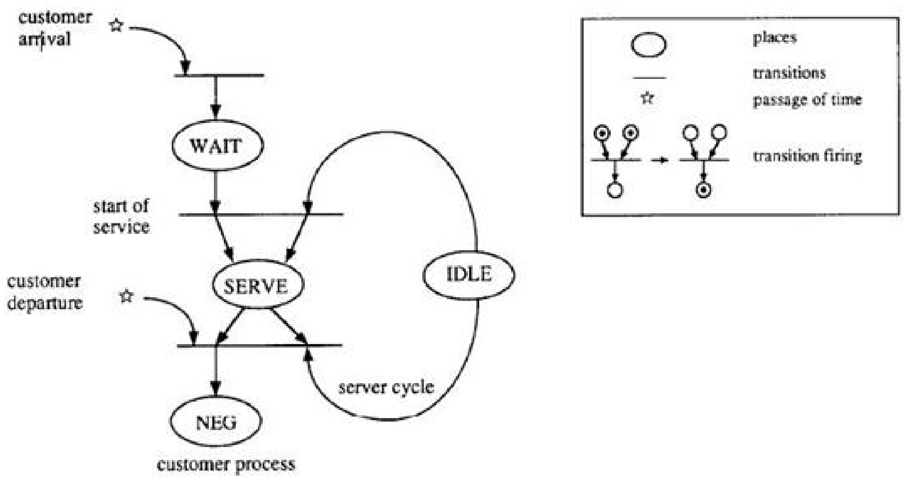
www.tebodin.com

Conceptualization Techniques

- Petri Nets
- Activity Cycle Diagrams
- Event Graphs
- IDEF (SADT)
- Example:A printshop with continuos arrival of customers. Customers wait to be served by a server or machine when its free.

