Competencies and Other Prerequisites for DES Application

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MASTER THESIS

Competencies and Other Prerequisites for DES Application

A master thesis that evaluates what competencies and prerequisites that facilitate the application of DES

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Competencies and Other Prerequisites for DES Application

A master thesis that evaluates what competencies and other prerequisites are required for a successful DES application

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Abstract

Competence requirements is a field that has reached broad recognition in areas such as the Logistics & Supply Chain Management (L&SCM). Yet, in the DES field, there is little research which emphasizes on competencies or prerequisites for DES application. The goal for this master thesis is to explore and analyse what competencies and prerequisites facilitates DES application. The focus of this master thesis is to investigate the competencies and prerequisites of three types of stakeholders involved in a simulation project; a buyer, a seller and a supplier. By conducting a case study based on one simulation project, the authors manage to reveal what competencies and prerequisites can facilitate DES application through observations of each step in the simulation project. The findings reveal that certain competencies are applied more often than others of which some are not directly connected to the specific field, that DES application requires a combination of competencies and prerequisites in every step throughout a simulation study in order to be successful and that DES application is resource demanding.

Keywords: Discrete event simulation, competencies, prerequisites, facilitation of DES

Sammanfattning

Kompetensbehov är ett område som har uppnått stort genomslag i andra ämnesområden, till exempel i Logistics & Supply Chain Management (L&SCM). Dock, i området för DES, är forskningen begränsad när det gäller kompetenser och andra förutsättningar för DES-tillämpning. Målet för det här examensarbetet är att utforska och analysera vilka kompetenser och förutsättningar som underlättar tillämpningen av DES. Inriktningen på det här examensarbetet är att undersöka kompetenserna och förutsättningarna hos tre typer av grupper och eller organisationer som är inblandade i simuleringsprojekt; en köpare, en säljare och en leverantör. Genom utförandet av en fallstudie baserat på ett simuleringsprojekt lyckas författarna visa vilka kompetenser och förutsättningar som underlättar tillämpningen av DES genom observationer i varje steg i simuleringsprojektet. Resultaten visar att vissa kompetenser är applicerade oftare än andra där vissa av dessa inte är tydligt kopplade till ämnesområdet, att tillämpningen av DES kräver en kombination av kompetenser och förutsättningar i alla steg genom en simuleringsstudie för att uppnå framgång, samt att DES-tillämpning är resurskrävande.

Nyckelord: Discrete event simulation, competencies, prerequisites, facilitation of DES

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Table of Contents

1 Introduction

This chapter seeks to give an introduction to the master thesis. Background, purpose, problem definition and delimitations are covered here.

1.1 Background

Manufacturing firms are today facing increasing competition and managers are constantly asked to reduce lead times and work in progress while improving the reliability and flexibility of the production. This requires the right choices in the process and equipment. To meet the competition without jeopardizing current production volumes, firms may use different tools to investigate new ways to remain excellent also in the future (Robinson, 1993). As manufacturing equipment often carries heavy investment costs and any major interruption in the production flow has a high financial impact, the cost of testing new ideas and improvements are difficult to motivate due to the risk of losing production volume and furthermore sales.

At a Swedish furniture retailer and manufacturer, the interest of creating an arena for testing new ideas in their factories has recently been put up on the agenda. By the use of *discrete event simulation* (DES), the company aims to gain benefits on the overall performance of their factories all over the world.

The company is interested in investigating one of their factories. Through this, the company is expecting to reveal the possibilities of DES application. Furthermore, if the possibilities turn out to be great, the company will become interested in bringing DES services in-house in order to cut down on consultancy costs and to tailor the DES application to a company standard. As for any other operation that is moved from third parties to in-house, there are several requirements that need to be met for a successful migration. Starting up a new department in a field far different from an organization’s core competencies is difficult and can in the beginning be very costly without many financial gains in return. This is mostly due to low experience and lack of standardized working structures, that causes the department to “reinvent the wheel” several times. The company is therefore interested in what competencies should be looked for in the DES analysts, and what organizational prerequisites should be in place to make the modelling more successful.

Scholars today have developed methods (Banks, 2004), tutorials (Robinson, 2015) and best practices (Bikram & Bury, 2011) for discrete event simulation. The common denominator from the research in this field seems to be to develop and tune the progress of a simulation study to enable for more accurate and cost-efficient simulation models. It is therefore surprising that the research on DES competencies today is limited, even if research evidence on similar fields such as logistics and supply chain management (LSCM) show that competence has a strong impact on business performance and financial competitiveness (Bowersox, Closs, Stank, & Keller, 2000).

(Balci, 2011) implies that simulation and modelling requires several areas of expertise throughout its life cycle, such as simulation modelling methodology, software engineering and project management. The life cycle breakdown of a large-scale modelling and simulation project may aid project managers in identifying areas of expertise in which to employ qualified people (Balci, 2011). By applying an approach which focuses on what managers or simulation experts do rather than what management or simulation expertise is, it is possible to reveal what competencies and prerequisites are required in DES applications to do what involved people do.

This master thesis seeks to evaluate what competencies and other prerequisites that facilitates DES application. The master thesis is performed in a close collaboration with a large Swedish furniture manufacturer's strategic office. The master thesis is built on a project performed at one of the company's factories.

1.2 Purpose

The purpose of the master thesis is to explore what competencies and prerequisites facilitate DES application.

1.3 Problem Definition

Since the company is interested in performing large scale DES projects in the near future, this master thesis is set out to analyse what competences and other prerequisites facilitate DES projects.

The following question will be answered in this master thesis.

- What competences and prerequisites facilitates DES projects with regard to model creation and experimentation.

1.4 Delimitations

The main reason for the delimitations is lack of time and lack of knowledge in certain areas. First, a delimitation is that that the competencies and prerequisites are only regarded inside the company's borders. Second, other competencies and prerequisites might facilitate DES if looking at other industries or simulation processes. Third, the relative importance of competencies and prerequisites are not regarded in this master thesis.

2 Methodology

This chapter describes to the reader the methodology used in this report. Research approach, research method, project approach, project plan and literature review is explained here.

2.1 Research Approach

Research is often conducted using three alternative approaches, inductive, deductive and abductive. The inductive approach uses the empirics as a central source for information and through the empirics find patterns that can be used to explain theoretical models. The deductive approach starts with a theory and the empirics either supports or rejects the theory as a verification of the theory. Conclusions can be made when comparing the empirics and theories. The abductive approach is a mix between the inductive and the deductive approach. (Höst, Regnell, & Runeson, 2006)

This paper uses a deductive research approach due to the reason that there is already a lot of theories on interconnecting fields and the question has most certainly been applied in other fields. The analysis in this master thesis is enabled by comparing literature on the competence field and on the DES field with how the theories are used in reality. The reality dimension is expected to come from the empirics. Where differences and similarities are found, an analysis regarding the perceived importance of the particular point is performed with regards to the empirics.

2.2 Research Method

The master thesis is performed as a case study at a manufacturing factory. According to Yin (1984) a case study has the following characteristics:

"Investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used"

The case study investigates a phenomenon in its natural environment where the boundaries between the context or the phenomenon is not clearly revealed. The case study has its own objectives and will provide the empirics to the master thesis. The empirics are used to compare theoretical frameworks with the reality and from there provide material that can be analysed and have conclusions drawn from it.

One of the greatest benefits of using a case study as a research method is that it is possible to apply more than one research method with the possibility to use several sources of information. In a case study, the information can be retrieved through three main categories; observations, documents and interviews. (Yin, 1984)

2.2.1 Strategy

Simply, there are three distinctive types of strategies in case studies. First, the descriptive approach, which seeks to understand the functionalities of the studied object or subject. Second, the exploratory approach, which seeks to understand the underlying function for the studied object. Third, the explanatory approach, which seeks to the explain the reason of a studied object's behaviour. (Yin, 1984)

This paper uses an exploratory case study strategy to find what competences and other prerequisites are required for DES application. This paper seeks to explore what competences can be of value when conducting a domain-specific task such as DES application and what prerequisites are of value.

2.2.2 Design

There are three categories of designs that can be appropriate when conducting a case study to answer a research question. First, the intrinsic design which is applied when the researcher is interested in learning more about an individual, a group or any other constellation of objects. The goal when applying an intrinsic design is not to generalize the findings of the case study in order to create a new theory. Instead, the goal is to create an understanding of the actual case. Second, the collective design, which aims to generate a theory from one or more case studies. Third, the instrumental design, where the goal is something other than understanding a particular situation. The instrumental design provides an insight that can be used to support or refine a theory. When applying an instrumental design to a case study, the findings of the actual case are considered of less importance compared to the findings that provides to the research question. (Yin, 1984) & (Stake, 1995)

A case study can be either be performed as a single-case or a multiple-case study. Either of the choice the analysis might include a single or multiple units of analysis, often referred as a holistic or embedded case study design. (Yin, 1984)

This paper applies an instrumental single-case design with multiple units of analysis. The authors determine competencies and prerequisites found in the empirics and compares them to simulation theory and other competency frameworks used by other researchers in similar fields. This will aid to refine theories from other areas and invent a framework for simulation projects. The units of analysis are described in the upcoming section.

The single-case study is in comparison to the multiple-case study considered less credible and applicable to a broader audience. Still, since there is only one case regarded, the quality of the outcomes can be higher due to the higher possibility to put more effort into it. The ability to make conclusions in a broader perspective from a single-case study is however limited due to the nature of its design. (Yin, 1984)

2.2.3 Data Gathering

Data crucial to a case study can be gathered in several ways. The three most common ways to gather data are through interviews, documents or observations. (Yin, 1984)

The current state competencies and other prerequisites of the units of analysis are in this paper found through observations. The company position level of the observed units of analysis covers the management level of the company hierarchy. This assists the evaluation of what level of competence and other prerequisites are needed at the management level when conducting simulation studies.

2.3 Project Approach

The project, in which the case study is a part of, is initiated by the top management team and uses some of its framework for projects. First, the project is prepared for approval where objectives, budget and expected outcomes are stated. This is later confirmed in a formal meeting with the involved entities of the project which are the top management team, the factory management team and the project team. After the preparation is done, the project is executed and enters an operating phase where the simulation modelling is the primary task.

Usually, when goods or services are traded there exists a buyer and a seller. In this project there is a buyer, which is named *the factory management team*. The seller is the top management team. Additional to a buyer and a seller, simulation studies may include a supplier of the purchased service or goods. In this project, the supplier is from here on named *the project team.* What might differ this project from other projects is that the top management team, the factory management team and the project team are all working for the same company. However, the top management team is the one who owns the factory and furthermore employs the factory management team as well as project team.

The factory management team, the top management team and the project team have different roles and responsibilities in the project. The roles represented in the project are presented in Table 1.

Table 1. Roles and responsibilities in the project.

ROLE	FACTORY MANAGEMENT TEAM	TOP MANAGEMENT TEAM	PROJECT TEAM
RESPONSIBILITIES/ TASKS	Process owner, receiver of results, data supplier, buyer of the project	Project support, seller of the project	Project leader, programmer, modeller, analyst, presenter, data collector, supplier of the simulation study

The factory management team shares relevant knowledge and information of the system to the project team. The project team interprets the knowledge and the information retrieved from the factory management team in order to conduct a simulation study. The top management team provides project support to the factory management team and the project team. A visualisation of the interconnection between the project team, the factory management team and the top management team is visualised in Figure 1.

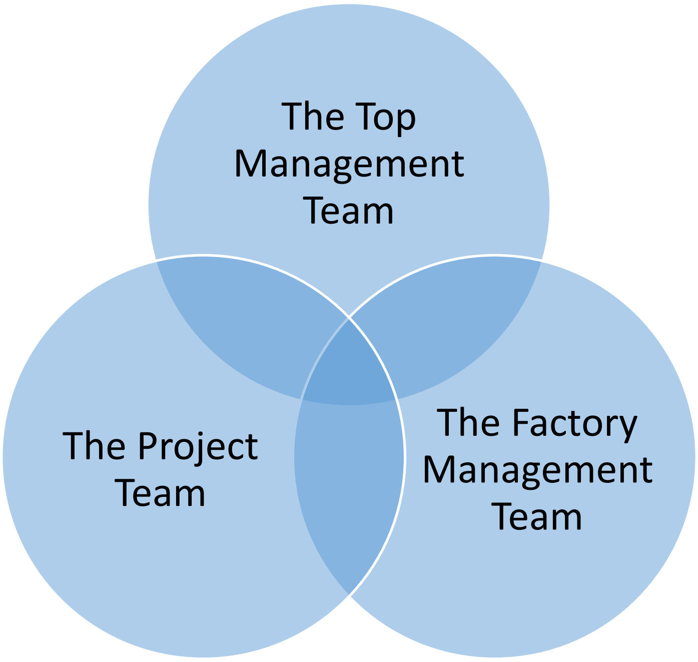


Figure 1. Visualisation of the interconnection between the project team, the factory management team and the top management team.

In this paper, the project team's competencies are the first unit of analysis. The second unit of analysis are the factory management team's competencies and prerequisites. The third unit of analysis are the prerequisites of the top management team.

Throughout the project the involved entities are communicated with on a regular basis with updates on the project's status. Upon the finalization of the case study, the outcomes are presented to the factory management team and the top management team.

The project deliverable is a DES model and a master thesis that evaluates competencies and prerequisites required for successful DES applications. The project's objective is at the beginning open with the definition of "improving an existing factory" with the possibility to be further specified throughout the project. There is also no problem defined other than it should a problem that can be solved through DES application. The project's progress will aid the case study in answering the research questions of the master thesis and fulfil its purpose.

2.3.1 Project Methodology

The project will be carried out by following the well used Banks' (2004) methodology, which is briefly explained below. Banks (2004) has created a flowchart that shows a series of steps to aid DES projects. The flowchart is visualized in Figure 2, and is further described in this section.

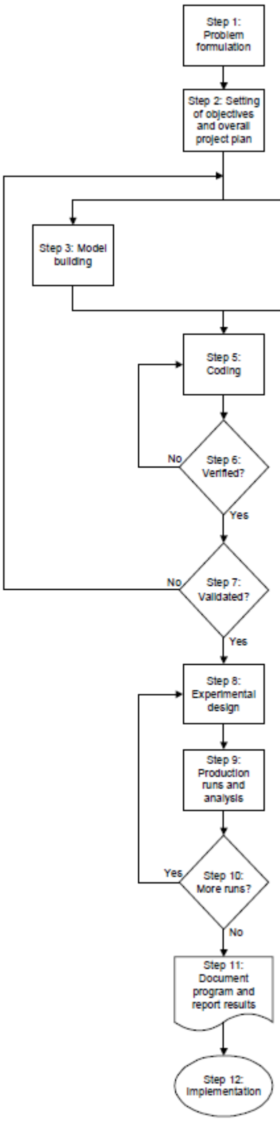


Figure 2. Steps in a simulation study. (Banks, 2004)

The first step in the methodology is the *problem formulation.* A simulation study is initiated with a statement of the problem. The problem can be stated by either the client or by the simulation analyst. The second step is called *setting of objectives and overall project plan.* The objectives in a simulation study are what questions that need to be answered. The client or the analysts can share a proposal of what questions should be answered in the simulation study, regardless if they work for the same company or not. In this step, an agreed project plan should also be provided which describes requirements for different resources such as personnel and software, a time plan, stages in the investigation and other information that is important to the simulation study. Most important might be that the project plan should include what scenarios that are to be tested in the simulation study. The third step is called *model building.* In this step a model is built. However, it is not a finished model, but rather a conceptualized model which is a process engaged in during a simulation project. The conceptual model serves as a description of a simulation model from a real world problem, which may, or may not, exist (Robinson, 2015). Robinson (2015) describes it as one of the most difficult and important tasks in a simulation study as well as the least understood part of it. The fourth step is called the *data collection* step, which runs parallel with the model building step, meaning that the conceptual model is developed in the rate of the amount of information that is gathered. Again, the more parameters that are regarded in the conceptual model, the more complicated the final computerized model becomes. There are two different types of data that are of interest when conducting a simulation study; quantitative data, which often is retrieved from an ERP or MES, such as cycle times and setup times and qualitative data retrieved from workshops and gatherings with the client that further describes the system. (Banks, 2004)

The fifth step is called the *coding* step, in which the conceptual model is interpreted and programmed into a computerized. The tool for creating the computerized model is a simulation software. A convenient way to avoid an inaccurate computerized model is to test subsections of the production system in the model, before assembling it to a complete model. The next step is the *verification* step, which is an iterative process in which the analyst verifies that the conceptual model or the computerized model functions as expected. This means that every step in Banks' (2004) methodology is in some need of verification, which could be, as described in the coding section, to test subsections of the steps. The next step is the *validation* step, which should determine whether the conceptual model is an accurate representation of the studied real system. A validated model should be able to figure as a substitute to the real system, with the possibility of experimentation. There are several subjective and objective validation techniques. Subjective techniques are for example face validation, sensitivity analysis and validation of conceptual model assumptions. An objective technique can be to validate input-output transformations from the simulation model and the real world system. (Banks, 2004)

When a complete, verified and validated model has been generated, the model inputs can be changed in order to test different scenarios stated in line with the simulation study's objectives. This is called the *experimentational design* step. During a production run of an experimental design, the output of a model is collected. The information that is collected is measured in order to estimate the performance of the tested scenario. This step is refered to as *production runs and analysis.* By analysing the previous experimentation runs the analyst determines whether *more runs* are needed and if additional experimentation scenarios need to be simulated. If the conducted experiments are of satisfaction, there are no need for further experiments. (Banks, 2004)

Documentation of a simulation study is as important as any other documentation. If, for example, the simulation model is going to be reused it might be a good idea to document how the model is functioning. A benefit from documenting a simulation study is that the client might be more comfortable with taking decisions based on the documented analysis. It also simplifies modification of the model. If the client finds the documented report credible enough it might want to implement what is suggested in the report. The simulation study should function as additional information that the client can use when making decisions. It is more likely that an *implementation* is successful if the client has been involved throughout the simulation study and if the analyst has followed all of the steps in the framework provided. (Banks, 2004)

2.4 Literature Review

The purpose of conducting a literature review is to objectively report the current knowledge and research status on a certain topic. From this, a summary can be provided from the best available research findings from previous studies on the topic. The literature study provides the authors with an informed perspective or extensive overview about the topic itself to enable a base for better research in the study conducted. (Baker, 2016)

When conducting a literature review there are two types of reviews, systematic and narrative. The systematic review is a structured and planned review used to answer a specific question. It should be structured in such a way a reader would get the same results if carrying out the literature review. A narrative approach on the other hand does not include a description of the search strategy. This is mostly based on the experience of the author who is usually an expert in the area. (Cipraini & Geddes, 2003)

This paper uses a literature study with a narrative approach. It introduces the field of simulation and gives a brief introduction on a common methodology and areas of application, benefits and limitations of DES. Methodologies for simulation was reviewed and scrutinized to determine prerequisites and competencies that facilitates DES application in every step. Furthermore, literature covering DES case studies were reviewed to find common success factors and prerequisites for simulation projects.

