CHALMERS

Design of a flexible and user adapted tool for production planning

- Combining the strengths of LEAN principles and dynamic simulation

Master's Thesis in the Master's programme Production Engineering

FREDRIK MATAR
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Department of Product and Production Development
Division of Production Systems
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011

MASTER'S THESIS 2011

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ABSTRACT

This project aim was to study the possibility to design a flexible and user-adapted tool for production planning by combining the strength of lean principles and discrete event simulation. Early in the process, the need to develop a methodology that supports the identification of needed input and output parameters that enable the design of a user adapted DES tool and that combines the strength of lean principles and dynamic simulation was identified. This methodology was developed and used during the case study to aid in the design of the flexible and user-adapted DES tool. The method enabled the design of a user interface comprehensible by production planners and thus supported the implementation of the proposed DES model into the production planning process.

The developed model was also designed to support the simulation of several similar production lines in order increase the return on investment for the DES model by increasing the lifespan and using the model simulate several different production lines. The developed DES model is able to simulate production lines that can be described by the conceptual model presented in Figure 7.

The developed DES model also enables the users to quickly assess different lean improvement strategies and future production volumes from within the user interface.

Keywords: Discrete event simulation and lean tools and methods, Flexible DES model, user-adapted DES model.

CONTENTS

Preface

This Master's thesis in Production Engineering was first initiated by SKF in cooperation with ÅF. Responsible institution of the thesis is the Department of Product and Production Development at Chalmers University of Technology. The project has been carried out at SKF with the help and guidance of simulation engineers from ÅF. The involvement, guidance and help from our supervisors at SKF, ÅF and Chalmers made this project possible.

We would therefore like to give special thanks to the following persons: Pär Ström, SKF, for your great dedication and involvement. Marcus Höglund, ÅF, for all your excellent tutoring. Niklas Magnusson, ÅF, for making this project possible. Anders Skoogh, Chalmers, for your awesome help and guidance with the report. Without all of you this project would not have been possible.

We have gained extensive knowledge and experience throughout the project and we are confident that this will benefit us in the future.

Fredrik Matar ***Patrik Glimvert***

Gothenburg, May 25, 2011

1 Introduction

The framework for this master thesis is the result from the production situation at SKF, a large bearing manufacturer. The general production process for bearings consists of several steps, where the different components that constitute a bearing undergo a number of manufacturing processes such as soft machining, heat treatment hard machining. In the last process different components are assembled together in a final assembly line. The manufacturing processes are grouped in different production lines depending on the type of processes and product variants. The final assembly lines produce a large number of bearing variants and the demand of the different variants and volumes fluctuates. This combined with the fact that one production flow produces components for several assembly lines creates difficulties in the production planning for the different production lines.

The uneven demand patterns of the assembly lines and the large number of variants produced in the different production lines results in many last minute changes of the production plan. These last minute changes results in changes in staffing, extra setups and high warehouse volumes. These solutions are expensive and also require manual adjustments of the master production schedule. The manual adjustments of the master production schedule requires a deep understanding of the dynamics of the different production lines and thus only experienced planners manages to successfully implement these changes.

Earlier solutions to similar problems within SKF were to use discrete event simulations to analyse production lines and enable a better understanding of the production flow in question. These simulations have been production line specific which make the simulation model development time very high. The use of the simulation models also require the user to be familiar with discrete event modelling principles and successful analyses of the simulation results often require previous experience from discrete event simulation.

This master thesis will opt to develop a flexible discrete event tool that will enable the production planners to analyse the flows of several different production lines without having to develop a new model. Due to the fact that the production planners have no experience of discrete event simulation a user interface is needed that enables the planners to use the model. The user interface will enable the production planners to analyse the consequences of different production scenarios with low needs of knowledge of discrete event simulation principles or programming techniques. The idea is to leverage the fact that production planners at SKF are familiar with lean principles and methods and to use this fact in order to design a DES model with a corresponding user interface that will enable easier planning of the production while at the same time being simple to learn. By presenting the input and output data in a way recognizable by the users the aim is to design a tool that can be used in several projects.

1.1 Purpose

During the course of our studies we have seen the potential discrete event simulation has to support manufacturing companies in their quest to improve efficiency and processes. Production planning personnel often miss this potential due to the complex nature of available simulation tools and the amount of time and effort required to complete a successful simulation project. In contrast lean principles and methods have gained a large support in many industries for their ability to identify and reduce different kinds of wastes and as result improve efficiency and productivity. The purpose is to leverage this fact to reduce the gap to start using DES models in the production planning process in order to detect different bottlenecks early and reduce their impact on the production system. In order to achieve this, the DES model should become a tool that can be used by production planning personnel.

This project will be carried out in a real production environment and, therefore, a second purpose is to increase the return on investment by developing a simulation tool with increased lifespan that can be applied to several different production lines and also be used in everyday production planning processes without the requirement of discrete event simulation knowledge. By using the lean methods and tools to design the user interface the goal is to reduce the threshold for production planners to start using DES during the planning process.

1.2 Aim

The aim of this project is to develop a tool by building a discrete event simulation model together with an appropriate user interface in order to enable the application of discrete event simulation into the production planning process. The developed tool should also be able to model different but relatively similar production facilities from within the proposed interface. In order to be able to generalize the model and the user interface relevant input and output parameters for the discrete event model and the user interface needs to be identified. This is done by developing a methodology that combines lean principles with discrete event simulation. The goal of the resulting product is to assist in the analysis of different production sequences from within the interface.

In order to reach the aim of this project the following objectives will be pursued:

1. Develop and evaluate a methodology with the help from lean principles, which enables the identification of relevant input and output parameters for a discrete event model.
2. Development of a flexible discrete event model with a corresponding user interface, based on the previously identified input and output parameters.
3. Assessment of the proposed model in a real production environment.

1.3 Problem Definition

From the stated objectives in the previous section two main tasks will be pursued. The first task is to identify relevant input and output parameters. In order to facilitate the identification of input and output parameters relevant to the discrete event model and the user interface lean production methods and principles will be studied. The lean tools have proven to be simple but powerful in improving efficiency and productivity while lowering production costs. These tools often deal with general situations and have difficulties coping with complex dynamical production systems. At the other end of the spectrum discrete event simulation deals with specific problems and models the dynamical nature of production systems. By combining these two quite different approaches this project aims to combine some of the benefits of both methods while mitigating their drawbacks. By integrating the identified input and output parameters into the user interface this will be achieved.

The second task is to design a flexible discrete event model with a corresponding user interface. The parameters identified in the previous step will be used as a base for the DES model and the design of the user interface. The developed model and user interface will also be implemented in a real production environment. A production line at the SKF factory with its corresponding final assembly lines will be simulated with the help of the developed discrete event model and user interface.

These two tasks can be translated into the following main questions that will be answered by this project:

Question 1:

Can relevant input and output parameters for a discrete event simulation model with a corresponding user interface be identified with the help of lean production principles and methods?

Tasks:

- Develop a methodology that enables identification of input and output parameters based on lean production principles and methods.
- Use the developed methodology in order to identify relevant input and output parameters.
- Evaluate the proposed methodology by comparing which parameters would not have been identified if the proposed methodology was not used.

Question 2:

Is it possible to build a discrete event model, with a corresponding user interface that can be used by production planners to model several different production flows?

Tasks:

- Build a discrete event model with a user interface, based on the identified parameters in the proposed methodology for the simulated model.
- Use the developed model and the corresponding user interface to simulate a real production flow with the purpose to validate the simulation model.
- Evaluate the flexible DES model with the corresponding user interface.

1.4 Factory Description

The DES model should be able to simulate four different production lines called PL1, PL2, PL3 and PL4 with their corresponding assembly lines, where PL1 is considered the most complex and critical. The PL1 line will serve a basis for the design of the flexible model and the model will be validated with production data from this line.

1.4.1 Description of PL1

The production line of most interest in this project, PL1, produces rollers that are assembled upstream into bearings. Forklifts from the warehouse W1, located in a different building, delivers the raw material for the rollers to PL1. The raw material consists of steel rods that need to be cut to the right size or steel rods that are already cut and turned to the correct size.

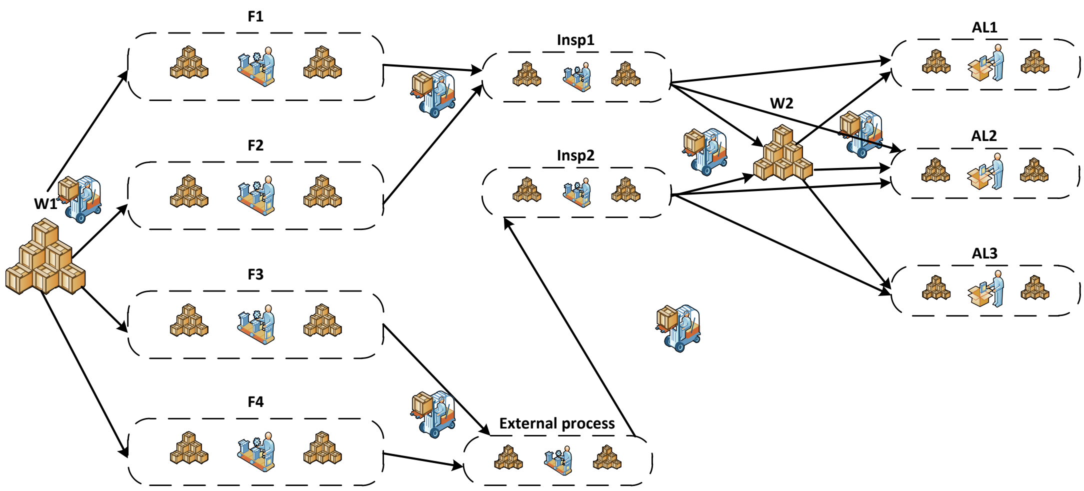


Figure 1 - Main flow of components in PL1

The production line PL1 consists of four different flows that together are capable of producing a large number of different variants of rollers. Depending on size and shape each variant follows a specific flow. The four flows are called F1, F2, F3 and F4. F1 and F2 are dedicated to the large rollers and are machined in two steps. All rollers from F1 and F2 need to be inspected. F3 and F4 are used to produce small rollers and consist of two machining operations. The small rollers need to be inspected.

After the inspection is finished the rollers are placed in an outbound buffer to be picked up by the material-handling department. The rollers are then transported to the main warehouse, W2. If the schedule requires it, the rollers can instead be transported directly to their respective end destination. The rollers from the PL1 supplies three final assembly lines called AL1, AL2 and AL3. These assembly lines are also supplied with rollers and parts from different production lines that are not considered in this project. The main flow of components can be seen in Figure 1.

1.4.2 Description of PL2 and PL4

Forklifts from the warehouse W1, located at bottom floor in the same building, delivers the raw material to PL2 and PL4. The raw material consists of steel rods that are already cut and turned to the correct size. The rollers are moved into PL2/PL4lines that consist of different types of operations. Depending on size and shape the variants must be treated in different machines.

After the inspection process, the finished rollers are packed and placed in an outbound buffer. Then the rollers are transported to the main warehouse for finished goods, W2. The rollers are then delivered to several different final assembly lines. The main flow of components can be seen in Figure 2.

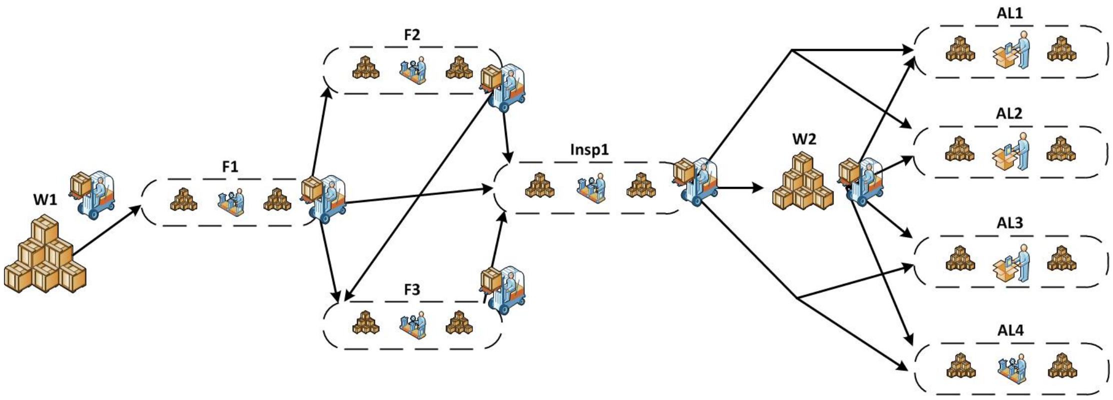


Figure 2 - Main flow of components in PL2/PL4

1.4.3 Description of PL3

Forklifts from the warehouse W1, located at bottom floor in the same building, delivers the raw material for the rollers to PL3. The raw material consists of steel rods that are already cut and turned to the correct size. The rollers are moved into PL3 that consists of several different operations.