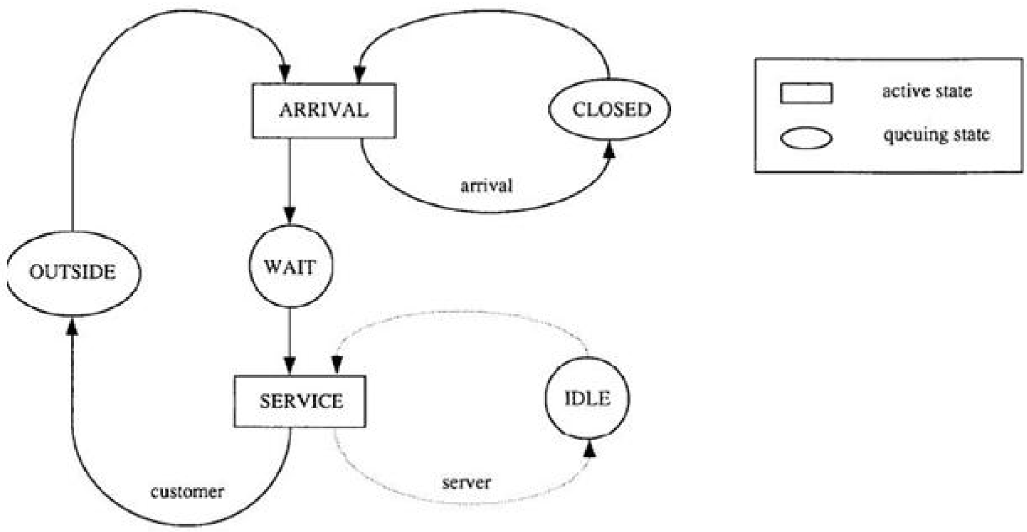
www.tebodin.com

Petri Nets



www.tebodin.com

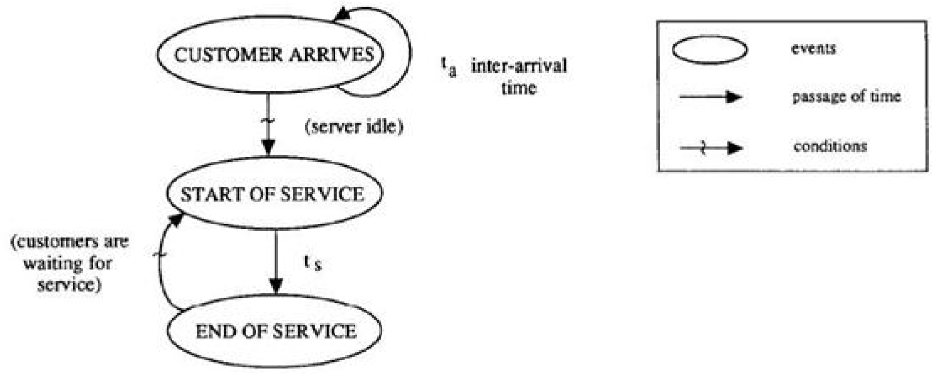
Activity Cycle Diagrams



www.tebodin.com

TEBODIN
Consultants & Engineers

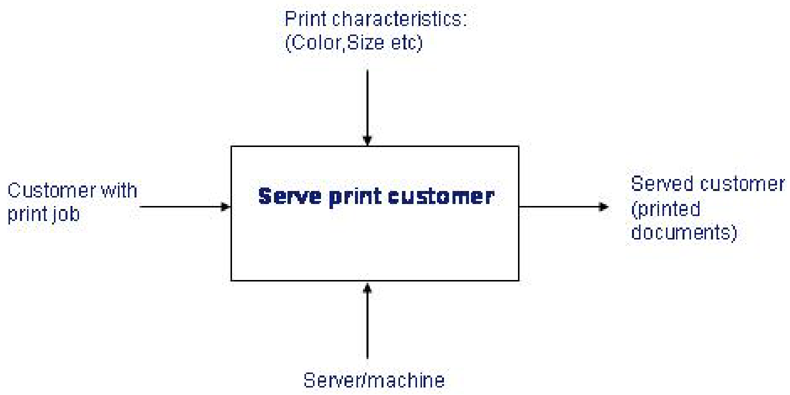
Event Graphs



www.tebodin.com

TEBODIN
Consultants & Engineers

IDEF Diagrams



www.tebodin.com

TU Delft

TEBODIN
Consultants & Engineers

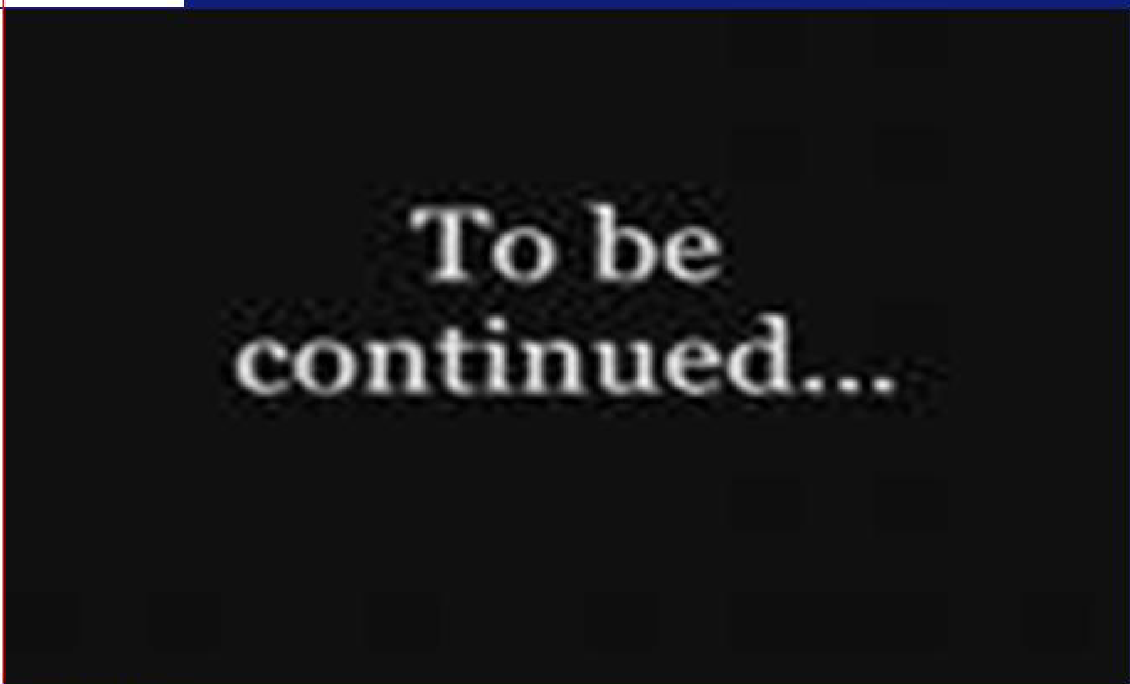
Comparison of Techniques

- Which one do you favour?
- Together we shall now try it out… … … … … … … … …
- Vessels with containers arrive continuos and wait till a Pilot is free and then continue to be unload by a Quay Crane.

www.tebodin.com

TEBODIN
Consultants & Engineers

Break

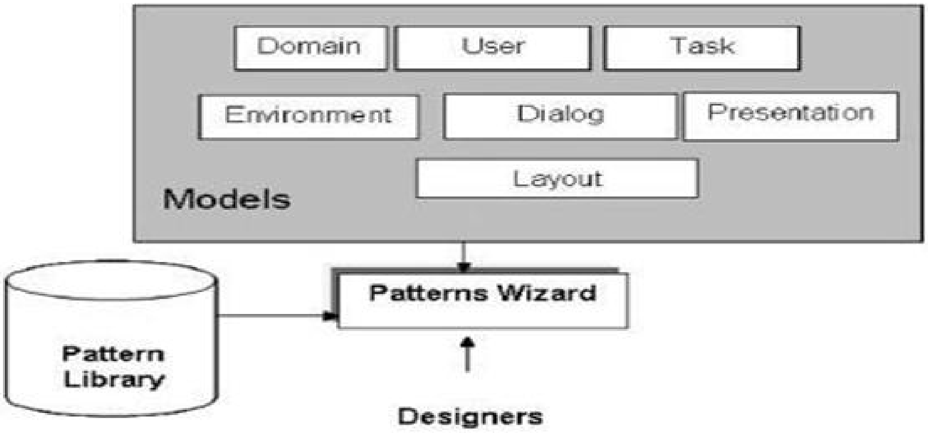


www.tebodin.com

TU Delft

Design Patterns

- The objective of a design pattern is to identify parts that are repeated in several instances of similar projects and to classify them in a systematic way. When faced with solving a new problem, the designer can use a design pattern as a solution without having to rediscover it. Design patterns are flexible because it uncouples its participants in such a way that each can easily be understood, reused and personalized.



Design Patterns

- Design patterns can have different levels of abstraction: High abstraction level targeting end users (how/ when to use simulation)………. Low abstraction level targeting human computer interaction (how to build a model)
- Design patterns contain a number of sections such as name, intent, context, problem ,constrains in use etc.
- An example will make things more clear……………

TEBODIN
Consultants & Engineers

Design Patterns : Advantages and Disadvantages

- **Advantages, what do you think?**
  - Use of design patterns in the analysis and design phase result in considerable gains in time and cost can be acquired
  - Self explaining/easy to use
  - Knowledge becomes independent of individuals
  - Agreement about all aspect of the development process

www.tebodin.com

TEBODIN
Consultants & Engineers

Design Patterns : Advantages and Disadvantages

- **Disadvantages, what do you think?**
  - It can be difficult to define patterns. Patterns are discovered rather than invented.
  - In order to be an effective knowledge-capturing tool in model-based approaches, developers have to find and select the most suitable patterns (possible "don't see forest though the trees anymore" syndrome and time consuming)
  - After finding a pattern, it is still necessary to make its adaptation to the needs of the problem that it is being solved, because a pattern represents a generic solution to the problem."

www.tebodin.com

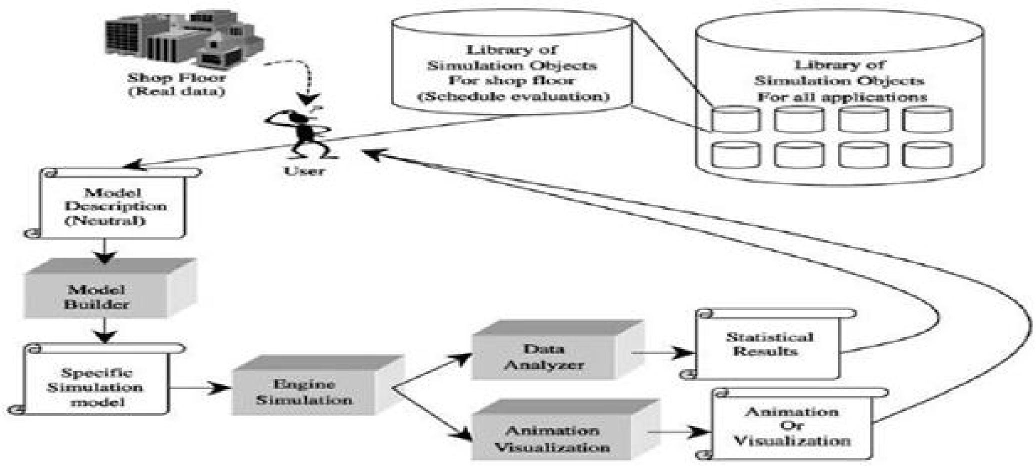
Design Patterns

- Which aspects of the development of simulation models should be defined as Design Patterns?
- Lay-out, Naming, Berth planning logic, Push vs Pull arrival schedules?

www.tebodin.com

Component Based Development

- Using reusable blocks to form a simulation model – when designed well –can represent an element of the system in the way the problem owner expects, both in structure and in behaviour. The concept of building blocks encompasses the idea of decomposing a prototypical system within a domain and implementing the observed domain elements in a standard simulation environment.



www.tebodin.com

TEBODIN Consultants & Engineers

Component Based Development : Advantages and Disadvantages

- Advantages, what do you think?