Competence literature is reviewed to briefly introduce the definition of competence, since definitions may vary. Literature on DES practitioner's experience in DES applications is dissected to provide a background on the master thesis research question. From these findings detailed explanations on respective identified area are studied to further pinpoint the actual competencies and prerequisites. Frameworks of competence on other fields are explored as a basis for refining competence requirements and other prerequisites for DES application.

Books and articles on the simulation field are explored too with the help of LUB Search and Google Scholar. Little regards are given to the publication year, but the most recent publications are favoured. Initial keywords used in the search of relevant literature were:

- DES
    - Tutorial
    - Methodology
    - Case study
    - Competence
- Competence
    - Framework
    - Measurement
    - Requirement

These keywords functioned as a basis for literature review. From relevant hits, popular sources and other keywords were applied to generate a wider search range.

3 Theory

In this chapter, simulation theory is introduced briefly together with a common methodology. Moreover, a framework for competencies in a related field is introduced and the last section provides a frame of reference on competencies and prerequisites that have been identified by other researchers for a large scale simulation projects.

3.1 Simulation Theory

In this section, simulation is introduced together with its areas of application and benefits and limitations.

3.1.1 What is Simulation?

Computer simulation has been used since the 1950s as an aid in developing solutions to issues in complex production processes. The technology has the abilities to imitate the important decision points in the production process and then iteratively test changes in the computer simulation instead of testing them in reality. The primary application of simulation is therefore a decision support tool with experiments performed on a trial and error basis (Robinson, 1993). There are several different definitions of what simulation is. (Shannon, 1975) defined it as:

”Simulation is the process of designing a model of a real system and conducting experiments with this model with the purpose of either understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system”

Another definition in the subject is the one by (Pidd, Computer Simulation in Management, 3rd edition, 1992):

”The basic principles are simple enough: the analyst builds a model of the system of interest, writes computer programs which embody model and uses a computer to imitate the system’s behaviour when subject to a variety of operating policies”

The two above mentioned definitions of simulation are rather different, but still they share the point of using a model that aims to function corresponding to reality.

The model is one of the fundamental parts of simulation. The model is an imitation of a system that can be existing or non-existing. A model can provide an analytical solution to a complex problem, which is very difficult to solve by using mathematics.

3.1.2 Areas of Application

Manufacturing organisations are constantly under the task of seeking improvements in the areas of throughput, WIP, flexibility costs and lead times. This requires the right choices in equipment, process layouts and production organisations (Robinson, The Application of Computer Simulation in Manufacturing, 1993). In large complex systems, finding the optimal parameters becomes impossible and advanced mathematical formulas in operations research becomes obsolete. In large complex systems, production planning heuristics are used instead, with the overhanging risk of sub optimisation.

Robinson (1993) states the eight following categories of simulation applications:

- *Facilities planning*
  How to build a completely new facility correctly
- *Obtaining the best use of current facilities*
  Determining if a current facility is performing correctly and testing changes to find improvement
- *Developing control logic*
  For example experimenting with alternative product routing and production planning
- *Materials handling*
  How the flow of materials affect the production facility
- *Company modelling*
  Simulation on a less detailed higher level investigating the interdependence among different locations
- *Operations planning*
  Simulation of day-to-day planning of for example a production schedule in a current facility
- *Training operations staff*
  Visualising the flows in a facility to educate the plant operators and supervisors about their facility

Overall, it can be determined that a modelling and simulation approach should be used in complex systems where the optimal result cannot be achieved analytically.

3.1.3 Benefits and Limitations of Simulation

The benefits of applying simulation to solve an issue is that it makes it possible to take interdependencies into account when analysing a complex system. The analyst usually spends lots of time analysing details in the system when building the simulation model and will therefore generate a great understanding about the system dynamics. One obvious downside of this is of course the cost generated by such amount of time investment. Moreover, a simulation project is dependent the accessibility of well-structured and reliable data (Perera & Liyanage, 2000). Also, if time and data is well accessible and the simulation model is a success, the solutions found from a simulation model are heuristics tested in a stochastic environment and will still be less credible than a solution based on mathematical analysis. Therefore, a simulation based solution should be applied only when no easier solution is possible and if the right resources are in place to build credible model. (Banks, 2004)

3.2 Simulation Prerequisites

Before a simulation project can be initiated, it must be determined that the resources and the data is sufficient to perform a successful project.

3.2.1 Organizational Resources

According to Banks (2004) simulation studies should only be executed if the savings are greater than the cost of it. Since simulation requires data, and sometimes a lot of it, the client and the DES analyst should be prepared for either sharing or retrieving it. If there is not any data available, a simulation study is not appropriate for the situation. This also applies for the personnel and time available as well as their expectations (Banks, 2004). In Eisert & Geer's *Pilot-study Exploring Time for Simulation in Academic and Hospital-based Organizations* (2016), it was found that 30% of time in a project is spend on simulation while 70% is spent on other activities. If there is insufficient time, if personnel are not available and if the expectations from managers are unreasonably high, a simulation study is not appropriate. Finally, if the system's behaviour is too complex and if it cannot be defined, simulation should not be an option. (Banks, 2004)

3.2.2 Input Data Quality

Despite the fact that simulation is a useful tool for decision making in the manufacturing industry, the project of developing a simulation model and performing experiments is usually conducted inefficiently. One serious factor contributing to this is inefficient data collection. When the right data is not available the project will of course be delayed. In a typical model building exercise, 40% of the project time is required by data gathering and validation. (Perera & Liyanage, 2000)

To further understand how to improve this phase in a modelling and simulation project, Perera & Liyange (2000) suggests seven causes behind this inefficiency. The reasons are briefly explained in the list below.

1. *Incorrect problem definition*
   It is a requirement that there is a good understanding about the system in which a problem is to be investigated, before simulation can be chosen as the optimal problem solving method. Simulation projects initiated with poor understanding have a higher risk of failure due to excessive time spend collecting inappropriate data.
2. *Lack of clear objectives*
   In simulation projects, clear definitions of project objectives is one of the most important aspects. Poor definitions of objectives can for example lead to wrong scope, leading to inappropriate details in the model. The right level of details in the model must be determined, or the data collection can become difficult.
3. *High system complexity*
   The variety and volume of data depends on the complexity of the system that is to be simulated. As the understanding of the system progresses, so does the data gathering. It is often important to cross-check data for completeness and integrity, leading to many iterations of data collection and validation before a sufficient database can be acquired. A common practice in simulation projects in complex systems is an ad hoc approach for data collection.
4. *Higher level of model details*
   The level of details is connected to the project objectives. A higher level of details does not necessarily produce a more accurate model, although it leads to longer data collection. A data set can have many attributes that includes some *core attributes*. A core attribute is an essential data element, for example process time. These core attributes are generally easier to collect than non-core attributes. The more detailed the model gets; the more non-core attributes need to be included in the model which leads to longer time spend collecting data.
5. *Poor data availability*
   Different kinds of data have different levels of availability, so the issue of data availability is

connected with the level of model detail. Figure 3 shows how participants of the 1997 winter conference perceived their effort in collecting different kinds of data items.

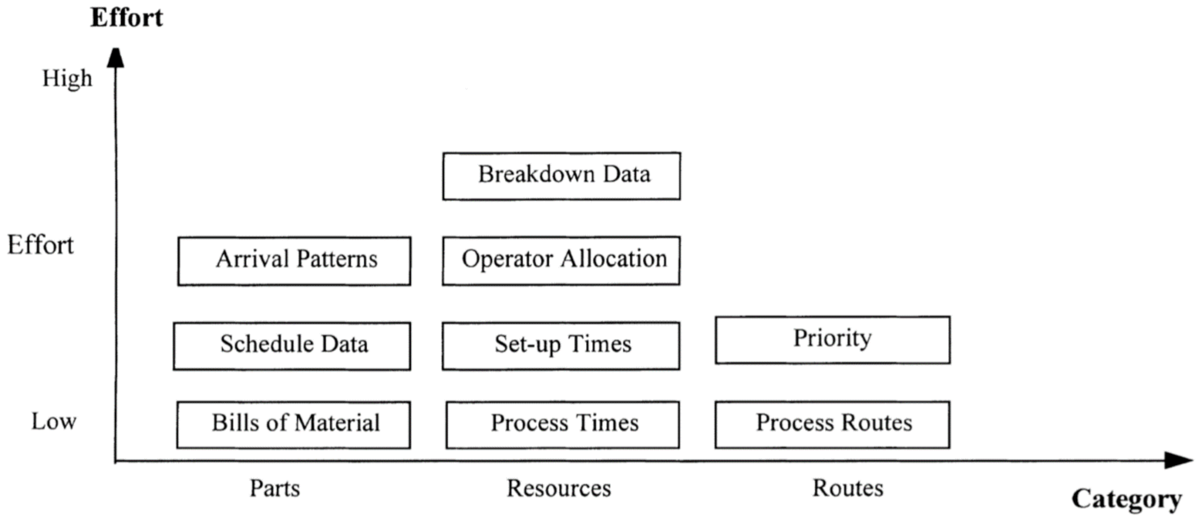


Figure 3. Effort required to collect the different categories of data. (Perera & Liyanage, 2000)

6. *Difficulty in identifying available data sources*
   When requiring many different kinds of data, it is often required to look at different sources, for example different information systems. For example, some information is often stored in an ERP system, while other is captured in an MES. If these systems are not well integrated, there can occur a problem when analysis of the same data can provide different values. Also, determining what source to search in takes time.
7. *Limited data handling capability*
   Most simulation software lack tools to organize, filter and analyse data. For this, registered data formats are often used. When the core data is altered, it may be necessary to revive the data for the simulation model.

(Perera & Liyanage, 2000)

3.3 Competence

Competence can be considered a wide field that describes a person’s knowledge or ability to perform a certain task. The meaning of competence can have different views. According to Ellström & Kock (2008) competence can be considered as an attribute of an employee or it can be considered as the requirements of tasks for a job. It is argued that competencies should be defined as the interaction between attributes and requirements (Ellström & Kock, 2008). Instead of searching for the smartest person, it can be beneficial to search for a person with the right attributes connected to a specific set of tasks. If one can identify required competencies according to predetermined models, organizations can easier align their initiatives to their overall strategy. When competencies are identified and aligned to the tasks, organisations can more easily recruit the right employees.

Competencies are mentioned in different contexts such as Balci (2011) who suggests that discrete event simulation requires expertise in, among others, systems analysis and statistics. Balci’s (2011) argument of what expertise is required in a certain area can be considered equal to what competences a potential employer should look for in a DES analyst. The same reasoning is also used regarding other professions. General nurse practitioners may hold certain competencies while nurse specialists may hold other competencies in order to perform a task properly (Quallich, 2015). Physicians need to know medicine, engineers need to know mechanics and the carpenter needs to know how to use the hammer.

When grouping competencies or defining what is the lowest common denominator in a certain ability, there are several frameworks developed for different positions and professions by researchers such as urology nursing (Quallich, 2015), nursing (Leung, Travena, & Waters, 2016) and managers in logistics and supply chain practice (Derwik, Hellström, & Karlsson, 2016). Considering the background of this paper, a framework that highlights managerial competencies can be motivated, since DES could be considered an interconnecting field that requires special training (Banks, 2004) and therefore increases the possibility to act on the management level.

Derwik, Hellström & Karlsson (2016) has grouped manager competencies in logistics and supply chain practice into several categories that may overlap and interconnect but that are still distinctive enough to be considered stand-alone competencies. The framework is used in the analysis when comparing identified competencies from the empirics with competencies identified by researchers.

Table 2. Manager competencies in logistics and supply chain practice (Derwik, Hellström, & Karlsson, 2016).

Competence	Examples of related manager practices
Behavioral competence	
Intrapersonal	
Self-awareness	Know your shortcomings and act accordingly; accept criticism; be comfortable talking about your weaknesses.
Self-management	Control your emotions; avoid hasty judgment; show integrity and trustworthiness. Consider personal grooming.
Self-motivation	Show inner drive and ambition; take pride in a job well done and strive for results. Learn by curiosity.
Interpersonal	
Empathy toward others	Coach others effectively by considering their personality. Have perspective of others' points of view.
Social skills	Show interpersonal skills; handle conflicts fairly; find common ground; negotiate; resolve problems; collaborate cross-functionally and in cross-culture teams, in multiple locations and countries.
Political skills	Be aware of the situation and adjust your communication accordingly.
Leadership	Motivate others; create openness for others to develop; gain commitment; ensure support for proposed ideas.
Business managerial competence	
Dynamic awareness	
Commercial awareness	Demonstrate business acumen and a general awareness of cost-to-serve analyses.
Industrial experience	Apply experience gained from specific industries.
Company experience	Demonstrate knowledge of operations; understand organizational infrastructure; show structural intelligence.
Ethics and sustainability awareness	Show respect for diversity, social justice principles, and the environment. Apply sustainable solutions.
Strategic awareness	Develop strategies based on the company's core values while considering risks.

Law and regulations awareness	Show a general understanding of contractual law and ensure compliance with all regulations and legal requirements.
Technology awareness	Be aware of recent technology. Be able to deploy hardware and software to solve process improvements.
Business management	
Planning and organizing	Plan and organize to achieve targets involving relevant parties and considering constraints and hurdles.
Performance evaluation	Use key performance indicators, benchmarks, and best practices to monitor and evaluate performance.
Decision-making skills	Set goals; prioritize and make holistic decisions based on goal achievement.
Execution skills	Ability to develop, recommend, and execute activities resulting in fulfillment of plans and strategies.
Stakeholder management	
Managing staff	Hire, schedule, train, motivate, and supervise subordinates to ensure carrying out of activities.
Managing external relationships	Develop and maintain long-term business relationships cross-functionally and inter-organizationally.
Generic competence	
Communication	
Information gathering	Actively take in written, verbal, and non-verbal information; extract and interpret the essence.
Information sharing	Use clear language; consider the receiver. Track responses from audience and demonstrate in presentation.
Cognitive	
Analysis	Demonstrate analytical ability and numerical techniques, as well as qualitative data handling.
Problem solving	Recall and apply information to propose alternatives based on goal-oriented thinking.
Functional competence	
Technology	
Basic technical skills	Handle databases, spreadsheets, and word processing and have web search ability.
Information systems	Handle information systems and L&SCM-specific software.
Modeling and optimization	Develop and use interactive decision support models based on simulation and optimization.
Administrative routines	
Administration	General administration practices.
Cost control	Demonstrate basic accounting skills, manage budget, and control costs.
SCM expertise	
SCM knowledge areas	

Supply chain management	Demonstrate understanding of the supply chain concept, synchronization challenges, and performance trade-offs.
Customer management	Measure customer satisfaction and ensure customer focus in all areas. Practice value-added customer relationship management.
Sales and marketing management	Understand and profile customers and analyse patterns to identify market opportunities.
E-commerce	Demonstrate an understanding of the function and effect of e-commerce on supply chain processes.
Order management	Order, monitor, review, and execute order flow and allocation.
Purchasing	Demonstrate knowledge of the criteria for assessing and evaluating suppliers. Undertake basic negotiations.
Production	Show an understanding of the manufacturing process, material replenishment systems, and the consequences of order scheduling.
Inventory management	Know and use inventory systems for demand planning and inventory management.
Warehousing	Control movements of materials, information, and services through factories and warehouses.
Transportation management	Prove operational knowledge of carriers, fuel, load planning, end-to-end-solutions, taxation, and customs.
Reverse logistics	Manage returned goods, parts, and scrap disposals.
Product development	Be able to design to manufacture. Be knowledgeable about new product introduction and packaging.
Quality and process improvement	Be knowledgeable about quality systems, TQM, ISO 9000. Visualize a process and propose improvements.
Applied SCM analysis	
Forecasting	Demonstrate an understanding of how to forecast using quantitative and qualitative methods.
Production scheduling	Schedule production and distribute products among manufacturing facilities, terminals, and customers.
Facilities location analysis	Be familiar with and able to plan the location for each facility.
Route planning	Reach optimal efficiency through vehicle routing, using both qualitative and quantitative data and techniques.

