MASTER

Simulation as a training tool for logistics and manufacturing

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Master Thesis

Simulation as a training tool for logistics and manufacturing

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Abstract

This master thesis describes the use of simulation as a training tool for logistics and manufacturing. This involves the design of a training in which simulation is used for the purpose of creating a better understanding of the processes. A simulation tool is used to develop an active way of training for the Business Process Innovation department of DAF Trucks N.V.

The simulation in this paper describes a wide spectrum of manufacturing situations and demonstrated that high utilization rates result in high inventory and longer lead times. Secondly, the influence of batching and set-up times on performance measured in lead time. Finally, the simulation shows the effect of variation and failures on the performance of the production process. The training is designed from scratch following a design science cycle. Problem understanding includes identifying training needs, the design phase include formulation of training objectives, design of simulation model and the validation is done using an experiment with a test and control group. Participants have been interviewed after the training using a semi-structured interview based on Kirkpatrick's taxonomy of training evaluation.

Acknowledgements

This master thesis is the final product of my master Operations Management and Logistics at the University of Technology Eindhoven (TU/e) at the faculty of Industrial Engineering and Innovation Sciences and marks the end of a total study time of almost 8 years. I started my bachelor in Industrial engineering at the HAN university of applied science in Arnhem. After finishing my bachelor, I have moved to Eindhoven and started with the pre-master and master Operations management and logistics at the TU/e. After almost three years of studying, the thesis project started. The project is executed at the Business Process Innovation department of DAF Trucks N.V. located in Eindhoven.

The start of the thesis was tricky since the assignment was not really clear and I did not know what was expected of me. During the assignment it became more clear what was expected. The project was challenging but also enjoyable to carry out.

I would like to thank DAF Trucks N.V. for the possibility to do my graduation thesis there. Especially I would like to thank Janco Spiekhout for the supervision, help and support during the thesis. Also the colleagues of the Business Process Innovation department for providing a nice working environment.

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Auke Sijbesma
Eindhoven February 26, 2019

Executive summary

Introduction

This report is the result of a master thesis performed at DAF trucks N.V. located in Eindhoven at the Business Process Innovation department. One of the activities of the BPI department is sharing knowledge and provide training. Simulation models could contribute in a better understanding of complex and dynamic systems and processes. Therefore this thesis project is looking in how DAF could make use of simulation models in training about logistic and manufacturing related processes.

The goal of this project is to develop a simulation training and find out how a simulation training module for DAF operations should look like. The main research question is:

How should a training module using simulation look like in order to improve the training process at DAF operations?

Research methodology

The design science research methodology by Wieringa is used to guide this research. This framework consists of four phases. These phases are problem investigation, artifact design, artifact validation and implementation. The first three phases are included in this research.

During the project, a literature review is performed in the field of simulation in training and simulation in manufacturing. Together with 16 semi-structured interviews this lead to the input for the simulation training. A simulation model was constructed based on the training needs in the organization. This simulation model was used in a training in an experimental setting. A test group worked during the training with the simulation model, while a control group participated in the same training and did a case study. Afterwards both groups where interviewed to identify what the added value of a simulation model in a training situation is. A focus group was also held with participants from both groups, to find out what factors in the simulation worked and what could still be improved.

Results

While the control group found it quite difficult to do the exercises by hand and lost focus and motivation after a while. Both groups thought that an introduction to the topic was value added and contributed towards a better understanding of why this topic was being lectured and a better understanding of the topic itself. The learning was comparable between the two groups. Both groups where able to answer questions related to the training objectives and where able to identify aspects that where intended.Therefore, the developed simulation game seems to be an adequate means for improving the understanding of the behaviour of manufacturing lines and it motivates participants in the training more than without a simulation model. There are however some issues related to the use of simulation in a training. The first is that people are using the simulation model only as an kind of calculator to fill in the asked values and write down the results. But for a complete understanding one also needs to take the reasoning behind these values into account. Therefore a debriefing or test should be held during or after the training to check if the participants understand the relationships and reasoning and did not only fill in the answers to the asked questions. Secondly, the introduction was by both groups seen as an important part of the training, since it introduces the parameters and other topics that are treated in the exercise

Conclusions & recommendations

First, it is neccecary to review the needs within DAF operations. These needs for training can then be reviewed and checked if simulation is an appropriate approach to educate the topics. If so, the objectives for the training and the simulation model need to be formulated. Literature have to be reviewed about the topic in order to create a correctly model . The third step is understanding the process that is being modeled. A conceptual model can provide meaningful insights about the process and the simulation model. In a conceptual model the scope, details, input and output can be specified. It could be that there are still aspects missing in the conceptual model when constructing the simulation model. Therefore simulation modeling is an iterative process.

When the parameters, scope and level of detail are determined the model can be built in the selected application for example in Siemens Technomatix Plant simulation. For specific simulation software, practice or experience is needed to model in this software. The model has to be fed with all the parameters and the different relationships between them. Additionally, a convenient user interface should be build to make the application user friendly. In this interface input, the simulation model and output should be displayed in a clear way. Depending on the complexity of the model, a manual could be added to explain how to use the model. The model finally results in the objectives of the model and therefore the objectives of the training. The simulation model should be validated to check if the solutions provided are valid and reliable before the use in a training. This can either be done by comparing it to results from a real life process or an alternative model.

The simulation should be embedded in the training with information about the topic, explanation about the simulation model and the different scenarios that have to be executed using the simulation model. Also there needs to be a form of feedback during the training, so a participant knows what they are doing or how to interpret the results from the simulation. A build in function in the simulation could provide feedback, otherwise this could be done in the debriefing after the training.

Limitations

First, a limited amount of people took part in the training and in the interviews and focus group afterwards. Therefore the results could vary if a larger group takes part in the same setting. Secondly, there was no significant difference in the learning occurred between both groups. A pre- and post test could significantly find a difference in learning between two different learning methods, but was not conducted during this project.
Looking to the practical application of the simulation model, there are some limitations of the research. The designed simulation model consists of a manufacturing line of four stations, in which the participant can through an user panel select settings for the all

of the stations of the manufacturing line. Not all the concepts that apply in reality to a manufacturing setting have been taken in to account in the model. It shows the general relations between several parameters, but in reality a similar manufacturing line has to deal with a lot more variables and complexity, like worker availability, experience, maintenance and more diversity in products. Now these aspects may be added to the model later to create even more scenarios that can be used in a training. However one should consider the trade-off between time it takes to model such complexity, and the added value of this effort. The model was suitable for its specific purpose and training objectives.

Lastly, some recommendations for DAF have been done to research the use and possibilities of simulation more. The first recommendation is to check if simulation is suitable for other training objectives. The use of a model motivated participants in the training, indicating they are more likely to enjoy and remember the topics taught during the training. Secondly, the developed model could still be expanded with more possibilities so more 'what-if'scenarios can be simulated in the same model. The third recommandation is to do furter research on how to facilitate simulation training. For example: It can be applied in an e-learning module, but also lecture-based could be suitable for simulation training. Lastly, other uses of simulation model could be examined.

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1 Introduction

Organizations are increasingly using entertaining ways to train and motivate their employees. Work versus play. To bridge the gap between these apparent opposites, companies are now resorting to games that combine a serious purpose with an entertaining method. Serious games comes in digital, board or role-playing formats.(Guignier, 2018). Simulation have been used in a variety of environments in order to train employees like in healthcare and the military. The most well known simulation training is perhaps the training in aviation with a flight simulator.

In manufacturing, logistics and operations management simulation mainly has been used in order to support decision making. Simulation has not often been deployed for training purposes in the field of operations management. However, the possibilities of simulation for training seems great based on the usage in other markets. Therefore this thesis is looking in to the possibilities to apply simulation as a training tool in a manufacturing and logistic environment.

This chapter gives an introduction to DAF Trucks N.V. and the thesis project. Section 1.1 provides background information on DAF Trucks N.V. Section 1.2 shortly explains the Business Process Innovation department. Next, the problem context is described in section 1.3 and the research methodology is presented in section 1.4. The research methodology consists of the research questions, research method used, the scope of the project and the phases and deliverables. Finally, in section 1.5 the structure of the report is presented.

1.1 DAF Trucks N.V.

DAF Trucks N.V. (hereinafter referred to as DAF) is a subsidiary of the American PACCAR INC. and focuses on the development, production marketing, sales and service of middle and heavy company trucks. The main office of DAF is located in Eindhoven. The van Doorne family started DAF ("Van Doorne's Aanhangwagen Fabriek") in 1928 and started out as a small machine factory. Since 1949 the first cars and trucks where produced at DAF. After the bankruptcy in 1993 DAF was taken over by the American company PACCAR in 1996.

DAF produces three different models of trucks: The LF, CF and XF. For all of the models numerous configurations are possible. The LF is used for city transport and small distribution. The CF is an effective all rounder and the XF is used for heavy and long distance transportation. DAF has production facilities in Eindhoven (The Netherlands), Westerlo (Belgium), Leyland (United Kingdom) and Ponta Grossa (Brazil). The DAF-engine factory, sheet metal components factory, pressing and assembly lines for the CF and XF models are located in Eindhoven. The axles and the cabins are produced in Westerlo. Leyland produces the LF-series as well as the CF and XF models. All the products are produced on order and are customer specific. The main components needed for truck assembly are the engine, the axles and the cabin. The axles and cabins are produced in the axle factory and cabin factory located in Westerlo. The engine is produced in the engine factory in Eindhoven. All components come together in the final truck assembly in the truck factory.

The sheet metal components factory is also located in Eindhoven and supplies all the other factory with components needed in the production and assembly of components and sub-assemblies. Next to these main components, a lot of small parts are delivered by multiple suppliers. The delivery of all components are controlled with the just-in-time principle (JIT). They arrive at the time when they are needed in order to minimize inventory levels. In lean management systems, zero inventory is the ideal state. In an ideal lean system, a single piece of a product or service is moved through the value stream, completed, and delivered exactly at the time the customer demands it (APICS, 2011). A simple process flow of DAF is displayed in figure 1.

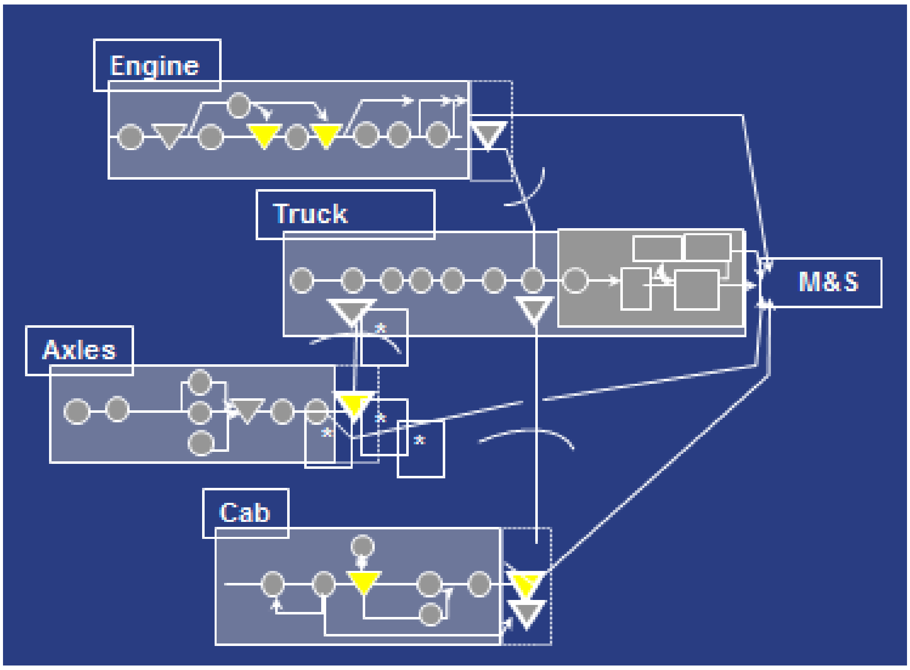

Figure 1: Simplification of DAF production process

1.2 Business Process Innovation

This master thesis project takes place at the Business Process Innovation Department (BPI) of DAF in Eindhoven. A visual overview of the departments of DAF and the position of BPI within DAF can be found in appendix A.

The BPI department is an indirect project-based department and belongs to logistics operations. The core activity of BPI is the performance of logistic and manufacturing improvement projects for multiple factories of DAF. In many of these projects it concerns the development of (new) concepts, tools or systems and processes. These projects are performed in close collaboration with several departments like production, logistics, purchasing, marketing and sales and the IT-Division. The BPI department has, among other things, the following defined knowledge areas:

- Logistic engineering
- Production engineering
- Capacity calculations
- Material control
- Transportation
- Packaging control
- Business Intelligence
- Supply chain management

The mission and vision of the BPI department is as follows: *"From a joint Vision, we direct the development of factory-wide and local Processes within DAF Operations, particularly in the field of Logistics and Manufacturing.*

We do this by implementing Innovation projects, supporting Continuous Improvement and the active development, training and guaranteeing of specialist knowledge."

1.3 Problem context

Design, improvement and the planning and control of the production processes are considered as complex processes. The engineers responsible for this are the production and logistic engineers divided over the different factories. The BPI department delivers the needed support and knowledge that is needed to improve and control these processes.

Currently there is no active way of providing this knowledge to the employees. Training is ad-hoc and unstructured if it is even available. This leads to the unavailability of manufacturing and logistic knowledge. Knowledge is not always documented, findable, complete, maintained, shared or actively offered.

The use of simulation could contribute towards a more efficient and active training and education process just like in healthcare and military training. Simulation is also considered to be a useful training tool because some of the concepts might be to complex to teach with other training methods. In order to facilitate training, this project is looking into the possibilities to simulate and visualize manufacturing plants and logistic processes for the purpose of better understanding and improving the processes. Options which may be selected are for example: Different system configurations that result in changes in performances and product flow, the throughput of the system combined with the availability of machines or the needed numbers and dynamics of KANBAN cards in a replenishment system.

1.4 Research methodology

This project can be defined as a business problem solving project. The specific problem is a design problem(R. Wieringa, 2009). In a design problem an artifact is created in order to improve something in a specific context. Table 1 represents an overview of the design problem used in this project. For the design problem four parts are needed: Problem context, the (re)designed artifact, the artifact requirements and the stakeholder goals.

Table 1: Design problem

Design Problem	
Problem context	The training process at DAF operations is unstructured and knowledge is often unavailable
(Re)designed Artifact	Method for training with simulation
Requirements	It should provide an active way of on the job learning
Stakeholder goals	It should help understand the complex processes and concepts in the field of logistics and manufacturing

This design problem formulated in the form by (R. Wieringa, 2009) is as follows:

Improve the training process by creating a model for simulation training, so that employees at DAF operations can learn concepts by using the tools in order to obtain knowledge and insight in various logistic and manufacturing concepts and processes.

1.4.1 Research questions

From the problem statement and the design problem the following research questions is derived:

How should a training module using simulation look like in order to improve the training process at DAF operations?

This research question is split up into more specific sub questions for each phase of the design science cycle:

Table 2: Research questions

Research questions	
Design cycle step	Corresponding research questions
Problem investigation	1. What simulation applications for training do exist in theory? 2. What is the current way of training employees? 3. What are the trainee needs within the organization?
Artifact design	4. How to improve the training process?
Artifact validation	5. What is the added value of simulation in a training situation?

1.4.2 Research method

Wieringa (2009) has proposed an engineering cycle as a research methodology to answer the practical problems. The cycle consists of four stages which are: Problem investigation, artifact design, artifact validation and artifact implementation.
For this research project, only a part of engineering cycle (design cycle) is implemented. The project does not include the final implementation phase of the engineering cycle. The steps of the design cycle (problem investigation, artifact design and artifact validation) are described briefly below. The research methodology is discussed in chapter 3 in more depth.

Problem investigation
The problem investigation is regarded as a knowledge question, since it asks for information and understanding about the given problem without performing changes. The problem investigation started with a structured literature review about training with simulations.The main findings of this literature review are presented in chapter 2. As described in the section 1.3, there is a lack of training for complex processes and simulation is considered a suitable tool to improve training.

Artifact design
The second stage of the design cycle is the artifact-design stage. This stage is mostly a practical problem that helps to improve the context for the stakeholder in a certain way. The main practical problem is to find what kind of artifact should be developed. This includes interviews to map the current way of providing training and mapping the training needs of the different departments. Guided by the literature review a process is designed in order to provide training with using simulation as a tool. This is the first iteration. The second step of the artifact design involves the selection of processes based on the training needs and identifying the training objectives. Subsequently working out these processes in conceptual models and simulation models so it can be used in the designed training process. This can be seen as the second iteration.

Artifact validation
The last iteration is done at the artifact validation phase. The artifact validation phase is a knowledge tasks in which it is established if the design indeed helps the stakeholder reach its goal. This will concern the testing of the designed simulation models in the training process. By performing a test with some of the designed models for training, feedback can be obtained about the design of the training, the simulation models and if simulation indeed improves the understanding of the complex processes.