All rollers are inspected at the end of the line. After the inspection the finished rollers are packed and placed in an outbound buffer waiting to be transported to the main warehouse for finished goods, W2. The rollers are then delivered to several different final assembly lines. The main flow of components can be seen in Figure 3.

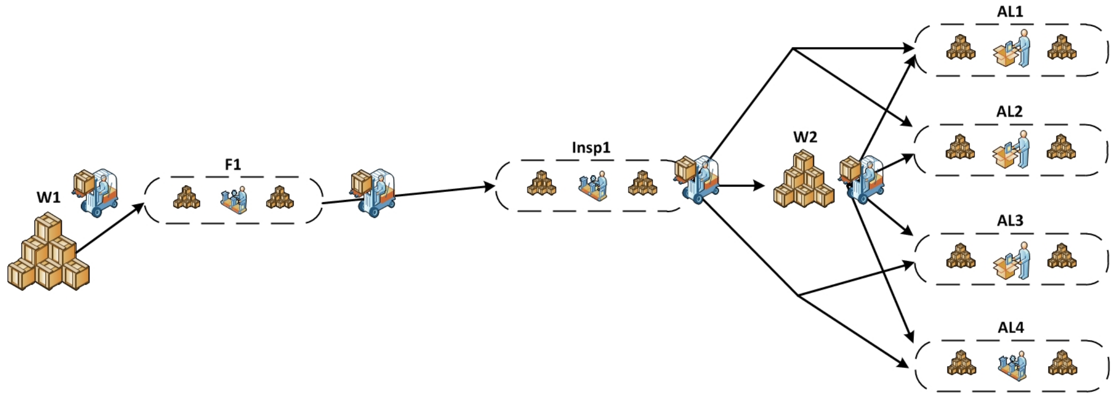


Figure 3 - Main flow of components in PL3

1.5 Delimitations

Operators

With the purpose in mind the operators will not be taken into account when simulating the flow of products. The model behavior assumes that operators are available at all times when the production is running.

Production lines

At SKF there are several production lines producing rollers for bearings. This project will consider the production lines PL1, PL2, PL3 and PL4 with a main focus on PL1. The simulation model is validated by the data from PL1. To handle the production lines PL2, PL3 and PL4 the simulation model will be generalized in accordance with specifications from each of the production lines.

Final assembly lines

This project will consider the bearing products assembled in AL1, AL2 and AL3 with rollers ordered from F1, F2, F3 and F4. All other material required for the bearing assembly will be considered available at all times at the assembly lines. The simulation model should be able to tell if the production lines can deliver rollers to the assembly lines in time. This means that there is no need for any deeper analysis of the assembly lines and therefore each assembly line is modeled as one resource with one in buffer and one out buffer.

Simulation model

During the project several assumptions regarding the simulation model are made, this will be described more in chapter 5, Implementation.

Interface

The user interface is developed to give a SKF user the possibility to use the simulation model without having deep knowledge about simulation or the AutoMod software. The design of the user interface will not take into account the theories and methods available for the development of user interfaces. This limitation is made based on the fact that the users of interface will be designed in spreadsheet software that the future users of the model are already familiar with.

Data collection

All data used in this project is gathered and analyzed from existing databases at SKF.

1.6 Thesis outline

The structure of this thesis is presented in this section.

1. Introduction

The purpose and aim of this project together with the delimitations have already been presented in this chapter.

2. Theory

In the theory section the theories needed to develop the proposed methodology together with reasons and benefits of combining lean principles and DES methods are presented.

3. Methods

In the third section the used methods to develop the methodology and the DES model is presented.

4. Proposed Methodology

The development of the proposed methodology is presented in chapter four.

5. Implementation

The application of the proposed methodology is treated in chapter five. The development of the DES model and the user interface is also presented in this section.

6. Results

The results from the proposed methodology and the development of the DES model are presented in chapter six.

7. Discussion

The results presented in the previous section are discussed in this chapter.

8. Conclusions

The conclusions of this project are presented in the last chapter.

1.7 Glossary

Flexible:
Flexible, in this case, is the ability to use the developed model in different but similar production units within the same company.

DES:
Discrete event simulation

Interface:
Term used for describing the excel interface developed in this project.

Specific DES model:
A DES model able only to simulate one specific production system.

Base conceptual model:
Refers to conceptual model the flexible DES model is built around.

Line:
A production line within a factory, a line can contain several flows

Flow:
A production flow within a line, a line can consists of one or several machines

Rollers:
Cylindrical pieces of metal, used as component in the production of bearings.

2 Theory

This section describes relevant theories identified during the literature study. It starts with reasons for combining lean production principles with discrete event simulation and also a presentation of what has been done in this field earlier. Then available methods to collect data and key theories needed to developing a DES model are presented. In order to identify relevant parameters relating lean principles and DES modelling applicable lean principles and methods are presented. In the last section important parameters to keep track off are highlighted in *italic*.

2.1 Lean principles with discrete event simulation

Both lean principles and discrete event simulation has become more used in later years. Companies find benefits of using either simulation or lean to continuously improve and to become more efficient and productive. This has lead to the hypothesis that a combination of lean principles and discrete event simulation might be able to combine the benefits of both while at the same time mitigating their intrinsic drawbacks. In the coming section the reasons and benefits of this combination will be presented. It will also show what have been done within this area until now.

2.1.1 Reasons for combining simulation and lean

According to Standridge and Marvel the main reasons for combining simulation and lean methods are(Standridge and Marvel, 2006):

1. Dynamical systems

Almost every production system has some sort of variation. The customer demand often varies during weeks, days or hours. Machines often have downtimes that vary depending on how often they are used and what products are going through. The variation can be either structural or random which influence the capacity, lead-time and inventory levels. The lean methods by themself cannot validate the choices concerning these variables. The lean tools can identify the need to reduce lead-times and downtimes but cannot pinpoint where the greatest return on investment will arise(Standridge and Marvel, 2006). At the same time this is one of the benefits of discrete event simulation.

2. Data analysis

When using data in a lean model it is usually some sort of average data describing for example down times for machines, repair times and customer demand. To make the model behave realistically it is often necessary to conduct a deeper analysis of the data, which can be made with the help of simulation.

3. Interaction between components

When using value stream mapping, one component is tracked through the system. If the system for instance is complex with hundreds of components it is often not possible to follow each of the components separately with the help of lean tools. The interaction of the components with the system is hard to follow and validate with lean tools only. Trial and error, which is both time consuming and expensive will probably be needed. This is why simulation is needed when the systems become more complex.

4. Future states

A future state map can be made with the help from one or more current state value stream maps. By evaluating these maps a future state can be made according to lean principles. Value stream mapping gives a static picture showing a snapshot of one product's current situation. The future state map cannot be validated neither can it ensure an optimal solution. By combining lean and static models with simulation and dynamic models it is easy to try different scenarios and to identify the best solution.

2.1.2 Previous studies

There are some studies made within the area of combining lean production principles with discrete event simulation. Most of them cover the combination of value stream mapping combined with discrete event simulation.

Adams et al.(Adams et al., 1999) combined lean theory with discrete event simulation by making two case studies at different companies. By analysing a general method for continuous process improvements it was possible to understand which parts that could benefit from adding discrete event simulation.

Results showed that simulation could be used as a tool to identify problems in the system. The problems could then be differentiated and prioritized according to cost or time saved. By adding graphics to the simulation it could also be used as a training tool to help operators understand the system. Simulation could also be used to evaluate different lean theories without having to implement them in reality. By implementing the improvements in the simulation model it was easy to measure the different impacts on the system.(Adams et al., 1999).

Results also showed that simulation models will be most effective if developed, verified and validated as early as possible in the process of change. By building the simulation model in a way that makes it possible to apply lean and continuous improvements concepts in it will make the effects of the simulation even better (Adams et al., 1999).

2.2 Data Collection

During the literature studies input data management was studied to choose how to design the user interface. When using the proposed methodology the identification of input data parameters was used to collect correct data.

2.2.1 Identification of input data parameters

An important step in the data collection phase is to determine which input data parameters will be needed in order to be able to run the developed DES model. This task can appear to be simple and straightforward in theory. In reality system complexity and the correct level of detail complicates this step. Skoogh and Johansson(Skoogh and Johansson, 2008)proposes several steps to systemize this process, first the system should be studied closely by the modellers. Then during the development of the conceptual model the identification of input parameters should be made simultaneously (Robinson, 1994). It's also important to clearly define how the identified input parameters are measured, here a system expert can explain how the chosen parameters are defined and measured.

2.2.2 Input data management

The nature of this project requires the users of the model to be able to input data to the model without the requirement of extensive simulation experience. Robertson and Perera identified four different methods of input data management(Robertson and Perera, 2002).

The first method is the simplest one where the data is collected and manually coded into the simulation model by the model builder. This is a simple method for the model designers that also allows for the input data to be verified. The main drawback of this method is that it requires that the coding of the model has to be changed when the input data needs to be changed.

The second method also requires the model builder to manually collect and condense the data into an intermediate interface. The concept is that all the data needed to run the model should reside in the external interface. This solution would allow the user of the model to change e.g. the product type or some of the behaviour of the model to reflect new situations in the production system. The main drawback of this method is the amount of time required to manually collect and condense the input data. This solution is today prevalent in the industry.

The third method presented takes the separation of data from the logic one step further, here the authors advocates a solution where the model communicate with an intermediate database to read and write the required data. Then this intermediate database will in turn communicate with the Corporate Business System. Thus the time needed to run different simulation is further reduced compared to the second method. The main drawback of this system is that it requires the modeller to build a communication module that can read and write information into the Corporate Business System, this is normally expensive and time consuming.

In the fourth method the needed data is directly accessed from the Corporate Business System via an interface. Here the model accesses the data directly from the source; this dramatically reduces the time, effort and errors. The user can choose what data to use from an interface. The method has great potential to detect new problematic situations in real-time in the production system and alert the user of this. The main drawback of this method is complex nature and size of Corporate Business System, this makes this method very complex to setup.

This project will use the second method proposed in this methodology. The main reasons for choosing this approach are that the users are familiar with the spreadsheet interface, the production data is available in spreadsheets and would not be possible to build an intermediate database nor directly access production data during the time frame of this project.

An overview of the four different methods is presented in Figure 4 where the different data input methods are also evident.

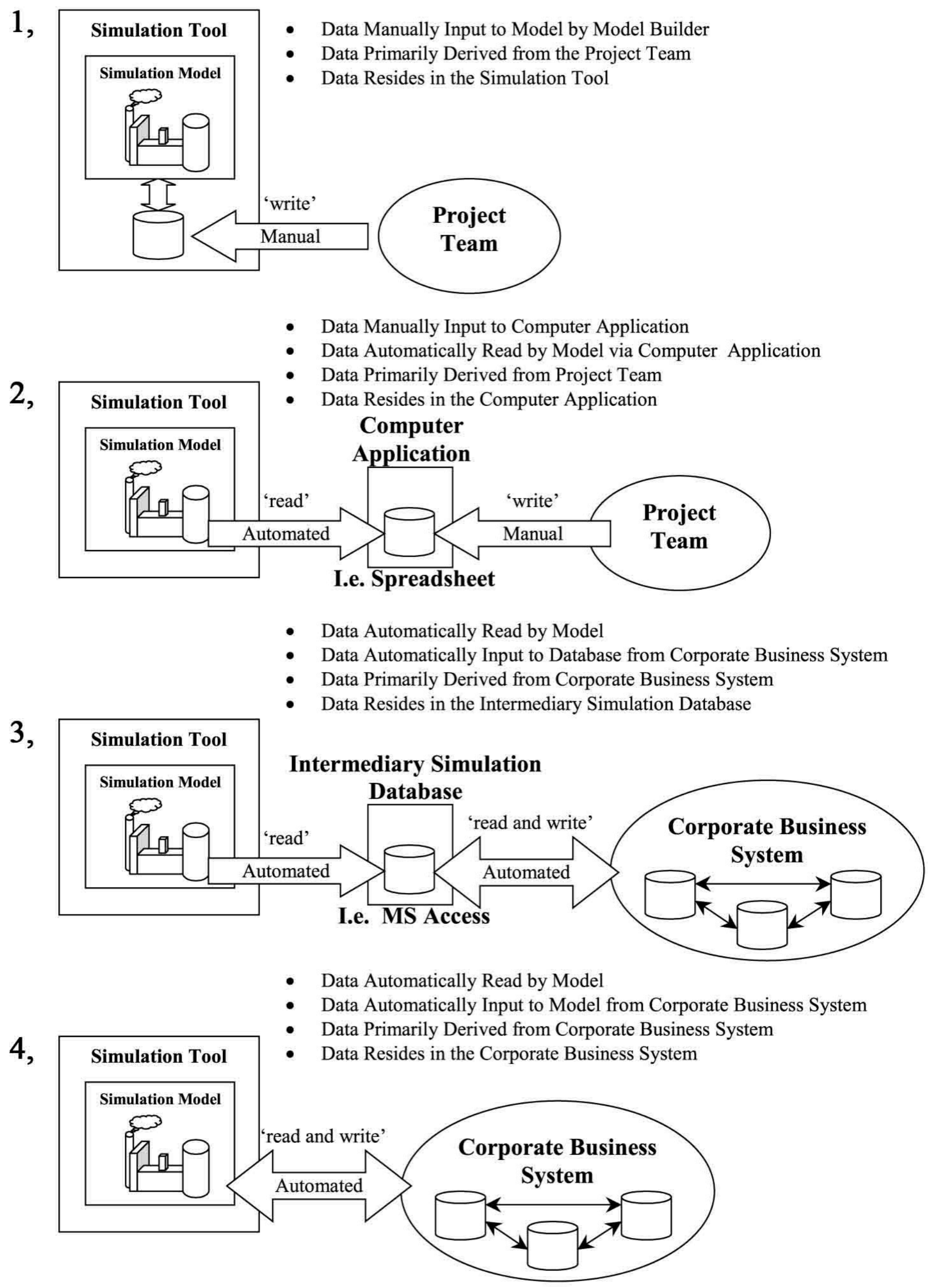


Figure 4 - Overview of different input data management methods(Robertson and Perera, 2002)

2.3 Discrete event simulation theory

Theory of constraints is used as a support when building the model and the interface. This is taken into account to make sure that a future user of the system easily could analyse a production line according to this systematic approach. To make the model flexible it needs to be simplified in some extend and that is where the simplification of models in DES has its purpose.

