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Creation of a bridge between Simulation and Solution

Master of Science Thesis in Production Engineering

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Master's thesis 2015

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Abstract

The purpose of the study is to exploit possibilities to export logic and solutions, developed in a Discrete Event Simulation (DES) model, to provide both internal and external customers with enough detailed information to create and construct the system in reality. To fulfill the study objectives a case-study was performed at WellSpect Healthcare. The project uses a DES-model to develop, verify and validate a new solution on WellSpect's conveyor system. The development resulted in a three-layer control logics. The first layer represented the basic structure built on pull principles. The second layer concerned active buffering and the third layer concerned distribution of capacity. The rules and logics were exported with a *bridge*, to translate the solution in the simulation model to internal and external customers. An evaluation indicates that the *bridge* in the case study succeeded in decreasing the gap between the simulation model and the customer. Additionally, the pre-installed production monitoring system was used in verification and validation purpose to provide data to support and communicate the performance of the new solution.

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Contents

1

Introduction

The chapter introduces the background and the problem related to the study. Thereafter a brief description of the company's profile follows. The chapter continues with the purpose of study and two study objectives are presented. At last a delimiting part frames the study.

1.1 Background

Computer Aided Production Engineering (CAPE) has during the last century shortened the gap between the idea (design) and automated manufacturing/logistics/production systems by providing computerized production and process development tools. Simulation is one of the tools representing the core of CAPE and provides significant possibilities of time reduction in production development processes (Jain *et al.* 2001). Discrete Event Simulation (DES) is a specific type of simulation used for modeling the flow of products, material or information on a virtual shop floor. DES is by many considered as one of the most powerful tools for production development and optimization. Arguably because DES has the ability to analyze and conduct experiments on complex automated systems (Law & McComas 1987). Klingstam & Gullander (1999) discuss the important issue of integrating the virtual factory model (simulation) with the real world shop floor. The virtual factory is no longer a stand alone platform for simulation studies, but can be integrated in the real factory system. Integration interfaces allows the control logics to be exported to the real system. Simultaneously, real world data can be transferred to the simulation model in improvement and validation purpose.

However, in the study by Klingstam & Gullander (1999), it is concluded that the interfaces are often "over-engaging", something which requires extensive training and expensive softwares. This aligns with the more recent work of Holst (2004), Randell (2002) and Mtaawa (2007) which states that most companies lack of infrastructure and expertise to integrate and practice simulation studies with higher quality in process and production engineering. As a result, DES is more commonly used within already established production line-ups for "one-hits"-fixes, troubleshooting or "fire fighting" rather than in development- and engineering purposes.

Additionally, in today's highly lean influenced industries many companies integrate production monitoring systems into the production. The possibilities of control and monitor the production in real time has sometimes functioned as a substitute for DES. Instead of using simulation support, companies use real time monitoring in "trial-and-error" procedures to optimize the production (Steinemann 2012). However, the systems also provides the companies with the opportunities to store data from all processes, machines, transports or inventories. Typical examples of data are downtime, planned service stops, changeover time, number of products passing through etc. In other words, useful data for simulations studies. Most researchers agree upon that input data is a critical factor for both quality and cost in a simulation study. Trybula (1994) and Skoogh & Johansson (2008) agrees that up to 40% of the time used in a project regards data gathering and validation. Perera & Liyanage (2000), states that the situation has not changed excessively over the years; even though the additional growth of production monitoring systems, mainly due to the lack of standard formats and integration between simulation softwares and production monitoring systems.

The study departs from the idea of a new conceptual solution and exploits a way to use DES and production monitor systems to develop, transform and export the idea into a solution for the real world production system.

1.2 Company Profile

The study was carried out at WellSpect Healthcare, located in Mölndal, Sweden. WellSpect was previously known as ASTRA Tech. The company was bought by Dentsply International in 2012 and split up into Dentsply Implants and WellSpect Healthcare. Today, WellSpect is recognized as one of the major global producer of medical supplies in health care. The facility in Mölndal, which is dedicated to both highly automated production and R&D-departments, hosting approximately around 1100 employee. WellSpect presents itself as an innovation-driven company and co-operates with both Chalmers University of Technology and Sahlgrenska University Hospital in several projects.