To further guide the steps of the design cycle, the steps of performing a simulation study are used. This involves the following steps: Problem understanding (Step 1 of the design cycle), Conceptual modeling and Simulation modeling (Step 2 of the design cycle) and finally Validation and experimentation (Step 3 of the design cycle). This process is described in more detail in section 2.3.

1.4.3 Scope

This project focuses on the development of a training module with simulation of with the goal of better understanding or improving the business processes. Taking this into account the definition of simulation described by Robinson is used:

Experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time for the purpose of better understanding and/or improving that system (Robinson, 2004).

As stated in section 2.1, there is a lack of available training when it comes to complex processes. The artifact that will be designed is a training module using simulation to teach and train the engineers. This module can include basic knowledge and needed skills about the logistic and production processes, from inbound logistics following the production process to delivery of the end product (outbound logistics). Figure 2 visualizes the scope with the green box, based on Porter's value chain (Porter, 1985). These processes are explained in more detail below.

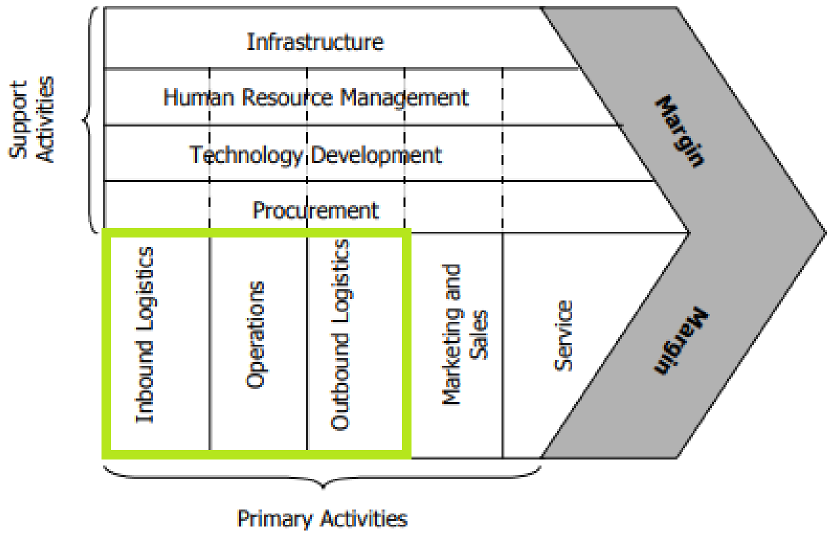

Figure 2: Visualized scope based on the value chain by (Porter, 1985)

- **Inbound Logistics:** Inbound logistics include activities associated with receiving, storing, and disseminating inputs to the product. For example: material handling, warehousing, inventory control, vehicle scheduling, and returns to suppliers.
- **Operations:** Operations, manufacturing or production activities are associated with transforming inputs into the final product form. Processes include: machining, packaging, assembly, equipment maintenance, testing and facility operations.
- **Outbound Logistics:** Outbound logistics include activities associated with collecting, storing, and distributing the product to buyers.For example: Finished goods warehousing, material handling, order processing, and scheduling.

1.4.4 Phases and deliverables

Based on the research method, three phases were identified in this section. These phases are visualized in figure 3. Each phase corresponds to the step of the design cycle by Wieringa. The deliverables are also displayed in figure 3 and will be briefly described.

First, in the problem investigation phase, a systematic literature review is performed providing the theoretical background. The literature review focused on the simulation methods used in training and is expended during this master thesis project with literature about training design, simulation modeling, logistics and manufacturing modeling and training validation. After providing the theoretical background, semi-structured interviews have been conducted to get an overview of the current situation and training needs. In the second phase, these training needs are translated to training objectives and worked out in conceptual and subsequently simulation models in order to provide the trainee with active training about the identified objectives. In the last phase, artifact validation, the created training is validated.

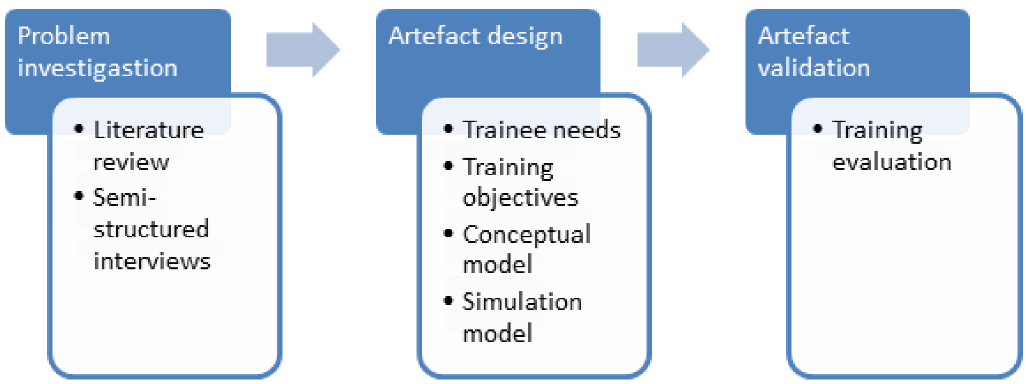

Figure 3: Phases and deliverables

1.5 Structure of report

The structure of this report is displayed in figure 4. Chapter 1, 2 and 3 and 4 presents the problem investigation. These chapters contain the introduction, the findings from the literature review, the methodology used in the project and the problem investigation. Respectively, chapter 5 and 6 contain the artifact design. Chapter 5 is about conceptual modeling. Chapter 6 describes the simulation models. Chapter 7 contains the artifact validation and describes the validation of the training module. Finally in chapter 8 the conclusions and discussions are presented.

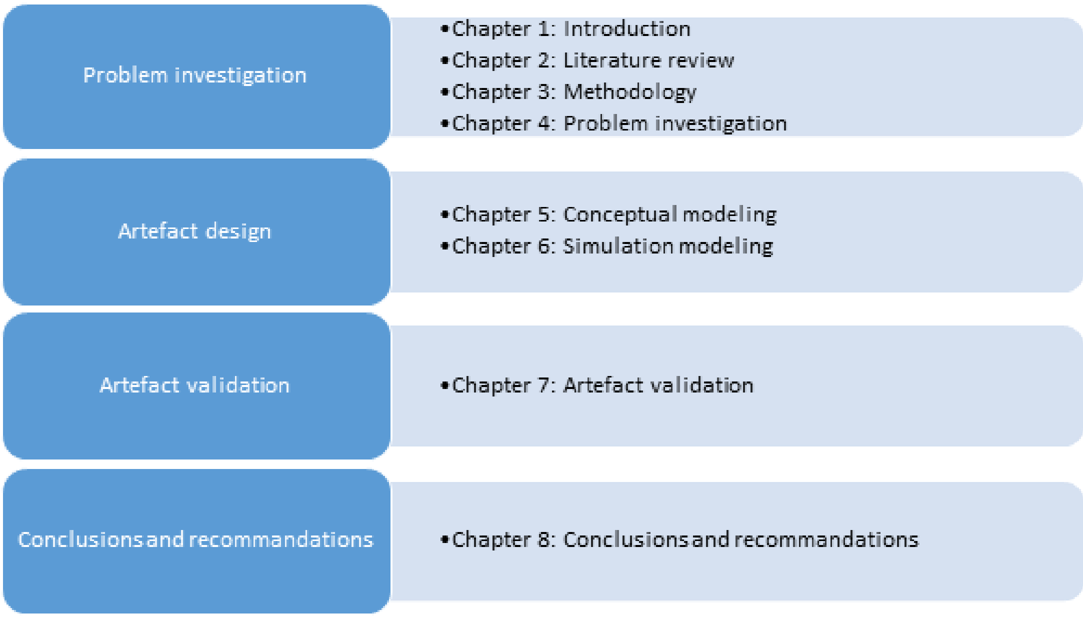

Figure 4: Structure of report

2 Theoretical Background

This chapter provides the theoretical foundation for the Master thesis and was conducted partly in advance and partly during the thesis project. First the main conclusions of the systematic literature review completed prior to this study are given in section 2.1. Then the chapter elaborates on what is written in literature about the following three parts: Training design, simulation modeling and modeling of manufacturing systems, and training evaluation. Training design will be discussed in section 2.2. In 2.3 and 2.4 simulation and manufacturing system modeling are discussed. And finally in section 2.5 the evaluation of a training is discussed.

2.1 Systematic literature review

Prior to this thesis a structured literature review was conducted (Sijbesma, 2018). Starting from a broad scope the research area was explored to gain insights in academic literature on the topic of simulation of processes in manufacturing industry and its applications. The research questions from the systematic literature review will be discussed here. In order to execute this structured literature review the method of (Kitchenham & Charters, 2007) was used. The steps of this method are displayed in figure 5. The research questions and conclusions are briefly discussed below.

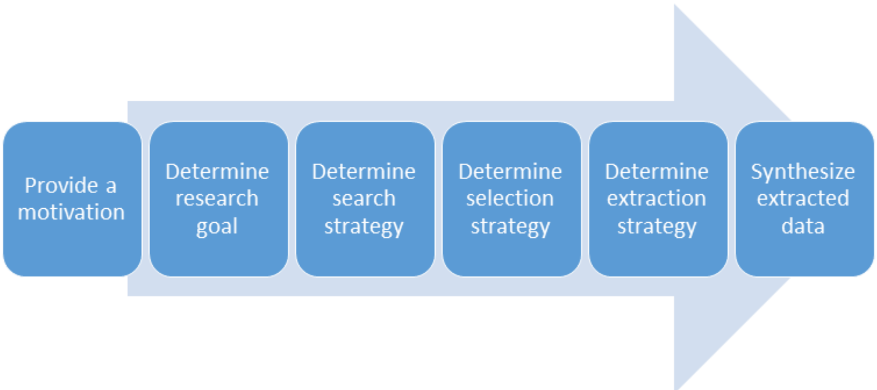

Figure 5: Review protocol systematic literature review(Kitchenham & Charters, 2007)

The goal of this literature study was to provide an overview of simulation methods used for training in a process environment. Simulation consists out of a broad spectrum of methods. Which method is most suitable depends on the goal of the simulation project. For the training of skills or knowledge different methods are suitable. The main research question of the systematic literature review was: How can simulation be used in training and organizational learning? In order to answer this question two sub questions were constructed:

1. What simulation methods used for training do exist in theory?
2. How can knowledge created by a simulation model be captured?

These questions were researched during the systematic literature review and will be discussed below.

Sub question 1: What simulation methods used for training do exist in theory?

The evaluation of a manufacturing system can be carried out in four ways (Wang & Chatwin, 2005). Experimentation with the real system, a physical model, an analytical model or a computerised simulation model. In the systematic literature review the papers where categorized in these four simulation methods. This resulted in two clusters: The use of a physical model and the use of computerized simulation. Experimentation with the real system is often not feasible due to high cost, or the system does not exist yet. Analytical methods lack the visual and dynamic abilities that the other methods do support and is therefore not used much in training (Robinson, 2004). Computerized simulation is mostly used for individual learning and simulation of complex production systems. A physical model is mostly used when accessing certain skills or interaction is needed between trainees (Tvenge, Martinsen, & Kolla, 2016). Which method is more suitable depends on a lot of factors including: the available time for modeling and training and the training objectives. In table 3 an overview of a couple of the involved factors is displayed and a comparison of the two clusters.

Table 3: Comparison of used simulation methods in training

Feature	Physical model of the system (Cluster 1)	Computerized simulation (Cluster 2)
Methods	Learning factory Role-playing	Specialized software Sheet software
Duration of model development	High	Medium
Ease of use	High	High
Time needed in training	High	Low
Training objective (focus)	Social interaction Practical skills	Multidisciplinary
Use when...	Simplified processes with social interaction between participants	Complexity increases

Sub question 2: How can knowledge created by simulation be captured?

Knowledge used as input for simulation studies often are (conceptual) models of the simulated process. The used models are often a representation of a real production system or a TO-be future production system that needs to be evaluated. The knowledge created by simulation studies can contribute towards decision making support, development of theories about the real world system and the conformation of hypothesis (Luban & Hincu, 2009). The created knowledge needs to be recorded and stored and maintained using knowledge management tools. Evaluation of the performed training in necessary in order to obtain the lessons learned and best practices of the performed simulation.

Main research question systematic literature review: How can simulation be used in training and organizational learning?

Simulation can be carried out both in the physical world as well in a computer model. Physical models, like learning factories are often used to train teams in practical skills and for the training of social interaction or team development. Often these simulations are simplifications of the actual system. More complex processes make use of computer simulations. For the development of computer simulations software is required. Different kinds of software are available. Sheet software is sufficient for simple analytical simulations. If complexity grows, specialized software becomes the best option to perform simulation.

Most of the studies follow a similar process of how to conduct the simulation (van der Aalst & M. Voorhoeve, n.d.) (Wenzel, Boyaci, & Jessen, 2010) (Davis, Eisenhardt, & Bingham, 2007). This begins with the need for a simulation project, an objective or a goal and the formulation of research questions and the understanding of the system or process. Sequentially, the conceptual model of the system is created. This is often a static display of the system with the possible states, processes and actors involved in the process. From the conceptual model the executable or simulation model can be derived.(Robinson, 2008a). The simulation model then needs to be validated and after validation it can be implemented and used for generating simulation results. These simulation results lead to new understanding and knowledge about the simulated system.

The conclusion drawn in the structured literature review is that within operations simulation is mostly used as a decision making support tool. For the analysis of a system, a model and data about the model is needed as input following a structured simulation methodology. The simulation is then used to provide an answer for a given objective or problem. This is displayed in figure 6. What method is used depends on this objective. Computerized simulation using discrete event simulation is most common due to complex production systems that are being analyzed.

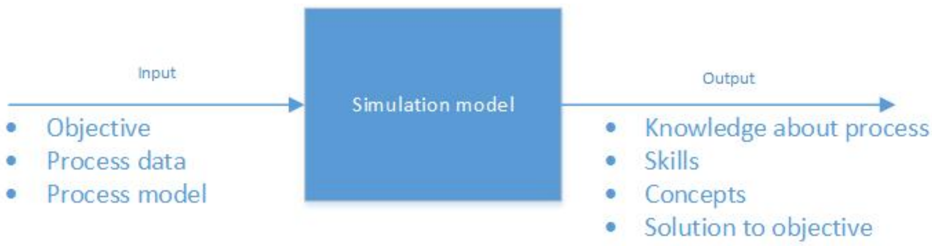

Figure 6: Input and output for a simulation model

2.2 Training Design

While the literature review focused on which simulation methods are available for training in theory, this section describes the development processes and the decisions during these processes. It is described what steps occur in the design process, and what decisions are made in each step.

A method to use simulation-based-training in management education is described by Salas & Wildman (2009)(Salas & J.L.Wildman, 2009).Training is a central topic in both the science and practice of organizations. There has been several studies about how to best design and develop training. Regardless of what level or type of simulation technology is involved, seven basic stages have been delineated as necessary to make simulation-based training effective (Salas & J.L.Wildman, 2009). The steps that are: Identify student needs, develop educational competencies, formulate learning objectives, trigger event exercises, performance measures, performance diagnoses, develop feedback and are explained in more detail below. An overview the steps is provided in figure 7.

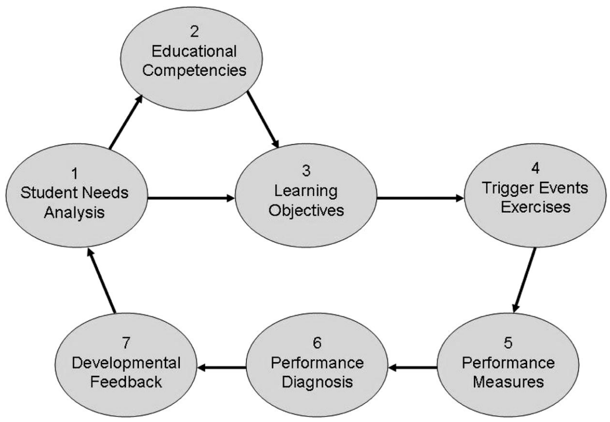

Figure 7: Design cycle of a training program (Salas & J.L.Wildman, 2009)

Step 1: Determine trainee needs
The first step of creating a training is the identification of the trainees. Before implementing any training, the scope and purpose of the training needs to be determined. Who needs training and what content should be included in the training module? In order to answer these questions the first step is training needs analysis. In this step one identifies the trainees and what content should be taught and at which level. For example: Beginning employees benefit for example more by an introduction training then experts.

Step 2: Develop educational competencies
Specific tasks and competencies that will be trained using the simulation can be formulated by using the training needs analysis. What change of knowledge, skills or attitude should occur at the end of the training is based on the gathered information from step 1. The training objectives can be specified at high overarching level.