2.3.1 Theory of constraints

This theory was first developed by Dr. Eli Goldratt in order to identify the bottleneck operations in a process. A constraint in a production or material flow is a limiting resource for the whole system. This theory could be used as a method to improve the lead times in production and material flows. The method developed by Eli Goldratt consists of five steps (Jonsson P, 2009):

1. Identify the constraint
2. Exploit the constraint
3. Subordinate everything else
4. Elevate the constraint
5. Go back to the first step

The main strength of this method is that often identifies the one process in a system that will give the best return on investment. In order to facilitate the detection of constraints in the simulated production system the developed user interface should support quick detection of bottlenecks and also enable the user to elevate the identified constraint.

2.3.2 Simplification of models in DES

One of many factors to consider for the success of a DES project is to keep the model simple. A widespread misconception in DES modelling is the fact that a more complex model will result in more accurate results, this might be the case in some situations but will generally result in models that are to complex to understand and increase the probability of errors during the coding phase(J. Brooks, 2000). One way to reduce the complexity in a simulation project is to model several consecutive operations with the help of one bottleneck operation. This is described by Brooks (J. Brooks, 2000). To illustrate this concept consider the 3 machines M1, M2 and M3 with respective cycle times of 1, 1 and 3 min. and buffers on the input and output side of 1, 1 and 1 parts respectively. If no breakdowns are considered M3 is clearly the bottleneck machine and thus this system can be modelled by one machine M4 with a cycle time of 3 min with input and output buffers of 3 parts each. The parts being processed in the new M4 machine should also be delayed by 2 extra minutes to account for the time the parts spend in machines M1 and M2.

2.4 Lean production principles

During the last two decades the lean approach to manufacturing and material handling has gained many followers. The lean approach can be described by a number of principles and methods. This section will present some of the core principles that relates to production planning and material flow. These principles are used in the proposed methodology to identify relevant input and output parameters.

2.4.1 Continuous flow and levelled production or Heijunka

To be able to implement a pull system in a manufacturing environment a couple of preconditions must be fulfilled. These conditions are short set-up times, small batch sizes, flow oriented layout and a levelled production (Jonsson P, 2009). A flow-oriented layout links the different operations together; in a flow-oriented layout the different processes must have similar cycle times and capacities. The core principle in a *levelled production* is to balance the different operations to similar cycle times or takt time. The takt time concept is to synchronize the production rate of an entire plant to current customer demand (Jonsson P, 2009). The interface and DES model should support the simulation of levelled production strategies.

2.4.2 Quick change over or SMED (single-minute exchange of dies)

In order to enable a levelled production and a continuous flow in the production the setup times between different variants must be reduced. This will help to reduce the batch sizes and enables the production line to respond quickly to changes in demand. One way to reduce *setup times* is to distinguish between internal and external setup operations. Internal setup operations can only be done when the machine is offline, such as removing or mounting the tool and bolts. External setup operations involve work that can be done while the machine is still running, transportation of e.g. die and required tools. The goal is to prepare all the external operations before starting the setup process; in the long run some of the internal operations can also be converted to external work(Shingo, 1985). The model should enable the user to set and change the setup times for different products.

2.4.3 Kanban

The goal of a pull system is to reduce overproduction and one way to control the number of items produced is to use a Kanban system. A Kanban system can help to increase the flexibility of the production system, coordinate the production of smaller batches of components, simplify the procurement process and tightly integrate the different operations in production lines. It also serves as simple visual tool in order to trigger material handling operations (Team, 2002). A Kanban system can be described as a control system to coordinate the production and/or transportation of a specific amount of components. The Kanban signal could be a physical card, container or electronic order from the MRP system (Jonsson P, 2009).

2.4.4 Reduce waste

At the heart of lean production is the *reduction of waste*, all operations and activities that do not add value to the product is considered as waste. The value adding work must be seen from the eyes of the customer, every time a product is processed or moved one have to ask the question if this particular operation adds value to the end customer. If not the operation is considered as waste and should be eliminated or reduced. In the literature seven major types of wastes have been identified and they are (Liker, 2004):

1. Overproduction
2. *Waiting*
3. *Unnecessary transport*
4. Over processing
5. Unnecessary movement
6. *Defects*
7. Unused employee creativity.

One way to identify the ratio of value adding work vs. non-value adding work is to draw a value stream map of for each product. This is discussed more in detail in the methods section. The user should be able to change the highlighted parameters waiting, unnecessary transport and defects.

2.4.5 Create continuous process flow to bring problems to the surface.

In a manufacturing setting most of the time the products spend in the system they are waiting to be processed, thus the main principle is to look at non-value adding time and try to reduce it (Liker, 2004). In order to be able to model this principle in the DES model the user should be able to set and change the flow of products through the simulated system.

2.4.6 Use "pull" systems to avoid overproduction

In a pull system the customer demand triggers the production of a certain product, this is desirable in order reduce overproduction. Overproduction is one of the most expensive forms of waste because it inherently contains all the other types of waste. In an ideal pull system the order to produce one unit comes from the customer and is then propagated upstream in the production chain. Due to the batch nature of many operations in the manufacturing industry a true one-piece flow pull system will be difficult if not impossible to realize. This intrinsic conflict between batch-and-queue operation and pull systems has led to the development of the Kanban system(Liker, 2004).

2.4.7 Level out the workload (Heijunka)

Heijunka is the concept of levelling out the production and schedule; the core idea is to balance the mixture and volume of variants produced over time. In an uneven production the workload would be higher at times resulting in an overburdening of people and machines. The consequences of overburdening people can lead to safety and quality issues, while overburdening machines leads breakdowns and defects. On the other end of the spectrum a low workload would lead to underutilized resources. This results in production systems often being designed for peak demand but operating at lower levels of utilization (Liker, 2004). The interface should enable the user to detect uneven workload and also provide tools to influence this outcome.

3 Method

This chapter will present the methods used to help to answer the main questions of this project. The used method presented aims to help in the development of a proposed methodology that will enable the identification of relevant input and output parameters for the model.

Here it is important to differentiate between the method used to develop the proposed methodology and the proposed methodology in itself, see Figure 5. This will be done in order to answer the question in *section 3.1*. The resulting proposed methodology will be presented in the next section as a result of the used method presented here. After this, the method used to develop the discrete event model is presented and at last the lean tools used in the identification process.

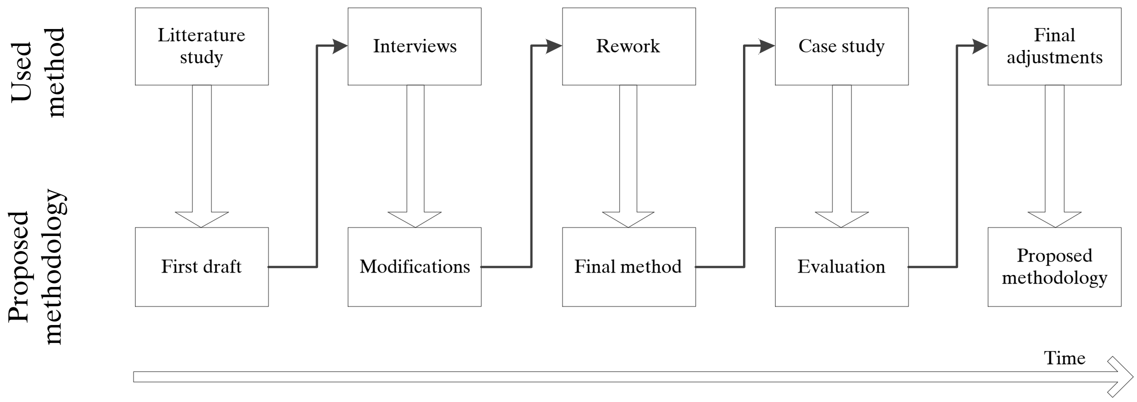


Figure 5 - Overview over the used method and proposed methodology

3.1 Used Method

In this section a method will be presented that will help in the development of a proposed methodology that will facilitate the identification of relevant input and output parameters for the desired discrete event model. The different steps of the method will be:

1. Literature Study of lean production and discrete event simulation methods

The process started with a literature study of relevant topics in the fields of lean production and discrete event simulation. This step aimed at identifying the different methods available in the respective fields. Each methods strengths and weaknesses was also presented. During this phase previous works treating the combination of lean production methods and discrete event simulation was also identified and presented. At the end of this step a preliminary methodology combining methods and tools from both Lean production and discrete event simulation was presented. The literature study has already been presented in the previous section of this report. Table 1 and Table 2 shows, which databases were used together with the different key words that gave the best results. The key words were to some extend also combined with each other.

Table 1 - Used databases

Database
IEEE Explorer
Science direct
Wintersim.org
Books24h7
Summon (Chalmers)

Table 2 - Used key words

Key Words
DES, Discrete event simulation, Automod simulation,
Flexible simulation model, multipurpose simulation model, Banks model,
Lean, Lean production , Lean principles, Lean methods, Lean tools, VSM
Value stream map, User interface, Simple user interface,
Lean and simulation, Input data management, Data collection

2. Interviews will be conducted in which the preliminary methodology is presented to different practitioners in the field of discrete event simulation and lean production.

In this step the resulting methodology will be presented to practitioners' of lean production strategies and discrete event simulation. The aim is to validate the proposed methodology.

The aim of the interviews in this section is to determine if users of lean production and discrete event methods can validate the proposed methodology; therefore the input from present practitioners is relevant. The interviews will be of a qualitative nature in order to capture both the participants' points of view and to test the proposed methodology (Bryman and Bell, 2007). There will be a specific list of questions and topics to discuss; in this situation Bryman and Bell (Bryman and Bell, 2007)recommends a semi-structured approach. The semi-structured approach was chosen to remove the focus from specific questions and take advantage of all the views that came up during the interviews.

3. A rework of the methodology

Input and feedback from the interviews will be used to develop the presented methodology.

4. A case study

The proposed methodology will be applied in a real production environment at SKF. The results from the use of the proposed methodology will be the basis for the modeling of the simulation model and will be used as input and output data to the simulation model that reads and writes input and output data from the interface.

5. Evaluation and final adjustment of the proposed methodologyand the results of the case study

In this step the final proposed methodology and the case study is presented in a workshop to practitioners' of lean production strategies and discrete event simulation. The methodology will be evaluated by considering what parameters DES methods would have identified compared to the proposed methodology. The methodology will also be adjusted if deemed necessary from the results of the case study.

3.2 Simulation of production systems

The success of this project will rely on the quality of a discrete event simulation model. The model will be built by following the proposed methodology combined with parts of the systematic approach proposed by Banks (Banks, 1998). Banks model consists of 12 steps and is presented inFigure 6. The first four steps in Banks model will be replaced with the proposed methodology. Model translation, verification and validation phase will be made according to Banks. Due to the fact that the final tool is a tool for planning and not optimization there is no need to make any experimental design and production analysis during this project. The users of the final tool will make their own test runs and will be able to detect bottlenecks and thereafter change the input parameters to come up with a solution to the bottleneck problem. At the end documentation and reporting will be made.