- Reduced cost and development time arising from reuse of components
- Easier model adaptation due to the features of extensibility and evolvability.
- The ability to transfer a simulation model to an environment where there is less experience in simulation and experimentation. (So client can do simulation themselves?)

www.tebodin.com

TEBODIN Consultants & Engineers

Component Based Development : Advantages and Disadvantages

- Disadvantages, what do you think?

- Components provide for rapid development this does not imply that any software developer will, by using components, find that the development process is a lot easier and faster, for the system developer needs expertise in component based software development.
- The use of component based development does not mean that first-time simulation users will be able to build extremely complicated models. This implies mastery of the architecture being used and significant knowledge of the components in the available libraries. If these requirements are not met the promise of faster development will not be fulfilled through component reuse.
- If components are to be reused in-house, then the budget that bears the cost of initial development may not receive the benefits of later, lower costs. Since projects often have tight budgets and time schedules this means that without a properly managed reuse program, it may not be worthwhile to build components.
- Component based development can only be effective under specific assumptions. Because of these assumptions the effectiveness of this type of modeling is limited. (example: push vs. pull)
- Expert and novice software developers use software components in a different way. The experts are more hesitant to use components and prefer to construct models or components themselves, because they are not sure whether they can trust a component made by others. Novices are glad the components are available and see them as their best option.
- The expertise reversal effect; methods to reduce cognitive load for novices can increase cognitive load for experts and thus design support and modelling support should be different for experts and novices.

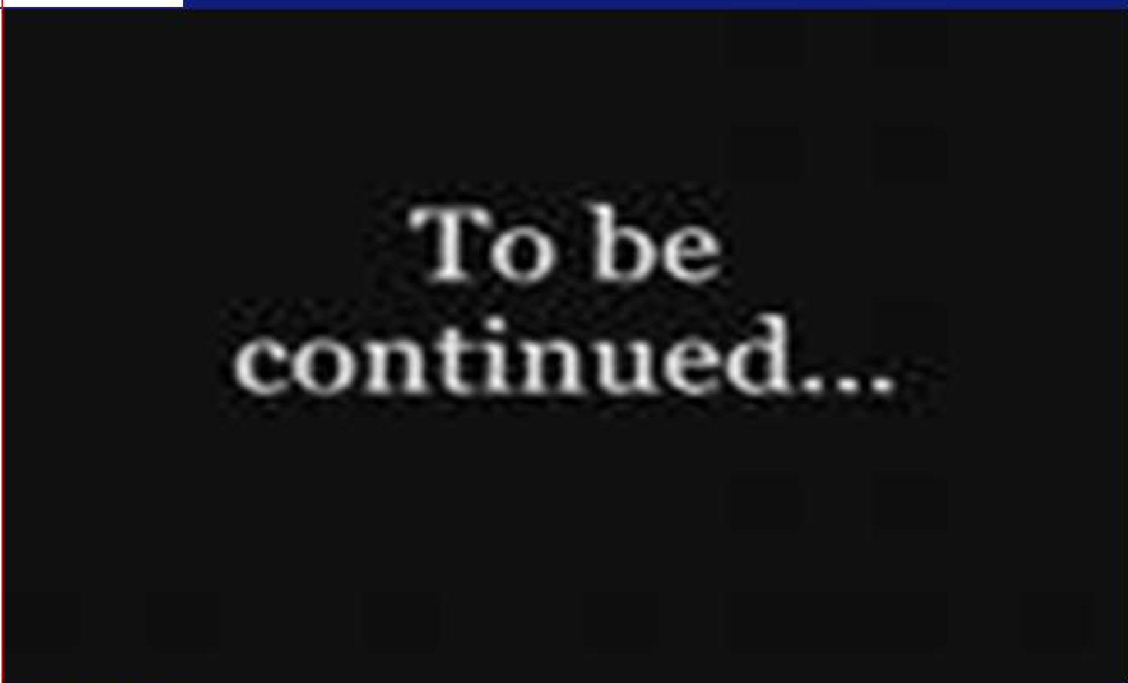
www.tebodin.com

Component Based Development

- Which parts of simulation models are suitable to convert into a generic library that can always be used………
- Weather generator?, Berth planning? Pilots?

www.tebodin.com

Break



www.tebodin.com

TEBODIN
Consultants & Engineers

Collaborative Learning

- Collaborative learning is an approach that involves groups of learners working together to solve a problem, complete a task, or create a product.
- In a collaborative learning setting, learners have the opportunity to present and defend ideas, exchange diverse beliefs, question other conceptual frameworks, and be actively engaged.
- Different techniques to enhance collaborative learning which depends on its particular function

www.tebodin.com

TEBODIN
Consultants & Engineers

Collaborative learning : Advantages and Disadvantages

- Advantages, what do you think?
  - Reduce design rework later in the process
  - Reduction in development time
  - Improvement of quality because of knowledge input by others
  - Reduction of knowledge centralization
  - Easy/inexpensive implementation

www.tebodin.com

TEBODIN
Consultants & Engineers

Collaborative Learning : Advantages and Disadvantages

- Disadvantages, what do you think?
  - Applicable and effective in conceptual phases (for single modeller projects)
  - Time investment for individuals with busy schedules
  - Less effective for specific issues like errors

www.tebodin.com

TEBODIN
Consultants & Engineers

Collaborative Learning

- Which parts of the development phase are suitable for collaborative learning?
- Define conceptual models, define model structure, discuss old models and concepts?

www.tebodin.com

TU Delft

TEBODIN
Consultants & Engineers

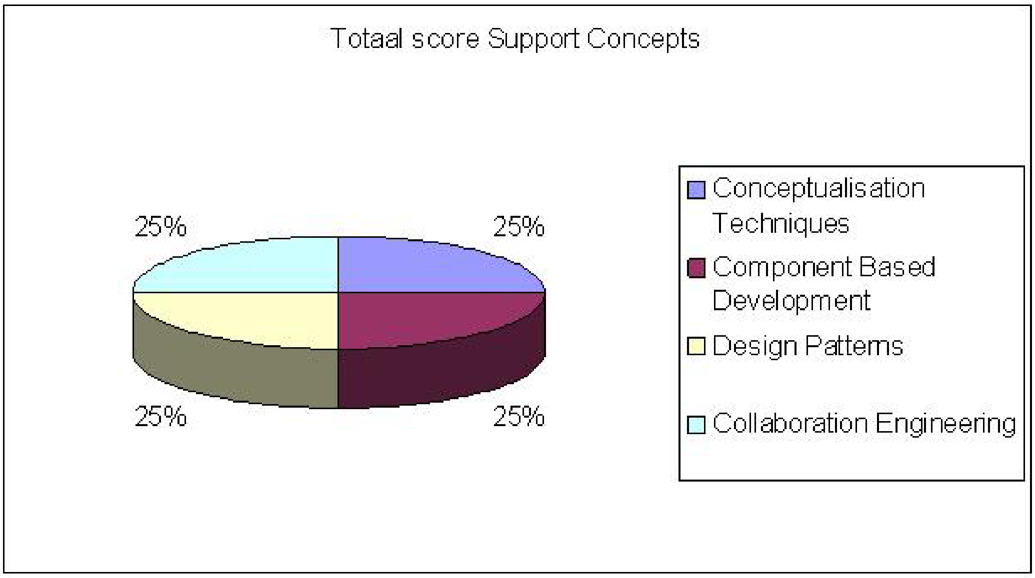
Assesment Results

Is there a "best" solution……………….