Step 3: Develop training objectives
The next step consists of specifying specific, measurable training objectives based on the overall training goal. It is important that they directly address competencies specified in the needs analysis. They need to clearly outline what constitutes acceptable and unac-

ceptable performance.

Step 4: Develop exercises
The simulation scenarios must be developed in order to trigger the required competencies after the training objectives have been specified. These scenarios must provide opportunities to the trainee to practice these relevant competencies and objectives. The training would not be very efficient if the training does not address these objectives and competencies. Hence, it is important to design training scenarios that match with the competencies found in the training needs analysis.

Step 5: Develop performance measures
The fifth stage assesses the development of performance measures. Once the simulation models are build and the simulation training is designed performance measurements are identified. Without measurement you are unable to manage, control and improve the training.

Step 6: Performance diagnoses
In the sixth step of the training development, the chosen performance measures are used to gather performance data and compare the performance of the students to the standards and objectives specified in step three. Without accurate measurement of student performance, it is impossible to assess whether the desired competencies are being gained, and therefore, whether the training is effective. It is critical that the performance measures capture both the outcomes of the training as well as the processes within the training. This allows for the causes of performance to be related to the outcomes, which will increase the utility of the feedback developed in the final step.

Step 7: Feedback
The last step is the development of feedback based on the performance measurement data. This feedback helps to develop the skills and competencies by providing guidance to the trainees. Feedback is what makes the difference between the use of simulation in training and just a simulation run.The key to the successful implementation of simulation based training is to guide the learning that is occurring and this guiding happens by providing prescriptive, process- or behavior- oriented feedback throughout the training process. This allows the trainee to adjust strategies and improve competencies while proceeding through the simulation. In the end, a simulation without systematically designed learning objectives, carefully embedded scenarios, accurate performance measures and detailed developmental feedback will not train anyone.

2.3 Simulation modeling

A simulation model could be a useful tool to gain insight into the operation of systems (Luban & Hincu, 2009). In general the steps follow the same logical order from problem formulation, conceptual modeling, simulation modeling and feedback. Before preceding steps are finished, other steps can be improved by their successors, transforming the performance of a simulation study in a dynamic process. A iterative model of simulation modeling is presented by (van der Aalst & M. Voorhoeve, n.d.) and is displayed in figure 8.

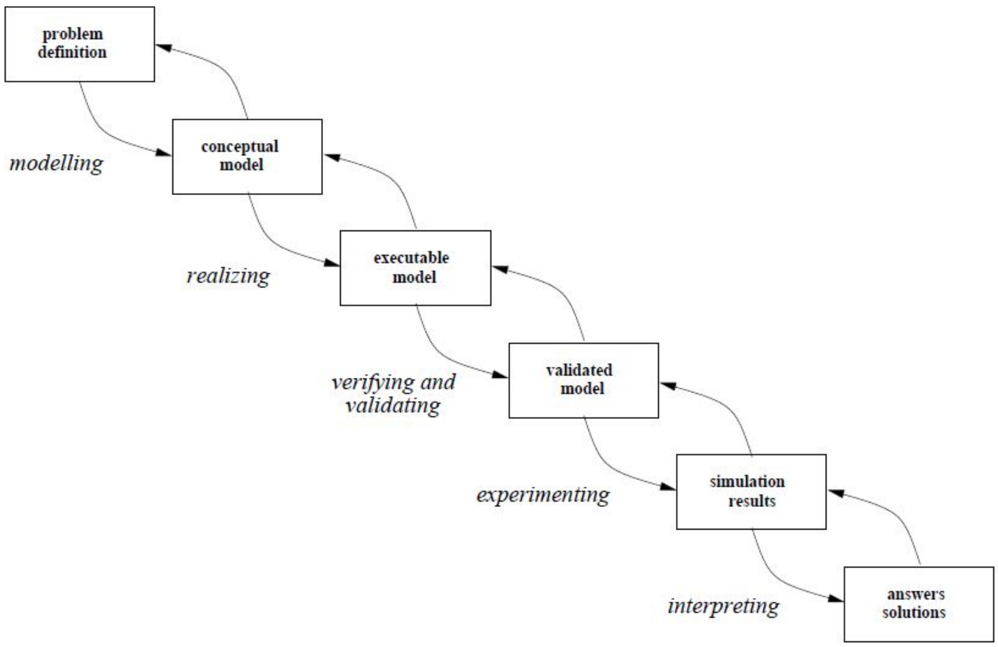

Figure 8: Steps of a simulation study (van der Aalst & M. Voorhoeve, n.d.)

2.4 Logistics and manufacturing modeling

Modeling of manufacturing system require an understanding of the types of manufacturing systems that exits.(Heilala, 1999) (Harrell & Tumay, 1995). Types of manufacturing systems as defined by Harrell and Tumay (1995) include the following:

1. Project shop
2. Job shop
3. Cellular manufacturing
4. Flexible manufacturing systems
5. Batch flow shop
6. Line flow systems (production and assembly lines, transfer lines)

Manufacturing and material handling systems can be arbitrarily complex and difficult to understand (Heilala, 1999). Heilala discussed the characteristics of these systems that are needed for system modeling. These parameters are displayed in table 4. When starting to model a manufacturing system one defines in the conceptual model phase which aspects to include in the model and to which level (scope and level of detail)(Robinson, 2004).

Table 4: Manufacturing system model characteristics

Subject	Parameters
Physical layout	Locations and size Type of manufacturing environment
Labor	Shift schedules Job duties
Equipment	Rates and capacity Breakdowns (failures) - Time to faillure (MTTF) - Time to repair (MTTR)
Maintenance	Preventive maintenance schedule Time and resources for maintenance Tooling and fixtures
Work centers	Processing Assembly Disassembly
Product	Product flow Routing Bill of material (BOM)
Production schedules	Make to stock Make-to-order
Production control	Order release Quantities (batch sizes)
Suppliers	Ordering Receipt and storage Delivery to workcenters
Storage	Suppliers Spare parts Work in progress (WIP) Capacity
Material handling	Conveyors Storage systems Transporters

2.5 Training validation and evaluation

The last step in training design is the evaluation of the training. (Kirkpatrick, 1996) developed a model for evaluation and validation of a training program: Kirkpatrick's Four Levels of Measurement. This model was developed in 1959 by Donald Kirkpatrick and is the most widely recognized model for training evaluation.

The criteria levels consist of reaction, learning, behavior, and results. Evaluation of reaction is related to the extent to which the trainee likes the training. Learning evaluation examines the level of knowledge and skills that were attained by trainees from the training process. Evaluation of behavior measures the changes that happen to trainee's on-the-job behavior which are related to training content. Result evaluation assesses the outcomes of training in terms of tangible measures such as production quantity, quality, or cost (Kirkpatrick, 1996).

A taxonomy that was made by (Alliger, Tannenbaum, JR., Traver, & Shotland, 1997) explained the 4 criteria of training evaluation by Kirkpatrick and their respective evaluation framework as shown in Table 5.

Table 5: Kirkpatrick's Taxonomy of training evaluation

Kirkpatrick's Taxonomy	Description
Level 1: Reaction	How do participants react to the training program?
Level 2: Learning	What did participants learn from the training?
Level 3: Behavior	How has the behavior of participants changed after the training program?
Level 4: Results	What occurred as the final results?

3 Methodology

In this chapter the framework of Wieringa is discussed in more detail and is applied to this thesis project. The framework of Wieringa is used that is based on the work of (Hevner et al., 2004). In section 3.1 the academic background is provided. In section 3.2 the research plan for this thesis project is presented.

3.1 Academic background

Wieringa (2009) has proposed an engineering cycle as a research methodology to answer the practical problems. The cycle consists of four stages which are: Problem investigation, artifact design, artifact validation and artifact implementation of which the first three stages are executed in this project. The steps of engineering cycle are presented in Figure 9 below.

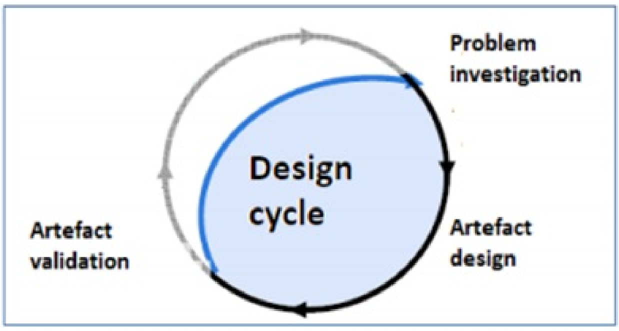

Figure 9: Design cycle (R. Wieringa, 2009)

The steps of the design cycle (problem investigation, artifact design and artifact validation) are explained in more detail below.

Problem investigation is regarded as a knowledge question because it asks for information about and understanding of the given problem without performing changes. Its goal is to describe the problem, to explain it, and possibly to predict what could happen (Wieringa, 2009).

The artifact design is mostly a practical problem that helps to improve the world in a certain way for the stakeholder. The artifact validation phase is a knowledge tasks in which it is established if the design indeed helps the stakeholder reach its goal. The artifact implementation concerns a practical problem that executes the artifact design.

Nested design science
Hevner developed a framework for IS research with two different perspectives: A behavioural-science and a design-science perspective. Behavioral science addresses research through the development and justification of theories that explain or predict phenomena related to the identified business need. Design science addresses research through the building and evaluation of artifacts designed to meet the identified business need (Hevner et al., 2004).

The framework developed by Hevner consists of an environment and a knowledge base contributing to the Information Systems, also known as IS, research can be found in Appendix B. The environment defines the problem space, the organization, people and technology, in which the phenomena of interest takes place. The knowledge base provides the raw materials for the research. (Hevner et al., 2004). The knowledge base consists of foundations and methodologies from prior IS research.

Wieringa distinguishes by defining knowledge problems and practical problems. Practical problems are problems that ask for a change of the world to satisfy stakeholder goals. Knowledge problems however, do not call for this change but are defined as the 'difference between current knowledge of stakeholders about the world and what they would like to know'. Knowledge problems use analytical and empirical research methods whereas practical problems follow an engineering cycle.

Wieringa argues that these two are mutually nested. In figure 10 is the refinement of his framework on the work of Hevner is displayed. Wieringa embraces this framework and has added an important part, which is the regulative cycle or design science cycle described before, which represents the interaction of the activities in the framework of Hevner.

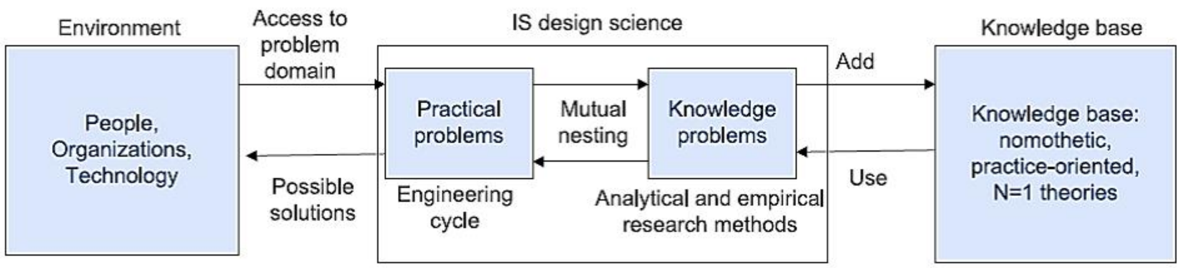

Figure 10: Information Systems Research Framework (R. Wieringa, 2009)

3.2 Research plan

In this section, the research plan is described. The framework of Wieringa is used for a deeper insight in the artifact iterations in each of the design cycle states. First the design science cycle is discussed, second the research plan using the framework of Wieringa is presented.

3.2.1 Design science cycle

There are multiple possibilities for problem investigation. In this case, it is an Goal-driven investigation which is described by Wieringa as an investigation that considers a situation in which there may be no problem experienced but where there are nevertheless reasons to change the world in agreement with some goals. Therefore it starts with identifying the stakeholder goals and training needs within the organization by conducting a case study. Together with a systematic literature review about the use of simulation in training within technical companies.

3.2.2 Research framework

The framework of Wieringa is used for a deeper insight in the artifact iterations in each of the design cycle states. In figure 11 this research framework is applied to this thesis project. As can be seen in the figure, each of the iterations has an environment and a knowledge base influencing the research. The goal of each iteration is described in table 6.

Table 6: Goals of each iteration

Goal of each iteration		
Iteration	Research Question	Goal
1	RQ 1, 2 & 3	Identify stakeholder goals and training needs in the organization.
2	RQ 4	Design of a simulation training module based on the training needs
3	RQ 5	Validate the solution of the simulation training module

Iteration 1
The goal of the first iteration is to identify stakeholder goals and training needs in the organization. Therefore an literature study about the use of simulation is conducted to research the current knowledge base about this topic. Combined with the practical problems of what the current state is within the company, and what their needs are for training their employees. Therefore, a case study is conducted where semi-structured interviews and a document analysis provided the input. One of these training needs is translated into learning goals in the next iteration stage.

Iteration 2
In the artifact design stage a training is created following the steps of Salas et al: Needs analysis, learning objectives, exercises, performance measures, performance diagnosis and feedback. Needs analysis is mainly carried out in the first iteration during the problem investigation. From the needs arising in the organization, learning objectives are formulated. Using these, a simulation model is created. The steps of creating a simulation model described by van der Aalst et al have been followed in this stage to create a simulation model. The steps for creating a simulation model are: Problem definition (given by the learning objectives), conceptual modeling, simulation modeling, simulation validation, simulation results, answers and solutions.

A first version of the simulation training is tested with engineers from the BPI department, since this department will be responsible for the use of the model for the final target group. Based on their feedback the model or the training or both can still be adjusted before applying it to the final target group. Completing the design cycle described by Salas et al.

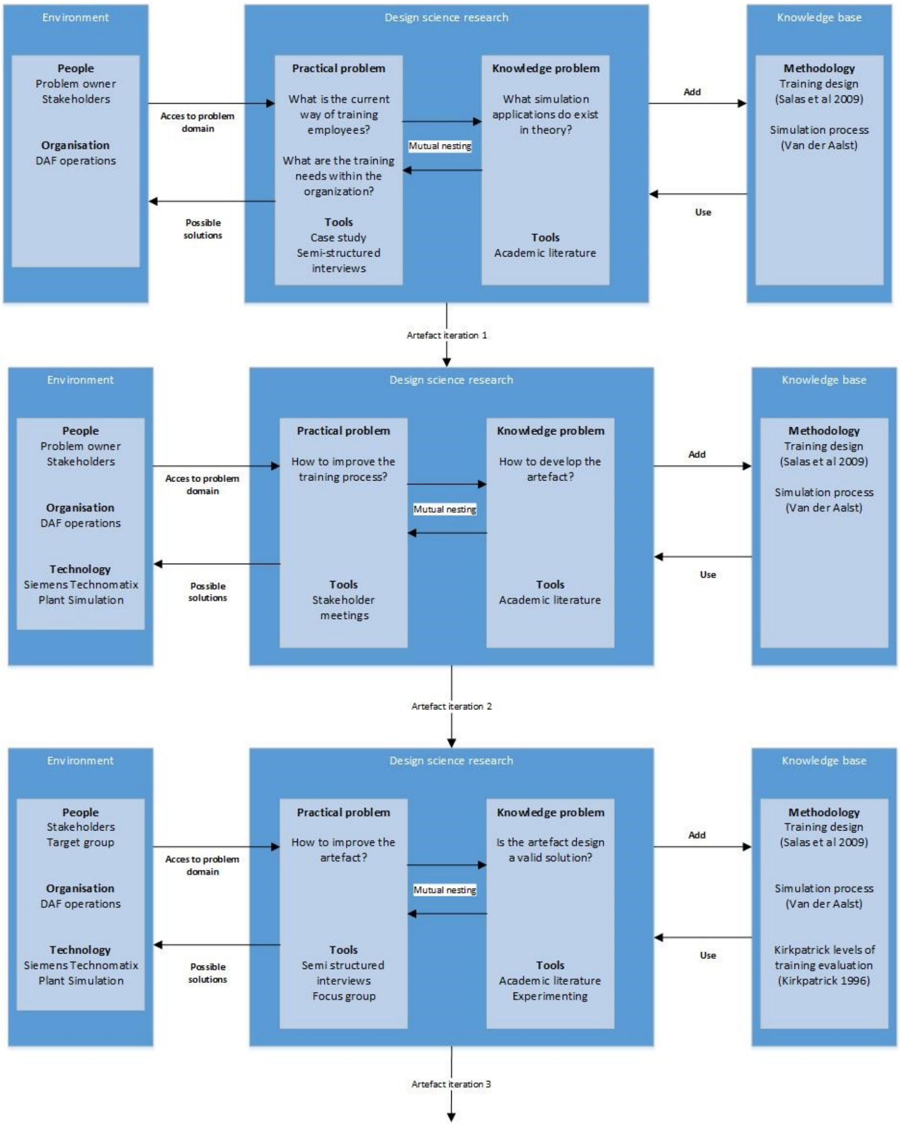

Figure 11: Information Systems Research Framework applied to the thesis project (R. Wieringa, 2009)

Iteration 3

Validation of the artifact was done in an experimental setting. In order to find an answer to the question what simulation contributes in a training environment the designed training was tested with an test and control group. In which the test group worked with the simulation model during the training and the control group without. After the training the participants where inverviewed. These interviews where in turn analyzed using the taxonomy of Kirkpatricks levels of training evaluation. Comparing the results of the test and control group leads to a differentiation of possible solutions and gives insight in which aspects are valuable in applying simulation in training and what the risks are.