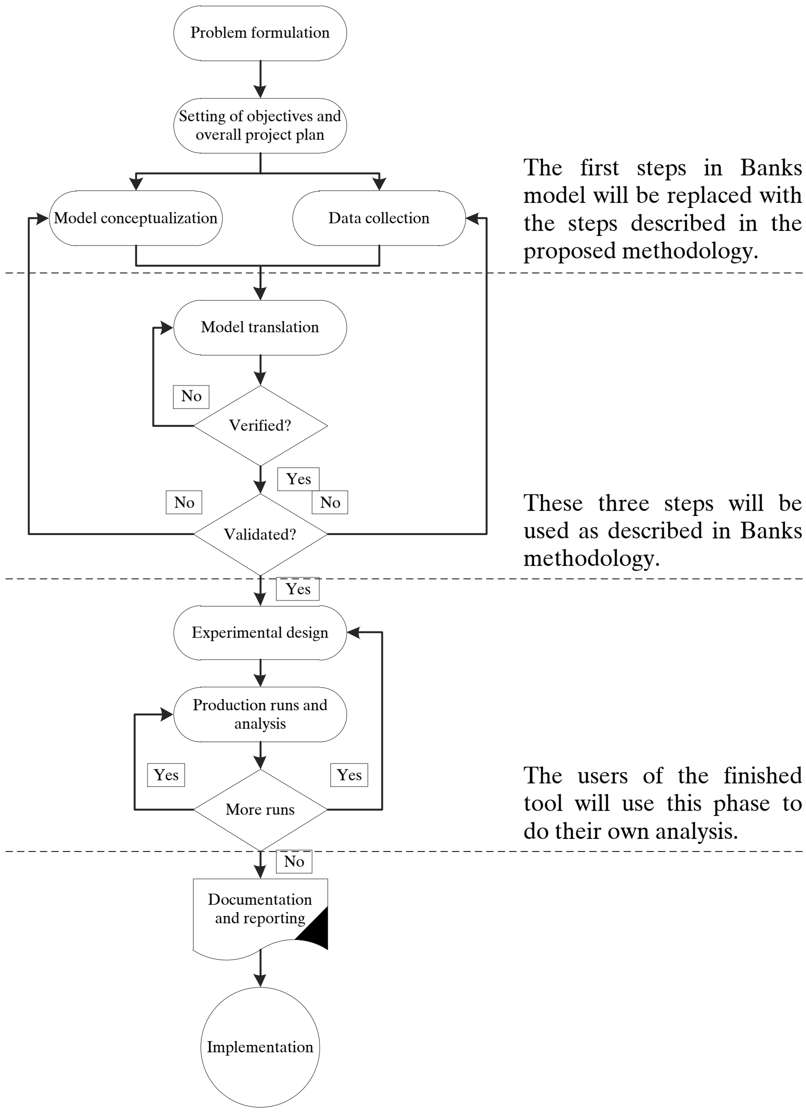


Figure 6 - Banks method

3.2.1 Model translation

The conceptual model will be converted into a simulation base model that can be analyzed and processed. The coding of a base model is usually done in some simulation software. When coding the base model it is important to take the time to consider a good and correct solution. This includes a code that is easily understood and flexible for future changes. It is easier for the modeler correct problems by continuously testing and validating during the coding process (Robinson, 2004). The model translation in this project will be described in the implementation chapter.

3.2.2 Verification and validation

When a system is first simplified to a conceptual model and then translated into a computer model there is a need of the two control processes verification and validation. These processes are important elements of a simulation project. Verification is done to ensure that the conceptual model has been translated to a sufficiently accurate computer simulation model. Validation is done to make sure that the model is sufficiently accurate for that specific purpose it is intended for. Different types of validation methods are conceptual model validation, data validation, checking the code, visual checks, inspecting output reports, comparison with the real system and/or other models (Robinson, 2004).

Verification

During the model building the code was verified continuously by implementing block by block from the conceptual model and comparing the input parameters with the output parameters and ensuring that the model behaved as expected. By always verifying small changes in the model it became easier to find and correct mistakes in the code. The code was also verified with the help from the built in debugger in the Automod software. The debugger made it easy to follow a specific load executing the code and thereby verify that it behaved as expected all the way from the beginning till the end.

Validation

As the model has been verified during the project the validation of the model has been made simultaneously. The validation phase is mainly based on the two different validation techniques described below.

Face validation

Inspired by the paper Validation and Verification of simulation models written by Sargent (Sargent, 2009) the face validation has been a part of the validation. By running the model and considering the graphical behaviour and the output data it is possible to discuss with operators and technicians on the production floor how the system behaves in reality. Without revealing the results from the simulation it was possible to validate the behaviour of the simulation model. Discussions with engineers both at SKF and ÅF that are familiar with simulation models and excel interfaces have also helped to validate the model. By presenting the output parameters number of setups, working time, idle time and starving time in a graph showing over 100 days of production the production personnel can verify if the graph are representing their production line.

Historical data validation

With the help from gathered historical data from SKF it was possible to compare the output data from the simulation model with real historical production data from the actual production line. Due to the fact that there are a lot of last minute changes of staffing and routing it is hard to compare the results at specific times. When the production system is up and running one product influences another that results in a chain reaction in the whole system. Because of this it is not possible to simulate only one order in the model and compare it with one order in the real system. By looking at the annual demand and frequency for the production line of interest it was possible to make a one year run with the same demand and frequency of random orders in the simulation model and look at the results and see that it took approximately one year to produce in the model as well as in reality.

3.3 VSM

Value stream mapping is a tool to visualize the flow of products and information inside a process. This method enables involved parties to quickly gather, analyze and present information (Nash and Poling, 2008). In this project the value stream maps will be used as a basis to understand the flow of products and information. Later on the value stream maps created will be used to construct a conceptual model of the production in PL1. The benefits of using value stream mapping includes helping involved parties create a common vision of current and future process, identify and visualize the different types of waste in the process and functions as basis to discover future improvement activities (Tapping, 2007). Value stream mapping can be carried according to the methodology presented by Tapping (Tapping, 2007). The value stream maps made for this project aims to create a common picture of the production system of interest. The goal is to clearly show the flow of products and information. Because the production flow of PL1 produces a large number of different variants cycle times, inventory levels, defects and uptimes will not be collected in this phase. A future state map will not be made, as the developed DES model should help in the identification of what improvements should be made.

The different variants are produced in four different production lines depending in the size of the parts. In order to reduce the number of required value stream maps needed the different variants will be divided into two categories:

- Category A: Large rollers produced in the lines F1 and F2.
- Category B: Small rollers produced in the lines F3 and F4.

The flow of products and information in category A variants is similar, this is also true for category B variants. It is important to note that a value stream map only shows the state of the system at a particular point time.

3.4 Software

This project will be carried with the help of the Automodsoftwaredeveloped by Applied Mechanics (Automod, 2011) for discrete event simulation. This software is chosen because both the model builders in this project and different involved parties have previous experience from using this software. This choice is also motivated by the fact that a model developed in a familiar environment will require less time and facilitate the validation phase.

The interface for the discrete event model will be designed in Microsoft Office Excel C, this software was chosen because the future users of the model are familiar with this software. In addition, a module that facilitates the communication between the interface and the model has already been developed.

4 Developed methodology

In this section the application of the used method is presented together with the result from the literature study and the interviews. The final proposed methodology is presented in *section 4.4*.

4.1 Background to the proposed methodology

From the literature study a couple of different steps were identified as critical for a successful implementation of a DES model. Also several useful lean production principles were identified that could aid both in the identification of relevant input and output parameters and relevant improvement strategies. As this methodology will in the end result in a DES model, the first step of J. Banks method of problem definition and objective setting was identified as a logical start. The importance of a thorough understanding of the system of interest is stressed by both approaches and the next step will be to formalize the mapping of the production system of study. In lean production this is done by making a VSM of the system in question, while in DES this is achieved by making a conceptual model of the different flows of components in the system. The data collection for both these steps can be performed simultaneously due to the fact that they both require the same type of data. Furthermore the conceptual model aims to formalize the production flow in order to facilitate the future design of a DES model while the VSM serves as tool to visualize the flow of products and information. The aim of performing both these steps is to better understand the system and also in an early stage identify some of possible areas of improvement. These identified problems can then be integrated into the DES model.

VSM is a tool that quickly enables involved parties to share a common vision of a production system; it cannot on the other hand by itself identify all the areas of improvement. In order to accomplish that it is imperative to study which of the lean principles presented in the theory section that can be applied while at the same time respecting the requirements of the customer. For instance the customer might not be interested in any solutions that would require a change in the layout of the production system. The decision to incorporate lean production principles into the methodology is also based on the fact that lean production principles are considered simple, easy to understand based on common sense (Hogg, 2003). This will hopefully later facilitate the implementation phase of the DES model into the production planning process.

By this stage it is necessary to collect the required data in order to be able build and simulate the system. Then the process of building the DES model is initiated, this is performed according J. Banks method(Banks, 1998). Some of the steps described in Banks method are already completed. In this step the previously identified input and output parameters and the improvement strategies should be integrated into both the DES model and the user interface.

The final step in this methodology consists of a verification and validation phase of both the DES model and the user interface to secure the desired behaviour and design.

The first draft of the proposed methodology is presented here:

4.2 First draft

1. Data collection I

Basic data collection is carried out in order to construct a VSM and a conceptual model of the production unit. This step is further discussed in the methods section for VSM and data collection phase of a discrete event simulation project. The construction of a VSM and initialization of a DES project requires a basic data collection (Tapping, 2007) and (Banks, 1998).

2. VSM and Conceptual model

From the basic data a VSM is constructed and then a conceptual model of the physical system is developed. This process is facilitated by the fact that the VSM clearly shows the flow of the products. The Value stream map is converted into a conceptual model that can be modelled in discrete event simulation software. The conceptual model is needed to facilitate the coding of the DES base model (Banks, 1998).

3. Use lean planning strategies to identify relevant input and output data

With the help from the VSM and the lean tools and methods input and output parameters are identified. At the same time lean improvements strategies are identified so that the proposed interface can support the simulation of these strategies. By presenting the data in the interface in a way that the users can identify with the objective is shorten and facilitate the implementation phase.

4. Data collection II

In this phase the data needed to simulate and validate the model is collected and analysed. The different types and categories of data needed are identified during the data collection I and conceptual model phases. In the method proposed by Banks a second data collection phase is made (Banks, 1998).

5. Build model

A parametrical DES model is build according to Banks method (Banks, 1998).

6. Implement LPS in model

The identified parameters and improvement opportunities are implemented in the DES model.

7. Build a user-friendly interface for the DES model

In order to enable production planners and managers to use the DES model during the production-planning phase a user interface needs to be developed. The interface should be intuitive to production planners to use and no previous experience from simulation should be needed in order to be able to analyse the simulated production. The user interface could also enable advanced analyses of the production system by simulation practitioners without the need to rebuild the discrete event model.

8. Final Verification and Validation

In the last phase the combined DES model and user interface is verified and validated. If the combined model fails this step, a return to step 7 is required. According to Banks methodology covering DES models the verification and validation part is important to make the model to behave as reality (Banks, 1998).

4.3 Interviews

In order to gather different view and perspectives on the proposed methodology five interviews were conducted with different persons. These persons have different experiences and areas of expertise related to the topic at hand. Their different areas of expertise are presented in Table 3 - List of interviewees.

Table 3 - List of interviewees

Interviewee	Area of expertise
1	Researcher: DES and Lean
2	Researcher: DES
3	User and client of DES
4	Researcher: Lean
5	Developer: DES

4.3.1 Interviews results

The interviews were carried out in semi-structured way and the different views resulting from the interviews are presented in Table 4. Opinions about the combination of DES and Lean, DES and Lean in general are omitted from this summary. Only opinions relating the methodology in question are presented.

Table 4 - Summary of the interviews

Interviewee	View N#	View
1	1	Combine step 5 and 6 in order to reduce the risk of rebuilding the model
1	2	Model building and the validation and verification process should be carried out simultaneously
1	3	Identify the relevant lean principles earlier in the process
2	4	Design the user interface earlier in the process to reduce the risk of an extra data collection phase
3	5	Define a purpose for the model in question
3	6	Determine and implement the improvement possibilities earlier in the process.
4	7	VSM is a good tool to visualize a flow but not enough to identify improvement strategies
4	8	The method does not propose a way to validate the user interface.
4	9	Can the user properly identify what input parameters the DES model requires?
4	10	Important to show what parameters can be changed in the user interface.
4	11	Difficult to handle multiple scenarios with a flexible model.
4	12	Step 7 should be performed earlier in the process.
5	13	Verify the identified parameters with the users
5	14	Separate the identification process from the model building.
5	15	Build the interface simultaneously with the DES model development.

4.3.2 Interviews Summary

From the interviews several improvements to the proposed methodology could be identified. The main opinion concerned the order the different steps were carried out in the methodology. From the interviewees opinions it' thought that building the DES model and the user interface simultaneously would increase the efficiency of the development phase while at the same time reducing the risk of rebuilding the model. Also the model-building phase could benefit if separated completely from the proposed methodology, this because well-established methods for developing DES models already exists. This coupled with the fact that a separation of the model building from the identification process would create a simpler and a more useable method.

Another important view to consider is the fact that the methodology did not mention any clear problem definition phase, this is an important step in order to early identify the purpose of the project.