3.4 Simulation Project Competencies and Prerequisites

This section emphasizes the underlying competencies and prerequisites derived from Banks' (2004) simulation methodology. Simulation projects are often dependent of the DES analyst's skills and experience, and is described as one of the disadvantages of simulation. Banks (2004) implies that simulation studies and model building requires special training and can only be mastered over time and through experience. Also, since DES analysts are individuals with different approaches to problem solving, it is unlikely that two models built of the same system by two DES analysts are identical in the end. (Banks, 2004).

When conducting large scale simulation projects, the steps might be performed by different individuals in a project team who have expertise in one or more of the steps. Perera & Liyanage (2000) implies that there needs to be correct problem definition and a good understanding of the system in order to evaluate whether simulation is the optimal problem solving method or not. Monks, Robinson, & Kotiadis (2014) discusses the importance of communication and involvement with the client, while Balci (2011) implies that modelling and simulation in large projects requires many areas of expertise including modelling methodology, software engineering, statistics, systems analysis, project management and other problem domain-specific knowledge. The following sub-sections further describes the competences connected to the areas mentioned by these researchers.

3.4.1 Identifying a DES problem

A simulation study begins with a statement from either a client or a DES analyst of the problem. If the client is in charge of stating the problem, the DES analyst must make sure that he or she understands it completely and vice versa. It might be a good idea for the DES analyst to prepare a number of assumptions to the simulation study that can be agreed on by the client already in this step. Still, even if this step is performed with extreme precaution, the problem formulation might be in the need of modification as the simulation study progresses. (Banks, 2004)

3.4.2 Communication and Involvement

Researchers in the field implies that clients gain knowledge from involvement in a simulation studies' different steps (Monks, Robinson, & Kotiadis, 2014), (Banks, 2004). Involvement of clients in the experimentation phase and the model building phase is expected to increase the clients' understanding and knowledge of simulation related problem solving and therefore possibly increase the probability of a successful simulation project cooperation, pin-pointing possible benefits from the *high involvement hypothesis* (Monks, Robinson, & Kotiadis, 2014).

3.4.3 Methodology

Established simulation project methods suggest a number of steps to provide a finished result. Banks' (2004) methodology includes a step-by-step guide on how to perform a smooth and solid simulation study. The steps include, among others, a problem definition, conceptualization, data collection, coding, experimentations, verification and validation, all of which requires skills and knowledge on how to perform them. (Banks, 2004)

Methodologies may also be tailored to an organization, industry or purpose to provide additional support for a simulation study's progress. Tako & Kotiadis (2015) have invented a framework with the intention to support participative simulation studies in the healthcare sector. The framework, PartiSim, combines several disciplines to incorporate stakeholder involvement in the simulation study's lifecycle. Tailoring methodologies complements general purpose frameworks and may aid in the progress of the simulation study. (Tako & Kotiadis, 2015)

3.4.4 Statistics

Simulation studies include the step of data collection. In order for the data to be applied in the simulation model, it is likely that data sets are approximated and fitted into a mathematical distribution. According to Banks (2004), statistics can be applied when validating a simulation model with the help of the well-known t-test and other methods to reveal a statistical error or significance.

3.4.5 Systems Analysis & Conceptualisation

Systems analysis can be used when analysing business processes impact on different stages during a system development. Systems analysis can also be conducted when analysing business process flows. (Kock, 2007)

In a simulation study, the systems analysis can be conducted to analyse how processes impact on each other and understanding, which could be argued to be closely linked to the conceptualization of a real system.

The DES analyst must investigate the real-world system and create a conceptual model that may include logical and mathematical decisions of the system's dynamics. The model should not be too complex as it will increase the cost of the simulation study, but still accurate enough to represent the real-world system. Determining the content of the model is, according to Robinson (2015), one of the most demanding issues when it comes to simulation modelling. In order to provide a simulation model, the DES analyst has to understand a real system, with all its complexities, to a certain degree and turn the understanding to an appropriate model (Robinson, 2015).

The conceptual model needs to make a trade-off between complexity and simplicity. If it is too complex you might spend too much time without increasing the accuracy. If it is too simple you might miss out on important data. The key to develop a successful conceptual model is to include the right level of simplification. This includes assumptions and approximation of the real world problem. (Robinson, 2015)

Robinson (2015) has developed a model where conceptual modelling is put in a wider context (see Figure 4). The four rectangles represent what Robinson (2015) call the *Specific Artefacts* of the process of conceptual modelling.

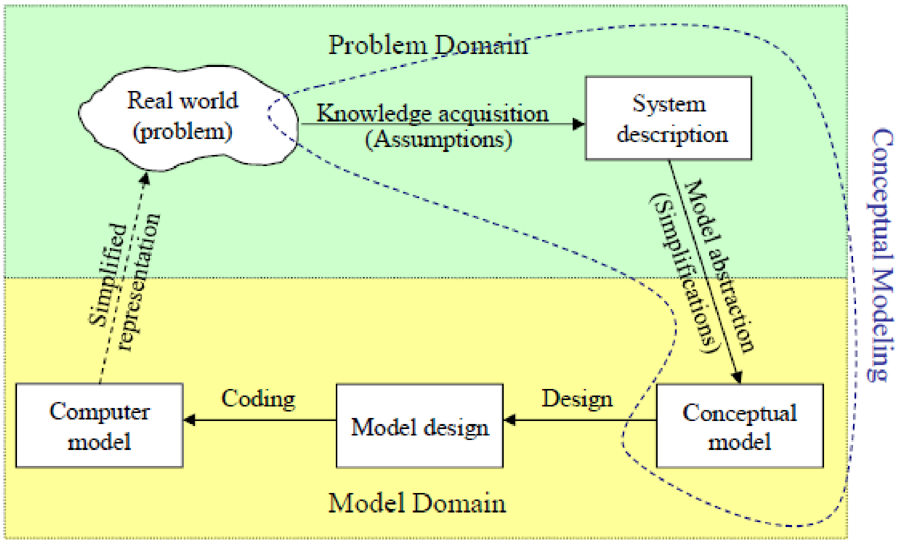


Figure 4. Specific artefacts in the process of conceptual modelling. (Robinson, 2015)

The specific entities represented in Figure 4, are not necessarily explicitly described or documented, except for the computer model which for obvious reasons will be documented automatically. The other entities might only exist in the DES analyst's own mind as a picture of the real world problem. (Robinson, 2015)

A description of Robinson's (2015) *Specific Artifacts* of conceptual modelling is presented below. However, the phase of conceptual modelling mainly includes only the two first bullet points.

- *System description*
  A description of the problem situation and the elements in the real world that can be related to the problem
- *Conceptual model*
  A description of the simulation model from the real world problem
- *Model design*
  A description of what entities that needs to be involved in the computer model
- *Computer model*
  A software specific representation of the conceptual model

(Robinson, 2015)

Robinson (2008) suggests five activities that are performed in the following order.

1. *Understanding the problem situation*
2. *Determining the modelling and general project directives*
3. *Identifying the model outputs (responses)*
4. *Identify the model inputs (experimental factors)*
5. *Determining the model content (scope and level of detail), identifying any assumptions and simplifications*

(Robinson, 2008)

The steps explained above is not a one-time operation, it rather figures as a stepwise iteration process, since many of the steps has to be remade as the situation becomes clearer (Robinson, 2008). Below, in Figure 5 is a visualization of how the steps are expected to progress.

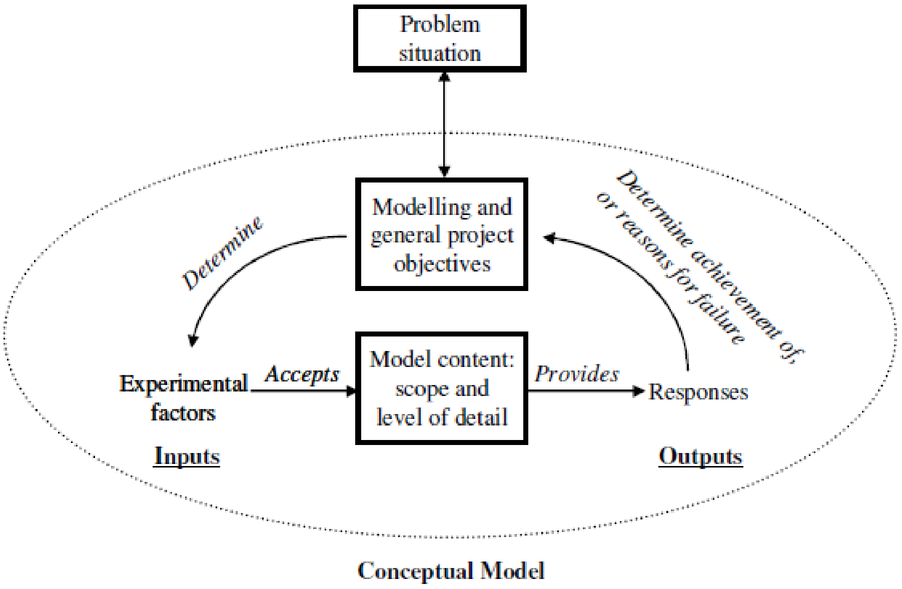


Figure 5. Visualisation of iterations when conceptualising a real system. (Robinson 2008)

3.4.6 Software Engineering

Software engineering is used in the coding phase when building large scale simulation models. Software engineering refers to the development of the model through the use of software development approaches such as programming. The common practice is that software engineering is the method to use in detailed, large and re-usable models (Pidd & Robinson, 2007). The conceptualized model is translated into code that can be read by a computer. To be able to code, the DES analyst requires competencies in the domain-specific coding language. The coding step in simulation studies can be considered one of the most demanding steps for the DES analysts' knowledge. (Banks, 2004)

An alternative to software engineering is building simulation models using Visual Interactive Modelling software's (VIMS) which uses a flexible software tool that can easily include clients. The common practice is that software engineering is the method to use in large models while VIMS can be used in fast modelling constructed in collaboration with inexperienced analysts. (Pidd & Robinson, 2007)

3.4.7 Software

When conducting a simulation study, many different software may aid in the progress of it. As Balci (2011) mentions, simulation requires expertise in many areas. The areas might differ so much that they require different software supporting tools. Louridas & Ebert (2013) have created an overview of different available software for statistical analysis. Some of them, such as Microsoft Excel, can also be used to structure and handle large amounts of data. Matlab can also be used as a software for statistical analysis. According to Louridas & Ebert (2013), Matlab requires a medium to high level of expertise, with the focus on numerical computation.

According to Banks (2004), AutoMod can be used in almost every situation when simulating manufacturing processes and material handling. AutoMod has recently been used in the following industries, among others; Automated material handling systems, the automotive industry, warehousing, airports and customer service centres. AutoMod simplifies coding by introducing a software-specific programming language, which the software translates into C++ code. The use of a simulation software is that it enables for easier model building and faster simulation. (Banks, 2004)

3.4.8 Trade-offs

In a simulation study, there are several steps that requires the DES analyst to make trade-offs, such as deciding what needs to be included in the model (Robinson, 2015) or whether to assume if data has poor quality (Perera & Liyanage, 2000). For example, in the validation step of a simulation study the DES analyst may work together with the client in a face validation or Turing test. A validated model means that the conceptual model and the computerized model are accurate enough to function for its intended objective. (Banks, 2004)

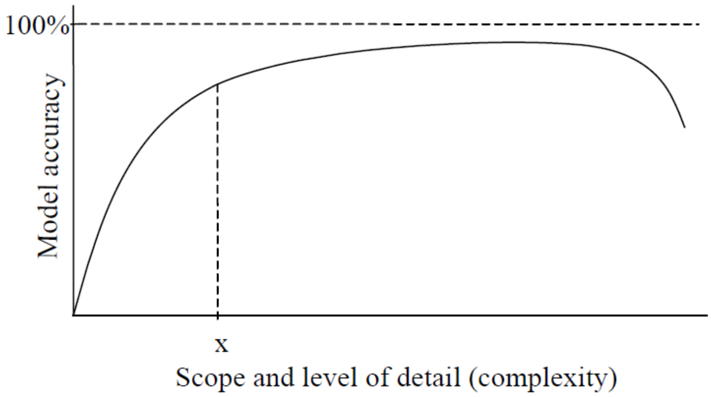


Figure 6. Trade-off between model accuracy and complexity. (Robinson 2015)

Since time is a crucial factor in many simulation studies, the buyer, the seller and the supplier of a simulation study must understand the impact on the accuracy if more or less time is spent developing it. Robinson (2015) has developed a function to describe the trade-offs between the level of detail in a simulation model and the model accuracy (see Figure 6). As the level of detail in a model is proportional to a heavier work load and time spent and therefore in the end cost, the DES analyst's and the client's validation of the computerized DES model needs to take this factor into account.

3.4.9 Data Handling

After agreeing on a problem formulation and the level of detail in the model conceptualization, the client should provide the DES analyst with data necessary to create the computerized model. The data collection is performed iteratively with the model conceptualization, and traditionally uses static or historical data retrieved from information systems. (Banks, 2004)

For DES applications, high quality input data is a requirement when conducting simulation studies (Bokrantz, Skoogh, Andersson, Ruda, & Lämkull, 2015). Without the accessibility of high quality input data, the data collection step might require significantly longer time to perform. Also, the DES analysts must investigate how to find input data if it is missing, or if the quality of it is poor.

4 Empirical Study

In this chapter the master thesis empirics are presented. The empirical study covers areas that are related to the case study that also are related to the master thesis' research question. The structure of this section begins with an overview of the project conducted and is followed by the project's progress.

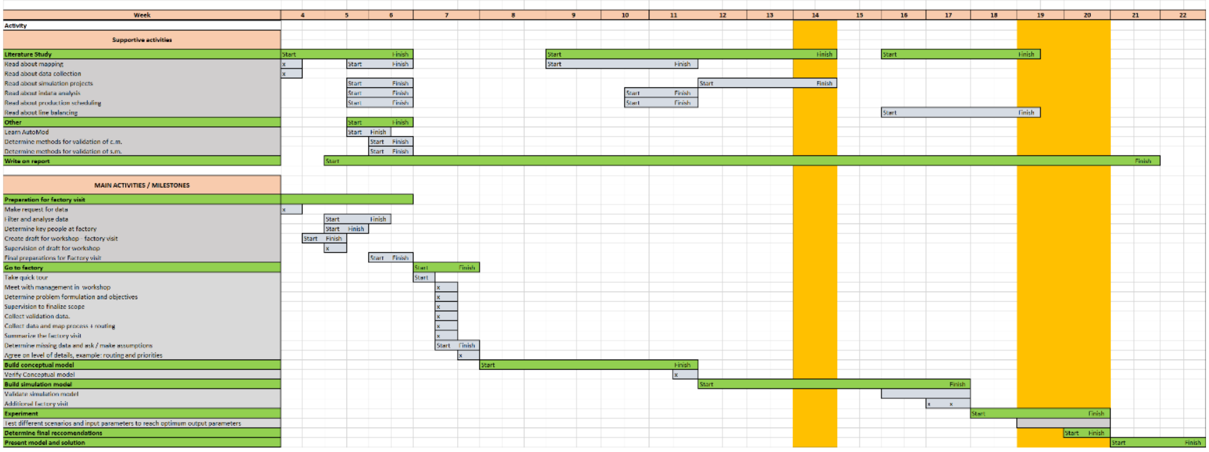
4.1 Empirical Description

The empirics in this paper comes from the case study performed at one of the company's factories. The following sections roughly describes what is performed in each of the steps suggested by Banks (2004). Since Banks (2004) framework follows a more or less chronological sequence of steps performed after each other, the empirics in this paper also does.

In the empirical study, the focus is on areas where the units of analysis require competences and other prerequisites. Detailed results from the actual simulation progress is therefore left neglected. In order to increase the readers understanding for the actual case in the empirical study, a short description of the factory and its key processes is presented in the next sub-section along with a description of the project plan.

4.1.1 Project Plan

The project was determined to span over approximately 20 weeks. During these weeks, the project team needed to perform several activities in order to complete the simulation study and the report. In Figure 7, a preliminary time plan is presented. The time plan was used as a support for the project team in the progress of the project. The time plan is a rough explanation of when and in which order the project's activities were performed.



Week	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Activity																			
Supportive activities																			
Literature Study	Start		Finish			Start					Finish		Start			Finish			
Read about mapping	x	Start	Finish			Start		Finish											
Read about data collection	x																		
Read about simulation projects		Start	Finish						Start		Finish								
Read about indata analysis		Start	Finish				Start	Finish											
Read about production scheduling		Start	Finish				Start	Finish											
Read about line balancing													Start			Finish			
Other		Start	Finish																
Learn AutoMod		Start	Finish																
Determine methods for validation of c.m.			Start Finish																
Determine methods for validation of s.m.			Start Finish																
Write on report		Start																Finish	
MAIN ACTIVITIES / MILESTONES																			
Preparation for factory visit																			
Make request for data	x																		
Filter and analyse data		Start	Finish																
Determine key people at factory		Start Finish																	
Create draft for workshop - factory visit	Start	Finish																	
Supervision of draft for workshop		x																	
Final preparations for Factory visit			Start Finish																
Go to factory				Start Finish															
Take quick tour				Start															
Meet with management in workshop				x															
Determine problem formulation and objectives				x															
Supervision to finalize scope				x															
Collect validation data.				x															
Collect data and map process + routing				x															
Summarize the factory visit				x															
Determine missing data and ask / make assumptions				Start Finish															
Agree on level of details, example: routing and priorities				x															
Build conceptual model					Start			Finish											
Verify Conceptual model								x											
Build simulation model									Start					Finish					
Validate simulation model																			
Additional factory visit														x x					
Experiment															Start		Finish		
Test different scenarios and input parameters to reach optimum output parameters																			
Determine final reccomendations																	Start Finish		
Present model and solution																		Start	Finish

Figure 7. Project time plan.