4 Problem investigation

This chapter is part of the design cycle of Wieringa (2009) presented in figure 9 and covers phase 1: Problem investigation. The goal of the problem investigation is to obtain an overview of the current way of providing training to the employees, and to identify training needs for the different departments. Answers for the second and third research questions (What is the current way of training employees and What are the training needs within the organization?) are provided by capturing the current situation at the manufacturing plants of DAF. First, the context in which the problem is investigated is provided. Secondly, the methods to explore the current situation are described, followed by the results, and finally partial conclusions.

4.1 Context of the problem investigation

As described in the introduction, there are several factories that all produce components for the final product. These factories can in general be divided into fabrication and assembly processes. The separation of these cases is based on the difference of type of production presented by Harrel and Tumay (1995) (section 2.3).

The fabrication environments can be characterized as a job shop environment. Job shops environments are organized around similar processes rather then around product flow. Similar machines would be grouped together in one area, grinders in another, mills in yet another. Products move between groups of machines as required by their production requirements.(APICS, 2011)

The assembly environments are mainly line flow systems in which multiple products are produced, that follow the same production steps. These products are produced in sequence on a production line characterized by one-piece-flow. At each of the production steps a part of semi-finished product is assembled to the main product. A differentiation of production type asks for another control of these factories. The next separation is based on physical layout, since all of the factories can been seen as individual operating factories. The differentiation of cases is presented in figure 12. In addition, there are some logistic processes that concern all factories in general, such as production planning and warehousing. These are added on top of the differentiation of the production facilities.

The last differentiation can be made based on location: Eindhoven and Westerlo. The cabin and axle factory are located in Westerlo, the engine, truck and sheet metal factory in Eindhoven. Since the thesis project takes place in Eindhoven, the focus was on the latter factories.

4.2 Method

In this section the method that is used to conduct the problem investigation is discussed. The problem investigation is done with an observational case study. In an observational case study is an real-world case studied without interfering with the case (R. J. Wieringa, 2014). Observational case studies are useful for descriptive problem investigation since there is no interfering with the case.

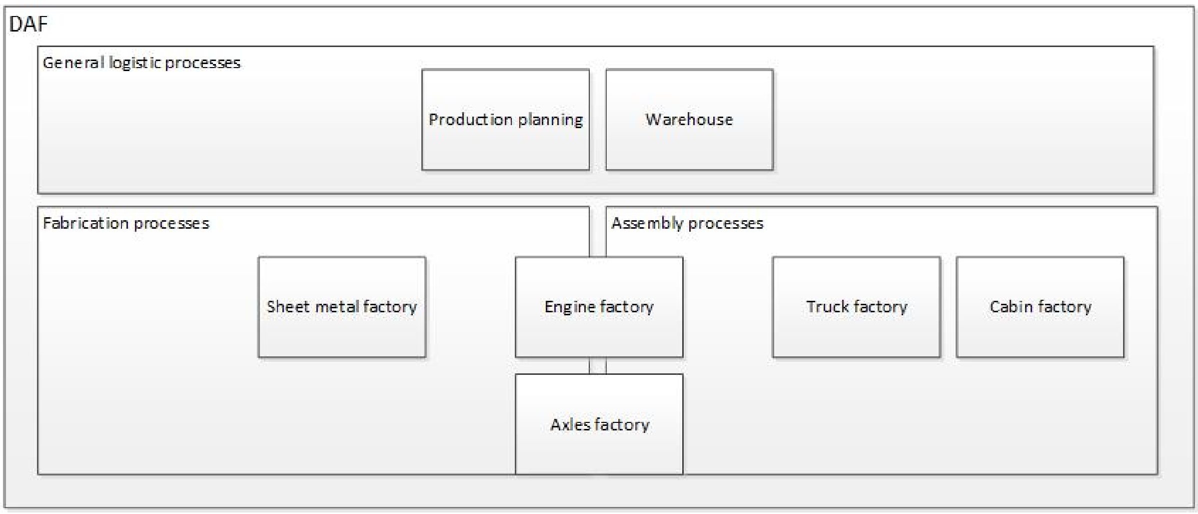

Figure 12: Differentiation of logistic and manufacturing processes

First the objectives of the case study is discussed. Second, the selected cases are described. Third the used data collection methods are described.

4.2.1 Objectives

The objective of the observational case study is of descriptive nature and the case study is used to answer the research questions from the problem investigation phase of the master thesis. The problem investigation phase is part of the design cycle presented in figure 9. The goal of the problem investigation phase is to find out what the current status of training process is and what the needs of the different departments are for training.

4.2.2 Cases

The cases that have been selected in the case study include: The sheet metal factory, engine factory and the truck factory. Since each of these factories is managed locally they are considered as separate cases. The other separation of cases is based on location in Eindhoven and Westerlo. The other factories are out of scope since time for the thesis project is limited and these three factories cover the differentiation of processes discussed in paragraph 4.1.

4.2.3 Research questions

The research questions that are answered in this part are derived from the research questions that are presented in table 2. For each of the selected cases the the following questions are answered: "What is the current way of training employees?" and: "What are the trainee needs within the organization?" For each of the identified cases these questions are answered and discussed in section 4.3. After providing an answer for each of these cases, conclusions are made to obtain an overview of the problem investigation phase.

4.2.4 Collection methods

The method used to gather information about the current situation and of the trainee needs was qualitative research. The most common method is a semi-structured interview. To gather a complete overview, interviews with experts of several departments are performed. The different identified cases are used as input to select relevant stakeholders to be involved in the interviews. Both production and logistic managers and engineers have been interviewed in order to obtain an overview of the current situation and the learning needs of the trainees. Semi-structured interviews start with a list of pre-determined questions and focus on interesting and relevant subjects when those occur (Saunders & Lewis, 2009). The format for interviewing can be found in appendix C.

Semi-structured interviews have been conducted in order to find out what the current situation of training employees is at DAF. The production environment consists of several factories that can be divided in assembly and fabrication processes. The truck and cabin factory are assembly lines. In the engine and axles factory are both assembly and production processes and the PKF is only production processes. The interviewed people are either working on the BPI department as engineers, or are the logistic or production heads of one the several factories within DAF in Eindhoven. By interviewing the heads of these departments the current situation of training is described and the needs for training have been identified. The list of functions interviewed is displayed in table 7.

Table 7: List of interviewed stakeholders

Department	Function(s)
BPI	Logistic engineers (8) Production engineers (2) BPI manager
Engine factory	Logistic manager
Truck factory	Logistic manager Production manager
Sheet metal factory	Logistic manager Production manager

To obtain a complete overview of the current situation document analysis has been performed next to the semi-structured interviews. At the BPI department, knowledge is divided over different knowledge areas. Each of these areas covers an aspect of the logistic and manufacturing work field. For the document analysis, the knowledge base in which these areas are maintained is inspected on documents suitable for training purposes. The document analysis can be found in Appendix D and the results are discussed in section 4.3.2.

4.3 Results

In this section the results of the current situation are discussed using the methods defined in section 3.1. First the training process is discussed for the identified cases, next the training needs arising from the interviews are grouped according to the existing knowledge areas are discussed.

4.3.1 Results of the interviews

Results of interviews in the Truck factory
In the truck factory the interviewed people are the logistic manager and the production manager. The truck factory is an assembly line where all components come together to assemble the final product. There is currently no focus on training, except for new employees. They have an training period at the start of their career. According to the production manager, the trainees can be categorized into four categories: Work floor personnel, logistic engineers, production engineers and planners. Further there was not much interest in a training module, but there was a need for a working simulation model for the cooperation between several factories (e.g. fine tuning between the engine and truck factory) to optimize the flow and minimize stock. Since the truck factory currently did not have clear training needs, the truck factory was not considered in selecting the specific training needs to be worked out in the training module. However, since the target group for the training covers logistic engineers as well as production engineers and material planners, the truck factory is within scope of providing the training.

Results of interviews in the Engine factory
In the engine factory the logistic manager is interviewed. The current way of training is unstructured and ad-hoc. Actually only new employees are given any form of training. Mostly by working with a colleague who is already experienced in the field. The logistic manager would like to do more in training and sees potential in using simulation as a training tool. The biggest concern is the implementation and assurance since it has to be defined who will be responsible for creating the training material, new training. The trainees within the engine factory are logistic engineers and material planners. Subjects that are considered are: Number of deliveries, transport sizes, stock levels and turnover and a general logistic awareness.

"For training I would like to have some basic insights in logistics. For example how many transportations we need to do in a certain amount of time."- Logistic manager engines.

Results of interviews in the Sheet metal factory
The production manager and logistic manager of the sheet metal factory have been interviewed. The sheet metal factory is a job-shop environment fabrication factory where sheet metal components for all the other factories are produced. Identified trainees in the sheet metal factory include logistic engineers and material planners, with a focus on new employees. Currently when a new employee enters the logistic department within this factory he get assigned to a mentor who teaches the tasks that the new employee has to perform. There is no standard way of providing knowledge. There are several issues when it comes to more complex logistic processes. Aspects that need to be addressed according to the logistic manager include: Determination of batch sizes,location and size of stock points, capacity planning of several machines, rush jobs and their effect. The

production manager mentioned planning of capacity in combination with batch sizes as one of the most critical aspects within this factory:

"Our biggest struggle is to find out how to handle lots of different products. How big do the batches of these products need to be and when to produce what. Now we often make a batch for two weeks of production but this can be more efficient" - Production manager sheet metal.

4.3.2 Results of the document analysis

At the BPI department, knowledge is divided over different knowledge areas. Each of these areas covers an aspect of the logistic and manufacturing work field. For the document analysis, the knowledge base in which these areas are maintained is inspected on documents suitable for training purposes. The identified knowledge areas that are within the scope (visualized in figure 2) of this project include:

- **General logistics:** The knowledge area of general logistics includes explanation of logistic concepts and how they are used within DAF.
- **Process engineering:** The process engineering knowledge area contains information about the process design, capacity calculations for process design and information about simulation in these projects. Next to this quality control for the design of these processes is captured in the quality assurance descriptions.
- **Fabrication control:** Fabrication control consists of the aspects that involve production orders (e.g. focused on the fabrication factories: sheet metal factory, axles factory and engine factory).
- **Material requirement and capacity planning:** Material requirement and capacity planning covers the field of MRP systems and materials needed for production of a truck using the bill-of-material.
- **Assembly management:** Assembly management contains the knowledge aspects about assembly processes. This includes knowledge about the following processes: Programming and master production scheduling, Assembly scheduling, Assembly Order release, Sequencing, Integral progress control, Order change management and local assembly control.
- **Materials management:** Materials management contains information about the coordination of the entire supply chain from the supplier towards the customer including the following processes: Transportation, packaging, physical infrastructure, receiving, line feeding, supply chain management,delivery reliability and material control.

Each of these knowledge areas is inspected on their content and the documents that they contain. The documents, their content, associated roles and number of documents are displayed in Appendix D in figure 23.

The analysis showed the availability of several knowledge documents. However, most of these knowledge documents or presentations have not been used for training. All of the currently available knowledge documents are documented in word, PDF or PowerPoint files and therefore do not need the stakeholder needs for active way of on job learning.

The content is mainly focused on job specific content: for example how to use certain software systems within DAF to report an order completion. The training curriculum can be expended with a module for dynamic training situations, like simulation to let trainees be able to study the consequences of their decisions in the production system over time.

4.3.3 Training needs

For the selection of processes to involve in the simulation training process interviews have been conducted with the managers and employees of the logistic departments of three factories of DAF. The interviews have been used to identify the trainees and their training needs. By determining the training needs for the different stakeholder groups an overview of possible processes that can be simulated for training purposes is created. This overview is displayed in table 8. The training needs are divided in the different knowledge areas identified in the document analysis. One of the aspects that was mentioned by interviewees from the BPI department, as well as the engine and the sheet metal factory was the insight in system dynamics within logistics and manufacturing. This training need is categorized in general logistics since it covers a broad spectrum of logistic knowledge areas, relevant for process engineers, logistic engineers and planners and roles that are indirectly involved with logistics.

According to production engineers of the BPI department concepts that are suitable for a training in the field of process engineering contain decision making about capacity and the design of processes: What should the capacity of a certain process be to obtain a certain output?

Table 8: Trainee needs in categories

Subject	Training needs
General logistics	Insights in the logistic concepts: Explanation and application of several logistic performance indicators.
Process engineering	Decision making in (Re)design of processes: What should the capacity of a machine / production line have to be to obtain a certain output?
Fabrication control	Managing of capacity: capacity requirements planning, and input/output control.
Material requirement and capacity planning	KANBAN training: Use of KANBAN material control (pull method) in a production process. What are the needed number of cards? What happens if a card is lost? How does KANBAN work?
Assembly management	Decision making in optimal order sequence and order release. What kind of consequences has the sequence of batches on other processes?

Materials management	Fluctuations in demand safety stock frequency of deliveries

4.3.4 Formulation of training objectives

After discussing the list of stakeholder training needs discussed in section 3.3.3, with the stakeholders is decided to start with the development of a training about the basic concepts of logistics. According to (Li, Blumenfeld, Huang, & Alden, 2009) throughput analysis is important for the design, operation and management of production systems. For the operation and management of production systems, a system understanding is needed, including the dynamics of a manufacturing system: This does not mean how to optimize or improve manufacturing systems, but simply describe how they can and do behave (Hopp & Spearman, 2011).This means that the training requires a precise terminology. Unfortunately, manufacturing terms in industry and operations management are not standardized at all (Hopp & Spearman, 2011). Some of the parameters included in the training and simulation model are: Lead times, work-in-progress, down-times, bottlenecks, batching and queuing.

The training module starts with an introduction to these subjects, their definitions and their dynamics with some theory. Since a presentation can not show these dynamics and their behavior over time, a simulation model was created in order for the trainees to experiment in a safe environment by testing different parameters and analyzing the results. The development of the simulation models that will be used in the training are discussed more in depth in chapter 5 and 6. In the simulation model trainees can change parameters to observe and describe what is happening with the manufacturing system. Including the following experimental factors: utilization of equipment, batch-sizes, and their influence on lead times in production environments. An experimental factor is a controlled independent variable which is a variable whose values are set by the participant. After the training participants are interviewed to research the factors that make simulation a suitable tool for training logistics and manufacturing or hinder the use of simulation in a training.

Based on the training needs the following objective for the training was constructed: Examine the influences of different parameters on the system performance of a production facility.

This objective was split up in several learning objectives:

1. Understand the effect of interruptions in a manufacturing system
2. Determine needed capacity for a stable process.
3. Sketch the relation between work in progress (WIP), utilization, lead time and throughput.
4. Explain the influence of variation in production processes

4.4 Conclusion

16 semi-structured interviews have been conducted in order to see what the current way of training employees in understanding logistic and production processes and to identify the training needs of the several departments. From the interviews it became clear that there is lack of training when it comes to explanation of complex processes. For most topics basic or no training is available. New employees learn the work processes from working together with their elderly colleagues in the training period in the beginning. Further, the need for a training module of several basic concepts seems larger at the fabrication processes rather then at the assembly processes.

Basic logistic processes lack explanation and training. According to the interviewees the need for insight in these processes is high. The current way of providing logistic training to the employees is unstructured, ad-hoc and done differently over the departments. The identified trainees are logistic engineers, production engineers and material planners. For each of the cases, there are several training needs identified. The requirements for a training module are captured in table 9.

According to the several departments, the business process innovation department should do more in providing logistic knowledge and training. In order to facilitate this BPI is structuring its available training material in a database. Using this database several key subjects are determined. The available knowledge of different processes is documented in the logistic curriculum divided over several knowledge areas. This curriculum currently exists only of static knowledge, knowledge that is constant over an extended period of time. A stakeholder requirement for the simulation training is that it provides an active way of training, where the trainees are working themselves.

In addition, thoughts about simulation are positive and managers are open to try out a simulation training module if this is available. Currently simulation is not a wide used tool and only used in a limited number of projects in order to support decision making of process engineering.