www.tebodin.com

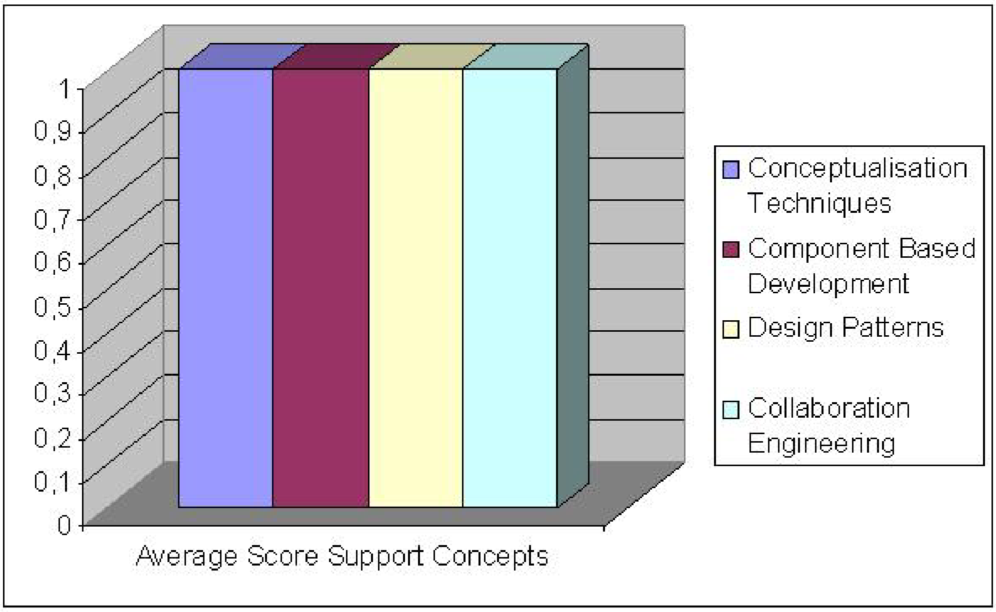
TEBODIN
Consultants & Engineers

Assesment Results



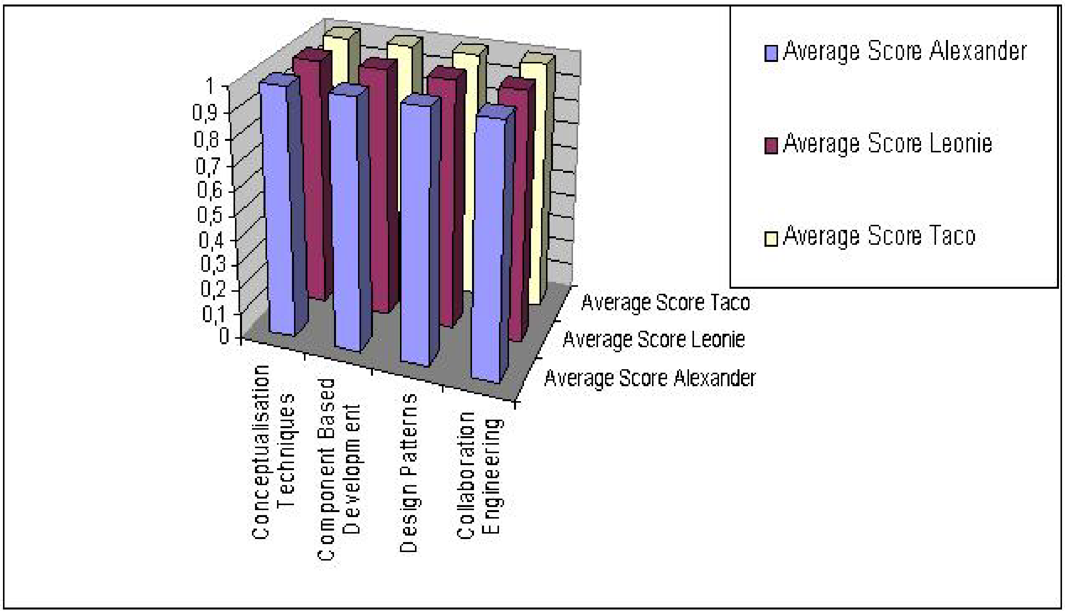
www.tebodin.com

Assesment Results



www.tebodin.com

Assesment Results



www.tebodin.com

TEBODIN
Consultants & Engineers

Discussion

- Do you all think this is the best concept? Hybrids?
- How should you implement this concept? Are there pitfalls?

www.tebodin.com

Appendix G: Scores support concepts

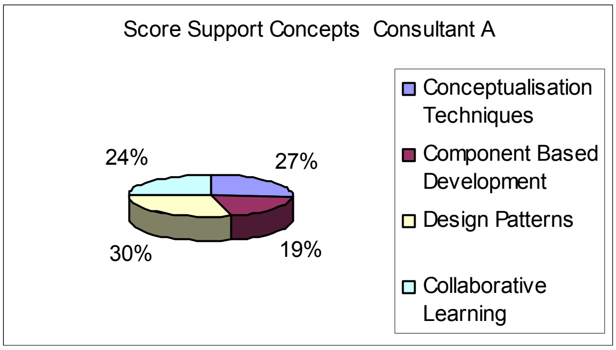
This appendix provides the outcomes of rating support concepts by simulation consultants on predefined performance indicators. Table G.1 provides an overview of the individual scores given to support concepts during the workshops. Graph G.1 provides the graphical representation of the individual scores of support concepts for each consultant. The following consultants have provided responses during the workshop:

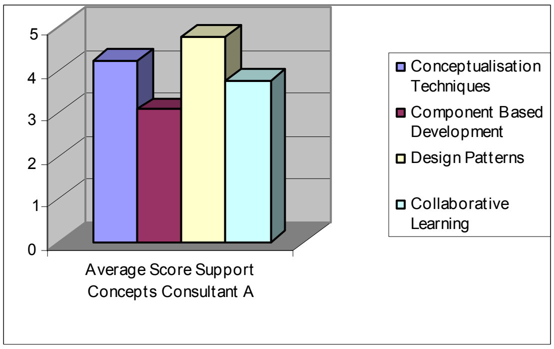
- Consultant A
- Consultant B
- Consultant C