When sufficient preparations regarding the project’s formalities are considered finished, the first scheduled activities in the time plan starts. The time plan includes several groups of activities with various level of detail. The supportive and main activities are described in the following sub-sections.

Supportive Activities

The early supportive activities such as literature studies and education is expected to aid the project team in performing an excellent project. Due to the lack of knowledge in certain project specific areas, the project team needs learn about a new DES software and how simulation studies and other projects are performed in an efficient and effective manner. The report writing is also considered a supporting since it has a limited effect on the quality of the upcoming simulation model.

Main Activities

The preparation phase begins at an early stage of the project. It includes several activities that are crucial to the project’s success. The most time consuming activity is considered to be the filtering and analysis of incoming data from the Request for Data. Many of the activities have a strong link to the upcoming factory visit, which requires a lot of time of preparations. In this phase there is also a draft for the upcoming workshop planned during the factory visit.

The first factory visit is planned on a day-to-day basis where activities crucial to the objective of the factory visit is presented. The factory visit includes a quick tour around the factory in order to make acquaintance with the factory management team as well as the processes. In the planned workshop, a problem formulation and a setting of objectives is planned to be retrieved.

After retrieving the problem and the objectives a supervision is planned to reveal what additional data might be required to succeed in the project. Collection of validation data and raw data, summarizes of the workshop and additional collection of details about the production system is also planned after the workshop.

The factory visit is followed by the conceptual model building phase, where conceptual models are built based on information retrieved from the factory visit and additional e-mail contact. The conceptual model is then verified to make sure that it functions as the project team expects.

The conceptual model is later on translated in to computer code which is validated during an additional factory visit.

After the conceptual model has been verified and the computerized model has been validated, an experimentation phase is planned where different scenarios are planned to be tested. The experimentation phase is followed by a determination of a final recommendation and a presentation of the model and a report.

4.1.2 Process Overview

The factory is today producing a series of product families with five to fifteen different products in each family. Every three weeks the factory receives an order provided by the master planner which describes the amount of products of each category is needed to be produced during that time period. After necessary operations the products are assembled and packed and thereafter sent to a finished goods warehouse which functions as a central warehouse for finished goods from several different factories in the proximity. From this point, the *master plan adherence* (from here shortened as MPA) is measured and the nearby factories’ performance are scored according to it. In Figure 8 a visualization of the manufacturing process is presented.

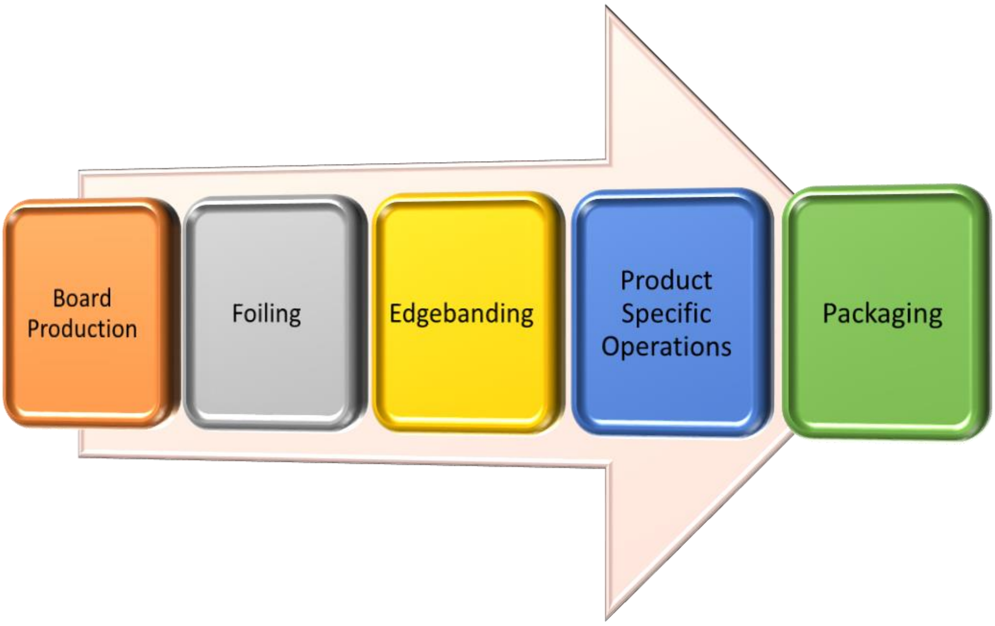


Figure 8. Simplification of the production process.

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The factory today is suffering from overcapacity while at the same time it has an unsatisfying level of *work in progress* (from here on shortened as WIP). The high levels of WIP have not yet had any direct or critical impact on the factory's perceived performance, but is still an area of great concern for the factory management. It is estimated that if the level of WIP is decreased, valuable space can be liberated which can be used for either lowering the WIP holding cost or enabling investments in new and advanced machinery for recently launched product ranges and therefore increased sales.

4.2 Problem Formulation and Setting of Objectives

In the beginning, the simulation study lacked a clear problem formulation with clear objectives, a series of information sharing activities was engaged in to reveal what could be done at the factory with the help of DES application. Since the factory management team had not stated a problem themselves, the project team needed to find and define a problem with clear objectives that the factory management team could agree on.

4.2.1 Request for Information

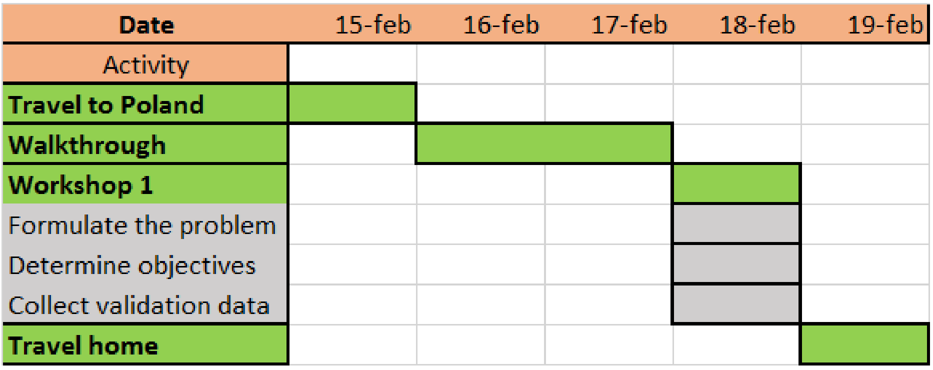
In this document, a formal request was shared to help the project team be better prepared for the factory visit. The document included requests for historic production data in excel format, detailed enough to provide a foundation for an early conceptual model.

The project team expected data provided from the ERP-system that was accurate enough to base an early conceptual model on. To complete this task, the data needed to be on raw format, on a sufficiently long time-span and answered according to the original request. The response included data that was filtered instead of raw, too short time-span and not answered according to the original requests.

4.2.2 Factory Visit

The purpose of visiting the factory was mainly to get an even better understanding of the problem situation and to collect necessary data that was not provided from the request for information. The visit was also expected to ensure the engagement from the factory management team. The factory management team were considered important to the project's success because a simulation study might require close collaboration in areas such as validation and data providing.

The factory visit was roughly planned in advance with activities that were considered important to the project's objective, which was to identify areas of DES application. Activities planned for the factory visit were, among others, a factory walkthrough and a workshop. The time plan for the factory visit is presented in Figure 9.



Date	15-feb	16-feb	17-feb	18-feb	19-feb
Activity					
Travel to Poland	🟩				
Walkthrough		🟩	🟩		
Workshop 1				🟩	
Formulate the problem				▨	
Determine objectives				▨	
Collect validation data				▨	
Travel home					🟩

Figure 9. First factory visit time plan.

Walkthrough

Upon arrival at the factory the project team participated a guided tour with one of the factory management team's members. The factory's processes were described thoroughly as the project team walked by machinery, buffer zones and conveyors. The main outcome from the walkthrough was a solid foundation and understanding of complexities and dependencies of the material flow in the factory. Also, it was the first time the project team was introduced to the company's production process with all its characteristics.

Workshop

The goal of the workshop was to agree on an objective and a scope that both sides of the project could sign on. The first step to reach this goal was to generate a process map on a large white board from the project team's current understanding and from there engage in a discussion regarding the workshop's objectives.

To begin with, the process map that was created from the understanding provided by the previous days of data gathering and factory walkthrough needed some modification to correspond to the factory reality. Once that was modified a discussion started regarding routing decisions and so called "what-ifs", which describes alternative routing decisions if for example the primary machine is down or if there is insufficient capacity. Also, each product's way through the production process was identified, giving important information for the conceptual model.

Once a clear enough picture of the production process was generated, the project team invited the factory management team to place post-it notes on the process map, pinpointing problems and improvement potentials in process-specific areas. The key idea to the post-it exercise was to engage the factory management team to invent their own problem definition and objective to fulfil their own set up goals. The factory management team provided a dozen of post-it notes on both problems and potential improvements

It was revealed that the factory suffered from high levels of WIP and overcapacity which from here on functions as the simulation study's problem definition. The agreed objective from the workshop was defined as "reduce work in progress while maintaining master plan adherence". The input parameters that the workshop decided on was batch sizes, technical availability, out sorting rates and setup times. The output parameters decided on was work in progress, master plan adherence and the possibility of introducing cost. Some simplifications were also made, including dismissal of some supporting activities such as repair and rework, raw materials' availability and alternative routing decisions. The workshop also revealed some constraints for the case study. These were lack of visibility of data and sometimes poorly captured data and that the model should begin in the BOS-line and end after the packaging line. The result of the process mapping exercise is presented below in Figure 10.

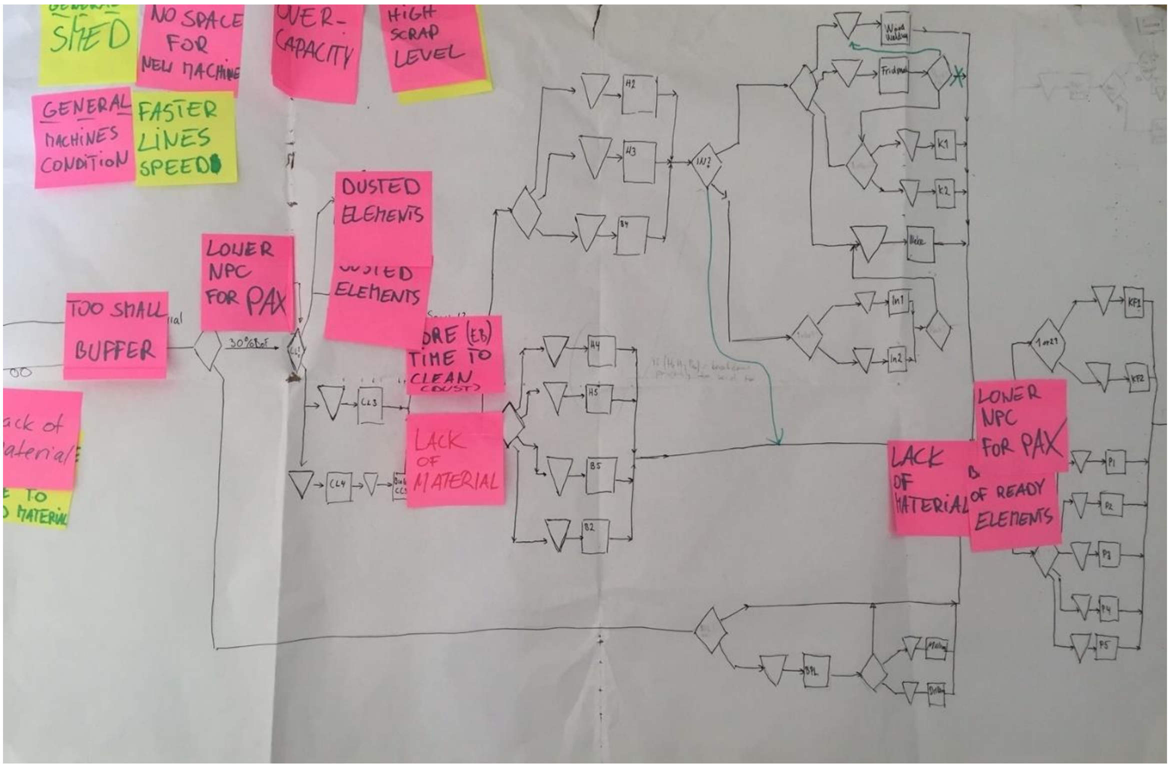


Figure 10. Process map and post-it notes exercise result.

4.3 Data Collection

As shown in Figure 2, the data collection should be performed iteratively with the conceptual modelling. Conceptual models were generated and revised as data arrived.

A large part of the data collection was performed during the visit at the company's factory which is also mentioned in the previous section. At first, the conceptual modelling phase was lagging behind because there was little information to base the model on.

4.3.1 Quantitative Data

The quantitative data was collected through close collaboration with the factory's management team, which have access to the ERP and MES-system, which made it self-documenting. Generally, data is measured automatically on a real-time basis through internal systems and should therefore be easy to collect by using any business intelligence. Also, for some of the data that was needed, the factory management team provided figures on a format that was decided on by the project team, and not immediately from any information system. The actual data that in the end was provided to the project team came from a cocktail of various information systems, syntaxes and quality. This fact made the data collection and later on the analysis and structuring very time consuming for the project team.

4.3.2 Qualitative Data

The qualitative data was collected through personal meetings and factory walkthroughs and works as a complement to the quantitative data. This could be data that is difficult for an ERP or a MES to capture in an appropriate way. Personal meetings with the production manager, production scheduler, lean coordinators and technicians were intended to increase the understanding of the current production system with all of its complexities such as routing decisions, production constraints, suggested model input and desired measured output. Sentences and words had to be interpreted into data that could be useful for the conceptual model and the project as a whole. The documentation of qualitative data is therefore not as structured as the quantitative data.

The routing decisions were in particular a large part of the documented qualitative data. For every unique routing-decision, every product, type or group was reported on a single row in Excel until the entire product and resource range was covered.

4.3.3 In Data Analysis

Both the quantitative data and the qualitative data was analysed before it could be useful for the future steps. Qualitative data was analysed with the help of a process map that can visualize routing and production complexity. In addition, qualitative data was interpreted into mathematics that is relevant for the simulation study.

Quantitative data was analysed using Microsoft Excel and MATLAB. Microsoft Excel was used in order to manage the amount of data collected and to prepare data sets for MATLAB to process. It was also used to verify the qualitative data in terms of routing decisions and production complexities. In MATLAB data sets describing Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) was analysed and fitted into mathematical distributions. Feasibility checks were also performed on the data containing for example cycle and setup times, based on common sense.

The data structuring was mainly performed to support the future coding step in the simulation methodology. Due to the design of the software AutoMOD data needs to be structured in a certain way in order to simplify the coding phase.

Data Structure

A common data structure standard was invented to simplify the simulation software’s ability to read data that was provided from the client. The data was classified into six categories, which more or less are expected to function good enough to cover the whole real system’s complexity. The following categories were used in the case study along with a short description on each point and on the data structure.

- *Cycle Times*
  Structured according to each product’s different parts and its cycle times in each machine. Each row describes information that makes the part unique to a certain finished product. This includes the colour, part type, product group, multiples and from which raw material it is produced from. The row also includes cycle times for each of those machines it has been

produced in during the last year. Multiple is the amount of pieces that are created from processing a part in a certain machine.

- *Setup Times*
  From the factory visit, it was found that setup time is dependent on at least two factors; what is run in the machine previously and the characteristics of the product that is going to be processed after the setup. The figures provided to the project team are rough estimates made by the factory management team, indicating less accuracy compared to values captured from an information system that monitors the production process. There are two types of setups included in the case study; colour change and size change. Colour changes are not expected to be dependent on the previous setup in the machine, which makes the setup time easy to estimate according to one single distribution. Size changes were found to be a lot more dependent on the previous setup which means that the setup times has to be structured according to a matrix with a mathematical distribution between each unique case of setup. Still, some machines' setup times are producing such low volumes that a matrix is considered unnecessary since it would not increase the accuracy of the model. In those cases, the setup time is according to one single distribution, regardless of what is run previously.
- *Allowances*
  Allowances are structured according to a fixed 7-day schedule where allowances are inserted manually according to the working shifts.
- *Technical Availability*
  The technical availability, or MTBF and MTTR, for each machine was analysed and fitted to a mathematical distribution. Each machine has information that reveals their MTBF and MTTR, which came from a data set on historical data.
- *Production Schedule*
  The production was created according to the production history for one year. This was expected to bring continuity to the production schedule due to the fact that some products was produced every week, while others are produced once every second, third, fourth or more weeks. The production schedule is structured according to an attribute that was introduced in the simulation model, which includes information on which week it is going to be produced.
- *Out Sorting*
  The rates for out sorting was structured according to a rate at which machine sorts out materials from the production process. Therefore, the out sorting is not dependent on the characteristics of the part that is processed. Instead, the out sorting rate was determined to be a constant rate at which products are out sorted from the current production process.