Many of the views could be accommodated if the methodology concentrated on identifying the relevant input and output parameters and also possible lean improvement strategies earlier in the process.

The identified parameters should also be verified with the users of the model in order to create a user interface that should be both recognizable and easy to use.

4.4 Final Methodology

The method was adjusted to accommodate the proposed changes from the interviews. The final methodology is presented here:

1. Problem definition and data collection I

It is vital that a project purpose is determined early in a project in order to facilitate a clear problem definition. Basic data collection is carried out in order to construct a VSM and a conceptual model of the production unit. The VSM is further discussed in the methods section for VSM.

2. Conceptual model

From the basic data a VSM is constructed and then a conceptual model of the physical system is developed. The Value stream map is converted into a conceptual model that can be modelled in discrete event simulation software. This process is facilitated by the fact that the VSM clearly shows the flow of the products and can also in an early stage point out possible bottlenecks in a production system. The conceptual model will at this stage help to identify some of the relevant input data parameters needed to build the system.

3. Identify relevant input and output data parameters and lean improvement strategies

By identifying applicable lean improvement strategies relevant input and output parameters can be determined and added to the model. The input and output parameters should account for all the data needed in order to be able to run the model.

4. Workshop

To make sure that the input and output parameters identified in step 3 are relevant, a workshop is held with operators, possible users of the simulation model and production development personnel. To make the interface user friendly it is of uttermost importance to know what parameters the user of the model are used to work with and also what data are available and how it is stored.

5. Collection of input data parameters.

In a first stage, preliminary data is needed to get a thorough understanding of the system. When this is achieved more specific data will be needed to build the simulation model (i.e. cycle times, breakdowns, components). When the model has been build it needs to be validated by comparing data output from the model with real data. Correct data is very central in the use of simulation models, without correct data the simulation model will be worthless (Robinson, 2004).

5 Implementation

In this section the implementation of the proposed methodology and the design of the DES model with the corresponding user interface will be presented. First the implementation of the proposed methodology on the PL1 production line with its corresponding assembly lines will be presented. Then the development of the DES model with the corresponding user interface will be presented. The DES model and the user interface were developed simultaneously but will here be presented in two different sections.

5.1 Application of the proposed methodology

The application of the developed methodology is presented in this section.

5.1.1 Problem definition and data collection

The developed DES model should be flexible enough to be able to simulate several different production lines as described in the first chapter. The main goal of the DES model is to aid production personnel during the planning process by enabling the simulation of different improvement strategies based on lean production principles. The model should also be coupled with a user interface that enables people without simulation experience to run the model.

The problem definition is set based on the following requirements from ÅF and SKF:

1. The model should be flexible enough to simulate at least four different production lines at SKF.
2. With the help of the developed DES model the production planners should be able to identify possible bottlenecks and try different solutions.
3. The simulation model should be easy to use in order to function as day-to-day planning tool.
4. The simulation model should be developed with the Automod software.
5. Input- and output data is handled by Excel software. The reason for choosing excel is described in the software chapter.

The data collection phase started with a walkthrough of the different production lines of interest at the factory. This was carried out in order to gain a basic understanding of the production systems. Information about the different processes, material handling, and production flow was gathered during this phase. The production flows of interest in this project are summarized in the first chapter. In order to better understand the flows of products and information in the system a value stream mapping of the PL1 production line with its assembly lines was done.

5.1.2 Conceptual model

From the data gathered and the VSM constructed in the previous step a conceptual model of the PL1 production line was made. This conceptual model is presented in Appendix B. This conceptual model does not take into account the remaining lines that the DES model should be able to simulate. The conceptual model needed to be changed in order to accommodate the production flow and logic of the remaining lines. The resulting DES model should also be flexible enough in order to be able to simulate similar production lines not considered. After considering these factors, a generalized conceptual model was developed. The developed conceptual model is able to simulate a production line with five consecutive processes and each process consists of four different machines or lines. It is up to the user to define the level of detail that the model should simulate. This could be done by modelling each specific machine as one resource or several consecutive machines as one resource. This conceptual model can be seen in Figure 7.

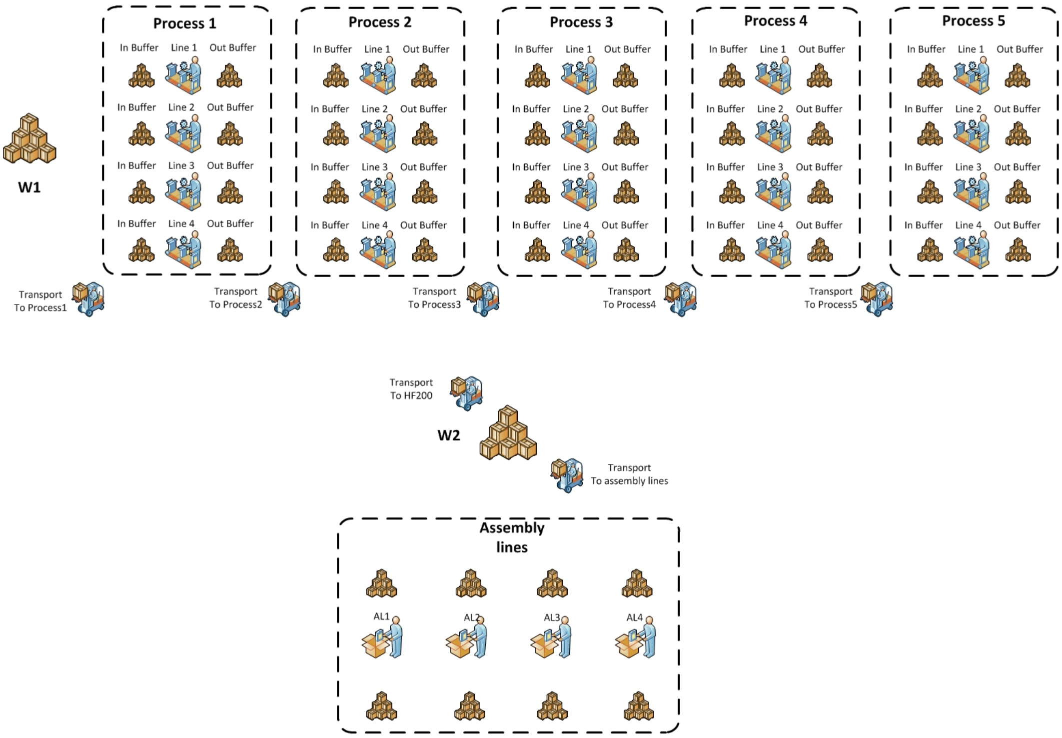


Figure 7 - Conceptual model

At this stage it is possible to identify some of the input data parameters that the user should be able to control and that the DES model will require. These parameters are summarized in Table 5.

Table 5 - Input data parameters

Descriptions	N# of parameters	Set by User	Needed by DES model
Routing	4096[1]	Yes	Yes
Cycle Time	24	Yes	Yes
Efficiency	24	Yes	Yes
Input Buffer	24	Yes	Yes
Output Buffer	24	Yes	Yes
Transport Capacity	7	Yes	Yes
Transport Time	7	Yes	Yes

[1]The number of possible routings in the conceptual model. 4^6=4096

5.1.3 Input and output data parameters

When studying the production system and demand patterns of PL1 from a lean perspective the first observation that can be made is uneven demand pattern this production flow experiences from its customer lines. The principle of levelled production is a key objective of lean production. A continuous process helps to bring the problems to surface and in turn forces action. Translated into a simulation model this generates a need for the user to be able to control the order volumes and timings. The user should also be able to evaluate the actual lead-time of the orders in the system. Another way to achieve a levelled production is also to control the level of work-in-progress in the production line; this can be achieved by enabling the user to determine the input and output buffer levels of the different processes or machines. It should also be possible to evaluate the levels of the buffer throughout the simulation time.

Another way to achieve levelled production when the demand fluctuates is the perform SMED kaizen events. By reducing the setup time product types can be produced in smaller lots and the production system becomes better at handling changes in demand volume and product mix. Thus the user should be able to simulate the effect of SMED projects on specific bottleneck machines. The model should also output the total amount of time a specific line or machine was down during setup.

In lean production the reduction of waste is also an important tool that helps in the development of an efficient production system. The different kinds of wastes that are relevant to the production line of PL1 for the DES model are waiting, unnecessary transport and defects. The remaining wastes are not considered because of the preconditions set by the customer. In order to enable the user to control the behaviour of these parameters it should be possible to control the transportation processes, the routing of the products and the efficiency of the machines in the system. The user should also be able to track the efficiency and how the different routings affect the system.

Table 6 - Input data parameters

Description	N# of parameters	Reduced N# of parameters
Open hours		
Processes	24	24
Transport	7	7
Routing	4096	120
Product Type	200	200
Routing	1	1
Cycle Times	24	6
Setup Times	24	6
Lead Times	24	6
Rollers per bearing	1	1
Theoretical Lead Time	2	2
Transport Size	1	1
Auto Orders		
Yearly Volume	1	1
Yearly Frequency	1	1
Replication Limit	1	1

The identified input and output parameters so far relates mainly to different improvement strategies and does not take into account the data needed by the DES model. Input data parameters needed by the model are presented in Table 6.

In order to simplify the interface it was necessary to reduce the number of input parameters where possible. This reduction could be achieved by reducing for instance the number of different routings in the model to better reflect the situation of the production system. It was also possible to reduce the number of cycle, setup and lead times by taking advantages of the fact that one product can only be associated with one flow and thus only need the time for one machine instead of four in each process.

From the information presented above two tables can be synthesized that summarizes the identified input and output data parameters. These tables are presented in Table 7 and Table 8.

Table 7 - Summary of output data parameters

Name	Description
Order Lead Time	The total time it takes one order to pass though the system
Product Lead Time	The average time it takes one product type to pass through the system
Machine States	The proportion of time the machine spends in different states. States: Setup, Working, Failure, Idle, Blocked, Starved
In Buffer level	The utilization of the in buffers of the different machines
Out Buffer level	The utilization of the out buffers of the different machines
General statistics	Number of products produced, the needed time

Table 8 - Summary of input data parameters

Name	Description
Product Type	The name of a product (200 different products)
Routing	Which routing flow is associated with the product
Cycle Times	The cycle times in the different processes
Setup Times	The setup times in the different processes
Lead Times	The lead times in the different processes
Rollers per bearing	Number of rollers required for one bearing
Theoretical Lead Time	The theoretical lead time used by planners in the current system
Safety Stock	The number of buffer days the product needs to be in stock
Transport Size	The number of units per transportation unit. (e.g. 100 rollers per 1 pallet)
Auto Orders	This data is used to generate orders for 1 year of production
Yearly Volume	The number of units produced in one year
Yearly Frequency	The number of times this product is produced in one year
Replication Limit	The least number of days that must pass before the same type can be produced
Machine data	The data set here control the behaviour of a machine (24 different machines)
Cycle Times	Increase or decrease the cycle time of the machine
Setup Times	Increase or decrease the setup of the machine
Efficiency	Set the efficiency of the machine or process
Opening hours	Number of open hours
In buffer Level	Maximum In Buffer level
Out Buffer level	Maximum Out Buffer level
Transportation data	The data set here control the behaviour of a transport process (7 transport processes)
Transport Capacity	The number of transport units the process can take simultaneously
Transport Time	The time duration of a transport
Open hours	Number of open hours
Order Data	The data that triggers the production of a product
Product Type	The product type
Volume	The volume of the order
Start Time	The start time of the order

5.1.4 Workshop

The next step is to present the identified input and output parameters that will be used in the user interface to the users. This was done during several meetings with production planners and project leaders of simulation projects. The main result of these meetings is categorization of the different parameters. This categorization will facilitate the design of the user interface in way that the future users can relate to. This will be presented later in the section about the development of the user interface. Also resulting from these meetings was the desire to have all the generated data from the DES model presented graphically.

5.1.5 Collection of the identified input data parameters

After the previous steps have been completed the data collection phase of the identified input parameters is initiated. A summary of the collected data is presented in Table 9.

Data will be gathered mainly from the planning systems at SKF. At this stage of the project it is understood that all the data needed for this project will be available in different databases and excel-sheets at SKF. Time consuming data collection in the forms of MTM-studies and stopwatch analysis will probably not be needed. The main focus will be to collect the most correct data available to give as natural behavior as possible. Data collection will be done in parallel with the system analysis and creation of the concept model.