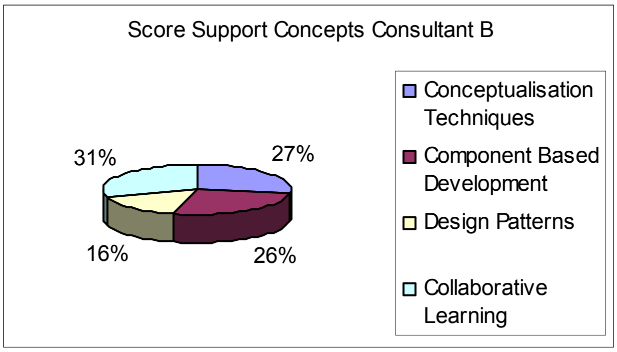
	Consultant A				Consultant B				Consultant C			
Performance indicator:	CM	CBM	DP	CL	CM	CBM	DP	CL	CM	CBM	DP	CL
Cognitive Load Reduction	6	3	5	6	3	7	3	5	5	5	2	4
Risk of lost knowledge	5	2	5	1	5	5	2	3	5	5	5	5
Quality of Process	5	3	3	6	5	3	4	6	6	1	4	5
Execution time simulation projects	3	2	4	4	2	5	4	4	3	6	2	5
Number of delays during sim. Project	4	2	5	5	4	4	3	5	5	1	1	2
Credibility of simulation models	4	5	6	6	5	4	5	4	3	4	2	4
Perceptual Load Reduction	5	5	6	4	3	5	2	4	5	5	3	5
Quality of Content	4	2	4	2	3	3	3	4	5	3	1	3
Pragmatic Quality	5	5	6	2	6	5	5	5	1	5	2	5
Quality of Process	5	2	6	2	5	5	5	5	3	2	1	3
Quality of Process	3	1	1	2	5	3	2	6	3	1	1	2
Required competence of developers	2	3	6	4	4	5	2	2	1	3	3	3
Quality of Process	4	3	5	5	2	4	4	4	2	4	1	5
	55	40	62	49	52	56	44	57	47	45	28	51

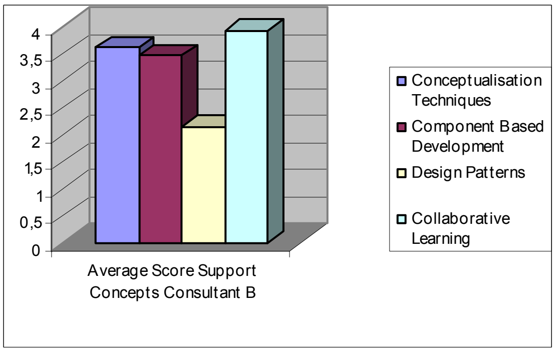
	tot.	avr.	stdv.
Conceptualisation Techniques	154	3,949	1,4
Component Based Development	141	3,615	1,5
Design Patterns	134	3,436	1,7
Collaborative Learning	157	4,026	1,4

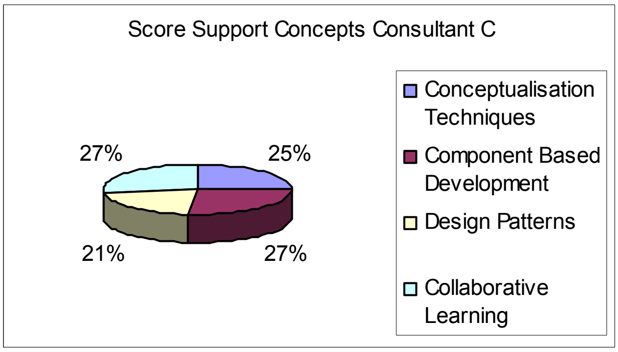
Table G.1: Individual scores of Support Concepts


Score Support Concepts Consultant A
24%
27%
30%
19%
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning


5
4
3
2
1
0
Average Score Support Concepts Consultant A
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning


Score Support Concepts Consultant B
31%
27%
16%
26%
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning


4
3,5
3
2,5
2
1,5
1
0,5
0
Average Score Support Concepts Consultant B
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning


Score Support Concepts Consultant C
27%
25%
21%
27%
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning

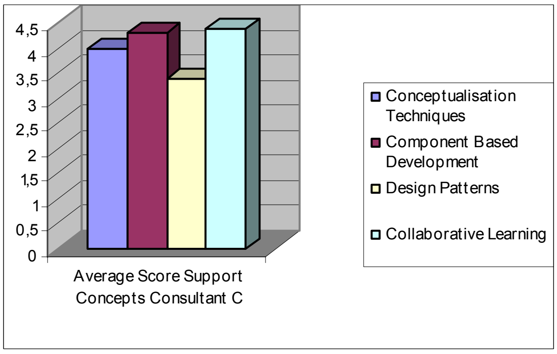
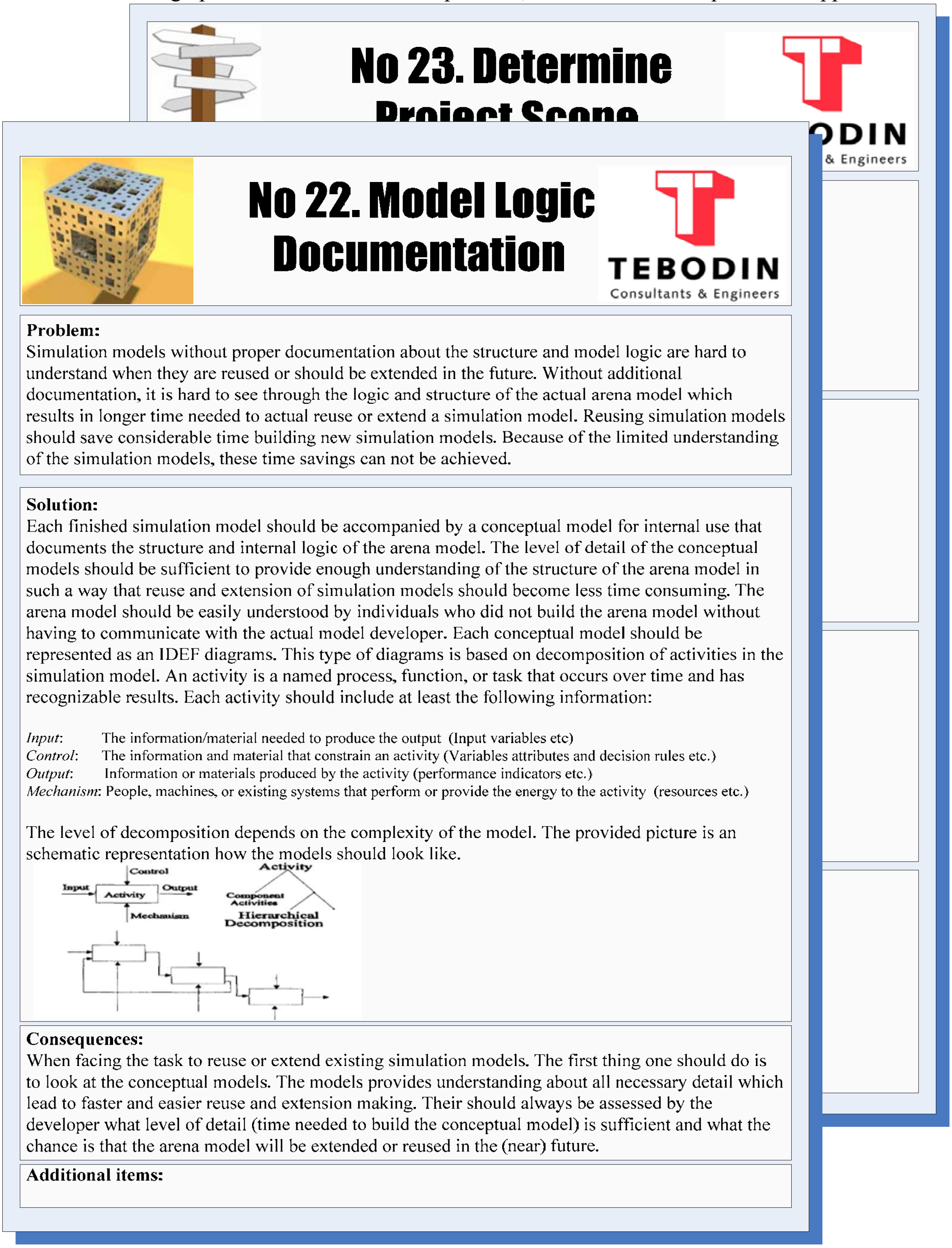