Table 9: Artifact design: Simulation training module

Artifact design	
Research question	How to improve the training process?
Artifact	Training module
Requirements	It should provide an active way of on the job learning and address the identified training needs
Stakeholder needs	It should help understand the processes and concepts in the field of logistics and manufacturing

5 Artifact Design - Conceptual modeling

The artifact design stage consists of two parts following the steps of (van der Aalst & M. Voorhoeve, n.d.). To create a simulation based training a simulation model is created. First, a conceptual model is created as input for the simulation model. This chapter contains the conceptual model. Second, the creation of the simulation model based on this conceptual model is discussed in chapter 6.

A conceptual model is a complete specification of the model to be build. Although it is an important part of developing a simulation, there is not much written about the content of a conceptual model (Robinson, 2004). The main reason for this is that conceptual modeling is more of an "art" than a "science" and it is difficult to define methods or procedures and it is largely learned by experience (Robinson, 2008a).

Robinson (2004) discusses the conceptual model and gives the following formal definition: "The conceptual model is a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model." The framework for conceptual modeling is adapted from (Robinson, 2008b) an displayed in figure 13.

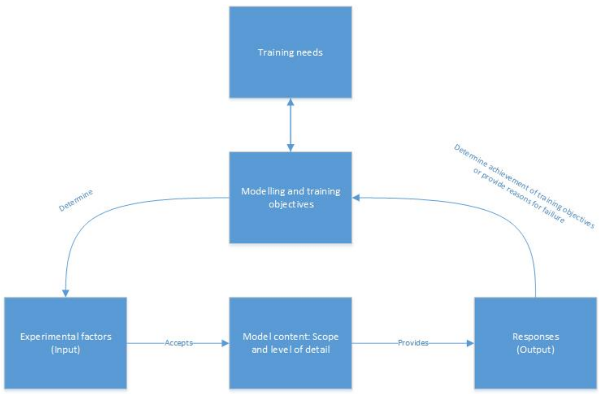

Figure 13: The framework provides the steps for designing the conceptual model based on (Robinson, 2008b)

From the definition of conceptual modeling the following sequence of activities is presented. First, the objectives of the study are presented. The objectives of the simulation model are derived from the training objectives discussed in section 4.3. Second, the input and output of the model are discussed. Third, the content of the model is described. Afterwards, the assumptions about the model are given. Fourth, the simplifications and finally, the conceptual models are presented. This chapter ends with a short summary.

5.1 Modeling objectives

As stated in the problem definition the goal of the simulation is to gain a better understanding of complex and dynamic logistic and manufacturing processes. From the interviews with the logistic and production managers was concluded that insights in logistic system dynamics is needed. Once the simulation is developed, experiments can be carried out with the model to obtain a better understanding of the dynamics in manufacturing. This includes experimenting with a simulation model to find out what aspects have significant influence on key performance indicators such as: lead time, throughput and utilization. Trainees learn by determining the input parameters, running the simulation model, inspecting the results and learning from the results in order to make changes to the input and so on. This process is displayed in figure 14.

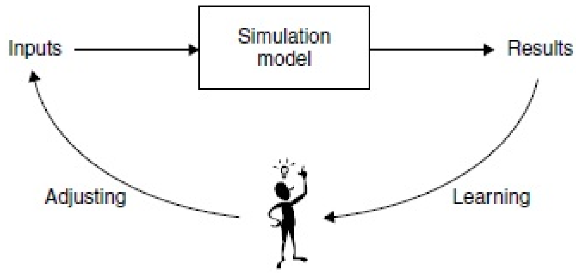

Figure 14: "What if?" analysis with simulation (Robinson, 2004)

As described in section 4.3, the case that was selected to work out in a simulation training is about dynamics in manufacturing and logistics. For this training module the following training objectives have been established:

Main objective: Examine the influences of different parameters on the system performance of a production facility.

Objectives concerned with this subject include:

1. Understand the effect of interruptions in a manufacturing system
2. Determine needed capacity for a stable process.
3. Sketch the relation between WIP, utilization, lead time and throughput.
4. Explain the influence of variation in production processes

5.2 Input and output

The output and input for the simulation model can be determined using the training objectives set in the previous section. The output of the model needs to provide the trainee with sufficient information about the performance of the process, so the trainee can learn what the effects are of different system configurations. As is displayed in figure 15.

Therefore, the output of the model needs to be measured in the set objectives of the training. This concerns measurements of the key performance indicators: utilization, work in process inventory ,lead time and throughput. The input parameters can be

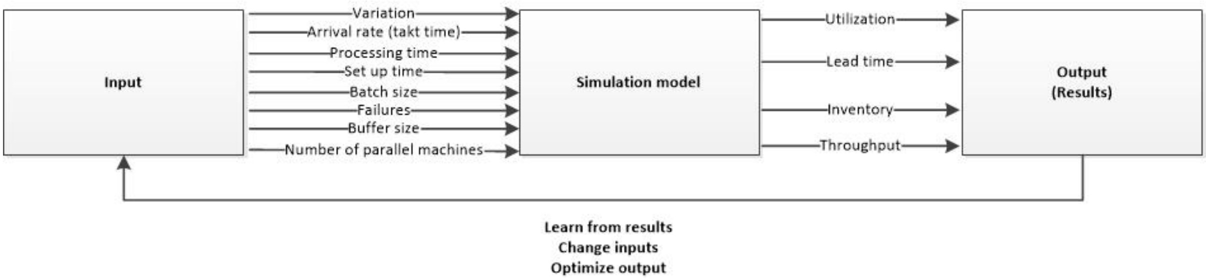

Figure 15: What if analysis applied to the to be designed simulation

changed in order to influence the output. In figure 15 the "what if analysis" is displayed for the simulation model designed during this project. On the left, the different parameters a participant can change during the training are listed. These include variation, arrival rate, processing time, set up time, batch size, failures, buffer size and number of parallel machines. On the right, the output, or results are listed. These include utilization, lead time, inventory and throughput. By interpreting and analyzing the results the participant in the training can adjust and change all or some of the input parameters to find the optimal output.

5.2.1 Input

The measures that are evaluated can be changed by changing the experimental factors of the simulation model. By changing the input, system behavior changes and lead to an understanding of the system dynamics. The factors that can be changed are listed and explained below.

The first factor is the arrivals to a workstation or arrival rate. This is the amount of jobs per unit of time that arrive at a station. (Hopp & Spearman, 2011). The arrival rate to a station can be described with either the mean time between arrivals, or the average arrival rate in parts per time period. The arrival rate follows a given distribution. Either a deterministic or continuous distribution (such as normal distribution or Poisson distribution).

The capacity of a station means the amount of products it can process in a certain time period and is determined by the processing time of that station. The processing times for each station determine how long it takes to complete a task at that production station. This determines the capacity of the station or the effective processing rate:
In almost all realistic cases, the capacity must be greater then the arrival rate in order to prevent the station from overloading.

A production station can, next to arrival and processing times, also have set up times. The set up times of a process or machine relate to activities that have to be performed in order to process a product. This activity does not add any value to the product, but consumes capacity of the workstation and it is necessary in order to process the products. Often the set up times are related to the size of the orders to obtain the same productivity by doing less frequency set ups or changeovers.

All of the different times can be modeled with certain distributions. In stochastic distributions random events can occur. This randomness is also called variance or variability. Causes of variability include downtime of machines, setups, operator unavailability and there are many other causes of variability. A measure of variability that is often used is the variance denoted by σ^2, an absolute measure of variability. (Hopp & Spearman, 2011)

Down times can greatly influence the variance of a production station. Down times are referred to Preemptive outages. Most tools cover for these random occurring outages by calculating the average availability. Availability is denoted as: The probability that a system is operation at any point in time.

$$Availiability = \frac{Uptime}{Uptime+Downtime}$$

Or the mean time to failure (Up time) and the mean time to repair (downtime). These measures describe the failures occurring at a station. With mean time to failure representing the average time between two failures occurring, and the mean time to repair the average time a failure lasts.

5.2.2 Output

The first output parameter considered is utilization. Utilization of a station is defined as the probability that a certain station is busy. Mostly utilization is displayed in a percentage. A bottleneck occurs when one operation runs slower than others, such that its speed determines the output of the entire process (APICS, 2011).
The second output item is lead time. Lead time is defined as the time an order spends in the production system, so from the moment it arrives until it leaves.

The third key performance indicator involved in the simulation is work-in-progress (WIP). This is the inventory between the start and end point of a product routing.

The last output performance indicator is throughput. Throughput is defined as the average output of a production system (machine, workstation, line, plant) per unit time (good, non-defective, parts per hour). Sometimes also called the throughput rate (Hopp & Spearman, 2011).

5.3 Scope and level of detail

Now that the input and output of the model have been determined the aspects that have to be included in the simulation model can be determined. The scope and the level of detail describe the boundaries and depth of the model. Using the objectives of the training and the input and output of the model the scope and level of detail is set.

Scope: In table 10 the selected parameters to include in the model are discussed and a justification why to include or exclude certain parameters is given. The included subjects are: Equipment, work centers, product, production control and storage. Physical layout, labor, production schedules, suppliers and material handling are out of scope for this model since they are not directly related to the modeling objectives and therefore is decided not to model them, but rather make assumptions.

Table 10: Scope of the model

Subject	Include / exclude	Justification
Physical layout	Exclude	Not relevant for modeling objectives
Labor	Exclude	Assumption each workstation has ample workers
Equipment	Include	Experimental factor
Maintenance	Exclude	Assumption that maintenance is available in case of failures. Preventive maintenance excluded since it is not relevant for modeling objective.
Work centers	Include	Workcenters include buffers and machines
Product	Include	Flow through the production process
Production schedules	Exclude	Only one product included in the model
Production control	Include	Experimental factor
Suppliers	Exclude	Not relevant for modeling objectives
Storage	Include	Experimental factor
Material handling	Exclude	Not relevant for modeling objectives

Level of detail:
The level of detail modeled for each subject included in the conceptual model is discussed here and is presented in table 11.

Table 11: Level of detail of the model

Subject	Detail	Include / exclude	Comments
Equipment	Capacity	Include	Experimental factor
	Production times	Include	Experimental factor, Modelled as a distribution
	Breakdowns	Include	Experimental factor, Modelled as a distribution
	Set up times	Include	Experimental factor
Work centers	Processing	Include	All work centers are modeled as an processing station
	Assembly	Exclude	
	Disassembly	Exclude	
Product	Type of product	Exclude	Type of product not relevant for modeling objectives
Production control	Inter-arrival times	Include	Experimental factor, Modelled as a distribution
	Batch size	Include	Experimental factor, impact on lead time and inventory
	Queuing	Include	Required for waiting time and queue size
Storage	Capacity	Include	Experimental factor, changing the buffer size has an effect on inventory and therefore on lead time and throughput

5.4 Process flow diagram

The conceptual model was constructed using the selected input, output, scope and level of detail. The conceptual model is displayed in figure 16. This conceptual model provides the input for the simulation model. It is used to construct the simulation model in chapter 6, and is used to check if the simulation model behaves as it is intended. The simulation starts with the trainee selecting the input values for the simulation model. Next, the trainee selects the speed and the run time of the simulation and runs the simulation with the selected settings.

The simulation starts by initializing all the selected input values and starting the simulation for the duration of the selected run time and store them in a table, that later can be used for analysis. When a product arrives, the simulation checks what the batch size is for the first station. If the batch is complete, the batch moves to the first station. If not, it waits for the next product arrival until the batch is complete. The machine at the stations fail according to a selected availability, the simulation checks if the machine is available, otherwise the batch waits in the queue until the machine is repaired. Subsequently, it checks if it is currently occupied by an item from a previous batch. If the machine is idle, the next batch is selected from the queue and the machine starts with setting up for this batch. Then processes the batch, and the items wait until a batch for the next station is completed and moves to the next station. At each station for each entity, the waiting time, processing time, setup time, lead time and inventory are calculated and saved. If it is the last station in line, all the statistics of the entity is saved into a table. After the selected running time, this table is used to give the final results. The trainee can then use these results to make an analysis of what the consequences are of changed input values. The input and output that is used in the model is presented in figure 15.

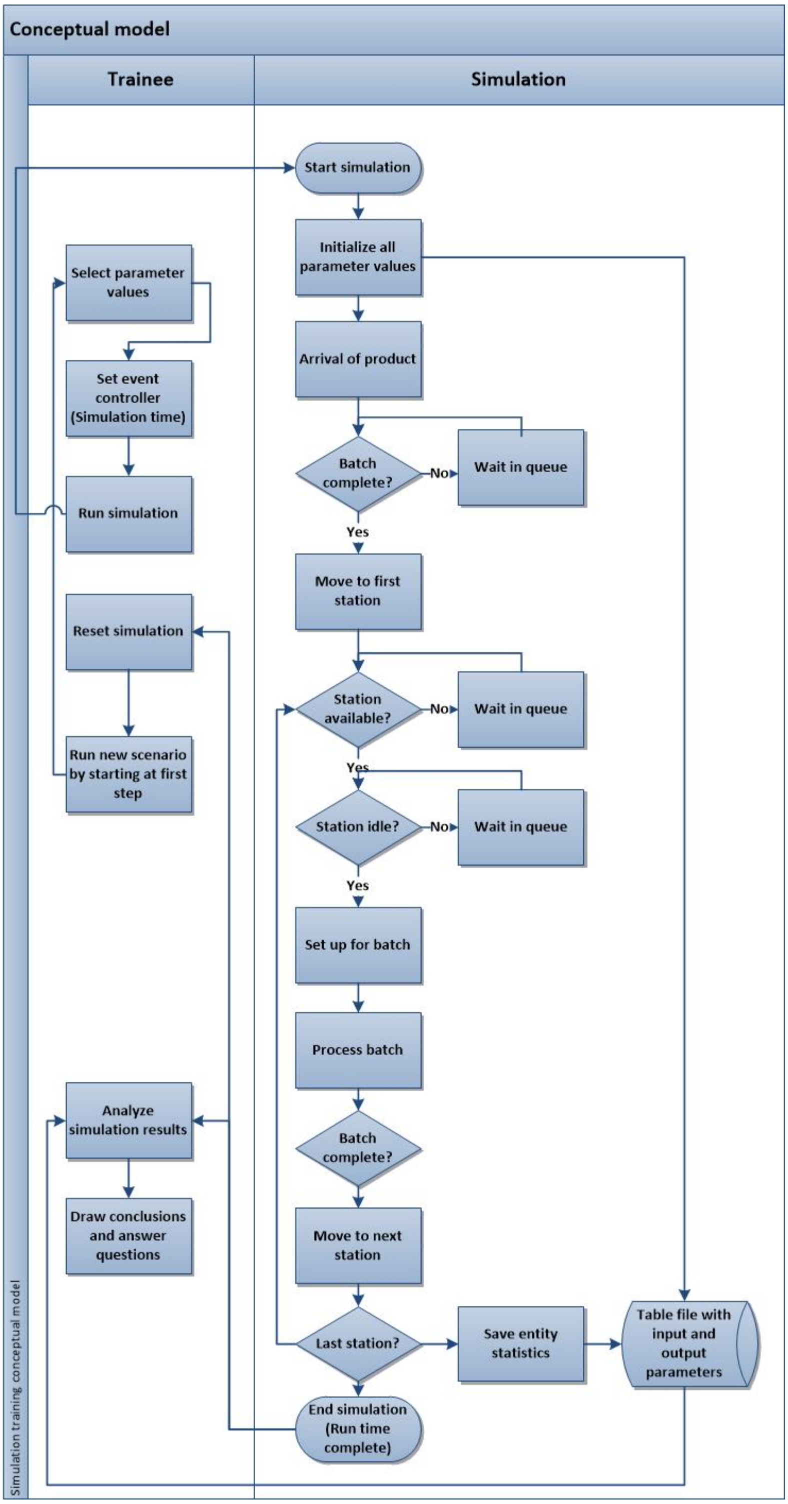

Figure 16: Conceptual model

5.5 Summary

In this chapter the conceptual model is discussed. Following the steps deducted from the definition of (Robinson, 2004) the conceptual model was developed. First the training needs are translated to objectives for the model. Second, the objects that have to be involved in the model have been determined and the scope and level of detail have been set. Resulting in the conceptual model. This conceptual model is used as input to create the executable simulation model discussed in next chapter.

6 Artifact design - Simulation modeling

In this chapter the process of simulation modeling is described. First the selected simulation tool is discussed in section 6.1. Then the selected processes from chapter 4 are modeled based on the conceptual models created in chapter 5 and are discussed in section 6.2. The objective of the simulation model is that it can be used in a training about the influence of the selected parameters on the performance of a production facility. The simulation model should provide an active and visual way of learning. The validation of the created simulation models is described in section 6.3. In section 6.4 the use of the simulation model is described and the chapter ends with a short conclusion about simulation modeling.