Availability and Quality of Data

- Production for one year
  The quantity of each operation in each machine was logged and accessible in unfiltered format from the business intelligence. It did not include processing times and it included an unreliable logging of scrapped material. The time span for the retrieved data was one year. In this file, there was no connection between unique material numbers for each operation and finished item numbers. Therefore, a list of all operations for each product was constructed manually by the factory management team.
- Process and setup time for each operation
  Information about process time for the major operations is captured by an MES while the rest are calculated by technical specialists and stored in an internal system which was easy accessible. Regarding setup times, there are no information caught by an information system. For the setup times, information was estimated by the factory management team.
- MTTF / MTTR
  During the workshop, raw data regarding the downtimes was requested by the project team

but according to the factory management team, raw data on event basis was not possible to retrieve. Instead the project team was given averages for each operation without any statistical distributions.

At the head office, the project team tried to gain access to the data through the business intelligence, but were informed that the raw data was only stored at a local server in the ERP-system. It was only after a second factory visit and extensive digging that this kind of data could be found.

4.3.4 Internal Business Transparency

The company is currently working actively with improving the internal sharing of information between factories and head office. Information that is considered important to share is filtered and easy readable data for making strategic decisions. This information can be retrieved easily from, for example, the company's business intelligence system.

It was found that some data crucial to the project's success could be collected via the company's cloud based information systems where local factories report to. Still, the project team were unable to retrieve it from the cloud due to licensing issues and limited willingness to share information with external players. This dilemma forced the project team to retrieve any necessary data directly from the local factory during visits. At the company it has not been considered important to share raw data internally which made it more difficult for the project team to retrieve important data.

4.3.5 Assumptions and Simplifications

Due to the large amount of different products, machinery, groups and other complexities in the production system, some simplifications were needed to be made in the data collection. Simplifications were made in almost every data category in order to reduce the amount of work needed and due to that a simplification might still not impact on the credibility of the model.

The setup times matrix, for example, would require an enormous amount of work if each unique product was included in it. The setup times matrix was therefore simplified according to which product group the unique product belongs to.

Another example is the cycle times for some products that are missing out from the provided data. If the information is difficult to retrieve, or if the actual cycle time is of negligible importance, the cycle time can be assumed the same as similar products in the particular machine.

4.4 Conceptual Modelling

The purpose of the conceptual model was to have complete understanding about how the shell of the program would look before the coding phase was initiated. The project team defined their conceptual model as a process map combined with a document containing all decisions, assumptions and. In order to facilitate the building of the conceptual model the project team put an emphasis on creating an all-covering process map including decision points and alternative routes for all different parts. The process map shows any alternative route that products may in the flow. The first conceptual model was based on data retrieved from the Request for Information document without any further knowledge of the production site or the real system's dynamics. All the decision rules were determined during the first factory visit, and then verified afterwards using the data of the production for one year. Afterwards the factory management team also found the process map valuable and requested a copy from the project team.

4.4.1 Routing

The methodology of the routing was to learn all the connection between different processes, followed by introduction decisions points after each process. By then successively looking for common attributes as base for each decision, such as product model, product family and part type the number of decision points can be reduced. During the workshop, all the what-if situations were collected and covered by many people with good understanding of the factory, which made the quality of the process map high. The project team could conclude that this exercise was rare among the factory management team. When most of the routing decisions were written, the project team went through the data of production for one year to verify the results.

All the routing statements that would eventually be directly translated into code were written in a text file that the factory management team had access to and were requested to read and determine if the statement was true or false. When a statement was false the project team went through the data and asked the factory management team for further information. After a few iterations, all the routing statements were considered correct.

4.4.2 Assumptions and Simplifications

Many data sets provided by the factory management team had to be interpreted and fitted so that it could be used in the simulation model. Also simplifications regarding exclusion of certain parts of the factory could be made, based on whether the parts would not impact on the simulation model or if a part would be out of scope of the project’s objectives.

Most simplifications are not documented. They are agreed on between the project team and the factory management team as an oral agreement and functions as a limitation of the project’s scope. The most important simplifications in the conceptual model are simplifications on a system’s level. What makes a simplification on a system’s level different from the previously mentioned input level is that system’s level simplifications simplify routing decisions and other dynamics, such as fifo, to make for an easier coding stage. Many of the complexities can therefore be erased from the conceptual model and still be credible.

Assumptions were also made where the factory management team cannot describe a certain behaviour, the dynamics of the system or if missing information is revealed. This could for example be the complexity of the production plan, retrieved from the data collection, which is very detailed and difficult to overview. The production plan was therefore assumed to be more simple and predictable than it actually was in the reality. Another assumption that was made was to exclude certain parts of the production that were considered unimportant to the project’s objectives.

4.4.3 Produced Products and Parts

All products that are produced over one year have been assumed to be produced with a minimal batch size of 1000 units. The products that in one year can be produced in 10 weeks or less with this batch size have been included in the model. The lower quantities have been excluded. Moreover, the most common parts, top, bottom, left, right, partition and shelves have been included, while a few product specific parts have been excluded from the model.

- Fifo system in the entire factory
  The planning is made according to the first process in the factory. From there on, there is a First in first out flow throughout the entire factory.
- Setup times are dependent on previous product group for the major processes, and independent of previous product on the small processes.

4.5 Coding – Building a Simulation Model

In this section the chronological order and methodology of how the authors wrote the actual code will be described. Also some challenges that happened in this phase will be described. The project team's methodology was to begin by working closely while building an extremely rough model and then to begin coding individually and successively including more and more details. Since the coding experience and education for the project team was limited, it was imperative that simplicity would be in focus during the coding phase.

4.5.1 Coding the Shell

The first step for the project team was to create a rough model containing a well structures syntax in which it would be possible to work individually towards a clear goal. The rough model needed to contain all the basic queues and resources to make the model get the same appearance as the conceptual model. Furthermore, the project team needed to agree on a well-structured syntax for all objects such as variables, resources, queues, etc. to be created in the future. In this case, the two models built their so called shell by having one person writing conceptual code in text documents, while the other person puts the conceptual model on a board and wrote the new suggestions for variable names on post-it-notes and placed them on the corresponding place as they appeared in the code. For each new line of similar machines with a shared buffer, the project team wrote the logic in different files since they should be assigned to different so called *processes* in AutoMOD. For all the decision points placed in the conceptual model, the project team wrote new logic files as well, but without any specified routing decisions.

Together the many logic files for the buffers, resource lines, and decision points made up the simplest configuration of the conceptual model and could be tested from start to finish. By testing that all loads could go from the first buffer through the last resource, it could be determined that the framework for the model was finished, and the next steps would be to successively include details to match the reality. The syntax for naming objects was in this step also agreed upon and would only slightly change throughout the course of the project.

4.5.2 Successively Implementing Logic Details

With a good foundation to work from, the project team had a large amount of details to include before the model could be considered a close imitation of reality. The logic that were successively included have been defined in two ways, primary logic that is made to explain the reality, and supportive logic that is needed to make the primary logic function properly and to read output from it. The following list gives a few examples of what kind of details that were needed to include to make the model run as described by the factory management team:

- Setup times and logic
- Routing decisions for all different parts

- Equipment breakdown and repair logic
- *Buffer Capacity constraints*
- *Production planning and sequencing*
- Schedules for breaks, maintenances and shift times.

The coding for this primary logic was relatively easy for the project team who have limited education in coding. However, the supportive logic required a much higher knowledge in the software and required a lot of coding experience. These kinds of logic took much longer time that the project team had expected. Examples of these kinds of codes are the following:

- State changes: The resources are assigned one of the states *Working, Idle, Setup, Break, Weekend, Maintenance* etc. depending on the current situation in the model.
- Bringing up or down resources depending on the current states of the machines.
- Writing output of the states and buffer levels
- Creating functions to catch and calculate for example MPA and lead-time.
- Making changes in the model user friendly and possible via text documents.

These examples above are just a few of the many issues that were far more complex than the project team had anticipated. However, by working in a structured and simple way it simplified debugging and asking for help when things were not working as expected.

4.5.3 Debugging and Getting Help

The code for the model increased in numbers and was very quickly adding up towards 10 000 words or 40 pages of code were interdependencies between different files could be found everywhere. When a problem occurred in a test run, the longest time of fixing the error would be spend locating the error, while the fixes would be easy. With the limited coding experience that the project team had, it was beneficial that some help could be found from other groups carrying out similar projects, and the supervisor of the projects.

4.6 Verification

The verification phase was mainly focused on making sure that the model functioned according to how the code was supposed to work, based on the project team’s understanding about the factory. Much of this kind of testing was done during the actual building of the model. The project team followed the methodology for verification explained in the theory chapter, however most of it was done during the actual coding and debugging.

4.6.1 Structured Coding

In order to verify that the code is written in the right way, and avoid simple but devastating errors as putting the wrong time units, the code was read through by both members of the project team. External verification on the code was only provided on the most difficult areas during debugging sessions. The code was written in a very simple manner, making it rather self-explanatory.

4.6.2 Animation

Throughout the building of the model, since the first shell of a model was written, animation was used to assure that the model functioned as expected. This functioned as a great tool to see when loads went the wrong way, got stuck, or if resources took breaks according to the written schedule, among other things.

4.6.3 Single Load

When the project team considered the model detailed enough, a variety of loads were sent through the model. Each of the loads path through the modelled production system, setup times and cycle times were monitored and verified with regards to how the production system was expected to function.

4.7 Validation

The validation of the simulation model was performed during the second factory visit. On beforehand, the project team had sent an inquire regarding what parameters and in which presentational setup the factory management team preferred validating. It was found that the validation parameters should be a set of parameters that in full can describe the whole system's performance.

The validation phase included different types of validating methods. An objective technique was to validate input-output transformations from the simulation model with the real world system. Subjective techniques used were face validation, sensitivity analysis, data assumptions and validation of conceptual model assumptions.

The project team spent a lot of time to simplify presentation of validation parameters to make them easy to understand. Still, there was already a common practice undertaken by the factory management team, which had a difficult time to adapt to other validation parameters or KPIs than the ones already established. From the project team's point of view, the established KPIs were not suitable to use for a simulation model, which forced them to present other similar validation parameters.

The factory management team decided that the most preferred parameters to validate should be buffer sizes measured as area of storage space in each particular buffer, average lead time of products and the states of the machines, described as averages. The project team also measured the MPA, scrap rates, details about arrival times of products and the state of every machine on a shift-to-shift basis. The tool for validation of the model was Excel, where output data where presented in a structured way and were easy to overview.

It was revealed that the factory management team had a difficult time to adapt to the setting of how the project team presented results for validation. The major issue was that there was a lack of knowledge about the average lead time of products and the manner in which the states of the machines were presented. This complication forced the project team to educate the factory management team in definitions of lead time and machine's states.

It was found that lead time was not a KPI that were considered important according to the factory management team. However, the MPA is affected from significant changes in lead time, indicating that the actual lead time measurement might be obsolete to the factory management team and even to the validation of the model. Still, the lead time parameter remained as a validation output but with less consideration.

The states of the machines were presented according to when a resource was working, in setup, broken down, unplanned, on break and when idle. The factory management team had never analysed the resources in this manner. Instead, the factory management team were more used to working with internally set up KPIs that were difficult to work with during validation, due to their definitions.

The four days of validation visit were very time-consuming and required a lot of backtracking to data or assumption errors and a lot of time rewriting code. On the fourth day, the group could finally determine the model to be valid.

4.8 Experimentation

The step of experimentation began with evaluating what possible scenarios might be of interest to the factory management team and potential investments that might carry a positive cash flow. The factory management team, were also included in the investigation of what parameters could be of interest. It was revealed that the factory management team were interested in testing how outsorting rates and certain routing decisions could affect the output parameters and the system as a whole. The project team also identified some input parameters that could be of interest to the company. Buffer capacities, setup times for each machine, demand increase and performance of the machines were input parameters considered worth experimenting with. The time spent on the experimentation phase was low compared to the rest of the project. The design of experiment was predetermined as a result of the problem formulation. Some time was spent on the optimisation tool, although it mostly consisted on correcting syntax and software issues, while the actual optimisation was automatic and not very time consuming.

4.8.1 Design of Experiments

It was early decided that the majority of the experimentation scenarios should be performed as percentile changes of input parameters applied to the whole series rather than many isolated changes of parameters at certain parts of the production process. Still, the identification of bottlenecks and areas of overcapacity were crucial to the choice of experimental scenarios performed. This was mainly due to that isolated changes in input parameters in critical areas might render in higher return on investment, which in particular is an area of interest.

Each experimental scenario had a series of input parameters of which only one was modified at a time. The first experimental was however to test the limits of the buffers in-between the major processes and to minimize these capacities. This revealed how MPA and WIP was impacted by a decrease of storage space at certain areas.

With the constraints from the buffer capacity experiment, the other input parameters were tested at level steps of 5, 10, 20, 50 and 80 per cent and the result was analysed. Furthermore, an average percentage of demand increase was tested in the steps of 5%, 10%, 15%, 20% to analyse bottlenecks and overcapacities.

4.8.2 Production Runs and Analysis

The different scenarios of the simulation model were run and analysed. The output parameters WIP and MPA was in detail analysed with the help of Excel. Other output parameters were also analysed to check utilization rates, lead times and buffer levels at each buffers.

4.8.3 Optimization Tool

To widen the complexity and range of potential experimental designs, the project team used an external optimization tool that supports large scale experimentation of parameters. Parameters that were considered of interest of testing in the optimization tool were inserted into the simulation model's code. The optimization tool tested a given range of changes of input parameters in all the different combinations, which in other cases would have been very time consuming. The optimization tool catched the results from each of these experiments which was plotted in a relevant MPA-WIP graph.

4.9 Result Documentation

From the production runs of experimental designs, each model was saved in a separate folder for clear separation of the models. Each folder included a short description of the following parameters:

- Tested scenario
- Input parameters modified
- Non-static coding dynamics modified (changes in the code)
- Expected results
- Retrieved results
- Comments on feasibility to implement the modifications
- Suggestions for additional experiments on the given model

The result documentation was of crucial value when the final recommendation was presented to the factory management team and the top management team. This was mainly because the project team were able to address what alternatives were tested with their respective results. The factory management team and the top management team also thought the simulation study as a whole was more credible due to the adequate, simple and straight-forward documentation.

4.9.1 Documentation of the Simulation Project Progress

Throughout the simulation study, the project team documented important steps that were made on a day-to-day basis. Most of the documentation were made by the help of pen and paper. When conducting a simulation study that spans over a longer time period, the project team found that the documentation of "what has been done" and "what we are going to do next" were of great value. This also applies both to notes that were documented as qualitative data, but also when handling with quantitative data, which usually is considered more or less self-documenting.

Starting from the conceptualization of the system, documentation of actions, thoughts and insights were in the beginning poor. The reason might have been that the amount of information included in the simulation thus far was not considered overwhelming and did not need any particular documentation. Some actions could be considered documentation, such as the creation of the process map, which in itself included a lot more information than words could describe.

When considering the data gathering, which in a large majority was retrieved through self-documenting excel sheets, the documentation was also considered to be poor in the beginning. Of course, data arrived was saved and stored and was therefore documented in some sense. Still, the project team had a difficult time when documenting valuable results and insights from the data collection in an organized manner. Typical errors that in the aftermath of the simulation study were that as more and more data were analysed and structured, it was also revealed that more and more data were missing, of poor quality and even wrong. A documentation system to address issues like this would have been of great value to the project team and would possibly save precious time.

In the coding step, the same issues as in the previous steps were troubling the project team. In the beginning of the step, when the amount of code included was small, it was never considered a problem that there was no documentation of where to find coding sheets, or what the actual code did. Still, the project team had some knowledge in programming, meaning that the code was actually self-documenting in a larger sense than for example in the data collection step. The coding step was also a bit more structured, with reasonable naming of resources, variables, queues and other objects used since the project team had learned from the previous steps. The code also followed a documenting logic were distinctive sections of the process map were coded in separate coding sheets. Issues found during coding regarding documentation was that the software did not support version handling. The project team also found the software to be unreasonable complex, perhaps due to their inexperience. The complexity of the software was a challenge to the project team when documenting the progress. Examples of complexities that made the documentation more difficult were that there were multiple software included in the coding step and that when the amount of code was large there was a drop in the ability to overview what was included, or not included, in the model. The project team found that there was a need to “do it right from the beginning”, indicating that experience might aid in the coding step with the particular software used.

The verification and the validation step of the simulation study were considered areas that from its immediate beginning demanded some sense of documentation. The verification was mostly performed through printing messages of code into the simulation software. Outputs were also checked with the help of the supporting Excel document. The verification of the conceptual model was documented in that sense that a model version was saved and used from there on out.

The validation was simplified by documenting results from runs of the verified model. The results from the simulation model were printed into an Excel sheet. Considering the amount of data that was printed into the Excel sheet, there was a need for simplifying the results into easy-to-read sheets where the results were presented. As mentioned in the previous validation section, the simulation model required some modifications. By having a structured way of presenting results for documentation, it was easy to simply ask the factory management team about what the results should be and modify the model accordingly until those results were achieved.