4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Average Score Support Concepts Consultant C
Conceptualisation Techniques
Component Based Development
Design Patterns
Collaborative Learning

Figure G.1: Individual scores support concepts

Appendix H: Example of design patterns

This appendix provides an example how a design pattern should look like. Each design pattern should include a number and title of the design pattern, which should be accompanied by a clear picture. The content of the design pattern should include the problem, solution and consequences of application.



No 23. Determine Project Scope

No 22. Model Logic Documentation

TEBODIN Consultants & Engineers

Problem:
Simulation models without proper documentation about the structure and model logic are hard to understand when they are reused or should be extended in the future. Without additional documentation, it is hard to see through the logic and structure of the actual arena model which results in longer time needed to actual reuse or extend a simulation model. Reusing simulation models should save considerable time building new simulation models. Because of the limited understanding of the simulation models, these time savings can not be achieved.

Solution:
Each finished simulation model should be accompanied by a conceptual model for internal use that documents the structure and internal logic of the arena model. The level of detail of the conceptual models should be sufficient to provide enough understanding of the structure of the arena model in such a way that reuse and extension of simulation models should become less time consuming. The arena model should be easily understood by individuals who did not build the arena model without having to communicate with the actual model developer. Each conceptual model should be represented as an IDEF diagrams. This type of diagrams is based on decomposition of activities in the simulation model. An activity is a named process, function, or task that occurs over time and has recognizable results. Each activity should include at least the following information:

Input: The information/material needed to produce the output (Input variables etc)
Control: The information and material that constrain an activity (Variables attributes and decision rules etc.)
Output: Information or materials produced by the activity (performance indicators etc.)
Mechanism: People, machines, or existing systems that perform or provide the energy to the activity (resources etc.)

The level of decomposition depends on the complexity of the model. The provided picture is an schematic representation how the models should look like.

Consequences:
When facing the task to reuse or extend existing simulation models. The first thing one should do is to look at the conceptual models. The models provides understanding about all necessary detail which lead to faster and easier reuse and extension making. Their should always be assessed by the developer what level of detail (time needed to build the conceptual model) is sufficient and what the chance is that the arena model will be extended or reused in the (near) future.

Additional items:

Figure H.1: Example of design patterns

Appendix I: Implementation planning

This appendix provides an initial planning for the implementation of the proposed support concept.

Id	Taskname	Begin date	End date	Time period
1	**Pre Implementation Phase**	1-9-2008	10-9-2008	8d
2	Determine responsibilities of implementation	1-9-2008	2-9-2008	2d
3	Determine feasibility of Templates	3-9-2008	10-9-2008	6d
4	**Implementation Phase**	11-9-2008	15-10-2008	25d
5	Additional education building/using templates	11-9-2008	17-9-2008	5d
6	Develop Design Patterns	11-9-2008	8-10-2008	20d
7	Develop index/search function (Excel)	9-10-2008	13-10-2008	3d
8	Determine stimulation measures for actual use/ information transfer	11-9-2008	15-9-2008	3d
9	Training use of design patterns	14-10-2008	14-10-2008	1d
10	Ready to Use set of design patterns	15-10-2008	15-10-2008	0d
11	**Post implementation Phase**	16-10-2008	16-12-2008	44d
12	Evaluation/improvement meeting	17-11-2008	17-11-2008	1d
13	Evaluation/improvement meeting	17-12-2008	17-12-2008	1d

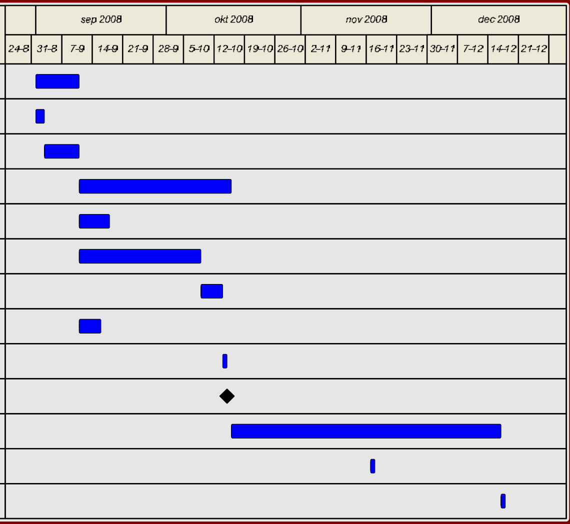


Figure I.1: implementation planning

The proposed implementation planning contains three parts; pre-implementation, actual implementation and post-implementation. It is advised to assign the implementation responsibility to the manager of the logistics department, who can be supported by a simulation consultants

Appendix J: Conceptualisation Techniques

This appendix provides a detailed description of the conceptualization techniques that are evaluated during the workshop. The following techniques are recognized;

- Petri Nets
- Activity Cycle Diagrams
- Event graphs
- IDEF0 graphs

Petri Nets

“The original Petri Nets contain the following components: transitions (represented by bars), places (circles), directed arcs and tokens. Arcs join transitions and places, while tokens are dynamic elements moving from place to place. Places and transitions alternate in the net, so that each transition has its preceding (input) and succeeding (output) places. The net is activated by firing its transitions: firing is enabled when all input places of the transition have tokens. After firing, tokens are removed from their input places and shifted to the output places. In augmented Petri nets used in simulation, time delays are added (using temporal events shown with a star symbol and which represents the condition for a transition firing). These time delays give individuality to tokens, which can therefore be created, destroyed, split or merged. Other additions are control arcs, route selection by AND and OR events etc. Transitions correspond to events in simulation, places to activities or states and tokens to dynamic entities. Figure J.1, an augmented Petri net for the job shop, shows the customer process and server cycle. The start of service transition (event) can be fired only when there is a customer in a “wait” place (state) and a server in the “idle” place. Customer arrival and departure transitions (events) require the passage of time, shown by temporal events (star symbols).” (Ceric et al , 1992, p. 383)