6.1 Simulation tool

Technomatix Plant Simulation is a software program that enables users to model an entire manufacturing plant including logistics and production processes. This software program is currently used by DAF to make simulation models. Several user licenses for this software are available. Since visualization is one of the key requirements, specialized software is preferred over other computer simulation methods like programming language and sheet software. Since Plant simulation already has some users within DAF, this software is selected to create the simulation models. Several meetings with the current users have been held, together with a performing a tutorial and the consulting the user manual, in to in order to learn how the software works.

Plant simulation contains several classes that can be used in the modeling process. The standard classes can be classified into six categories (Bangsow, 2010):

1. Material flow objects
2. Resources
3. General objects
4. Mobile objects
5. Lists and tables
6. Display objects

Mobile and static material flow objects are the basic objects of a model. Mobile objects (transporters, containers, parts) represent the physical objects that move through the model. The static objects can hold on to a mobile object and store them for a while before passing them on through the connectors to the successor. Static objects represent machines, buffers and tracks. Resource objects can be used for simulating employees. In this case, the modeling of employees is out of scope as explained in chapter 5.

General objects refer to the frame, event controller and the connectors. The frame is the basis for the all models. Objects can be inserted to the frame to create a simulation model. By inserting a frame into another frame, it is possible to build models in several hierarchies. The EventController coordinates and synchronizes the different events taking place during a simulation run.

Next to these standard objects that the simulation software provides, customization is possible by programming methods, use of tables and variables.

6.2 Simulation model

Using the conceptual model described in chapter 5, the simulation model was created. The model is created using the software Plant Simulation which is described in section 6.1. The training is developed following the steps of Salas & Wildman (2009). First the trainee needs and objectives where determined and are described in section 4.3. The tasks for these objectives have been applied by creating a conceptual model and subsequently a simulation model. The trainee can perform several tasks that trigger the required competencies in the simulation model. From experimenting with the simulation model the trainee can gain insight in the production processes and the basic logistic concepts that influence these processes.

The model represents a relatively simple production process that exist of four work stations with a buffer and a machine. On the left side trainees can select the input of the model. This includes the inter-arrival time of orders, the size of the buffer for each station, the processing times at each station, the failures of each work station and the capacity (number of machines) for each work station.

After selecting the input the simulation can be run by clicking the start button on top of the model. On the right side of the simulation the graphs of some of the performance indicators are displayed. The trainee can monitor these performance indicators of the simulation model. After the simulation is terminated, the results of the simulation are saved in a table file. Using the data in the table file the trainee can then make his final analysis of the systems performance and the behavior under different parameter settings.

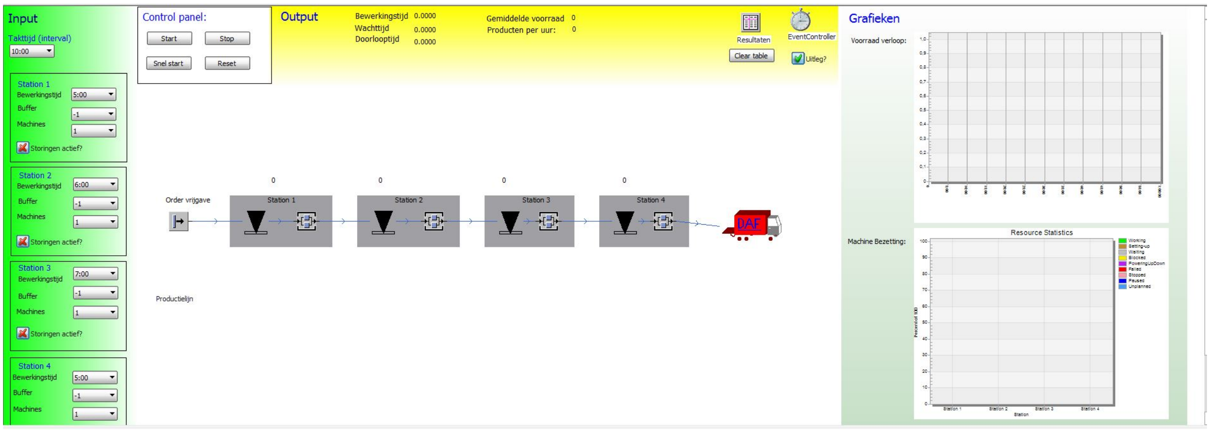

Figure 17: Simple model in Plant Simulation

6.3 Validation of the simulation models

In order to be able to use the designed simulation models they need to be validated. Validation of the simulation model is determining if the simulation is working as intended and is sufficiently accurate for the purpose of the model (cite Carson 1986). The validation of the simulation models was done with the following steps:

- The model was programmed and debugged in steps using a debugger
- The model was developed in close cooperation with the company employees
- Theoretical calculations have been made to compare the simulation with analytical methods.

The debugger is a build in application of plant simulation. By running the model and watching how each element behaves, both the logic of the model and the behaviour of the model can be checked. By turing on the debugger, it is possible to step through the model event by event. The simulation could be stopped at any time to check if it behaves like expected. The debugger also returned errors in line of code in the model. When an error occurs, the debugger highlights the error and states what is wrong. Subsequently, the error can be improved so that the code is correct.

As an alternative to comparison with the real-world system, the model is compared using a simpler model: a mathematical model. This is displayed in fig 18.

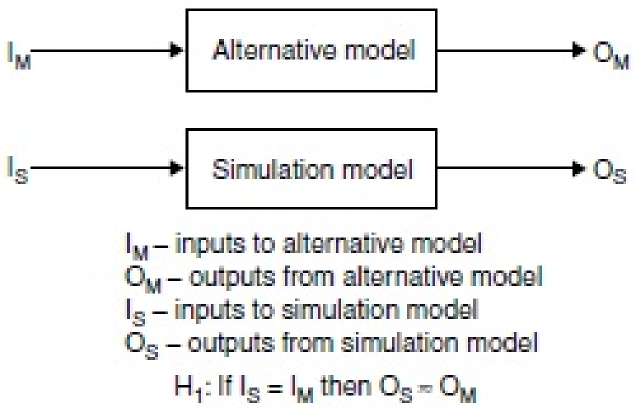

Figure 18: Validation of the simulation model (Robinson, 2004)

Mathematical models include spreadsheet analysis and queuing theory. It is unlikely that a mathematical model exactly predicts the outcome of the simulation, since it can not take it's full dynamics into account (Robinson, 2004). Theoretical calculations of the model have been made to check the outcomes of the simulation. In order to do so, mathematical methods have been used in an excel sheet to check model outputs. This Excel sheet was retrieved from the website of Factory Physics (Inc, 2018). The inputs of the model have been used in the calculations in order to compare model output with the calculations. The outputs of the model where close to the mathematical calculations and therefore the model was deemed accurate enough for training purposes. The comparison of the simulation model and the mathematical model can be found in appendix E.

6.4 Running the simulation model

The simulation models can be used for experiments after they have been validated. Running the simulation starts with an initialization of the system. Events of the simulation model are then handled in order. Each event triggers another event by calling the methods coded on the background of the model. The simulation runs until the stopping criteria is met (e.g. simulation time or number of generated entities).

After the simulation stopped, the results are saved in a table file. A new simulation run can now be executed by selecting new input parameters and running the simulation again. After conducting several experiments, all the output can be analyzed and an analysis of the parameter settings can be made by the participants of the training.

The procedure of running the simulation model can be summarized as follows:

1. Set system parameters by selecting the input in the input area
2. Set EventController
3. Run the simulation by clicking start or quick start (snel start) to run the simulation with or without visualization aspects subsequently and wait until the simulation run is finished.
4. Check table file for results
5. Reset the simulation
6. If more scenarios have to be simulated: Return to step 1
7. Analyze the results and draw conclusions from the simulation training

The analysis ends in conclusions about the behavior of the system, and The interaction between system dynamics. The trainee has to describe what happens with the performance of the system with an higher utilization of resources, together with determining the optimal batch size for certain system configurations. Scenarios that can be executed in the simulation model include among others:

1. Increase of utilization by increasing capacity use.
2. Increase or decrease of variation and utilization by adding or reducing failures.
3. Introduction of set-up times and finding optimal batch sizes.
4. Explanation of relations between: Utilization, lead times, WIP and throughput
5. Introduction to bottleneck station.

6.5 Conclusion

In this chapter the development of the simulation model was discussed. The simulation models were created with discrete event simulation software that was already used at DAF: Siemens Technomatix Plant Simulation. Several training needs have been included in the simulation models. The simulations were validated by comparing the results with analytical calculations made in an Excel sheet. Now the simulation models can be used in a training situation to check if they contribute to a better understanding of manufacturing and logistic processes compared to other training methods. This is done in the last phase of the design science cycle: Artifact validation.

7 Artifact validation

In this chapter the validation of the artifact, training with simulation, is discussed. The simulation model created in the artifact design stage was applied in a training setting as an experiment. In this chapter the results of this experiment are presented. The setup of the experiment is discussed in section 7.1. The results of the experiment are discussed in section 7.2. After the experiment participants were invited to take part in a focus group meeting. The results of the focus group meeting are discussed in section 7.3. The chapter ends with the general conclusions of the artifact validation in section 7.4.

7.1 Validation through an experiment

The result of this research is a simulation model based on training needs within DAF. This model was built in Technomatix Plant Simulation and was validated by comparing its behaviour with theoretical calculations. This section discusses the validation of the artifact. As described above, the validation of the artifact is done with an experiment. An experiment in software engineering is an enquiry that manipulates one factor or variable of the studied setting while keeping the other variables constant(Wohlin et al., 2000). This while adhering to the principles of control and randomization(Mettler, Eurich, & Winter, 2013).

In an experimental setting there are two groups: a test group and a control group (Wohlin et al., 2000). Control refers to the presence of a control group. (Mettler et al., 2013). Only the test group is exposed to a stimulus (i.e., the new or better design), but not the control group. In this case, the test group worked with the simulation model during the training and the control group with the same case study but without simulation model. In figure 19 the design of the experiment is displayed. After the experiment the reactions and learning of the participants of the test group are compared to those of the control group using semi-structured interviews.

Randomization means that the participants are randomly assigned to either the test and or the control group: They are not already involved in the project or emotionally attached to the solution design (Mettler et al., 2013). In this way the prior existent differences between the participants are reduced and the testing results are more stable, because known and unknown confounding factors are distributed in a uniform way among the test users.

The goal of the experiment was to find out what the effect of simulation is in a training situation. Therefore, a training was designed in which the training needs, identified in chapter 4, where addressed. These training needs where: Examine the influences of different mechanisms on system performance. This is, the effect of choices that can be made in a production setting on the performance measured in throughput, lead time and stock (work-in-progress). The training was designed according to the training design of Salas et al. First a theoretical introduction about the topic was provided, afterwards was an exercise where the test group worked with the simulation model and the control group without the simulation model. The outline of the training can be found in Appendix F.

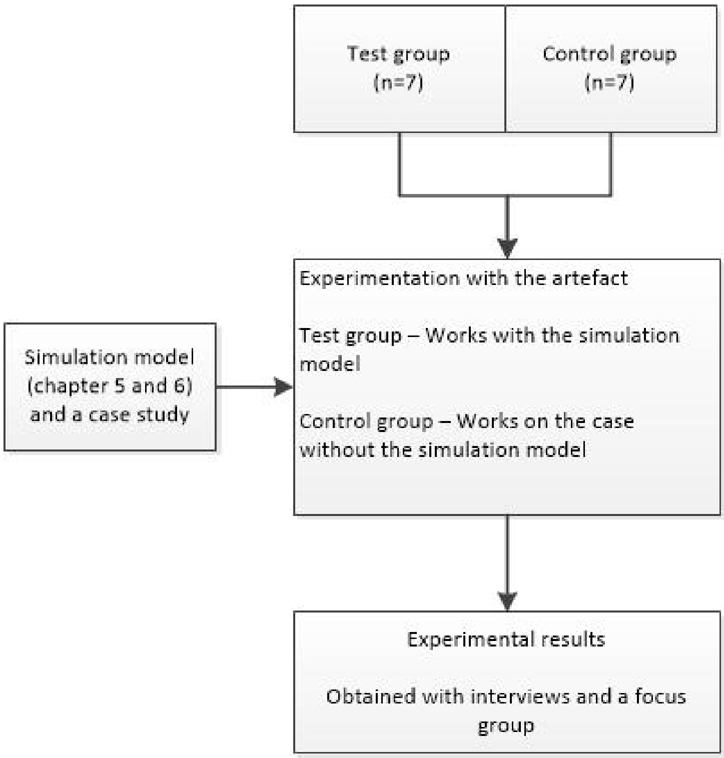

Figure 19: Design of the experiment

7.2 Results of the experiment

The experiment was carried out with a total of 24 employees, of which the first 10 worked with a prototype version and where only used as input to improve the simulation and the experiment. The other 14 participants where logistic engineers, production engineers, six sigma black belts and the manager of the BPI department.

After the experiment the participants where interviewed following the semi-structured interview format in Appendix G. The interviews were transcribed and coded using the software QDA miner. The codes were based on the first two levels of the evaluation framework of training evaluation (Reaction and learning) (Kirkpatrick, 1996). The main findings from these interviews are presented in table 12. It was interesting to see the test groups enthusiasm. From the interviews it appears that the test group enjoyed the training more then the control group did. General evaluation in the interviews showed that participants from both groups where able to demonstrate their understanding of production line design and control. These effects could also be expected in case of other simulation scenario's within these groups.

Reaction
The main difference between the test and control group was in the reaction category. The test group seemed to be a lot more enthusiast about the training. The test group indicated that the use of a simulation model made it a lot quicker and made it easy to change scenario's, and to see the correlation between multiple parameters at the same time. While calculating these effects takes a lot of time and effort, participants from the control group quickly lost focus, found it hard to do all the calculations by hand. The theoretical introduction was by both groups seen as value added, introduction to the topic.

Table 12: Findings of the interviews after the experiment

Experiment interviews findings		
Topic	**Test group**	**Control group**
Reaction	Regardless of some unclear parts in the questions it was pretty easy to carry out the exercises	It was hard to carry out the exercises by yourself
	Simulation is an easy, attractive and simple way to show different effects and relationships	With a tool you can of course calculate everything a lot easier
	When you can actually play with the subjects, and see what is going on, you get a better understanding then just by telling someone	Simulation makes it also more fun
Learning	Influence of inventory and throughput on lead times and the effect of variation and a bottleneck on those parameters	
Other uses	Keep to the basic elements if you want to specifically use the model for training	
	Simulation can be used for training when a decision has to be made and where you can adapt parameters to play with the results.	
Issues	The use of a real case in the simulation could improve the realism and connection to practice	There where to many questions, that caused loss of concentration and motivation
	Danger of leaving out the critical thinking and only write down the answers provided to the question by the simulation model	
	Theoretical introduction about the topic is valuable	

Learning
The learning of both groups did not differ much. Both groups where able to relate to the learning objectives that where presented at the beginning of the training. The test group and the control group where both able to answer questions related to these training objectives.

Issues
Next to the benefits of the use of simulation in training, mainly related to the reaction of participants there where also some issues mentioned. Most of the issues where related to the design of the training like consistency, and the use of specific company cases. Also some issues that where mentioned where related to the technology and its application: You have to keep thinking about what you are doing and not just adjust a button and write down the result. So interpreting these results seems to be important to train the participants in truly understanding the correlation between different parameters.

Other uses Other uses of simulation included other topics to include in a training Also the application in decision making was mentioned in a variety of processes.

7.3 Results of the focus group

After the experiments all the participants where invited to join a focus group about the use of simulation in training manufacturing and logistics. The total number of participants in the focus group has been six of which three participants out of the test group and three participants out of the control group. The focus group meeting was recorded and transcribed. From the transcript meaningful quotes where used to check what aspects of the simulation worked, what where issues, what could still be improved and what the other possible uses for simulation are, both in training as in decision making, which seem closely related in the field of manufacturing.

Statements from the focus group transcript are displayed in table 13. The results from the focus group indicate that the use of the simulation model was value added in a training. The model helped trainees in quickly finding answers to the questions, visualization helped in understanding what was going on in the model and to visualise relations. This indicates that these aspects made the training for the test group more engaging and interesting than it was for the control group. One of the advantages of the simulation model is that it could show multiple parameters related to each other at the same time. This showed the importance to interact with engineers from several departments to focus on the same result instead of focusing on different aspects separately: Process engineers, logistic engineers and maintenance engineers all have their part in the bigger picture.

One of the other important aspects of the training concerned the application of the simulation. The introduction part in which the parameters, relations and concepts where explained was seen as important and indispensable. It could help to relate the simulation scenario's that are used in the case that is used during the training to more to the practical situation where participants have to deal with everyday. The case that was used now, was pretty high level, but could be made more specific to the real world situation. Secondly, there needs to be a kind of feedback involved during or after the training to make sure the concepts and relations have been thought correctly and participants did not only just used the simulation as an calculation tool, but used it to thoroughly understand the relationships between the parameters and the reasoning there. Therefore, a test, reasoning questions or a debriefing should be part of the training.