5 Analysis

In this chapter, an analysis is carried out on the observations found during the project to answer the research question. The first section of the analysis is divided up according to the steps of Banks' (2004) methodology since the project contains a variety of unique steps which may require different competences and other prerequisites. Each step is analysed individually.

Furthermore, all competencies and prerequisites that has been identified to facilitate a simulation project will be presented and explained together with an explanation about in which steps it is needed and who should hold the competency or prerequisite. As described in the method regarding units of analysis, competencies and prerequisites for factory management team, top management team and project team will be separated entirely in the analysis of the steps conducted in the simulation study. The factory management team and the project team can possess competencies, while the top management team cannot. The top management team and the factory management team can possess what is defined as prerequisites, which the project team cannot.

Afterwards, the findings are analysed with a holistic perspective in order to find similarities between distinct identified competences and prerequisites for the whole simulation project to enable categorising. The many competencies and prerequisites will be categorised accordingly and all the findings will be presented in a structured framework that shows the competence and category for each methodology step and entities.

5.1 Simulation Project Progression

5.1.1 Problem Formulation and Setting of Objectives

Due to the fact that there was no real objective from the stakeholders other than finding a problem where DES can be applied, the problem formulation was forced to match a simulation application. According to Perera & Liyange (2000), one should have a well-defined problem before deciding that the best solution should be a simulation based. The reason for the in this case backwards way of working could be that the stakeholders want to broaden their simulation acceptance to their factories. Inventing problems that can be solved through simulation is a way to reach out to them. In this case, the initiation phase of the project was slow and consisted mostly of trying to explain to the factory management team what was going to happen and to explain what kind of information would be needed beforehand.

Request for information

The factory management team did not respond to the RFI in complete. Since the factory management team and the project team had little or no experience in working with simulation projects the prepared request for information was possibly poor, or the factory management team's abilities to understand the request where non-sufficient.

One can evaluate whether the reason was due to the lack of experience, education or abilities in simulation projects from any or both sides or if the choice of communication media was not suited for these kinds of requests. Still, it could be expected that the next simulation project's request for information might be more proper than the one provided in this case indicating that the used communicating channel can function when dealing with a request task.

Workshop

As mentioned in the empirics, the factory management team provided a dozen of post-it notes on both problems and potential improvements. Still, they had a difficult time adapting to systems-thinking instead of operational silo-thinking. This made the quality of some of the notes low and inadequate to support an upcoming objective. The reason for this might be due to the lack of experience in process mapping and its simplifications of a factory layout, low knowledge of the factory besides their own area of responsibility or poor choice of communicating media from the project team.

However, the workshop produced a mutually agreed objective, scope, input and output parameters that are the fundaments of the case study. This were also the goal with the workshop from the beginning, indicating a successfully performed activity.

5.1.2 Data Collection

The quality of the data collection could be considered limited, with regards to time and results. The data collection requires a lot of close collaboration and conversations between two or more parties, which requires a structured way of working and a knowledge of what and where one can find the information that is asked for. During the data collection phase, there were many moments when the data was unreliable or insufficient, where the factory management team needed to make assumptions. In these moments, it was found that the ability to communicate the factory management team regarding how the data should be structured, and how it affects the project was crucial for their assumptions to be usable in the project.

Quantitative Data

It was expected on beforehand that the quantitative data could be retrieved easily from the company's information systems. It was discovered during the data collection that this was not the case. The information system structure at the company encouraged the factory management team to use the business intelligence regardless of the situation, due to its easy-to-use characteristics, leaving the project team with possible information gaps since not all the information was gathered there.

To make the collection of quantitative data more efficient and proper, the high involvement hypothesis (Monks, Robinson, & Kotiadis, 2014) could be the solution to the problem. Still, when considering a single project where the client has never performed a simulation study before, the impact on the current project would not be very high. It is not expected that the benefits of involving the client in a simulation project at each of its stages can be harvested until the next project. However, the acceptance, and therefore the willingness to use the results from the project, might be higher when having a high level of involvement from clients, but this is disregarded in this paper.

Having a structured setup of information systems with a high level transparency and willingness of sharing between different company departments would have increased the efficiency of the quantitative data collection. It could be considered that the data collection does not actually demand any face-to-face interactions, which would mean that the quantitative data collection, in best cases, could be performed from any place where connection to the company server is available.

The factory management team had rarely worked with any other system than the business intelligence that was considered basic to the project. The MES was used on occasions but in a manner that did not aid the progress of the simulation project. The project team also had little experience in working with data collection, and none for simulation projects, leaving a large gap of knowledge of what information that could be found in which system. Considering the low awareness of where to find appropriate data from both the factory management team and the project team, the collection of quantitative data could have been performed more smoothly and possibly even off-site.

Given the different standards of the data provided to the project team, an installation of information systems that catches relevant data to simulation projects would decrease the time consumption during structuring and in-data analysis drastically. Still, this is only one side to the issue. The case in the data collection might as well have been that the information is actually gathered, but the awareness of its existence is disregarded by the players of the project.

When considering the competence of retrieving and providing quantitative data for a simulation project, it could be basic to simply be aware of that the data is gathered in some system somewhere. This statement is only true when there exists some form of information system, which therefore can be considered a prerequisite when collecting data and furthermore when conducting simulation studies.

Qualitative Data

The qualitative data was easier to retrieve than the quantitative data. This might be due to the possibility that the factory management team were more used to reason regarding the production rather than using information system reports. Still, the qualitative data was much more difficult to document in a structured way, compared to the quantitative. The large amount of information and disinformation provided in a qualitative manner might have been the reason for the difficulty in documentation. Also, qualitative data was not provided through pre-determined interview questions, but rather conversations in between general discussions about the production system. Considering this, the collection of quantitative and qualitative data could be considered equally easy or difficult, but with different requirements of skills from the project team and the factory management team.

Experience in documenting valuable qualitative information would have helped the project team in the collection, especially during the first factory visit. Still, the amount of qualitative information that in the end was needed for the conceptual model was very small. This made re-requests for qualitative information very convenient and straight-forward.

In-Data Analysis

The analysis of quantitative data was much more difficult and time consuming than the analysis of qualitative data. If the quantitative data would have been provided on a more standardized format, the amount of time spent on structuring would have been significantly lower. Also, the possibility to overview what information that was actually provided and its quality would have been easier to overview.

When structuring large amounts of data on different standards, expertise in data handling software could be considered a key competence. Without having experience and knowledge of data handling software, the structuring of quantitative data would have nearly impossible considering the time aspect of the project.

The amount of work put into in-data analysis and structuring was strongly correlated to the amount of unfiltered data provided in the data collection. With regards to this, involving the factory management team in providing data in a pre-determined format decreased the workload of this task significantly. Data provided in this way required a minimum amount of analysis and structuring, indicating that structuring and in-data analysis is proportional to the amount of raw data provided.

Since the project team had limited experience in the manner data needed to be structured to function in the simulation software, there is a possibility that this step could have been performed more properly and efficient. Awareness of how data structuring is connected to the simulation software would relieve the workload of the structuring process.

Prerequisites to perform a proper in-data analysis is tools to handle data, such as Excel and tools to mathematically approximate distributions of data sets, such as MATLAB. Approximating data sets into mathematical distributions, such as when approximating a mathematical distribution for MTBF and MTTR, requires statistical expertise and knowledge of how to use domain-specific software.

Factory Visit

The most critical part of the factory visit was in advance expected to be the workshop. In the workshop the project team wanted to decide on an objective and a scope for the simulation study. Input parameters and output parameters were also expected to be delivered at the workshop. Since no problem was stated by the factory management team, most of the factory visit consisted of educating them in what simulation can do while also gaining knowledge regarding the production flow.

At this time, it became apparent that one reason for why the response on the RFI was insufficient was that the factory management team barely knew what kind of problem was going to be simulated, i.e. that the project team searched for a production logistics problem, rather than a technical problem. This points to that a basic understanding regarding simulation from the factory management team would have been beneficial, although the lack of a predetermined problem that would fit for simulation was the real issue.

5.1.3 Conceptual Modelling

The project team who had very limited experience in simulation projects still managed to perform the conceptual modelling successfully. This was mostly because of the project team’s experience in production management studies that delivered a good competence in creating a very detailed process map. Still there was some lack of simulation experience that made the authors unaware of what level of detail that should be applied, since an experienced project team would know what details are imperative to dedicate lots of attention to and what details can be neglected. Overall, the project team where extremely satisfied with the conceptual modelling phase of the project. The fact that the factory management requested a copy of the process map points to that the exercise was a success.

Routing

The collection of all the routing decisions was made with high quality, but in a rather time consuming way for the factory management team. One reason for the success could be that the project team really focused on being thorough when conducting this exercise, and probably more thorough than the factory management team was used to when conducting similar exercises. If speaking about competences, one could argue that the act of being very thorough in collecting details might be why the reason why the process map generated by the project team was more detailed than any that the factory management had created. However, no matter how thorough a project team is, the quality would not have been possible without the high level of involvement and knowledge about the production flow from the factory management team and this is considered a prerequisite.

The routing decisions were documented in the qualitative data collection and functioned very well in the creation of the conceptual model due to its straight-forward structure and due to the easy-to-use coding language of the simulation software. For a project team, with little experience in interpreting a real-world system into code, the choice of routing documentation was excellent. With this in mind, the process of including every entities’ path through the production system in the conceptual model could have been incredible difficult, if the documentation of the qualitative data was poor. This indicates that knowledge of how to document routing decisions when using different software or coding language could decrease the time consumption of a simulation study significantly.

Assumptions and Simplifications

The need for simplifications was obvious with this kind of scope in this timeframe. The difficulty lies in knowing what level of detail to attain without losing credibility in the model. An experienced project team will usually know which parts in a simulation model can be simplified, although the factory management team will know which parts in the factory are more important to consider. This points to a need to educate the factory management team in how simplifications will affect the model in order for them to aid in making simplifications.

5.1.4 Coding

The majority of the time spent in the simulation project was spent coding. It was also expected from the beginning of the project that the coding step would be very time consuming. Considering this, the time spent coding could in this case have been decreased significantly if the project team had more experience from both the software and conceptualizing, or if easy accessible methodologies had been existing.

The choice of coding method, with a step-by-step approach of increasing the complexity in the model, could be considered excellent since the model eventually was finished in an acceptable time frame. Still, most progresses in any activity begin in a somewhat chronological sense where complexities are increased successively indicating that the choice was more of a natural decision than a consciously and scientifically evaluated one.

The coding step of the simulation project lack of clear methodologies on how to perform it, besides being structured and using common sense in the choice of naming objects and variables. This made the coding step dependent on the project team’s own experience and knowledge of coding and their ability to *learn-by-doing.* Considering this, the coding step is in total reliant on the project team’s skills in programming. As coding is considered one of the most time-consuming steps in a simulation study, it is of great importance that the employer, or as in this case, the top management team has a flexible mindset towards deadlines and time-plans.

To increase the efficiency in the coding phase in this case study, the top management team might provide support internally or consultation from external players in the simulation field. The choice of simulation software has also a great impact on the coding step, since some VIMS do not require any programming knowledge at all. Education of project team in the use of a specific software will probably increase the time efficiency of a simulation study.

The coding phase did not include the factory management team significantly, since it was mainly a process of putting the conceptualized model into code. Thus, there are no competencies needed for the factory management team in these kinds of large complex simulation model projects. Although, theory suggests that involvement with the client improves the credibility of the model and the chance that the results are trusted for decisions increases. This should create an incentive to include the client in the coding phase. In order to include the client in this phase, there are two ways to go. One way is to use a team from the client’s side that is educated in software engineering or required to have these competences. One other way is to use a simpler, more visual and user-friendly software, VIMS, that can be used to make so called “quick-and-dirty” simulation models together with the client who is inexperienced in simulation and software engineering.

5.1.5 Verification

Competence-wise, the verification step was closely linked to the coding step. The verification step required that the project team had an understanding of how the code behaves when executed. The main difference in competencies required when verifying the code was that verification also requires knowledge in the real-system itself. The choice of verification methods was a combination to cover the full model's complexity.

Most errors found in the code were solved by simply having more than one person to check it. The quality of the code was by this increased significantly by having an extra person checking it and the possibility to reuse the code could be considered higher. Still, as in this project, the introduction of two people during the coding process with cross-checks once in a while could be a source of inefficient verification and coding since errors might come from different code-writing personalities. With the help from structured coding and a pre-structured way of naming objects and variables, problems from involving more than one person in the coding was avoided.

When inserting a single load into the model, knowledge about the real production system were of great value. The prints provided by a single load indicated that the data collected, including routing, cycle times and setup times were in fact true also in the model. As previously mentioned, having an understanding of whether routing decisions and other parameters, helped in the verification when using a single load. Mainly, the help came from knowledge of how loads are processed and in what time frame they were expected to be processed in. Verifying without this type of knowledge is, of course, also possible but would require a larger amount of time to be able to check many single loads.

When comparing the coding step and the verification step, it was found that the verification step was very intense for the project team, meaning that it requires a lot of effort from the project team and less from the factory management team and the top management team. The verification step could involve the factory management team, if they hold software engineering competencies and are involved in the coding step. However, it can be considered unlikely that a buyer of a simulation project possessing such knowledge would hire a consultant to conduct tasks that can be performed in-house. If the unlikely event of hiring in such a situation occurs, it should be seen as even more unlikely that the competence is present during the actual project, indicating that the verification must be performed by the project team alone.

5.1.6 Validation

The choice of validation outputs decided on by the factory management team were very much welcomed by the project team due to previous experiences in working with the decided outputs. Preparing the validation sheets in Excel in advance gave the project team sufficient time for evaluation and correction of details in the model.

The actual validation of the model could be considered quite chaotic. The fact that the project team and the factory management team had only met once before, and that a lot of work had been performed in-between the two meetings, made the validation even more difficult. At this point, it was revealed that a lot of information that was gathered in the earlier data collection step, was either wrong, incomplete or interpreted in a wrong way. This points to that the validation step should be an iterative procedure throughout a simulation study, which is also suggested in theory (Banks, 2004).

Performing the validation as an iterative or continuous process could be considered difficult due to the distance between the project team and the factory management team. Also, the factory management team were occupied by other tasks and projects. Validating using online media could be an option, but in a case like this, it would be impossible due to the low experience from both sides and the complexity of correcting and modifying until the simulation model is validated.

The parameters that were used to validate machines' states lacked context for the factory management team since they had never worked with the measurements before and could therefore not validate without education of their respective definitions. The ability from the project team to adapt the factory management team's own KPIs for resource utilization were poor, since the circumstances around them were input manually in a manner that could not be simulated. The KPIs for resource utilization at the factory were set up to serve on an operational or possibly on a tactical level and were not suited for simulation validation.

Taking the many difficulties in validation parameters into consideration, the project team invented parameters with the "lowest possible denominator". A clear example of this is the buffer sizes validation. The factory management team were used to measuring the buffer levels either by looking manually on how filled a certain inventory is or by checking other connected resources' performance-reports. To simplify the validation with the factory management team, the project team introduced square meters as a measurement for buffer utilization. Still, the factory management team were not used to measure their inventories in square meters, but the easy-to-understand unit of square meters made the validation of buffer levels prodigiously painless.

As a prerequisite, the time consumption for a simulation study should be considered, especially when performing crucial steps that requires personal meetings such as validation. If there is insufficient time, a simulation study might not be appropriate. From the validation step of the case study, it became clearer that the time aspect of a simulation study should be considered with care.

Competencies that are basic to a validation are, of course, the knowledge of how the factory is performing with regards to basic measurements such as lead time, buffer levels and resource utilization. This applies to both the project team and the factory management team. If the factory management team's competence in this area is non-existent, it should be considered a prerequisite that the organization catches basic performance measurements in an easy-accessible information system. Considering higher levels of or more complex performance measurements when conducting simulation studies might be difficult since many basic factors impact on the final measurement, making the source for impact difficult to trace.

5.1.7 Experimentation

The design of experiment was very quick to do, as it was a direct result of the problem formulation. Also, during the conceptualization and the validation, the project team had acquired lots of process understanding to further generate experimentation ideas. The choice of design of experiments was mainly motivated by the complexities of the real system and that the possibilities of introducing additional machineries for increased capacity were considered low. Therefore, the focus on the design of experiments were to evaluate potential performance increases from maintaining or trimming machines to produce faster or to break down less often.

The choice of including the optimization tool when experimenting could be considered a great time saver as experiments can be performed in an automated manner. Still, conducting experiments without any such tool would also be possible, but requires more time to analyse production runs to avoid unnecessary and time-consuming additional runs.

Experimenting with an optimization tool with the decided design of experiments made the experimentation step very easy for the project team. In order for the optimization tool to function as intended, the only measure necessary to take was to adapt the code to the optimization tool's syntax.

From the empirics, it was determined that most of the work in the experimentation phase was done by the project team. The only thing that the factory management team needed to provide was alternatives to test in the model. The alternatives were even possible for the project team to determine, although they should be of a feasible quality and easy to test for the project team. When elaborating whether the factory management team could have helped by being more involved, the authors concluded that the if the project team and the top management team had presented this opportunity, the factory management team would have been more involved. Just as according to theory, the more the client, in this case the factory management team, is involved in the experimentation, the higher is the chance that the results will be used in decision making (Monks, Robinson, & Kotiadis, 2014).. Seeing as it is the project team's responsibility to create high acceptance leading to high involvement from the factory management team, the only thing that can be considered a prerequisite for the factory management team is to provide feasible scenarios to test. The factory management team should have good process understanding regarding which alternatives are reasonable, and which are too expensive or complex.