WellSpect produces mainly urology articles for surgeries and medical use. The products has high requirements on being sterile. To meet these requirement WellSpect uses E-beam radiation-chambers to sterilize their products, located as the final step in the production line. The chambers receive the products on a conveyor system. Today's solution is pushes the products into the E-beam chambers. To regulate the flow the system automatically sends products to an unloading zone, which requires personnel to deal with the unloading of products. Additionally, the E-beam chambers runs inefficiently due to the high variation in production flow. Consequently, today's solution causes expensive service stops, high energy consumption and cost of manual labor for manual unloading.

Engineers at WellSpect has designed a new layout for the transport into the radiation department. The goal with the new layout is to allow the system to handle disruptions in the production flow and to increase the utilization of the E-Beam chambers. In the near future WellSpect plans to initiate a project for an upgrade to the new layout. Wellspect has pronounced interest in verifying, validating and further develop the new system with a discrete event simulation study.

1.3 Purpose of Study

The purpose of the study is to contribute to an improved quality in the communication between companies requirement specifications and the supplier/line builders whom is to realise the solutions. This by exploit how to export logic and solutions developed in a discrete event simulation model, with enough detailed information to create and construct the system in reality.

Additionally the study aims to elevate the possibilities to use data from production monitoring systems together with Discrete Event Simulation (DES). In this case to develop, verify and validate a conceptual model with a requirement specification

1.4 Study Objectives

Two study objects was formed to cover the previous mentioned purpose.

> *By using a Discrete Event Simulation (DES) model and logged data from a production monitoring system, identify the possibilities to compare and evaluate the performance of the "new solution".*

> *By using a Discrete Event Simulation (DES) model of a given "new solution", develop and export computer logics to exploit the possibilities of a "bridge" between line builders and simulation/concept creators.*

1.5 Scope and Delimitations

The use of DES in engineering purpose puts different requirement on the communication of the result generated from the study. In a study on an already established production line the customer can get data on improvement and results direct from the simulation model. Whilst when using DES as a development tools the results generated are logics and system rules. Direct access to the simulation model in this situation puts higher requirements on understanding/knowledge of DES in order to de-code the actual result. Figure 1.1 illustrates the usual communication way between simulation and customer.

Figure 1.1: Information flow between simulation and customer.

1.5.1 Scope

The main scope of the study is based on testing the usage of a *bridge* between the simulation model at Wellspect Healthcare and internal- and external customers, illustrated in figure 1.2. The internal customers refers to in-house project groups, operators, managers and decision makers at different company level. External customer refers to suppliers and future line builders.

Figure 1.2: Information flow between simulation, bridge and customer.

The study uses an conceptual new solution for further development and validate it with data from the production monitoring system. Once validated, simulation runs and experiments aims to compare the new solution to the current solution which is represented by previously logged data from the production monitoring system. Finally the rules and logics from the simulation model will be exported with a *bridge* to the customers for further implementation. Figure 1.3 illustrates the outline of the case-study, from idea to the final customer.

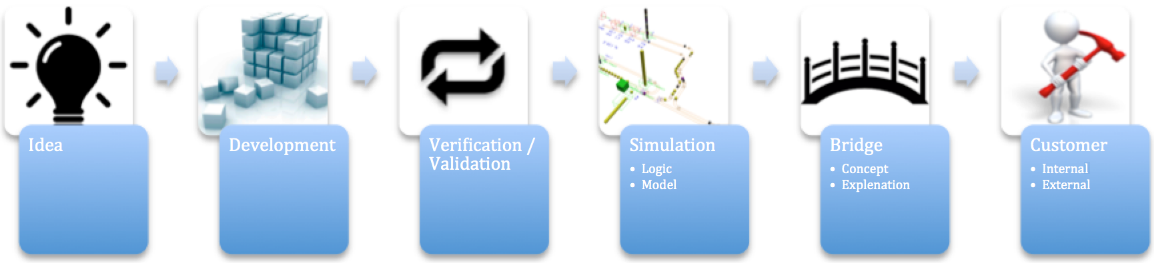

Figure 1.3: The chain of events, from the idea to the customer.

1.5.2 Delimitations

Wellspect is a small/medium size company with limited knowledge- and experience within simulation. Additionally, the company does not have comprising and stable relations with large sub-supplier. Consequently, the outcome of this study may not appeal in the same way as, for example: a large car manufacturer with high integration of DES in both in-house production and at sub-suppliers.