Table 13: Findings of the focus group after the experiment

Experiment Focus group findings	
Topic	**Findings**
Reaction	Without simulation the exercise was harder to carry out.
	With simulation trainees find the answers to the case more quick.
	The added visualization aspect of the simulation model contributes to a better understanding
	The theoretical introduction is important.
	Start with a theoretical simple model and compare it with a practical example. In that way the link between theory and practice is better obtained
	Simulation makes a training more engaging and interesting then a lecture based training
	Simulation makes a training more appealing
	Simulation creates a short feedback loop
Learning	A simulation model contributes towards the better understanding of the total system, where the trainee can see all the variables together instead of separately.
	With both analytical methods and simulation methods can the relation between parameters be thought. The added value of simulation here is to make it visual to see what is happening. Most of the trainees, depending on the group, do not use the analytical formulas daily and will not remember them. But visualization contributes towards an understanding what is happening.
	In the simulation model it was clear that variation influences the process more then you think it does.
	Simulation is value added in a learning process when a lot of variables create a certain complexity in which it is to hard to imagine how it will behave. If it is only one variable you can easily make a calculation, but with many variables it becomes to hard.
	Due to the simulation model trainees gain insight in the working together part. Process engineers, logistic engineers and maintenance engineers are all responsible for a part, but it all comes together in a process
	Creation of a common goal for multiple stakeholders
Other uses	KANBAN simulation for training
	Calculation for manufacturing and decision making in how to design a proces for a certain output and which machine to buy
	Flow between different buffers
	Decision making and prediction model for determing the buffer sizes of engines
	Use of simulation as a decision making tool to determine the needed numbers of employees at a working station
	Possibilities in lean and green belt training
Issues	The risk of simulation is that a trainee uses the simulation tool only as an calculation to find the answer to the question without the reasoning behind it.

	If group discussions are needed, simulation is not applicable to e-learning
	Terminology has to be known by the trainees.
	A lot of different terms exist for the same concept or variable. Make sure you use the terms that are known by your trainees so they can link it to their daily activities.
	A practical example should be included in the training
	Keep the practical example relatively simple for training compared to the real situation
	User friendly
	For the structure of a simulation model it is recommended to introduce the topic first, then work with the model.
	"Structure of a simulation training: - Start with a short theoretical introduction and build complexity along the way "

7.4 Conclusions validation

The validation of the simulation training module was done with an experiment. The participants where randomly assigned in one of the two groups: Test and control group. The test group was exposed to the improved version of the artifact that makes use of simulation to conduct the exercises in the training. The control group did the same exercises but without the simulation tool.

Afterwards the participants where interviewed to view their reaction on the training and the aspects that they have learned from the training. The main finding was the difference between the groups in the area of reaction towards the training. The test group was a lot more enthusiastic about the training then the control group. Working with a simulation contributed in this case to the focus and enjoyment of the participants.

While the control group found it quite difficult to do the exercises by hand and lost focus and motivation after a while. Both groups thought that an introduction to the topic was value added and contributed towards a better understanding of why this topic was being lectured and a better understanding of the topic itself. The learning was comparable between the two groups. Both groups where able to answer questions related to the training objectives and where able to identify aspects that where intended.

Therefore, the developed simulation game seems to be an adequate means for improving the understanding of the behaviour of manufacturing lines and it motivates participants in the training more than without a simulation model. There are however some issues related to the use of simulation in a training. The first is that people are using the simulation model only as an kind of calculator to fill in the asked values and write down the results. But for a complete understanding one also needs to take the reasoning behind these values into account. Therefore a debriefing or test should be held during or after the training to check if the participants understand the relationships and reasoning and did not only fill in the answers to the asked questions. Secondly, the introduction was by both groups seen as an important part of the training, since it introduces the parameters and other topics that are treated in the exercise.

8 Conclusions and discussion

In this chapter the conclusions, discussion and limitations of this research and the possibilities for further research are discussed. First the general conclusions from this thesis project are discussed in section 7.1. Secondly, the discussion and the limitations of the research are presented in section 7.2 and finally the suggestions for further research are discussed in section 7.3

8.1 Conclusions

This thesis project looked in to the application of simulation as a tool in a training situation in logistics and manufacturing. The goal of this research was to develop and test a simulation training for DAF Trucks NV about logistic and manufacturing concepts. In order to fulfill this goal the research question used was:

How should a training module using simulation look like in order to improve the training process at DAF Operations?

This research question is split up into more specific sub questions for each phase of the design science cycle:

Table 14: Research questions repeated

Research questions	
Design cycle step	Corresponding research questions
Problem investigation	1. What simulation applications for training do exist in theory? 2. What is the current way of training employees? 3. What are the trainee needs within the organization?
Artifact design	4. How to improve the training process?
Artifact validation	5. What is the added value of simulation in a training situation?

To answer the problem statement first the research questions need to be answered.

The first research question was a description of the available simulation methods that available and suitable in a training situation. This research question is answered during the systematic literature review. Multiple simulation methods are suitable for different purposes. Which one fits the best depends on a number of criteria. In this thesis is chosen for discrete event simulation software. The specific software used is Siemens Technomatix Plant Simulation. This because of the costs and ease since it was already used within DAF with several licences.

The second and third research question was related to the problem investigation phase, in which the current situation of the training, and the training needs within the organization. DAF consists of multiple plants and each of these plants is organized locally. Therefore, different cases where used as input to identify the current way of training and the training needs within each of these factories. Together with the involved stakeholders was decided that a basic simulation model that covers the relations of utilization, throughput, lead time and inventory and batch sizes was a logical choice for a simulation training.

The fourth research question focused on the design of the simulation model following the methodology by (van der Aalst & M. Voorhoeve, n.d.) and the training with the simulation model where carried out following the steps of Simulation training design described by Salas et al. (2009) had let to the design of a simulation model with an suitable user interface to cover the objectives of the simulation training and training needs.

Finally, the last research question compared the designed simulation model with an alternative for a simulation training. The validation of the artifact was done with an experiment. In an experimental setting there are two groups: A test group, that is exposed to the improved artifact, and a control group without the artifact worked on a designed case with questions related to the training objectives. A four station manufacturing line was included in the case. By adjusting input settings a change in output was obtained, challenging the participant to analyze what was the influence of certain parameters on the output. Interviews after the experiment indicated that the test group was more enthusiastic about the training. Suggesting that simulation training contributes towards a better motivation and reaction on the training, as well in understanding of the objectives taught during the training.

Now that the research questions have been discussed, the problem statement can be answered.

How should a training module using simulation look like in order to improve the training process at DAF Operations?

First, it is necessary to review the needs within DAF Operations, by either determining what employees should know, or obtaining needs from the organization and define which contents should be taught in the training. These needs are then translated into specific objectives for a training.

Second, the objectives for the simulation model needs to be formulated, literature have to be examined to understand how to build a model for the specified objectives and third, various parameters have to be identified to include in the model both in scope and level of detail. A modeling technique has to be selected, and the objective should be in accordance with the objectives of the training.

The third step is understanding the process that is used in the training. Understanding the production environment can be a challenging and complex task, a description or expert knowledge about a process is essential to correctly develop the process in the simulation model. Describing the parameters and the process in a conceptual model helps in correctly developing the simulation model.

Finally, when the parameters, scope and level of detail are determined the model can be built in the selected application for example Siemens Technomatix Plant simulation. For specific simulation software, practice or experience is needed to model in this software. The model has to be fed with all the parameters and the different relationships between them. Additionally, a convenient user interface should be build to make the application user friendly. In this interface input, the simulation model and output should be displayed in a clear way. Depending on the complexity of the model, a manual could be added to explain how to use the model. The model finally results in the objectives of the model and therefore the objectives of the training. The simulation model should be validated to check if the solutions provided are valid and reliable before the use in a training. This can either be done by comparing it to results from a real life process or an alternative model.

The simulation should be embedded in the training with information about the topic, explanation about the simulation model and the different scenarios that have to be executed using the simulation model. Also there needs to be a form of feedback during the training, so a participant knows what they are doing or how to interpret the results from the simulation. A build in function in the simulation could provide feedback, otherwise this could be done in the debriefing after the training.

8.2 Discussion

This section discusses the results and limitations of the research.

First, a limited amount of people participated in the training, interviews and in the focus group. By expanding the number of participants other or more factors can be obtained that influence the outcomes of the research. Secondly, the validation of the simulation training module was done by interviewing the participants in the test and control group. Both reaction and learning statements where identified in these interviews. However, results about learning where limited. More profound and specific questions should have been asked about the understanding of the learned matter. A pre- and a post test before and after the training may provide more detailed and significant differences about the occurred learning of both groups.

A simulation model provides the opportunity to simulate various scenarios based on a number of input values. Simulation models in industry are mostly used to support decision making, but in this thesis a simulation model was used to introduce employees to certain knowledge of the manufacturing plant and its terminology. The simulation model could indeed improve understanding of these concepts and in addition motivates participants of the training more than a case without the simulation model. However, one should be aware of a number of demands relative to a classical simulation model, that is typically used in analysis and decision making. In simulation training or simulation gaming both the simulation as the learning process need to be evaluated. This thesis project focused on the design and test of a simulation training module. The influence of other factors like trainee characteristics or work environment can also influence the outcome of the research but have not been taken into account in this project.

Looking to the practical application of the simulation model, there are some limitations of the research. The designed simulation model consists of a manufacturing line of four stations, in which the participant can through an user panel select settings for the all of the stations of the manufacturing line. Not all the concepts that apply in reality to a manufacturing setting have been taken in to account in the model. It shows the general relations between several parameters, but in reality a similar manufacturing line has to deal with a lot more variables and complexity, like worker availability, experience, maintenance and more diversity in products. Now these aspects may be added to the model later to create even more scenarios that can be used in a training. However one should consider the trade-off between time it takes to model such complexity, and the added value of this effort. The model was suitable for its specific purpose and training objectives.

8.3 Recommendations

The first recommendation for DAF is that they should use simulation where it is applicable. Different needs are identified in this research and could be that simulation in those scenarios also can be value added. It offers many opportunities to 'play' with all kinds of data and scenarios to gain insight in logistic and manufacturing processes.

Secondly, the developed simulation model already provides a lot of different scenarios that could be embedded in a training situation. However, the current model could still be expended with more options. For example the addition of workers to the processing stations, the availability of packaging (like pallets), transport from one station to the other station or different with trains or other vehicles, or different control rules, could create even more and more difficult and realistic scenarios. There is however a trade-off between complexity and time to create the model that should be taken into account while modeling. A simplified model could create the same insights as a more complex model, but could save a lot of time in the development.

The third recommendation for DAF is to do further research in the use of simulation in training and to evaluate how to facilitate simulation training. Looking into different traditional education settings like lecture-based learning or e-learning and research the factors that provide the best suitable training setting for simulation based learning.

The last recommendation is to do further research in the use of simulation and evaluate the possibilities to use simulation also in a decision making process. First, research could be done to see how simulation models can contribute in decision making and how employees make decisions based on the outcome of these simulation models. Secondly, looking more into the development of simulation models and how to correctly build a complex process in a simulation model with the right amount of complexity while still simplified enough.

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Appendices

A Organizational chart DAF Trucks N.V.

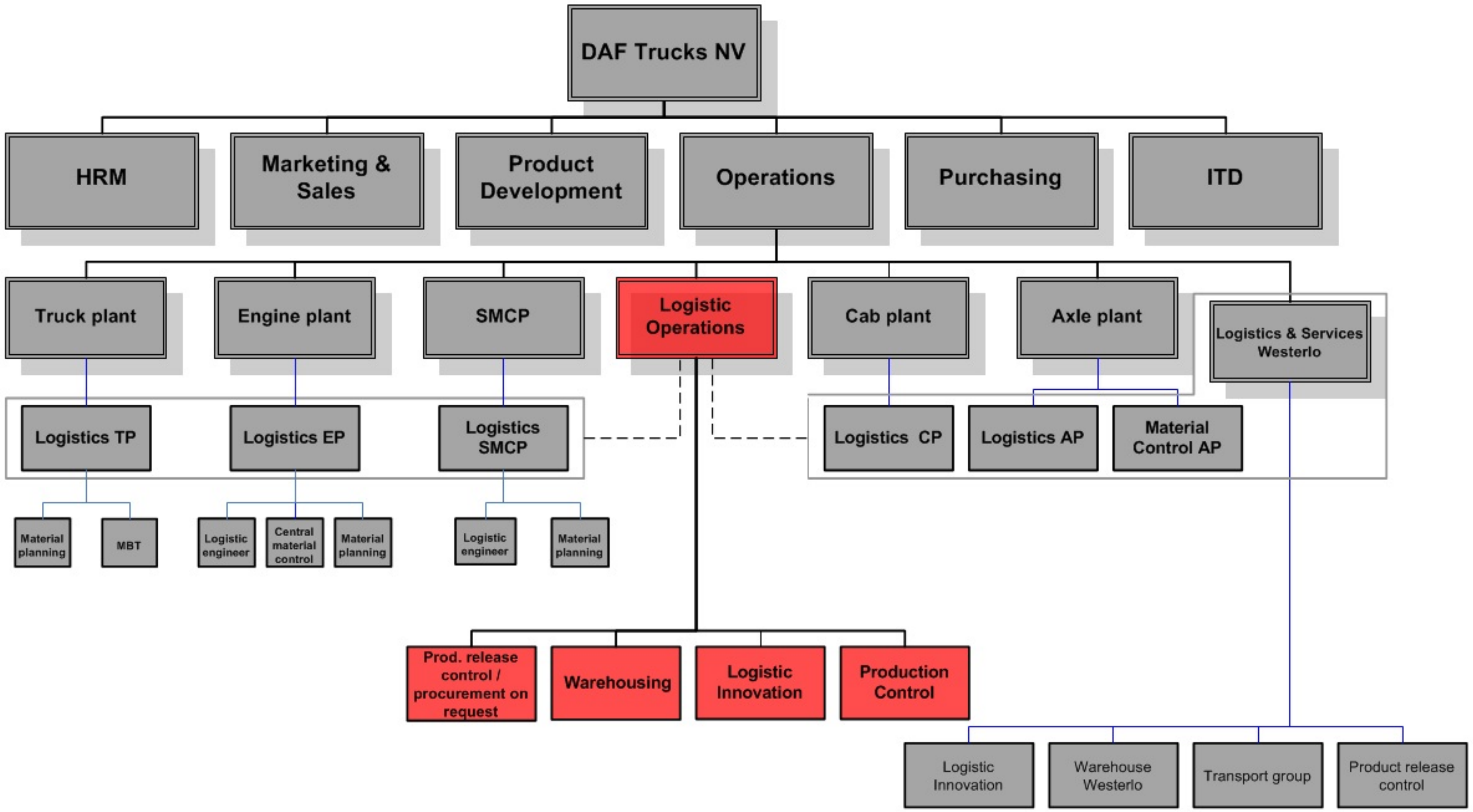


Figure 20: Organizational chart of DAF Trucks NV

B Additional figures Methodology

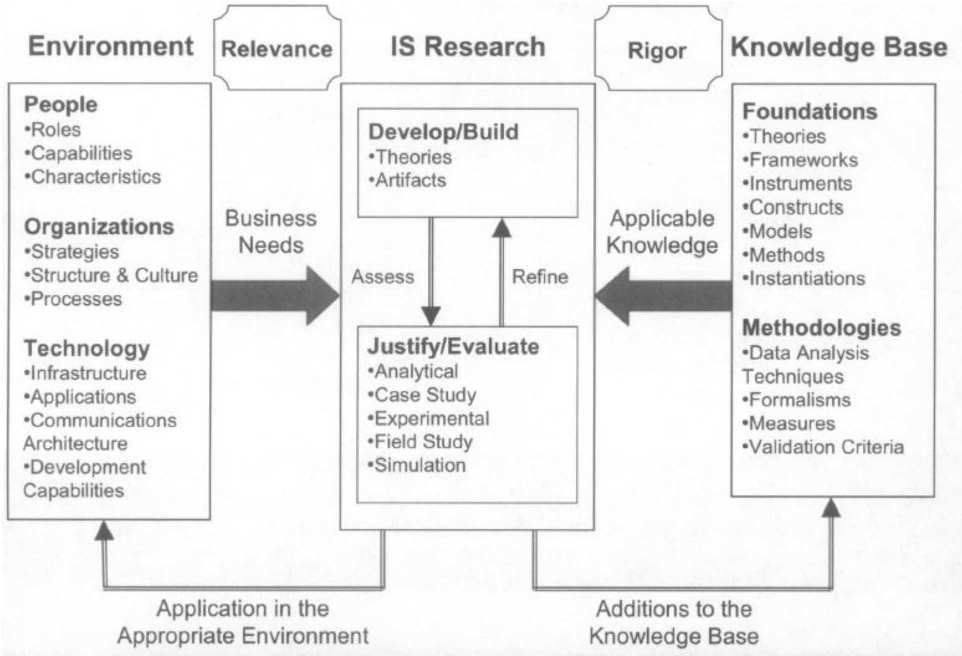


Figure 21: Information Systems Research Framework (Hevner et al., 2004)

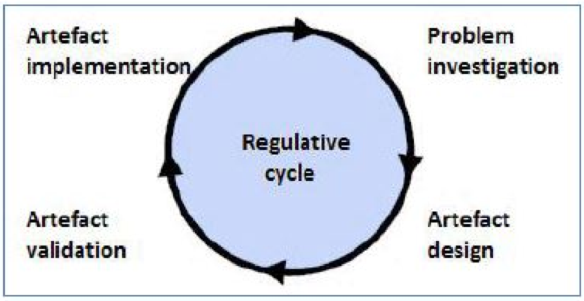


Figure 22: Regulative cycle, adapted for design science research (Wieringa, 2009)(R. Wieringa, 2009)

C Problem investigation Semi-structured interviewing format

In the problem investigation phase situation semi-structured interviews were used, with the following questions:

1. Context
   - Who are the trainees according to you?
   - How are processes explained at the moment?
   - Which processes are difficult to explain?
   - What is the current way of training employees? Is this enough?
   - What are the objectives of the training?
2. Simulation tool
   - What are your thoughts about simulation?
   - Do you already use simulation?
   - If yes, why and what kind of tool?
   - If no, why not?
3. Simulation in training
   - Would you make use of a simulation for training?
   - Why (not)?
   - Which processes are suitable in your area?
   - What are the core problems of these processes?
   - Which data is needed for a simulation of these processes?