Results derived from the optimisation tool might be very complex. It is therefore crucial that the top management team has an open mindset when introducing the use of an optimisation tool. Also, experiments might reveal uncomfortable "truths" that might be difficult for the top management team to take in. From the project conducted, it was found that certain experiments that were of interest to the top management team were not as successful as expected. Considering Banks' (2004) statement on whether to conduct a simulation study or not, the expectations from people or organisations involved in the project should not be too high.

5.1.8 Documentation

The documentation of the different processes in the simulation study was considered of less importance throughout the project. Considering the complexity of the project, documentation could be regarded as a key component due to the potential time savings and the increase of credibility of the project as a whole. The documentation also enables the simulation study's model to be reused by other people than the project team themselves.

Documentation in this project was easy to overlook since it was not a main task of any kind and did not immediately impact on the project's quality in short term. Taking this lack of proper documentation into account along with the time plan of the project, it could be expected that if proper documentation was conducted, many errors and difficulties could have been solved faster and thereby save precious time.

Inventing documentation in a simulation study as a primary task, equally important as the other steps of a simulation study, both the quality and the possibilities to reuse every step of the progress could be significantly higher. Considering the traceability of data, documenting at a level that enables reuse of the simulation model would also enable full transparency of data. By being able to trace the origin of data the credibility of the simulation study can be considered higher and would furthermore increase the chance that the simulation model actually functions as a support during decision making.

Regarding what competences are required when documenting results and the progress of a simulation study, it is difficult to pinpoint what is actually required. Certainly, knowledge of how to conduct a simulation study also enables the conductor to document what he or she has done during it. Still, documentation can be regarded as more sophisticated than simply taking notes on what has been done in a project or a process. From the project, it was found that documentation of both results and the progress were of significant value, and if it was performed in a pre-determined and well-defined manner, the overall time and cost performance of the progress and the results of the project could be higher.

5.2 Identified Competencies and Prerequisites

All the identified competences and prerequisites from the simulation project conducted are presented in this section. In the following sub-sections, the competencies and prerequisites identified are explained along with how and when the competence or prerequisite is applied in Banks' (2004) methodology for simulation studies. The competencies and prerequisites identified may be used in several of the steps in Banks' (2004) methodology for simulation studies and its appliance is described for each time it appears in the simulation progress. Competencies and prerequisites identified may be shared also between the units of analysis. The relative importance between competencies or prerequisites applied in several steps or by several units of analysis is not regarded.

Some competencies are defined by comparing with Derwik, Hellström & Karlsson's (2016) manager competencies in logistics and supply chain management, while other competencies are defined with the support from other parts of the theory chapter that focuses more on DES application.

5.2.1 Time

Time considers that there is enough time allocated to the simulation project. Time could be considered a key prerequisite due to the nature of the simulation project. Complexities and other circumstances may have emphasized the need of having a lot of time resources.

Time is a prerequisite throughout a simulation study. According to Banks' (2004) , a simulation study is dependent that several conditions are met in order to be successful. Conducting a simulation study could be considered a highly resource demanding task, which requires more than an extensive amount of time and a high budget. By possessing the right resources and the right amount of it, the option of conducting a simulation study could be evaluated further as other competencies and prerequisites are required for a successful DES application.

The time prerequisite was found to be used in every step of the simulation progress. However, the quantity or amount of time devoted to each step were different. Still, time can be considered a key ingredient in a simulation study. The time prerequisite emphasizes the need to allocate the time resources throughout the steps of the simulation study. For example, for the factory management team, time considers that people involved in the team can allocate sufficient time to fulfil each of the steps. This also applies to the top management team, whom must allocate time to the project as a whole as well as personnel allocation.

In the first step of the progress, when formulating the problem and setting the objectives, time needs to be allocated to fulfil the mission. The most time consuming steps in this project are considered to be the data collection and the coding step, while other steps required less time. The project's time consumption in the data collection step and the coding step is not surprising, as (Perera & Liyanage, 2000) implies that gathering of data might take up as much as 40% of a simulation study's total time pool and Banks' (2004) implies that coding is one of the most demanding steps knowledge-wise. However, Robinson (2015) suggests that determining the model content in the conceptualization step of the real system is one of the most demanding challenges in a simulation study. Still, in the project conducted, the conceptualization of the real system did not require as much time compared to the data collection and the coding step. The top management team is the one who employs the factory management team and the project team and should therefore be the one to allocate time.

5.2.2 Money

Money considers many aspects, such as personnel, consultants, software, hardware and other things that can be purchased or acquired through payments. Money was allocated from the top management team to the simulation project in the form of travelling, software licenses and supervisor’s payroll. Money was considered a prerequisite to begin the simulation project and was needed in every step of the project. Money is largely connected to the amount of time allocated to the specific steps, although certain activities require more resources such as in the beginning of the project for licences and traveling costs, as well as traveling costs for the validation and experimentation phase which should involve the factory management team as much as possible. For the data collection phases, the money covers software’s for analysing large quantities of data as well as cover the time spent analysing and collecting data. In the same sense, money should cover DES software licences for the coding phase and the project team’s payroll in this time-consuming phase. The conceptualisation phase was considered less resource demanding in both time and fixed costs, than the other phases since it was only carried out by the project team and did not need specific software’s.

5.2.3 Company Specific Methodology

The existence of a methodology is considered to be a physical asset and is therefore a prerequisite. The methodology includes detailed standards and best practices such as in PartiSIM (Tako & Kotiadis, 2015) on how to conduct a simulation study as efficient and effectively as possible within the company, or possibly industry, borders.

The prerequisite of possessing a methodology is found to be advanced to a simulation study, and should be acquired by selling organizations’ top management team. The application of such a methodology should be carried out by a project team conducting simulation studies or projects, which of course requires the project team to hold competence in applying methodologies. Methodology as a competence is however not regarded in this paper, since it is expected that any project team conducting a simulation project should be able to apply any simulation methodology.

From the project conducted, a standardized methodology for a simulation study within the organization may have aided the project team in the project’s progress, resulting in less time consumption and furthermore cost for every step om the simulation study.

A company-tailored methodology for simulation studies was considered to be useful for every step of the simulation progress. Most importantly were the first steps of the simulation study, since the project team lacked experience in how to conduct any project in the first place. If a methodology, including clear steps of how to perform certain tasks within the steps in Banks’ (2004) simulation methodology, was applied the project team’s progress might have been easier and less resource and time demanding. An example of what could be included in such a methodology on the first steps in the simulation progress is detailed approaches on how to generate a problem or how to set an objective as efficient as possible. Another example could be on how and where from to retrieve correct and high quality data as fast as possible, how to structure code accordingly and how results should be presented.

5.2.4 Capturing of Data

Capturing of data was considered one of the key identified prerequisites for the project conducted. The capturing of data includes the previously identified resource of money, but stresses the application of a certain resource. In this case, the use of an information system to capture and store important information that can be valuable for simulation studies. The capturing of data includes the components of monitoring basic data, possessing high quality data and easy-accessibility of data. The prerequisite of monitoring data and having the possibility to retrieve it was found in the data gathering phase as well as the validation phase and should be provided by the factory management team.

This project would have been impossible to perform if no data was collected in the factory. In this project, there were many occasions were data was limited and assumptions were made, which risks the credibility. If less data would have been accessible, it would have been too many assumptions to determine the model to be credible. From the theory it was found that a simulation project should not be performed without lots of stored data (Banks, 2004), and the empirics from this study suggest that if data had been more available for the project team , these kinds of projects will be carried out more efficiently, which would also be of financial benefit for the customer. This area can be divided up into the most fundamental prerequisite of storing most relevant data, while a more advanced prerequisite is to have the data easy accessible for the project team members.

A prerequisite for validation is that the factory management team possesses some sort of information he or she can use to validate whether the simulation model can substitute the real system. The information does not necessarily need to be captured in an electronic system; it can be stored in the client’s own mind (Robinson, 2015). As it was in the project conducted, lots of validation details came from the factory management teams experience while only some basic KPIs that were retrievable from information systems were used. KPIs such as MPA, average lead time and WIP were in particular important to capture to enable a validation of a project’s simulation model. If there is no data captured and stored from the real system, the validation of a simulation model could be considered impossible. It was in this case possible with only a handful of KPIs although the credibility and efficiency of the validation exercise will increase with more data.

5.2.5 Communicational Ability

The competence of communicational ability was found from the empirics to be of great value to the project success. From the project conducted, the communicational ability was only considered a project team competence, meaning that the factory management team and the top management team are isolated from having the competence of communicational ability. The project’s success was not considered as strongly dependent on the factory management team’s communicational ability compared to the project team’s. This is an assumption of the setting of most simulation projects, where the supplier of the simulation study is expected to possess a greater knowledge in the simulation field compared to the buyer or the seller.

The communicational ability emphasizes the need of educating and involving the factory management team in DES. This requires the project team to hold competencies in the field that he or she wants to educate the client in, but also all the behavioural skills found in Derwik, Hellström & Karlsson’s (2016) manager competencies in logistics and supply chain management. The communicational ability also stresses the ability to make appropriate choices of communicating media which can be compared to Derwik, Hellström & Karlsson’s (2016) competencies of basic technological skills, company experience, and information sharing. Lastly, the communicational ability incudes good presentational skills, which requires the skill of information sharing identified by Derwik, Hellström & Karlsson (2016).

The communicational ability can be identified in many steps of the simulation study’s progress. Some steps disregard the need for communicational ability since they can be considered heavily demanding on the project team’s other capabilities and does not require any communication with the factory management team or the top management team. How the communicational ability was needed in different steps is described below.

Firstly, the communicational ability could be considered extra important to the first step of *formulating the problem and setting of objective* since the project lacked a problem definition and objective, which forced the project team to find one themselves. The communicational ability in the first step was also expected to make the factory management team more involved from the beginning and therefore increase the probability for further collaboration in the upcoming steps. In the *data collection step,* the communicational ability was applied to make the factory management team understand what data was needed and how its quality impacted the conceptual model. In *the conceptual modeling step*, an important aspect is to make the factory management team involved in the conceptualizing, because the factory management team has valuable knowledge regarding which simplifications can be made and what decisions are important to consider. In the *validation step* it is essential for the project team to assure that the results of the model are presented in a matter that the factory management team can understand. The project team should function as a middle ground between the model and the factory management team's reality because it is they who holds the information required to validate the model. Furthermore, when the factory management team is insecure about a result, it is the project team's responsibility to educate the factory management team in how the result should be interpreted. In the *experimentation step*, the communicational ability was important in the sense that project team needed to suggest testing scenarios and present findings and outputs. Furthermore, the project team needs good communication skills to involve the factory management in the design of potential scenarios. By involving the client in the experimentation phase the likelihood of a successful project is higher as the findings from the project can be considered more credible and therefore more likely to be used for decision making (Monks, Robinson, & Kotiadis, 2014).

5.2.6 Open Mindset

An open mindset emphasizes the basic prerequisite of having an open point of view to simulation studies and projects. The open mindset is only regarded to the factory management team and the top management team since it is expected that the project team already has some DES knowledge before the project is initiated. An open mindset stresses the need of being flexible with resources and the acceptance of potentially quick circumstantial changes. Being flexible towards resources emphasizes the need of making generous time plans and other unexpected events that might occur. Accepting circumstantial changes emphasizes the ability to switch focus quickly and to manage expectations which is stressed by Banks' (2004) as a prerequisite for simulation studies.

From the empirics it was found that the mindset of the top management team and the factory management team were of great importance in the project. This prerequisite, should be regarded almost as crucial as time and money. The open mindset is especially important when simulation is a new field for an organization. The top management team or the factory management team may not have the insights regarding the difficulties and challenges of conducting a simulation study. Having an open mindset should be considered a basic prerequisite for DES application, as well as any other new application within any company or organization.

The prerequisite open mindset was identified to be valuable in every step of the simulation progress except for the verification step. When *formulating the problem and setting the objective* the result from this step might end up different than expected. It was therefore important that the factory management team and the top management team managed their expectations and accepted circumstantial changes. In the *data collection* step, an open mindset regarding sharing of licenses or sharing of sensitive information might have helped the project team. From the *conceptual modelling* step, there was an identified need for the factory management team of accepting circumstantial changes in the sense of inclusion, exclusion, assumptions or simplifications of certain parts of the process. The top management team were also required to be flexible towards resources since conceptual modelling requires many trade-offs regarding level of detail and cost. From the *coding* step, the top management team has to understand that coding can be very time demanding. During the *validation* step, an open mindset with regards to acceptance of circumstantial changes were of great value for the factory management team and the top management team, as the project team presented validation outputs differently compared to company standards. The top management team were also in this step required to be flexible towards resources with emphasizes on time. From *experimentation* step, results derived from the project team's different tests might be uncomfortable for the top management team and the factory management team. By having a high level of acceptance regarding circumstantial changes, the project's progress was simplified.

5.2.7 Documentation Skills

Documentation was identified as a competence crucial to the conducted project's success. Documentation should preferably be conducted in every step in a thorough and clear manner, to simplify the simulation project's progress. The difficulties regarding documentation are many. However, by overcoming the difficulties, it was found that there could be substantial gains with regards to cost if documentation is carried out appropriately. Still, there are no clear suggestions in this paper on how to document in an efficient and effective manner. Although some information in certain steps might exist only in a simulation analyst's own mind (Robinson, 2015) this competence emphasizes the need of proper, straight-forward and structured documentation in writing in the simulation study.

5.2.8 Process Mapping

Process mapping describes a person's ability to create a map of a process. This requires the competences of analysis and production identified by Derwik, Hellström & Karlsson (2016). This project team's competence was identified in the first step *problem identification and setting of objectives*. From the empirics of this paper, the development of a detailed process map of what is going to be involved in the simulation study aided the project team when formulating the problem. Furthermore, having a detailed process map also simplified other steps such as coding and conceptual modelling by serving as a communicational tool. Despite being used in only one step; the process map is an important feature that should not be neglected.

5.2.9 Systems Analysis

The competence of systems analysis requires the ability to study a system, analyse it and to describe its underlying functionalities through the use of industrial experience, analysis, modelling and optimization. Systems analysis is a fundamental project team competence found in the steps of conceptual modelling and validation. In the *conceptual modelling* step, systems analysis is applied when analysing the real system with all of its complexities and interpret the system into a conceptual model. This competence is also applied in the *validation* step as the project team were required to fully understand the conceptualized model's complexities.

5.2.10 Process Understanding

Process understanding is a wide area and is similar to systems analysis but without the analytical ability. Process understanding is the ability to understand and explain a process on an operational level. The process understanding involves several of Derwik, Hellström & Karlsson's (2016) identified manager competencies such as industrial experience, company experience, commercial awareness, basic technological skills, supply chain management, order management, production, warehousing, and all applied supply chain management analysis competencies. From the project conducted, the competence of process understanding was shared from the factory management team to the project team through meetings and information sharing.

From the carried out project, the competence of process understanding was mainly identified as a production process owner competence. The competence of understanding the own production process is the foundation of a simulation study.

The factory management team's process understanding was identified in the steps of *problem formulation and setting of objectives, conceptual modelling* and *validation.* The project team is expected to possess the competence in the *experimentation* step.

When *formulating the problem and setting the objectives* process understanding was valuable in the sense that the factory management team had a good understanding of their own processes shortcomings, which helped to identify a problem. The setting of objectives was also simplified through the competence of process understanding due to the factory management team's knowledge of what KPIs are important to increase performance on. In the *conceptual modelling* step, the factory management team's process understanding simplified the trade-off on whether to include, exclude or simplify certain parts of the process and in particular how such simplifications should be designed. In the *validation* step, the process understanding was of great importance as the project team did not manage to generate validation outputs that the factory management team were used to. With competence of process understanding, the factory management team were able to validate the simulation model based on other KPIs or validation outputs than the ones they were used to. From the *experimentation* step, the factory management team's process understanding helped the project team in coming up with feasible scenarios that were considered of interest to create experiments on. The project team's increased knowledge from previous steps conducted qualified the project team to also suggest such scenarios, indicating that the process understanding is also a competence that the project team can possess.

5.2.11 DES Application

The competence of DES application involves the knowledge of identifying a DES applicable problem, DES software knowledge and ability to identify DES applicable data. The knowledge is considered fundamental to a simulation project. Identify a DES applicable problem requires insights in the DES field and ability to evaluate whether a stated problem can be simulated or not. DES software knowledge includes the awareness of how steps in the simulation progress impact on the used simulation software. Ability to identify DES applicable data emphasizes the ability to know what data is useful when conducting simulation studies.

From the step of *formulating the problem and setting of objectives* the project team were required to evaluate the possibilities of using DES as a solution tool. Since Banks (2004) suggest that this step also can be conducted by the buyer of the simulation study, this competence could also be of value for the factory management team if they are formulating the problem. From the *data collection* step, the competence of identifying DES applicable data was valuable to the project team. This included the knowledge of what data can be used in the simulation model. For example, the competence of identifying DES applicable data helped reveal the correct MTBF/MTTR data that in the beginning was difficult to collect due to monitoring issues from the factory management team. The competence can also be applied to the factory management team who supplied the data to the project team. This would enable for faster and more convenient data collection, since the project team would not have to validate incoming data in the same manner as in the project conducted. In the *conceptual modelling* step, DES software specific knowledge was identified as a project team competence. This competence stresses the need of understanding how the conceptual model can be interpreted in the further step of coding by using a DES software.