2

Theoretical Framework

The chapter aims to introduce and present theory connected to the areas of Logistics, Manufacturing, Virtual Integration and Discrete Event simulation. At last it exams the methodology presented by Banks (2010), regarding how to perform a simulation study.

2.1 Logistics in Manufacturing and Logistics Management

Logistics System has a central role in the area of Manufacturing systems. Logistics involves material- and product handling, packaging, inventory, transportation, storage etc. Logistics Management includes the planning, coordination and organization to provides the possibilities to support the logistics system, with the goal of increase the performance of the manufacturings system and reduce the overall cost (Mallik 2010 and Wu *et al.* 1997).

2.1.1 Logistic Automation

Logistic Automation refers to the application of automated systems of hardware and software to facilitate and improve the logistics operations. It is a relatively broad term which has strong connections with supply chain management and resource planning (Yam 2009).The major benefits with logistics automation are the possibility to maintain customised order handling with higher efficiency. It can drastically reduce the need for human interference, which reduces cost and possibilities of human errors.

A logistics system typically consists of several key components. Bar codes or RFID (Radio Frequency Identification) tags are a typical solution for a automated logistics system to identify its products. (Xiaoguang 2008). Information of product ID, destination, attributes are stored in the codes/tags, and when scanned (e.g when passing by a tag reader/QR reader) it provides the system with the information.

This allows the system to keep track of the products. Information as processed and handled by a control unit, such as a programmable logic controller (PLC) system. A PLC consists of a processor, a programmable memory and several in- and out ports. The programmable memory is used to store instruction and to implement functions, timers, sequencing etc. The PLC uses the in-ports to "read" from the system, and the out-ports to "speak" to "the system" (Bolton 2009).

Physical transport is required in most logistics systems. Common transport solutions are cranes, conveyors, robots etc. Wellspect Healthcare uses conveyors as the main transportation element. Conveyors belts consists of two or more pulleys, a motor or similar driving unit and a carrying medium, the actual belt. Conveyors are common in today's manufacturing industry due to its reliability, capability of handling large volumes and versatility in terms of placement and customization.

2.1.2 Buffer Systems in Logistics

In manufacturing, buffers are used to compensate for variations in production processes, customer demand or supply of goods. Buffering is defined as *"maintaining enough supplies to have the production running smoothly"* (Robertson 2015). Supplies can often be material, partly processed products or finished products waiting for shipment. Buffers are also used to maximize process efficiency and reduce cost, e.g by keeping downstream processes from starving or optimizing the use of expensive resources. In today's lean-manufacturing, companies aims to use the smallest amount of buffering as needed. This to minimize the Work In Progress (WIP) while still maintain a smooth operation running. (Robertson 2015 and Bellgran & Säfsten 2010).

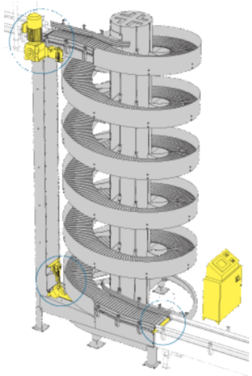

Figure 2.1: Illustrative image of a ring buffer. Source Ryson (2015).

The spiral (or ring-) buffer, used in the case-study, is a combination of a conveyor and a buffer, see figure 2.1. It is operating as a First In First Out (FIFO) buffer and is seen as a space-efficient buffer solution as well as a pure transport solution for vertical transportation. The spiral buffer uses the conveyor-band to control the speed of which the packages travels with in the buffer. Additionally it provide the possibility to accumulate packages into batches.

2.1.3 Pull/push and continuous flow

Interchangeably flow is often connected to the term "pull" or "push". The two terms are connected but not the same. Flow defines the state of moving packages from one process to another. The ideal flow between processes are, due to Liker (2004), continuous flow, or one piece flow. If it is inaccessible, a pull system is the next best option. In a pull system a measured queue of material are necessary and ready to be pulled by the next process on a given signal. The product is then replaced by a product from the process upstream. To avoid overproduction and high WIP, small quantities of only what is needed are kept in stock.