D Document analysis

In this appendix the document analysis is discussed. In figure 23 the overview of available knowledge documents is presented in the corresponding categories. The associated roles of each of the knowledge areas and the type and number of documents are displayed together with the content they cover.

Category	Associated roles	Subject	Type of document	number of files	Content
General logistics	Everybody connected to logistics	General logistics	PowerPoint presentation	2	Short introduction to logistics within DAF
			PowerPoint presentation	8	Introduction training to logistics
			PowerPoint presentation	1	Explanation of material management
Process engineering	Process Engineers	Simulation	PowerPoint presentation	1	Introduction to simulation software
		Quality assurance	PowerPoint presentation	1	Introduction to quality process management
Fabrication control	Logistic engineers & Planners	Fabrication orders	PowerPoint presentation	1	Explanation of how to register fabrication orders
			PowerPoint presentation	1	Explanation of different software systems for production
Material requirement and capacity planning	Planners	Material resource planning	PowerPoint presentation		Explanation of MRP within DAF
Assembly management	Logistic engineers	Advanced planning systems	Word document	3	Advanced planning System of DAF
			PowerPoint presentation	4	Advanced planning System of DAF
		Line balancing	PowerPoint presentation	1	Introduction to assembly line balancing
Materials management	Logistic engineers & Planners	Supply chain engineering	PowerPoint presentation	6	Introduction to supply chain engineering, supply chains of DAF and software systems
			Word document	1	Manual for material planner
		Packaging management	PDF file	2	Packaging instructions
			PowerPoint presentation	6	Explanation of different packaging used within DAF
		Transportation	PowerPoint presentation	2	Logistics and transportation
		Receiving	PDF file	2	Process descriptions of receiving shipments
			PowerPoint presentation	1	Overview of unloading stations
		Delivery reliability	PowerPoint presentation	4	Vendor Rating Logistics within DAF
			Word document	2	Manuals for Vendor rating Logistics
		Physical infrastructure	PowerPoint presentation	1	Instruction for layout design
		Material management	Word document	3	Workinstructions
			PDF file	2	Instructions material handling
			PowerPoint presentation	4	Workinstructions
		Line feeding	PowerPoint presentation	4	Instruction for linefeeding processes
		Packaging and shipping	Word document	3	Instructions for packaging and shipping processes

Figure 23: Document analysis: Current available knowledge documents

E Validation simulation model

The simulation model build in Technomatix Plant Simulation will be compared to calculations with formula's from the book Factory Physics by (Hopp & Spearman, 2011). These formula's are build in an Excel sheet. This excel sheet contains the formula's to calculate the performance of manufacturing systems. The input for both models is takt time of orders (number of orders that arrive per hour), processing times for each station, set up time for each station, MTTF and MTTR for each station. Outcomes are evaluated on utilization of the stations, lead time, work in progress and throughput.

For the validation of the simulation model the following settings where used: The simulation model consists of four stations in line. Each station equipped with a infinite buffer and a machine (or processing station). Each of the stations got a processing time: 5, 6, 7 and 6 minutes respectively. This were also the begin settings used in the case of the training. The thrid station takes 7 minutes to complete on average and is therefore the bottleneck station. A bottleneck in a production line is the machine with the least amount of capacity and therefore the lowest amount of items it can produce in a given time period.

E.1 Scenario 1: Increase of utilization

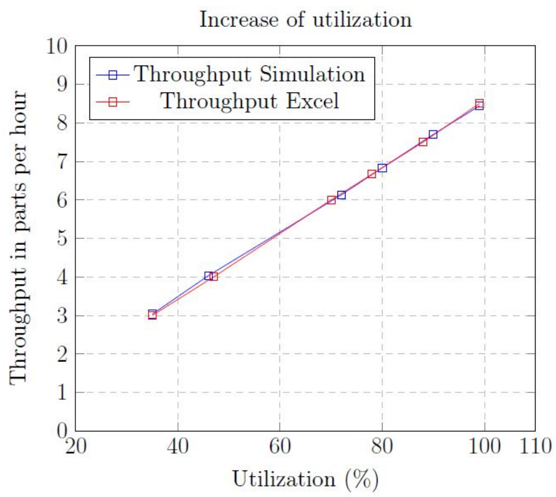
In the first scenario the utilization of each station is increased by increasing the frequency of arrivals (decrease of takt time). In the tables below the scenarios for both the simulation model and the calculations made in Excel are displayed. In the graph the comparison between the utilization of the bottleneck station (station 3) and the results of both the simulation and the spreadsheet calculation. Both the simulation and the calculation show similiar results in this scenario.

Table 15: Scenario 1 of the simulation model

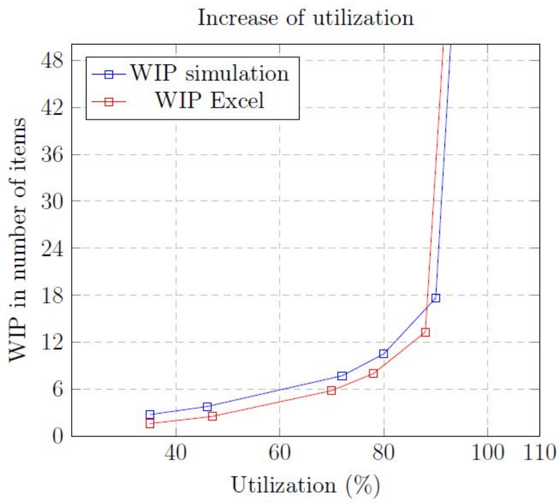
Takttime (minutes)	Utilization Station 1 in %	Utilization Station 2 in%	Utilization Station 3 in%	Utilization Station 4 in%	Throughput in parts per hour	Work in progress (WIP)	Lead time in hours
20:00	25%	31%	35%	31%	3,035	2,768	0,574
15:00	33%	42%	46%	41%	4,036	3,806	0,684
10:00	50%	62%	72%	62%	6,130	7,730	1,113
9:00	57%	69%	80%	69%	6,834	10,516	1,402
8:00	65%	77%	90%	77%	7,701	17,642	2,158
7:00	74%	89%	99%	84%	8,437	119,915	13,321

Table 16: Scenario 1 of the Excel sheet

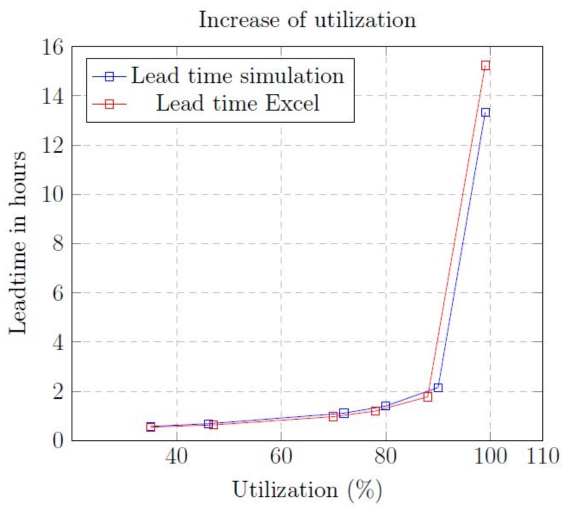
Takttime (minutes)	Utilization Station 1 in %	Utilization Station 2 in%	Utilization Station 3 in %	Utilization Station 4 in %	Throughput in parts per hour	Work in progress (WIP)	Lead time in hours
20	25%	30%	35%	25%	3	1,6337	0,545
15	33%	40%	47%	33%	4	2,542	0,635
10	50%	60%	70%	50%	6	5,833	0,972
9	56%	67%	78%	56%	6,667	8	1,2
8	63%	75%	88%	63%	7,5	13,333	1,778
7	71%	85%	99%	71%	8,5	129,523	15,238



(a) Throughput



(b) Work in progress (inventory)



(c) Lead time

Figure 24: Plots of scenario 1: Increase of utilization

E.2 Scenario 2: Increase of utilization with outages

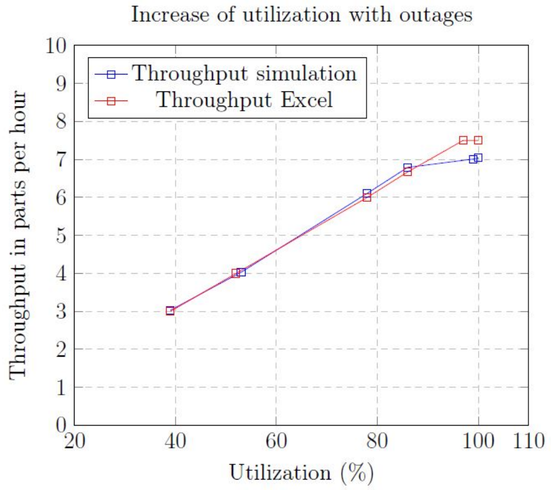
In the second scenario outages are added to the same settings as in scenario 1. The difference is that all the stations now have a mean time to failure (MTTF) of 9 hours and an average mean time to repair (MTTR) of one hour and therefore an average availability of 90%.

Table 17: Scenario 2 of the simulation model

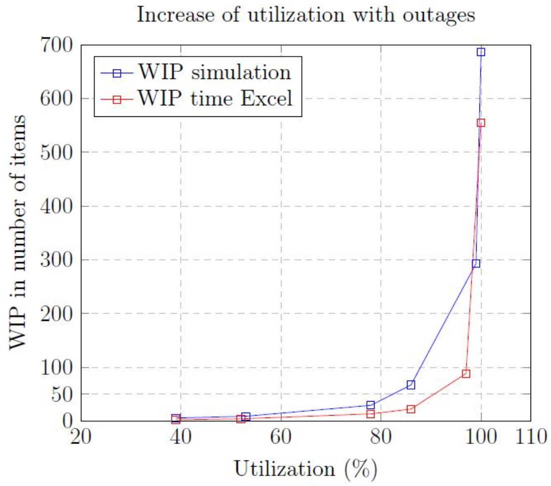
Takttime (minutes)	Utilization Station 1 in %	Utilization Station 2 in%	Utilization Station 3 in %	Utilization Station 4 in %	Throughput in parts per hour	Work in progress (WIP)	Lead time in hours
20	28%	37%	39%	37%	3,031995	5,9913	1,639333
15	38%	44%	53%	44%	4,031308	9,257064	2,070833
10	56%	64%	78%	65%	6,107242	29,5482	4,689667
9	63%	71%	86%	71%	6,790591	67,51647	9,725833
8	70%	83%	99%	82%	7,018532	293,8595	13,751
7	79%	89%	99%	74%	7,048793	687,4922	77,0185

Table 18: Scenario 2 of the Excel sheet

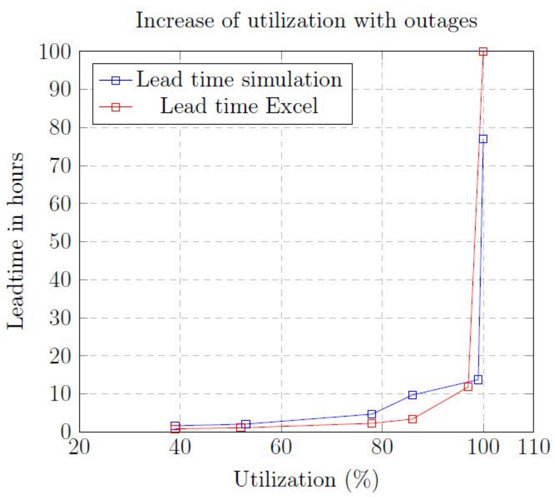
Takttime (minutes)	Utilization Station 1 in %	Utilization Station 2 in%	Utilization Station 3 in %	Utilization Station 4 in %	Throughput in parts per hour	Work in progress (WIP)	Lead time in hours
20	28%	33%	39%	28%	3	2,508178	0,836059
15	37%	44%	52%	37%	4	4,385842	1,09646
10	56%	67%	78%	56%	6	13,69419	2,282365
9	62%	74%	86%	62%	6,666667	22,64523	3,396784
8	69%	83%	97%	69%	7,5	88,54326	11,80577
7	Overload	Overload	Overload	Overload	Overload	Overload	Overload



(a) Throughput



(b) Work in progress (inventory)



(c) Lead time

Figure 25: Plots of scenario 2: Increase of utilization with outages

F Training outline

In this appendix the outline for the training that is used as an experiment is presented. The training itself was used at DAF but will not be part of this thesis since it is confidential. The outline however is presented here.

Time	Subject	Content	Learning Objective	Training Method / Execution	Material Required
	Start of the training	• Get to know each other • Agenda • Learning objectives		Ice breaker to make sure all participants are at ease and familiar and willing to learn. Also show them the agenda and learning objectives to make sure there is no gap in prejudice. Make sure all participants have passed the prerequisite.	
	Quiz	• Misconceptions about management theories in manufacturing	• Understand why these answers do not lead to a shorter lead time	A short quiz about misconceptions in manufacturing	PPT
	Introduction to factory dynamics	• Introduction and explanation of performance measurements in manufacturing	• Throughput, cycle time, lead time, utilization, WIP	Provide an overview of the measurements in a factory and give an example of how these measurements are influenced.	PPT
	Little's law	• Little's law (calculation of leadtime, wip and throughput)	•	Explain the effect of Work-In-Progress (WIP) on the lead time if throughput remains the same. Provide some simple examples of the applications of Little's law: L = λW (WIP = leadtime * throughput)	PPT
	Variability	• Introduction to variability in processes	• Understand the effect of and how to handle Interruptions • Explain the influence of variation in production processes	Let trainees come up with examples of variability. Show some examples and explain the influence of variability.	PPT
	Batching	• Introduction to the influence of batch sizes	• Determine optimal Batch sizes for a station with setup times	Explain the effect of batches: Introduction to set up times, transfer batches and the effect on production performance	PPT
	Case study	• Apply the concepts of factory dynamics on some easy exercises.	• Determine needed capacity and stock points and stock sizes for a stable process. • Sketch the relation between WIP, utilization, lead time and throughput.	Case study: Create some simple examples and let the trainees experiment or determine the effect of changes on system parameters: Lead Time, WIP, Utilization, Throughput	Case study and answers
	Interview	Interview about the training afterwards		Interview the trainees about the training and question them about the training and the things they have learned	Interview

Figure 26: Training Outline

G Validation semi-structured interview format

After the training experiment participants from both groups were interviewed using the format below. The interviews were transcribed and used in the validation phase of the research.

General

- What is your current function or role within the organization?
- What is your educational background?
- How many years of experience do you have within the field of manufacturing or logistics?

Training objectives

- Were the training objectives easy to understand?
- Were you able to translate what you have learned to these objectives?
- Were the training objectives fulfilled?
- Was the training relevant for your work?
- For what functions do you think similar training is relevant?

Training content

- What are the most important things you have learned from this training?
- What are you going to use in your work from the training?

Simulation model / case study

- Was the simulation / case study easy to use?
- The simulation model / case study was suitable to the content of the training
- Did you like working with the simulation model / case study?
- Do you recommend the use of simulation in training?

Other

- What did you like / not like about the training?
- What are the things that still can be improved?
- Do you have any other remarks or comments?