5.2.12 Software Engineering

Software engineering is a competence that was identified from the project conducted. This competence is strongly correlated to the project team’s ability to interpret a specification to a program, which emphasizes the ability to use coding language. Coding a program and interpreting a specification can be compared to cognitive competences in analysis and problem solving found in Derwik, Hellström, & Karlsson’s (2016) identified manager competencies in logistics and supply chain practice as well as functional competences connected to the DES software.

In the project conducted, the software engineering competence was identified in the steps of coding and verification for the project team. From the *coding* step, software engineering was used to interpret a specification, which in this project was the conceptual model, into computerized code. In the *verification* step, software engineering was a competence that was identified and was used to test whether the computerized code worked as intended.

Considering software engineering as interpreting a specification it is likely that the quality and speed is strongly proportional to the project team’s experience and knowledge in the field. This could imply that the level of the project team’ competence in software engineering must be on higher level if the simulation study has a tight time plan.

5.2.13 Mathematical Statistics

Mathematical statistics was found to be a stand-alone competence which emphasizes the ability of applying statistics in certain steps of a simulation study. Mathematical statistics can be used for analysing interarrival times and to test significance of simulated results. Mathematical statistics requires the competencies of analysis and basic technological skills identified by Derwik, Hellström & Karlsson (2016).

The competence of mathematical statistics was identified in two of the steps in Banks’ (2004) simulation methodology; in the data collection and in the validation. In the *data collection* step, interarrival times of products, breakdowns or people were analysed, which requires the competence of mathematical statistics in order to create statistical distributions fitted to the data set. In the *validation* step, mathematical statistics can be used to test whether simulation outputs are significantly correct compared to the real system output. The project team should possess this competence in these steps.

5.2.14 Data Handling

Data handling was identified as a project team competence in the project conducted. Data handling requires the ability of dealing with large amounts of unstructured, unfiltered or incorrect data retrieved from information systems or specialists. From Derwik, Hellström & Karlsson’s (2016) manager competencies in logistics and supply chain practice, data handling can be described as a combination of basic technological skills and information systems. The competence of data handling wasidentified in the data collection step of Banks’ (2004) simulation methodology.

In the *data collection* step the project team must be able to structure and analyse data to check if more data is required or if the quality of the data is poor. This competence is considered fundamental to a simulation study, since simulation studies might include a lot of data (Banks, 2004).

5.2.15 Ability to Make Assumptions and Simplifications

The ability to make simplifications emphasizes the need to simplify complex situations or systems, that are relevant to the simulation study's progress. Since simulation always includes the trade-off between level of detail and model accuracy (Robinson, 2015), a discussion regarding simplifications is always needed. In the empirics, it was determined that an ability to make assumptions is needed by both the project team and the factory management team in the stages of data collection and conceptual modelling. For the project team, it can be considered the responsibility to make the right assumptions, which will be much connected to the project team's experience in the field, while the factory management team will be forced to look at the system in a new way.

In the *data collection step*, the data that is requested from the project team might not be available, which forces the second-best alternative of retrieval which is to let the factory management team assume it. Considering the credibility, letting the factory management team assume data should increase the overall acceptance and the credibility of the model, compared to if the assumptions were made by the project team. On the other hand, some assumptions or simplifications might be difficult for the factory management team who has limited experience in the DES field, forcing the project team to make the assumptions. Similar to the data collection step, the *conceptual modelling step* requires the project team and the factory management team to work together to create simplifications and assumptions.

5.3 Identified Categories

From the project conducted, several categories of competencies and prerequisites could be identified. The distinct competence and prerequisite categories found are the following; resources, project management, operations management and analytical abilities. Competencies and prerequisites identified from the project conducted are put in to its respective category depending on the competence or prerequisite characteristics. Competencies found in each category share some similarities, which is described in the naming of the category. Competencies that are put into a certain group may still overlap in two or more other categories, but with its main weight in the category suggested.

5.3.1 Resources

The first category involves basic resources that may be needed when conducting a simulation project. From the project conducted, resources are found at the top management team and the factory management team only, meaning that the project team cannot possess resources. The resources are prerequisites for a simulation study. The contents of the resources category were identified as time, money, methodology and capturing of data.

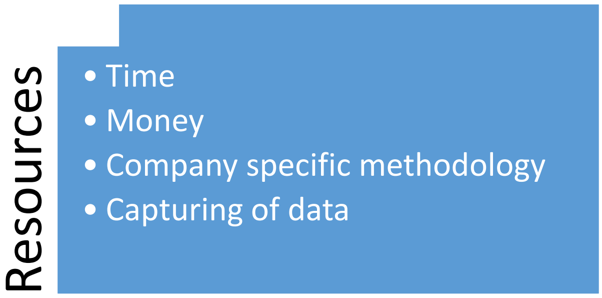


Figure 11. The category of resources.

5.3.2 Project Management

The second category emphasizes the need for project management when conducting a simulation project. Competencies or prerequisites that are included in the category all have characteristics that can be related to project management, The category includes the competencies communicational ability and documentation skills and the prerequisite open mindset.

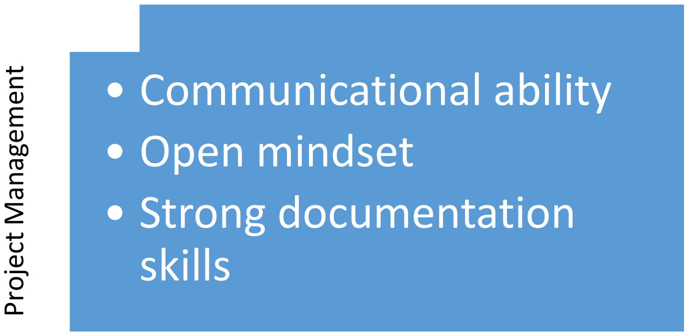


Figure 12. The category of project management.

5.3.3 Operations Management

From the project conducted, expertise in operations management was identified as a category. Operations management stresses the need of understanding the operations in the system and the ability to use the knowledge retrieved from the real system. The operations management category includes competencies in systems analysis, process understanding and process mapping. Systems analysis was found to be both an analytical ability and operations management competence. However, the main weight of systems analysis is considered to be in the category of operations management.

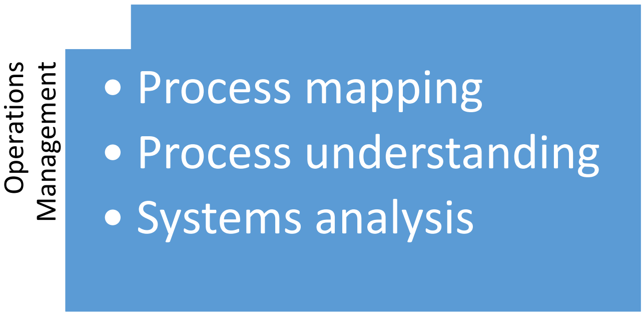


Figure 13. The category of operations management.

5.3.4 Analytical Abilities

The final competency category identified from the project conducted was the category of analytical abilities. The category stresses an individual’s ability to analytically approach challenges and to handle supporting disciplines that may be retrieved from other fields than the DES field. The analytical abilities category includes the competencies of DES application, software engineering, mathematical statistics, data handling and the ability to make assumptions and simplifications when approaching challenges.

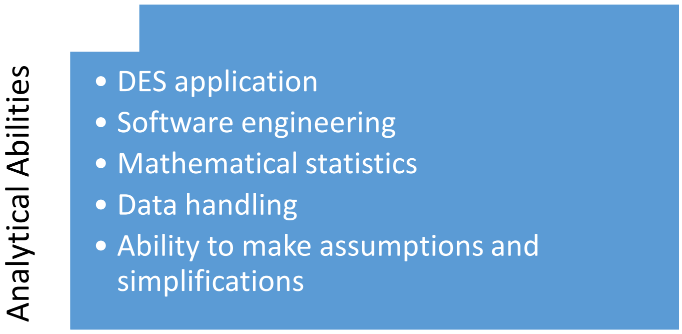


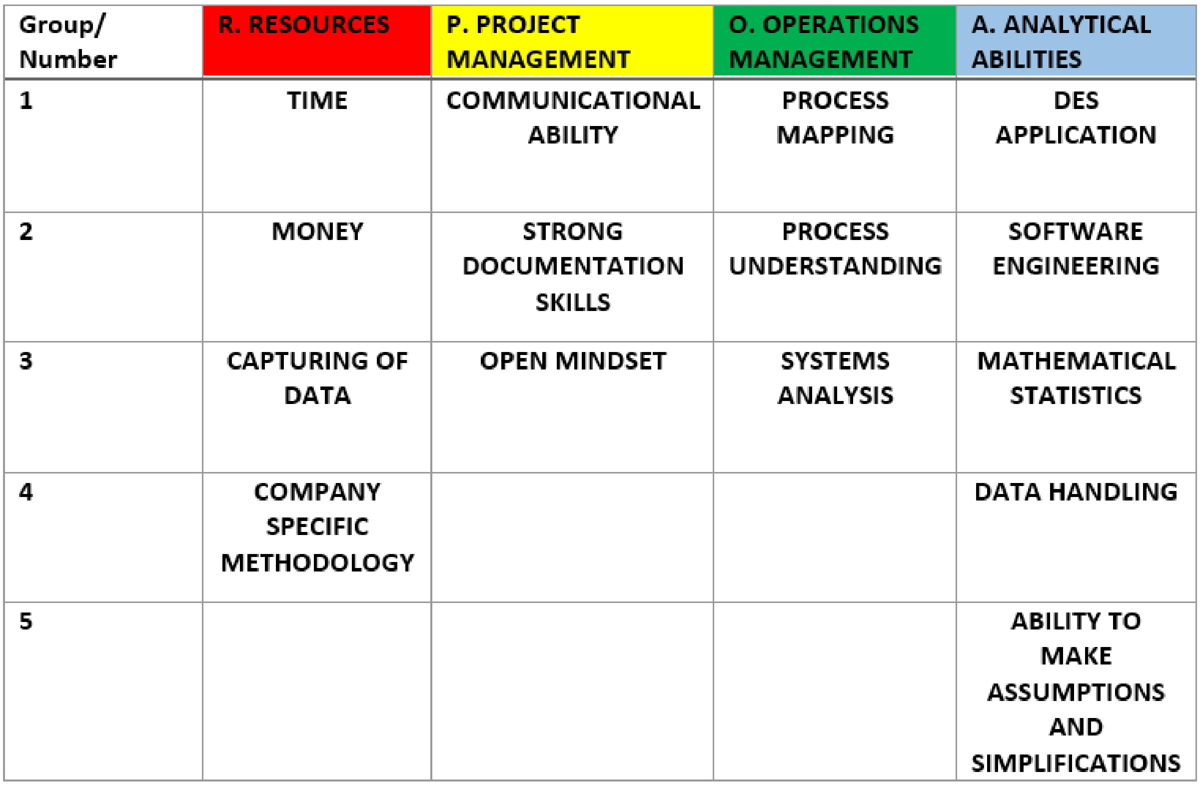
Figure 14. The category of analytical abilities.

5.4 Competence and Prerequisite Overview

To simplify the findings derived from the analysis, an overview of the competence and prerequisite situation was generated. The framework uses colour coding to further simplify what categories of competencies and prerequisites could be considered valuable for DES applications and where the categories are the most intense.

In Table 3 all the competencies and prerequisites identified from the analysis are gathered. Each category has a colour along with a number of the competence or prerequisite within the group.

Table 3. Categories, competencies and prerequisites overview.



Group/ Number	R. RESOURCES	P. PROJECT MANAGEMENT	O. OPERATIONS MANAGEMENT	A. ANALYTICAL ABILITIES
1	TIME	COMMUNICATIONAL ABILITY	PROCESS MAPPING	DES APPLICATION
2	MONEY	STRONG DOCUMENTATION SKILLS	PROCESS UNDERSTANDING	SOFTWARE ENGINEERING
3	CAPTURING OF DATA	OPEN MINDSET	SYSTEMS ANALYSIS	MATHEMATICAL STATISTICS
4	COMPANY SPECIFIC METHODOLOGY			DATA HANDLING
5				ABILITY TO MAKE ASSUMPTIONS AND SIMPLIFICATIONS

To further visualise what competencies and prerequisites are valuable in each of the steps in Banks' (2004) simulation methodology, an additional visualisation is introduced. In Table 4 each of the competencies and prerequisites within its respective category are presented on a time line which represents the steps in Banks' (2004) simulation methodology. Each of the competencies or prerequisites represented in Table 3 are the ones identified as facilitators for DES projects.

Table 4. Competencies and prerequisites identified in the step of Banks' (2004) methodology for simulation studies.

Unit of analysis / Step in Banks' (2004) simulation methodology	**Project Team**	**Factory Management Team**	**Top Management Team**
Problem formulation and setting of objectives	O1 P1 A1	A1 O2	R1 R2 R4 P3
Data collection	A1 P1 A4 A3 A5	R3 A5 A1	R1 R2 R4 P3
Conceptual modelling	P1 A1 O3 A5	O2 A5 P3	R1 R2 R4 P3
Coding	A2		R1 R2 R4 P3
Verification	A2		R1 R2 R4
Validation	A3 O3 P1	P3 R3 O2	R1 R2 R4 P3
Experimentation	O2 P1	O2	R1 R2 R4 P3
Documentation	P2		R1 R2 R4

As seen in the figure above, the top management team requires a lot of resources, while the project team and the factory management team requires a lot of analytical abilities, throughout the simulation progress. The purpose of using colour in the synthesises of what competencies and prerequisites facilitate DES projects, is that it simplifies the readability and creates a comprehensive overview of the competency and prerequisite situation.

6 Conclusion

In this chapter, the findings in the analysis are concluded and the research question is answered.

6.1 Research Findings

The categories, competencies and prerequisites identified, presented in Table 3, reveals the full spectrum of what competencies and prerequisites facilitate DES projects. Table 4 applies these competencies and prerequisites in Banks’ (2004) simulation methodology to create an additional dimension to the overview of where and when the competencies and prerequisites might be useful.

The separation of the units of analysis in Table 4 is very useful for an organisation interested in DES application to get a more holistic understanding regarding what to look for in the factory management team, the top management team and the project team. This framework provides a general understanding and since every project will be slightly different, it needs to be considered that these areas might overlap.

Overall, the findings demonstrate that beginning steps of a project require very many different competencies in a good combination, while the middle and last parts of the project require fewer and more specialised competencies. To give examples; the setting of objectives and the data collection steps require much cooperation and a mix of many competencies, while the coding and verification steps requires mostly coding skills.

6.2 Conclusions

In this section, the authors of this paper would like to conclude their four most significant findings on the research question. The first conclusion is that the categories presented in Table 3 provides a clear answer to the overall competencies and prerequisites that facilitates DES project. The second conclusion is that the major people involved in a DES project need to have good communicational abilities. The third conclusion is that the competencies and prerequisites are highly interconnected. One cannot say that one competence alone can make for a successful DES application, it is the combination of them that will lead to success. In a larger project than the one conducted in this paper, with a larger project team, the competencies would probably be divided among more involved people, creating even more demand for good communication. The last conclusion is that DES application is very resource demanding. The conclusions to the research question are listed and explained in the bullet points below:

- Categories
  In Table 3, the three categories identified as project management, operations management and analytical abilities are a general but accurate description of the competence or prerequisite

that facilitate DES projects, while the fourth category stresses that DES projects are facilitated by different kinds of resources.

- Communicational ability
  It was expected by the authors that communication would be of great importance. Still it is interesting that in such an analytical field as DES is, the communication is one of the most important things to consider.
- Combination of competencies
  The competencies identified in this paper have been separated to create a general overview, although it is important to point out that it is the competencies and prerequisites overlap in many ways and the combination of them that will generate successful DES application.
- Resources are required
  In the framework presented in Table 4, the colour coding shows the emphasises for resources. DES application will be very resource demanding and should be kept in mind for any organisation interested in it.

6.3 Suggestions for Further Research

Throughout the work carried out to generate this paper, several areas of further research were identified. Due to the limitations of this report and the project conducted, these fields were never explored or further analysed. The following recommendations for further research may be conducted through another master thesis or similarly.

The empirics of this paper does only cover one case study. For a study as the one carried out, it could be discussed whether a multiple case study would be more appropriate to conduct. However, there was no possibility for the authors to conduct several case studies due to the nature of its design. A multiple case study may aid in finding common denominators regarding what competencies and prerequisites are applied in every case which furthermore can aid in generalizing the findings in a broader perspective.

The company specific methodology identified as an advanced prerequisite would require a massive amount of research in order to develop it. The methodology itself should be tailored to fit the company so that simulation studies can be carried out with minimum efforts regarding resources, while maximizing the outcomes of the simulation study. These kinds of methodologies have already been developed in the healthcare sector such as in PartiSIM (Tako & Kotiadis, 2015).

Documentation is an area that is suggested for further research. The documentation in this project could be regarded as poor in the beginning and good at the end. The reason for the poor documentation was mainly that the documentation itself is never regarded in simulation study methodologies. Even if the documentation is regarded, there are no clear steps or syntaxes to follow. The suggestion is therefore to evaluate how documentation can be performed more smooth and convenient for the project team in a simulation study.

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