Table 9 - Summary of collected data

Name	Collected from	Type of Data
Product Type	Production plan for the year 2010. Unique for every type	Static
Routing	Manually summarized from the production plan for the year 2010. Common between similarly sized types	Static
Cycle Times	Production plan for the year 2010. Unique for every type	Static
Setup Times	Production plan for the year 2010. Unique for every type	Dynamic
Lead Times	Not used in this simulation	
Rollers per bearing	Production plan for the year 2010. Unique for every type	Static
Theoretical Lead Time	Production plan for the year 2010. Average lead time for the production line	Static
Safety Stock	Production plan for the year 2010. Average Safety stock time for the production line	Static
Transport Size	Logistics Data. Unique for every type	
Auto Orders		
Yearly Volume	Production plan for the year 2010. Unique for every type	Static
Yearly Frequency	Production plan for the year 2010. Unique for every type	Static
Replication Limit	Logistics Data. Unique for Line	
Machine data		
Cycle Times	Set by the user default value 100%	
Setup Times	Set by the user default value 100%	
Efficiency	Production key data for 2010. Unique for every line	Static
Opening hours	Data from the production planner	Static
In buffer Level	Set by user. Default 10	
Out Buffer level	Set by user. Default 10	
Transportation data		
Transport Capacity	Set by user. Default 2	Static
Transport Time	Set by user. Default 60 min	Static
Open hours	Data from the production planner	Static
Order Data		
Product Type	Set by user	Static
Volume	Set by user	Static
Start Time	Set by user	Static

5.2 Development of the DES model

The DES model will be developed by following the proposed methodology together with the method proposed by J. Banks (Banks, 1998) in the methods *section 3.2*. All the steps in the proposed methodology have already been performed and described in the *section 5.1*application of the proposed methodology. The next step will be to develop the DES model and the user interface. This will be described in the next section.

5.2.1 Model translation

The translation from the conceptual model to the base model was made by dividing the conceptual model in different blocks. Each block was then specified in different excel sheets containing all the information needed such as variables, attributes, processes, queues, resources, loads, states and order lists. This specification made it easier to divide the coding phase between different persons.

The block that was first implemented was the first process with the raw material warehouse and corresponding transportation process. Processes taking care of the input and output reading were also implemented to be able to verify the code. The key to successfully code a flexible model was to use entities listening to variables or attributes instead of having specific data e.g.:

OL_InBufferFull(V_OrderListNo(A_NextProcess,A_NextLine))

In this case a specific load gets into an order list when the in buffer in the next line at the next process is full. Which order list to get into is decided by a variable whose number is set depending on the next line and process which is specified in the routing table set by the user.

When the raw material warehouse and the first process had been implemented the next step was to implement the remaining processes, starting with process 2. After process 5 a warehouse for finished goods was implemented and thereafter the final assembly lines as the last process. The transportation between the different processes was coded and verified simultaneously as the different processes were added.

When all the basic blocks were implemented the challenge was to add details and support processes. There is one order process handling manual orders set by the user in the excel interface and one automatic order process which generates random orders, depending on annual volume and frequency. Furthermore there are several shift control processes that control the times the production lines are open for production according to the different shifts specified by the user. There are also several processes taking care of all the internal transportations. There is also an initial process declaring variables, queue pointers, resource pointers, queue capacity and buffer sizes.

During the model translation it was necessary to make some assumptions and delimitations as shown below.

Assumptions

1. The raw material will always be available in the main warehouse.
2. Transportation times are process specific which means that all transportation to e.g. process 3 is set to a certain time chosen by the user of the model. If this time is set to 1 hour it will take 1 hour to transport products from the raw material storage, process 1 or process2 into process 3.
3. Products will be transported up streams and not down streams, e.g. it is not possible to transport products from process 3 to process 2.
4. The capacity of the machine resources in each process will be set to 1.
5. The capacity of the lead-time resources in each process will be set to infinite.
6. All products must be delivered to the warehouse for finished goods before proceeding to the final assembly lines. If there is a need of transport directly to the final assembly lines the transport time to the warehouse for finished goods can be set to 0.
7. Parts needed by the final assembly lines but are not manufactured in the simulated production line will be available from the warehouse for finished goods.
8. Goods are transported on pallets from the main raw material warehouse, between the production processes and into the warehouse for finished goods.
9. In the warehouse the pallets are split into set of rollers for bearings. The transportation from the warehouse to the final assembly lines needs to be specified in number of sets or bearings.
10. When the set of rollers have been assembled into a bearing the bearings will be counted in the final assembly lines and then sent to die.
11. It is assumed that the data available from SKF is correct and the model is validated according to that specific data.

Delimitations

1. Suppliers and transportation times from suppliers is not considered.
2. The model should be able to simulate four different production lines with corresponding final assembly lines within SKF. But due to the flexible nature of the model it should be possible to simulate other lines that can be modelled by the used conceptual model.
3. The DES model will not support a graphical simulation, as all the required data will be presented in the developed interface.
4. Some of the identified input parameters are dynamic in the real production system but are modeled as static parameters in the DES model. This is further discussed in section 7.6.

5.2.2 Verification and validation

The verification and validation part of the DES model is described in the methods section.

5.2.3 Documentation and reporting

Documentation has been done in different ways during the project. The simulation code has been documented and commented continuously while writing the code. At the same time this report has been updated with relevant results and information from the simulation.

5.3 Development of the user interface

The user interface was developed in parallel with the DES model with a couple of goals in mind. First of all the user interface should enable people with little or no experience from DES to quickly run a simulation. One of the purposes of this model is to aid in the day-to-day planning operations of the production. In order to achieve this purpose it is important that user interface enables the user to change relevant parameters quickly. In an effort to aid the user to evaluate which parameters might impact the performance of the production system and subdue the currently present bottlenecks the user interface is designed in way that enables the trial of different lean improvement methods. This also means that the interface should also be able to present when and where different bottlenecks arise in production system. The second major goal was to develop a DES model that is flexible enough to enable the simulation of different lines within the same interface and with the same DES model. In order to achieve this the user interface should enable the user to define new production systems that can be modelled by the used base model. This functionality should in the interface be separated from the day-to-day planning improvement functions. By separating the definition of new production lines and the parameters planners needs to change during the simulation the number of required input data parameters could be reduced specially in the case of an already defined production lines.

After considering the presented preconditions together with the identified input and output parameters in *section 5.1.3*the following main classification in the interface could be identified:

1. Input parameters that enable the definition of a new production system.
2. Input parameters that enable the change of different production factors.
3. Output parameters that visualize the states of the production system over time.

During the workshop with future users of the model a categorization of the different parameters was suggested as way to clearly present the input and output data from to and from the model. These categories will serve as subcategories to the earlier proposed classification. The resulting classification is presented in Table 10.

From the presented Table 10 below the different subcategories were respectively translated into different sheets in a excel workbook. An overview of the developed interface is presented in Appendix C.

Table 10–Classification of input and output parameters

Main classification	Subcategory and Variable	N# variants
Input Data - System Definition	Product Data	200
	Routing	
	Cycle Times	
	Setup Times	
	Lead Times	
	Rollers per bearing	
	Theor. Lead-Time	
	Safety Stock	
	Transport Size	
	Yearly Volume	
	Yearly Frequency	
	Replication Limit	
Input Data - System Definition	Routing	20
	Routing ID	
	Process	
	Machine	
Input Data - System simulation	Machine data	24
	Cycle Times	
	Setup Times	
	Efficiency	
	Opening hours	
	In buffer Level	
	Out Buffer level	
Input Data - System simulation	Transportation data	7
	Transport Capacity	
	Transport Time	
	Open hours	
Input Data - System simulation	Working Schedule	8
	Schedule ID	
	Weekday	
	Start time	
	End time	
Input Data - System simulation	Order Data	500
	Product Type	
	Volume	
	Start Time	
Output Data	Order Lead Time	Orders x Production Days
	Product Lead Time	Products x Avg. lead-time
	Machine States	Machines x Production Days
	In Buffer level	Buffers x Production Days
	Out Buffer level	Buffers x Production Days
	Warehouse Volume	Products x Production Days

6 Evaluation results

In this chapter, the results from the different phases and steps performed during this project will be presented.

6.1 Evaluation of the proposed methodology

The proposed methodology was developed with the aim to help in the identification of input and output data parameters for a DES model. The methodology used the fact that users of the model were already familiar with lean concepts. The methodology will be evaluated by comparing what parameters would have been identified if only available DES methods were used. The identified parameters from the case study presented in Table 10will be studied in order to determine which of the parameters would have been identified if only DES methods would have been used. Each parameter will be graded with a scale from 1 to 3. Where 1 represents that the parameters would have been identified, 2 represents that the parameters probably would have been identified and 3 represents the parameters would not have been identified. The summary of this assessment is presented in Table 11.

Table 11 - Evaluation of identified parameters

Parameter name	Identified with DES method	Identified with the proposed methodology
Input Data		
Product Data		
Name	1	1
Routing	1	1
Cycle Times	1	1
Setup Times	1	1
Lead Times	1	1
Rollers per bearing	1	1
Theoretical Lead Time	1	1
Safety Stock	1	1
Transport Size	1	1
Yearly Volume	1	1
Yearly Frequency	1	1
Replication Limit	1	1
Routing		
Routing ID	1	1
Process	3	1
Machine	3	1
Machine data		
Cycle Times	2	1
Setup Times	2	1
Efficiency	1	1
Opening hours	1	1
In buffer Level	1	1
Out Buffer level	1	1
Transportation data		
Transport Capacity	1	1
Transport Time	1	1
Open hours	1	1
Working Schedule		
Schedule ID	1	1
Weekday	1	1
Start time	1	1
End time	1	1
Order Data		
Product Type	1	1
Volume	1	1
Start Time	1	1
Output data		
Order Lead Time	2	1
Product Lead Time	1	1
Machine States	1	1

In Buffer level	1	1
Out Buffer level	1	1
Warehouse Volume	3	1

The parameters identified with DES method came up during an interview with a simulation engineer at ÅF. The parameters identified with the proposed method came up during the case study. From Table 11it can be seen that the proposed methodology was able to identify 3 additional parameters that would not have been identified if only DES method would have been used. The proposed methodology also identified 3 parameters that probably would have been identified with DES methods. It is also important to consider the fact that the proposed methodology inherently identifies all the parameters that the DES methods identify. The difference in identified parameters between the methods is relatively small; the design of the DES model would primarily not have been affected if the parameters had been identified with the help of DES methods. In contrast, the designs of the user interface, specifically the implementation of lean improvement strategies and the presentation of the output data was largely influenced by the identified parameters from the proposed methodology. It is in the presentation of the output data that the main strength of the proposed methodology lays. During the application of the proposed methodology, it is weakness in supporting the development of flexible DES model was exposed. The proposed methodology could be improved by considering the flexibility dimension.

6.2 Proposed methodology

The main weakness of the proposed methodology as identified during the evaluation phase is its inability to support the development of a flexible DES model. To improve the methodology, enable the development, and design of a flexible DES model a step will be added that addresses this issue. After this change the different steps of the proposed methodology are:

1. Problem definition and data collection I
2. Conceptual model
3. Identify relevant input and output data parameters and lean improvement strategies
4. Identify parameters that are required and support the development of a flexible DES model.
5. Workshop
6. Collection of input data parameters.

6.3 Capabilities of the developed DES model and user interface

The functionality and the capability of the DES model and user interface will be described in this section. From the user interface the user can set and change all required parameters in order to run a simulation, define a new production line and analyse the simulation results.

The functionality that enables the definition of a new production line will first be presented. The user can from within the user interface define a production system that can consist of up to five processes in sequence where each process can consist of four different machines or lines. This defined production system produces parts that are needed by the four assembly lines. The possibility to define lead-times for each machine also enables the machines in the model to simulate a line. The model is capable of handling 200 different product variants where each variants have it is unique set of data needed by the model. The flow of products through the system is defined in a routing table. The model can handle 20 different flows in one simulation. It is also in the routing table that the users define the active machines or processes. The model can also handle independent operating hours for every machine or line. In order to account for different types of losses that arise in a production system it is also possible to set an efficiency factor for every machine or line. The model also supports the automatic generation of production orders for a year if the user provides the model with yearly production volumes and frequencies. This function facilitates the validation of a new production system. The base model can be seen in Figure 7.

The next category of functions to be described relate to the different parameters the user can set in order improve the simulated production system. The amount of time required to change these parameters is reasonably minimal compared to the required time needed to set up a new production system. The user can choose to run a simulation based on the yearly production volume and frequency or manually define a number of production orders. From the user interface the user can choose to alter parameters that reflect how different lean improvement strategies will affect the production system. These improvement strategies earlier describe in *section 5.3* are levelled production, work-in-progress, SMED and reduction of waste. These improvement strategies can be analysed by changing the order volumes and timings, input and output buffer capacities, setup times, transportation capacities and times, efficiency factors and operating hours. Screenshots of the user interface are presented in Appendix C.

After a simulation run the model produces large amounts of data that needs to be formatted and presented to the user. The output data from the model is presented to the user in a number of charts. These charts enable the user to identify when and why different situation arise. In the machines state charts the user can often determine the reason of a bottleneck or order delay by observing the proportion of time a machine spent in a specific state. The different states displayed by the chart are working, setup, idle, blocked (the in buffer of the next process is full), starved (the previous process is to slow), failure, and closed. The available charts are presented in Table 12.