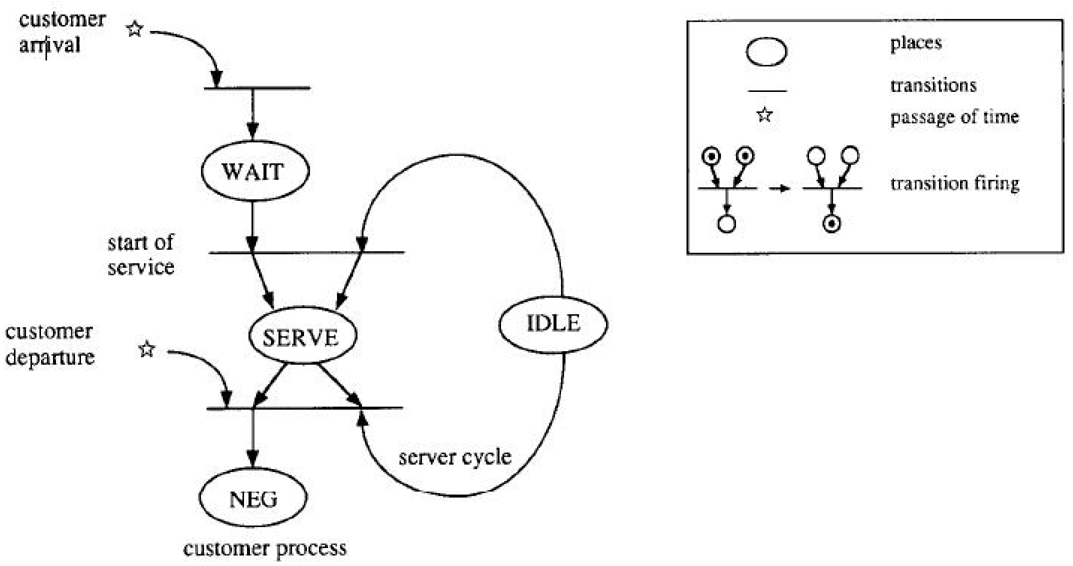


Figure J.1: Petri Nets (Ceric et al, 1992)

Activity Cycle Diagrams

"The Activity Cycle Diagram (ACD) is a model representation technique, disseminated since the late 1960s. Originally, it was based on Tocher's idea of stochastic gearwheels. The ACD depicts the interaction of entities (any component of a system which retains its identity through time), by composing their life cycles. An entity could be either in a Passive State (Queue) or in an Active State (Activity) and the Queue and Activity are the only two symbols that appear in an ACD graph (see Figure J.2). For activity cycle diagrams it is important to note that:

- The duration of an activity is always known in advance (given by some stochastic distribution), and an activity state usually involves the co-operation of different types of entities.
- The duration of an entity in a queue cannot be known in advance.

There are some basic rules or conventions for constructing an activity cycle diagram:

- A Queue must contain only one type of entity.
- An activity always follows a queue and vice-versa (when there are no reasons for queuing before an activity, dummy queues may be incorporated into the representation).
- All life cycles of each entity type should be closed. The most common and classical example of an ACD representation is the ''Pub Example''. Here, for brevity, we will show a simplified version. In this case, the model contains three entities: ''man'', ''barmaid'' and the ''glass''. The man drinks or waits for drinks. The barmaid either pours a drink or is idle. The glass could be used by the barmaid to pour the drink or used by the customer while drinking, or is either waiting to be drunk by the customer or waiting to be poured by the barmaid. If we add entity tokens to the ACD graph (each token representing a single entity), it is possible to do a manual simulation and the position of each token in an activity or queue gives the state of the system." (Chwif et al, 2006, p.940)

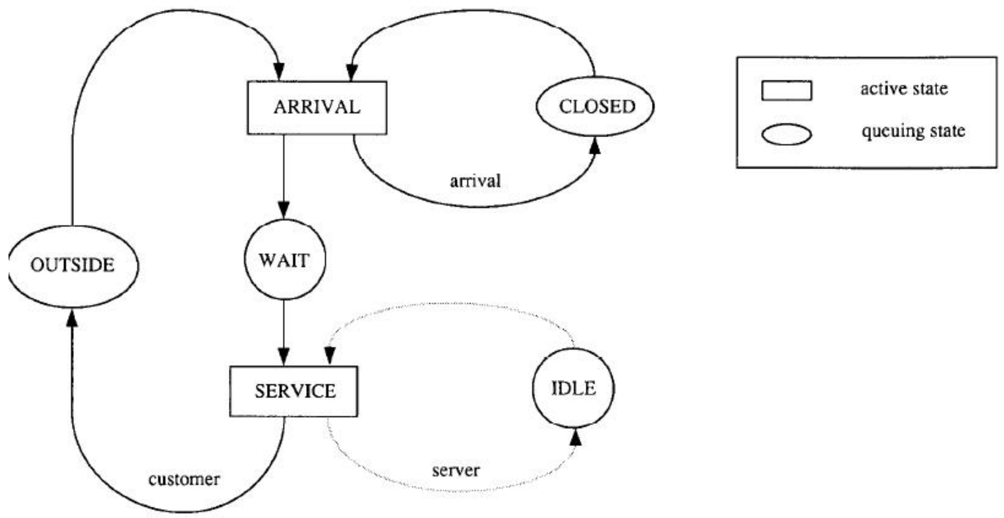


Figure J.2: Activity Cycle Diagrams (Ceric et al, 1992)

Event graphs

"Event graphs, as shown in Figure J.3, are a diagrammatical tool for the event scheduling simulation strategy. The events are described by nodes, while the relationships between events are described by directed arcs between events. The arcs can cause either event-scheduling or event-cancelling and each of them can have attached the time delay and some condition for its activation. Figure J. 3 shows the three events for the example system (customer arrivals, start of service and end of service), with the mutual scheduling event logic of the system. So the customer arrival event schedules both the following customer arrival event after an inter-arrival time delay and the start of service event when the condition "server idle" is fulfilled." (Ceric et al, 1992, p. 392)