Table 12 - Output data charts

Output data type (Y-Axis)	N# of charts	Plotted against (X-Axis)
Order Lead Times	1	Defined production flows
Product Lead Time	1	Product types
Machine States	24	Production Days
In Buffer level	24	Production Days
Out Buffer level	24	Production Days
Warehouse Volume	4	Production Days

Screenshots of sample charts are presented in Appendix D

6.4 Validation of DES model

As described earlier the DES model was validated through face validation and historical data comparison. The results of the one year production validation is showed in table 6.4.With respect to SKF's privacy policy the data showed below is normalised with the real production data as an index base 100. The total number of setups is less in reality due to last minute changes and consolidation of similar variants.

Table 13 – One year validation

Parameter	Results in [%]
Total days in production line	94%
Total setups in production line1	47%
Total setups in production line2	94%
Total setups in production line3	89%
Total setups in production line4	92%
Total setups in model compared to order frequency	99.8%

7 Discussion

The results previously presented will be discussed in this section.

7.1 Proposed methodology

The lean production principles served as a good way to initiate the discussions about the future discrete event model, partially due to the fact that production-planning personnel were already familiar with these concepts. The goal of this step was to identify which production parameters the planner's uses to asses the current state of a specific production system. The amount of data presented by the DES model was possible to reduce with the help of the lean principles. This simplification facilitated both the initialization and implementation phase of the discrete event model by providing a common language understood by both the model developers and the customers. The presented output data did not require extensive explanation during the implementation phase and the planners were able to quickly spot the bottleneck process for a specific run. This approach also assisted in emphasizing the usefulness of a discrete event model to complete the lean tools and methods by putting into contrast the statical nature of lean methods versus the dynamical nature of a DES model (Standridge and Marvel, 2006). Most of the input parameters could have been properly identified without the use of the proposed methodology. The proposed methodology's main contribution regarding the input parameters was how to present the different improvement strategies in the user interface. Also during the implementation of the methodology it is lack of support to identify parameters required in order to build a flexible model emerged.

The used method proved to be a suitable approach to structure the work while developing the proposed methodology. The used method consists of several steps to ensure that modifications to the proposed methodology can be done in order to get a useful final methodology. There is however some aspects that needs to be considered. In the used method one of the steps is the application of the developed method in a case study. To ensure a stable result, the methodology could have been applied and tested in several different case studies. The reason for only interviewing five persons in this project was due to the fact that there is not that many people working with DES and lean that had time to help us with the interviews. By involving more people in the interview phase it could have been possible to get more feedback.

7.2 Developed DES model and user interface

The developed DES model and the user interface enable the production planners to discover when bottlenecks will arise in the studied production system(Jonsson P, 2009). The model also enables the analysis of different solutions that can alleviate the identified bottlenecks. These simulation runs can be made reasonably fast after the initial setup of a new production system. In order to reduce the amount of data and time needed to run a simulation dynamic data was modelled with the help of averages. This was done because the users of the model clearly stated that the time required to gather and analyse dynamic data would prohibit the use of the model in day-to-day planning. The developed DES model is capable of simulating a specific category of production systems, however the model cannot simulate systems that cannot be described by the base conceptual model presented inFigure 7.The flow of products is also limited to one direction; the model cannot simulate rework of parts neither the assembly of more than one part in the final assembly lines. If a product requires more than one part in the final assembly lines the logic of the model assumes that all parts not simulated in the previous lines to be available when needed.

7.3 Advantages of a flexible DES model

The flexibility of the proposed DES model enables the implementation of changes made to production system such as layout and process changes. The DES model is also able to simulate different production lines such as PL2, PL3 and PL4. Further the model can simulate production lines that can be modelled by the conceptual model presented in Figure 7. Alongside being able to model different production system and changes to it the model and the corresponding user interface enables the simulation of several different improvement strategies. These factors combined together helps increase the lifespan of the proposed DES model and reduce the risk of the model becoming obsolete rapidly.

The changes mentioned in the previous paragraph could all be done from within the proposed interface without the requirement of previous simulation experience.

7.4 Disadvantages of a flexible DES model

The main disadvantages of a flexible DES model is that is more time consuming to develop due to the fact that the DES model should be able to simulate different production systems. The logic of the model needs to be able to handle several different options as specified by the generalized concept. The data collection phase is also more time consuming because several production lines needs to be considered.

The user interface for a flexible model is also more complicated than a user interface for a particular production system. The user is required to specify product, machine, transportation, flow, and order data. This disadvantage is somewhat alleviated by the fact the once the user has learned the interface it's possible to simulate different production system.

One disadvantage that is also important to account for is that if the base conceptual model is not well understood by the user and wrong assumptions are made early in the initialization phase. This can create undesirable effects that could be hard for the user to detect.

7.5 Trade-offs between a flexible and a specific model

It is important to consider the trade-offs that arise when developing a flexible DES model. The first and most important trade-off to take into account is the level of detail the model is able to simulate, in order for the model to be able to simulate different processes or manufacturing cells these entities needs to be generalized to some extent. The user of the model should be well aware off the conceptual model running behind the interface in order to be able to run successful simulation that produces correct results. When a new production system is to be simulated with the flexible DES model the user should opt to validate the model with the automatic order generation feature that simulates a year of production based on historical data.

The second trade-off to consider is to the number of input parameters the user needs to provide in order to be able to run a simulation, with a flexible model more data parameters is required and this conflicts with the criteria to reduce the number of input parameters. This criteria is important to consider otherwise the model could risk to become too time consuming and cumbersome to use.

The third trade-off relates to the graphical abilities that simulation software offers, in a flexible model the resources models different machines or lines in different simulations and a graphical representation will be misleading.

The forth trade-off was mentioned in the previous section about input and output data requirements, it is desirable to have a simple user interface that easy to use and understand. A flexible DES model requires a more comprehensive interface compared to specific model and thus require more time to lean.

7.6 Variation

Some of the identified input parameters are dynamic in the real production system but are modeled as static parameters in the DES model. This is the case for the setup and breakdown times. The reasons for not modeling these parameters dynamically are that the available production data for setup and breakdown times are average times in the manufacturing planning system. The time and effort required to collect and analyze this data would prohibit the use of the model in day-to-day planning activities by production planners. Another reason is that the project sponsor, in this case SKF, have previously successfully carried out and implemented DES projects without this type of dynamic data. The project sponsor also explicitly expressed a desire for a model without dynamic data for these parameters. The model and the user interface do however support the simulation of unique setup times but this function was not used during the validation phase.

8 Conclusion

This project's purposes was to first develop a methodology that facilitates the identification of input and output parameters during the design of a DES model and to develop and design a flexible DES model with a corresponding user interface. The conclusion from this work will be presented in this section.

8.1 Proposed methodology

This section will present the conclusions relating to the proposed methodology and aims to answer question 1 defined in *section 1.3*problem definition. The presented paragraphs relates to the three subtasks developed methodology, application and evaluation.

8.1.1 Developed methodology

The proposed methodology's aim was to facilitate and enable the identification of input and output parameters during the development of DES project with the help of lean principles. The two main reasons for using lean principles in the identification process was to simplify the identification process and to design a user interface recognizable by the users of the DES model. This is based on the fact that lean principles are well established and known by the users of the DES model. The final proposed methodology is presented in the results *section 6.2*. The methodology was adjusted after the case study in order to better support the development of a flexible DES models.

8.1.2 Application

The proposed methodology was used to identify input and output parameters for the DES model and user interface. The methodology was capable of identifying the required parameters for the DES model and parameters that users need to be able to change in order to implement different improvements. The methodology was also able to identify which output parameters should be presented to the users in order to enable an analysis of current simulation run. The methodology identified 3 parameters that would not have been identified and 3 parameters that probably would have been identified if the proposed methodology were not used. The identified parameters also supported the design of the user interface. Summaries of the identified parameters can be seen in Table 10**.**

8.1.3 Evaluation

The methods main strength is its ability to present the input and output data in the user interface in a way that the users can easily relate to. It also emphasized which output parameters should be presented in the user interface in order to facilitate the analysis phase. The methodology also enabled the identification of improvement opportunities early in the design phase of a DES project. These improvement strategies were then implemented in the DES model and the user interface. The presented methods advantages are its capability to determine how the input and output parameters can be presented to the user in order to facilitate the analyses and improvement of the production system of interest. The methodology does not however facilitate the identification process of the required parameters by the DES model, due to the fact that a DES model requires a specific set of parameters irrelevant of which method used to identify them.

8.2 Developed DES model and user interface

In this section, conclusions regarding the developed model and the user interface will be presented and aims to answer question 2 in section 1.3 problem definition. The presented paragraphs relates to the three subtasks built DES model and user interface, simulation and validation and evaluation.

8.2.1 Developed DES model and user interface

The developed models main objective was to help production planners in day-to-day planning activities to identify bottlenecks that arise under different circumstances in the production system. The model should be user adapted in order to simplify the implementation process and also be flexible enough in order to be able to simulate different but similar production lines. The model was developed by integrating the input and output parameters identified by the proposed methodology into the model logic and the user interface. One step of the proposed methodology resulted in a conceptual model that was translated into a computer model. The developed conceptual model allows the DES model to simulate several production systems without the need to change the developed DES model. This was achieved by separating all production data needed for the definition of a new production system from the coding process. The definition of a new production system can be done from the user interface. It is important that the user is well aware of the conceptual model and its logic in order to be able to correctly define a new production system. The user should also be aware of the made simplifications, assumptions and model limitations.

8.2.2 Simulation and Validation

The developed model was used to simulate the production of 2010 for the production line PL1. From the output data it was possible to identify when and why bottlenecks developed, it was also possible and straightforward to try out different improvements that reduced or eliminated the identified bottlenecks. The decision to implement the identified solutions can only be determined by the production planners, the developed DES model enables them to analyse the impact of different solutions.

The DES model with the corresponding user interface was validated by face validation and historical production data.

8.2.3 Evaluation

The DES model is capable of simulating production systems that can be modelled by the used conceptual model presented in Figure 7. In the user interface the definition of a new production line is essentially separated from the day-to-day simulation activities. This was done in order to enable a faster implementation of the DES model as a day-to-day production-planning tool. Production planners can relatively quickly input future production orders into the interface and run a simulation to determine when and where bottlenecks will develop. The interface also enables the planners to easily try different improvements in order to reduce or eliminate the discovered bottleneck. In contrast, the process of defining a new production system is more time consuming but can still be done from the user interface. Here the user also has access to a function that generates production orders for one year in order to facilitate the validation process.

8.3 Future work

The usability of a flexible DES model is limited to a specific type of production system, for instance the proposed model cannot simulate a production system where several components from different flows within the line are assembled in a final assembly line. It would be interesting to investigate the possibility to categorize different kinds of productions systems into several categories where the intrinsic characteristics of the production system serve as basis. The next step would be to build several or maybe possibly one flexible DES model that can simulate these different production systems. We would also recommend to use more variation in order to get a more robust planning tool.

9 References

ADAMS, M., COMPONATION, P., CZARNECKI, H. & SCHROER, B. J. 1999. Simualtion as tool for continuos process improvement. *Winter Simulation Conference 1999.*

AUTOMOD. 2011. *Automod* [Online]. Available: www.appliedmaterials.com [Accessed 2011-05-24 2011].

BANKS, J. 1998. *Handbook of simulation : principles, methodology, advances, applications, and practice,* New York, Wiley.

BRYMAN, A. & BELL, E. 2007. *Business research methods,* Oxford ;, Oxford University Press.

HOGG, D. 2003. Simplicity: Common sense behind lean. *Plant.*

J. BROOKS, A. M. T. R. 2000. Simplification in the simulation of manufacturing systems. *International Journal of Production Research,* 38**,** 1009-1027.

JONSSON P, M. S.-A. 2009. *Manufacturing, Planning and control,* London, McGraw-Hill.

LIKER, J. K. 2004. *The Toyota way : 14 management principles from the world's greatest manufacturer,* New York, McGraw-Hill.

NASH, M. A. & POLING, S. R. 2008. *Mapping the total value stream : a comprehensive guide for production and transactional processes,* Boca Raton, CRC Press.

ROBERTSON, N. & PERERA, T. 2002. Automated data collection for simulation? *Simulation Practice and Theory,* 9**,** 349-364.

ROBINSON, S. 1994. *Successful simulation : a practical approach to simulation projects,* London ; New York, McGraw-Hill.

ROBINSON, S. 2004. *Simulation : the practice of model development and use,* Chichester, West Sussex, England ; Hoboken, NJ, John Wiley & Sons.

SARGENT, R. G. Verification and validation of simulation models. Winter Simulation Conference, 2009. 162-176.

SHINGO, S. 1985. *A revolution in manufacturing : the SMED system,* Stamford, Conn., Productivity Press.

SKOOGH, A. & JOHANSSON, B. 2008. A methodology for input data management in discrete event simulation projects. *Proceedings of the 40th Conference on Winter Simulation.* Miami, Florida.

STANDRIDGE, C. R. & MARVEL, J. H. Why lean needs simulation. Proceedings of Winter Simulation Conference, 2006. 1907-1913.