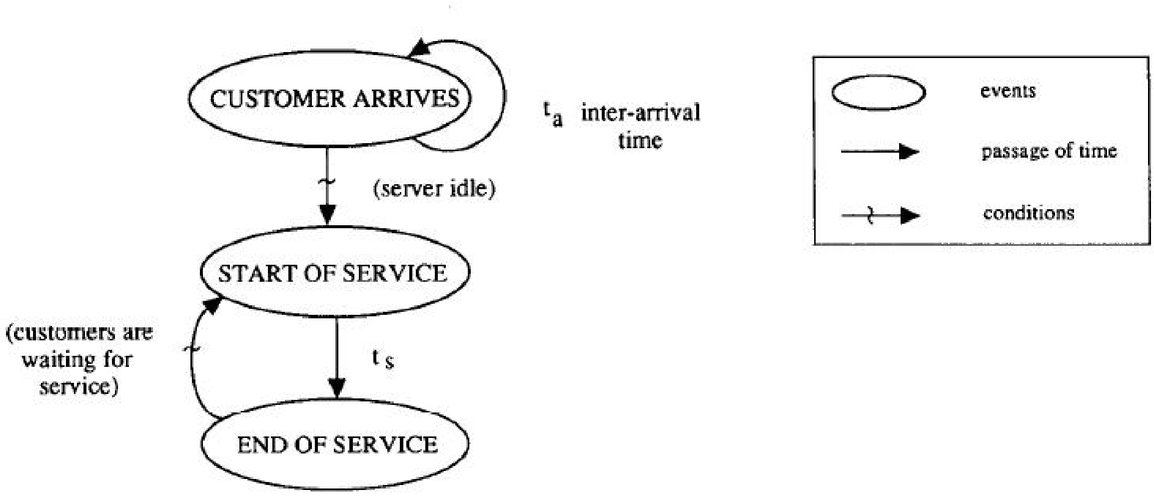


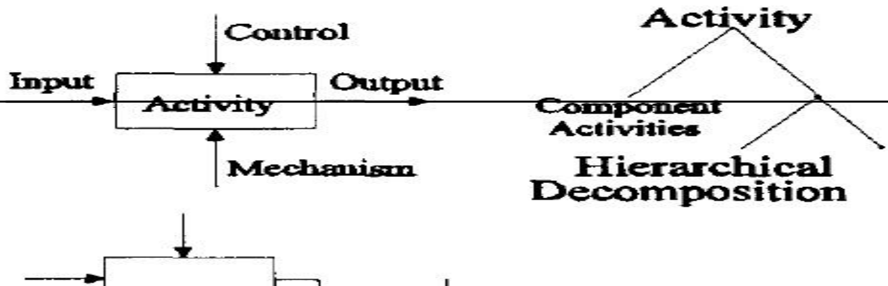
Figure J.3: Event Graph (Ceric et al, 1992)

IDEF diagrams

IDEF0 technique is an easy, yet powerful analysis tool that describes business environments through activities and concepts. The IDEF0 technique was developed during the seventies by the US Air-force, which involved into a method for modelling functions of an organization (decisions, actions and activities) and the relationship between those functions. The basic building block of the IDEF0 technique is represented in figure J.4. The following definitions are recognized for the building block:

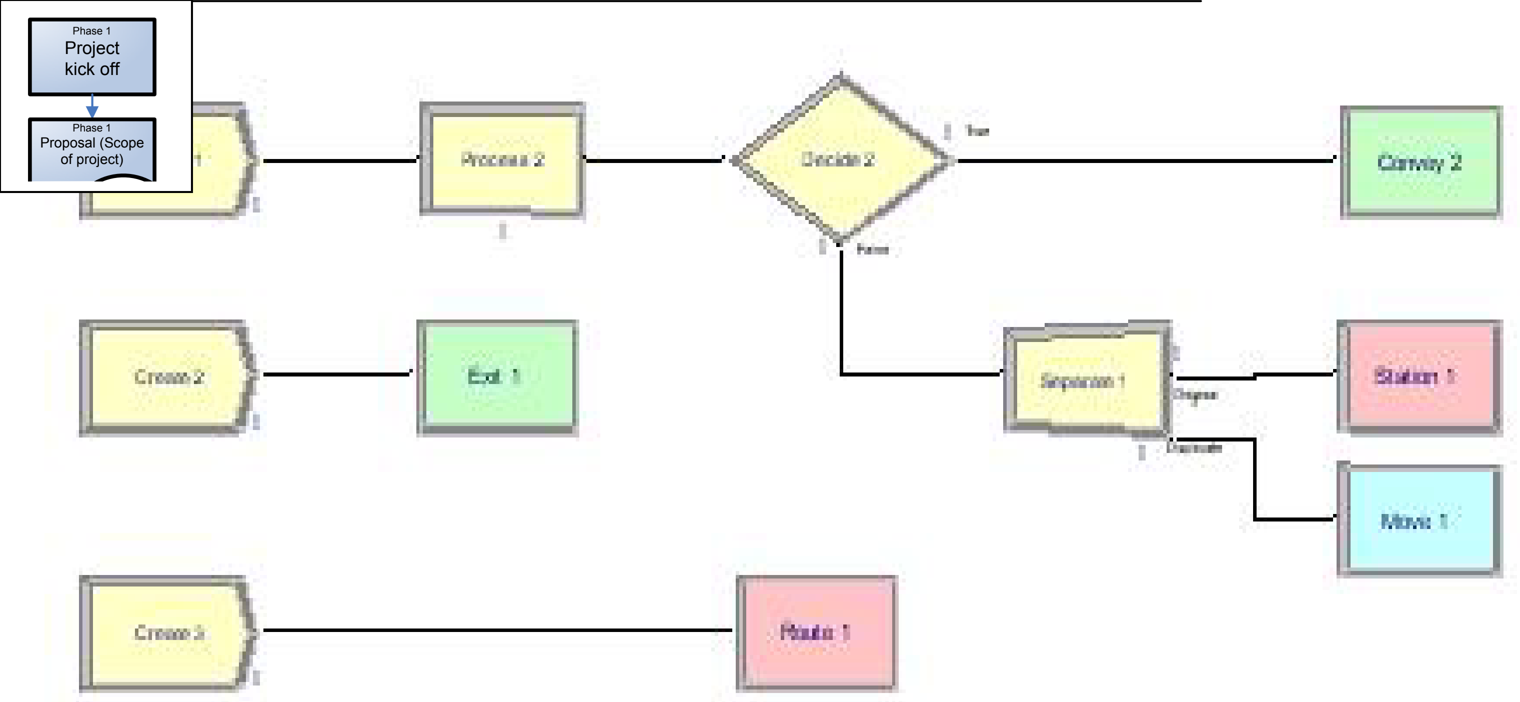
Activity: An activity is a named process, function, or task that occurs over time and has recognizable results.
Input: The information/material needed to produce the output of the activity.
Control: The information and material that constrain an activity.
Output: Information or materials produced by the activity
Mechanism: People, machines, or existing systems that perform or provide the energy to the activity.

Fig



The modelling technique uses a hierarchical approach (Figure J.4), in which the process starts with the highest possible analysis level for the problem, then decomposing the problem to an appropriate lower level. Each level will contain a set of activities. The aim of the technique is to enhance the human-to-human communication within a business environment to understand and document all relevant business processes that exist within the given problem scope, or objective. (Rensburg et al, 1995) The authors furthermore conclude that the success of the application of the IDEF methodology was significant and achieved:

- *Reducing the problem analysis time* The project team estimated that the IDEF methodology saved up to 50 percent of the time it would have normally taken to analyse activities.
- *Accurate simulation specifications* All the simulation models developed were useful and very little of the project time was devoted to the correction of misinterpreted models.
- *Quality of the simulation models.* Results from the simulation models were accurate and accepted by the client,



Simulation Model Development, The Devil is in the Detail! is a master thesis that is the final product of the program Systems Engineering, Policy analysis and Management at the faculty of Technology, Policy and Management that is part of Delft University of Technology. The research was done on behalf of Tebodin Consultants & Engineers.

The main research question of this master thesis is:

How can simulation model development within Tebodin be supported and how can a support concept be implemented in order to increase the effectiveness of simulation models and improve the efficiency of the simulation model development process?

TU Delft