TAPPING, D. 2007. The New Lean Pocket Guide XL - Tools for the elimination of waste! : MCS Media.

TEAM, P. P. D. 2002. Kanban for the shopfloor. Books24x7: Productivity Press (C).

APPENDIX A - VSM

VSM A

This appendix has been removed due to confidentiality reasons.

VSM B

This appendix has been removed due to confidentiality reasons.

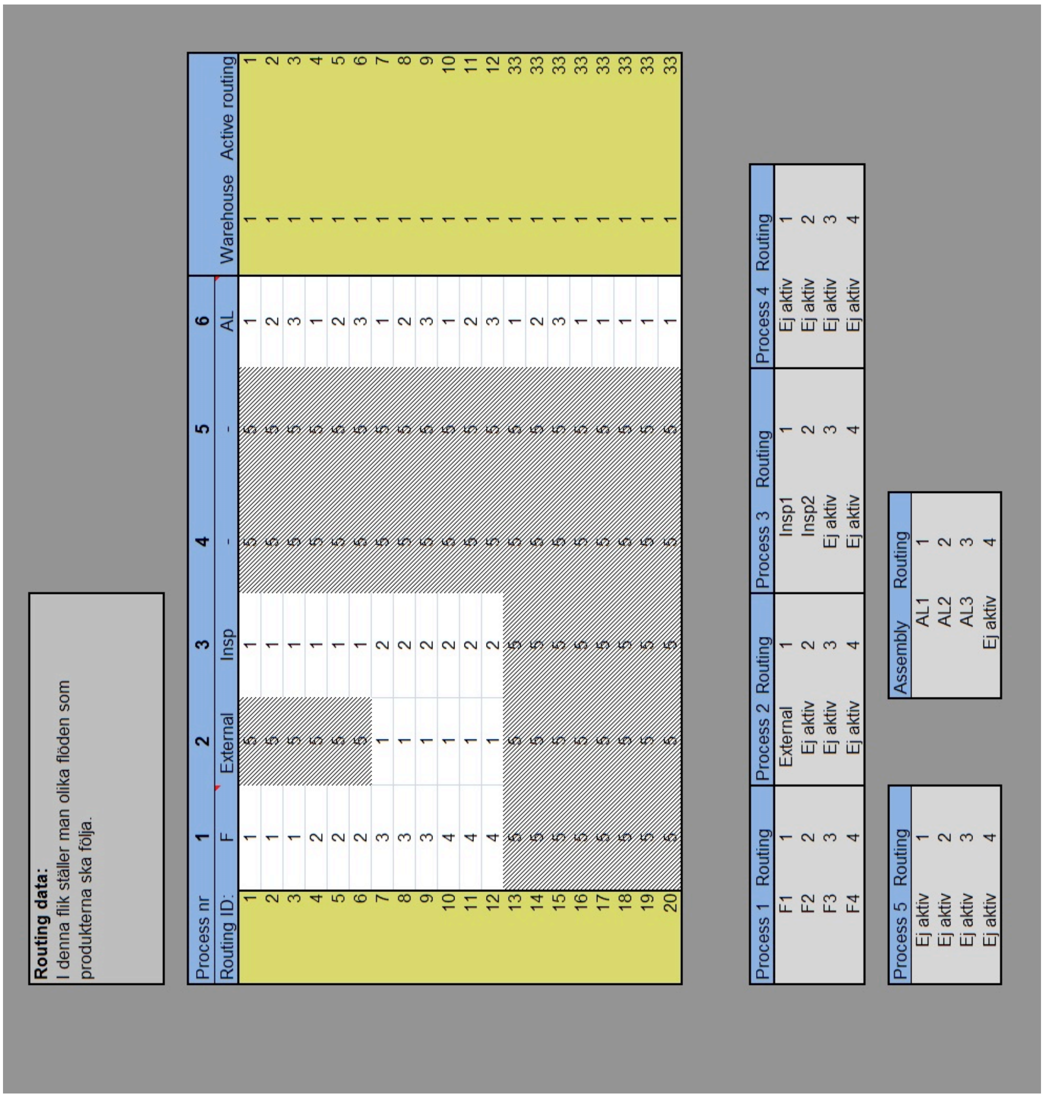
APPENDIX B – Conceptual model I

Conceptual model

This appendix has been removed due to confidentiality reasons.

APPENDIX C – User Interface

User Interface – Routing Table



Routing data:
I denna flik ställer man olika flöden som produkterna ska följa.

Process nr	1	2	3	4	5	6		
Routing ID:	F	External	Insp	-	-	AL	Warehouse	Active routing
1	1	5	1	5	5	1	1	1
2	1	5	1	5	5	2	1	2
3	1	5	1	5	5	3	1	3
4	2	5	1	5	5	1	1	4
5	2	5	1	5	5	2	1	5
6	2	5	1	5	5	3	1	6
7	3	1	2	5	5	1	1	7
8	3	1	2	5	5	2	1	8
9	3	1	2	5	5	3	1	9
10	4	1	2	5	5	1	1	10
11	4	1	2	5	5	2	1	11
12	4	1	2	5	5	3	1	12
13	5	5	5	5	5	1	1	33
14	5	5	5	5	5	2	1	33
15	5	5	5	5	5	3	1	33
16	5	5	5	5	5	1	1	33
17	5	5	5	5	5	1	1	33
18	5	5	5	5	5	1	1	33
19	5	5	5	5	5	1	1	33
20	5	5	5	5	5	1	1	33

Process 1	Routing	Process 2	Routing	Process 3	Routing	Process 4	Routing
F1	1	External	1	Insp1	1	Ej aktiv	1
F2	2	Ej aktiv	2	Insp2	2	Ej aktiv	2
F3	3	Ej aktiv	3	Ej aktiv	3	Ej aktiv	3
F4	4	Ej aktiv	4	Ej aktiv	4	Ej aktiv	4

Process 5	Routing
Ej aktiv	1
Ej aktiv	2
Ej aktiv	3
Ej aktiv	4

Assembly	Routing
AL1	1
AL2	2
AL3	3
Ej aktiv	4

User Interface – Improvement strategies

Random Seed	1

Define Process Names

Process 1	Process 2	Process 3	Process 4	Process 5	Assembly
F	External	Insp	-	-	AL

Producer Processes

Machine index	Machine /Line name	Resetting time [%]	Cycle time factor [%]	Efficiency Factor [%]	Shift Scheme	Queue In Capacity[pallar]	Queue Out Capacity [pallar]	
1	F1	75%	100%	60%	2	20	20	Process 1 : Line 1
2	F2	75%	100%	60%	2	20	20	Process 1 : Line 2
3	F3	100%	100%	60%	1	20	20	Process 1 : Line 3
4	F4	100%	100%	60%	1	20	20	Process 1 : Line 4
5	External	0%	100%	70%	1	20	20	Process 2 : Line 1
6		100%	100%	70%	6	10	10	Process 2 : Line 2
7		100%	100%	70%	6	10	10	Process 2 : Line 3
8		100%	100%	70%	6	10	10	Process 2 : Line 4
9	Insp1	100%	100%	70%	1	20	20	Process 3 : Line 1
10	Insp2	100%	100%	70%	1	20	20	Process 3 : Line 2
11		100%	100%	70%	6	10	10	Process 3 : Line 3
12		100%	100%	70%	6	10	10	Process 3 : Line 4
13		100%	100%	70%	6	10	10	Process 4 : Line 1
14		100%	100%	70%	6	10	10	Process 4 : Line 2
15		100%	100%	70%	6	10	10	Process 4 : Line 3
16		100%	100%	70%	6	10	10	Process 4 : Line 4
17		100%	100%	70%	6	10	10	Process 5 : Line 1
18		100%	100%	70%	6	10	10	Process 5 : Line 2
19		100%	100%	70%	6	10	10	Process 5 : Line 3
20		100%	100%	70%	6	10	10	Process 5 : Line 4

Customers

Machine index	Machine /Line name	Resetting time [%]	Cycle time factor [%]	Efficiency Factor [%]	Shift Scheme	Queue In Capacity [Lager]	
21	AL1	100%	100%	80%	2	10000	Assembly : Line 1
22	AL2	100%	100%	80%	2	10000	Assembly : Line 2
23	AL3	100%	100%	80%	2	10000	Assembly : Line 3
24		100%	100%	100%	6	10000	Assembly : Line 4

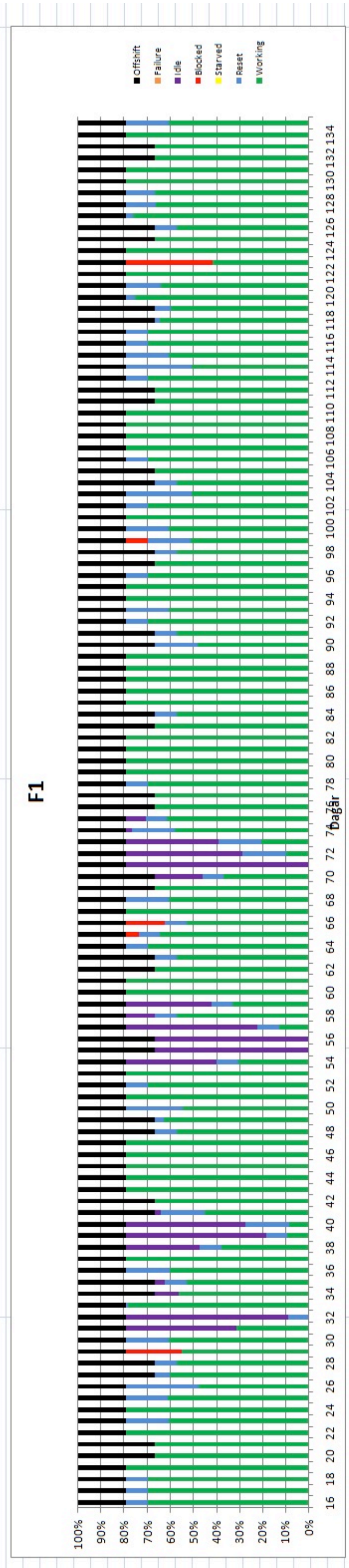
User Interface - Orders

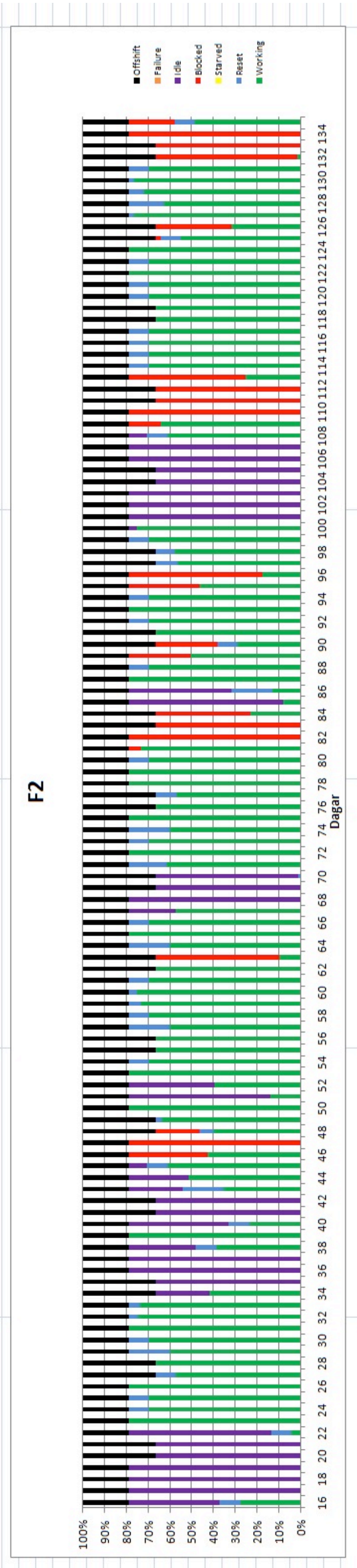
☑ Override automatic order generation

Order ID	Type	Product ID	Volume	Order date	-	Lager	N# Batche	LastBatch
1	22260	1	100	15	0	1	33	36
2	22264	2	100	15	0	1	33	36
3	22348	3	100	16	0	1	10	0
4	22352	4	100	16	0	1	10	0
5	22356	5	100	17	0	1	10	0
6	22260	1	100	17	0	1	33	36
7	24164	7	100	18	0	1	50	0
8	29276	8	100	18	0	1	100	0
9	29280	9	100	19	0	1	100	0
10	29284	10	100	19	0	1	50	0
11	29472	101	100	20	0	1	100	0
12	29468	100	100	20	0	1	100	0
13	29464	99	100	21	0	1	100	0
14	29460	98	100	21	0	1	100	0
15	22260	1	200	16	0	1	66	72
16	22260	1	200	17	0	1	66	72
17	22260	1	200	18	0	1	66	72
18	22264	2	200	19	0	1	66	72
19	22348	3	200	20	0	1	20	0
20	22352	4	200	20	0	1	20	0

APPENDIX D – User Interface

Output charts





HF warehouse volumes