Push indicates by a process that produces regardless the the receiving process status. Push system builds on forecasting of the demand and "pushes" the products into the next process. To adapt the flow of products to the process, buffers/storage are used to support the process in case of blockages. A typical push system is the current solution of WellSpects conveyor system to the E-Beam chambers. The system is further described in chapter 3.1.1.1.

2.1.4 Production Monitor Systems

Measuring of performance in a production system is a key ability in lean production. This applies also for logistics systems. Many companies uses Production Monitoring Systems (PMS) today for measuring the Overall Equipment Efficiency (OEE) of their systems. PMS then provides data and tools which enables work of continuous improvement, capacity analysis and maintenance (Axxos 2015 and Abacus 2015 and Liker 2004).

2.1.5 Theory of constraints

Theory Of Constraints (TOC) is a management philosophy introduced by and described by Goldratt (1986) in the book "The Goal". The theory is founded on the idea that a "chain is only as strong as its weakest link". An basic assumption in TOC is that there is always at least one weakest link, a constraint, that limits the whole production/system. This is known as the bottleneck.

Goldratt & Cox (1986) developed a 5 step method to detect and deal with the constraints. These steps are well described in the literature of Stein (1997) and can be summarized by:

1. **Identify** the bottleneck/constraint.
2. Decide how to **Exploit** the constraint
3. **Support/Subordinate**

4. **Elevate**
5. **Repeat**, be aware of **"inertia"** that can become/activate the previous constraints

2.1.6 Theory of time studies

Time studies is a way of observe and continuously measure results from the production. Even though its history goes all the way back to the days of Taylor and Ford, and the techniques to perform the studies has seen many changes, it is still highly effective and a very common way to determine productivity (output/input) in a company (Björheden 1991).

Time study include some central time concepts such as:

- Cycle time: the time from one product enter a machine/process, until the next product can enter the machine/process.
- Lead time (in production): the time to go through the whole process.
- Changeover time: the time required to stop production when changing product(s) or tools.

(iSixSigma 2015)

Figure 2.2 illustrates the time concepts regarding breakdowns and downtime, explained below:

- Mean-downtime/Mean-time-to-repair (MDT/MTTR): the average time between breakdown and repaired machine/process.
- Mean-time-to-failure (MTTF): the average time to failure of a machine/process.
- Mean time between failure (MTBR): the sum of MDT and MTTF

(iSixSigma 2015)

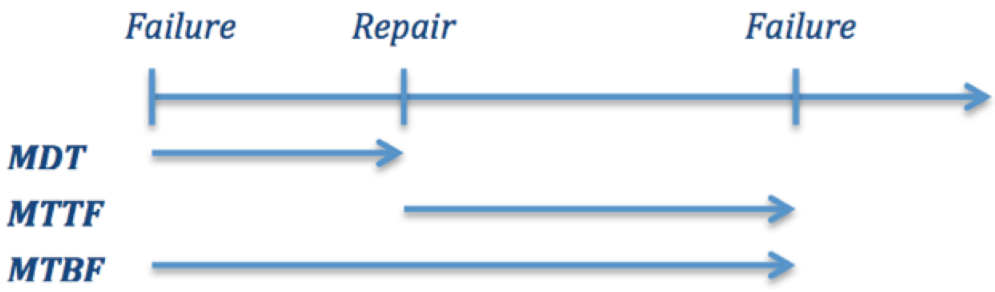

Figure 2.2: Failure and repair relationship.

2.2 Integration of Simulation

Computer aided production engineering (CAPE) provides the opportunities to speed up the development and modification of manufacturing capabilities. The virtual factory, a simulation model of major subsystems within the factory which provides advanced decision- and support capabilities, functions as a testbed for solutions of in the real factory (Jain 2001). For logistics systems within manufacturing this concerns mainly the flow of parts and material, the flow of information and decision made by the real shop floor control system.

Klingstam & Gullander (1999) and Son & Wysk (2001) discuss the link between the shop floor in the real world and the virtual world, illustrated in figure 2.3. The virtual world communicates with connections to the real shop floor control system. The article of Klingstam & Gullander (1999) provides an overview of different types of integration tools between the shop floor simulation system and the real world shop floor control system. It concludes that advanst external modules to the simulation softwares are used to communication with PLC- and SFC systems on the real shop floor. Additionally, simulation softwares has the ability of extracting data from the real world in the purpose of go from the real world to a virtual model.

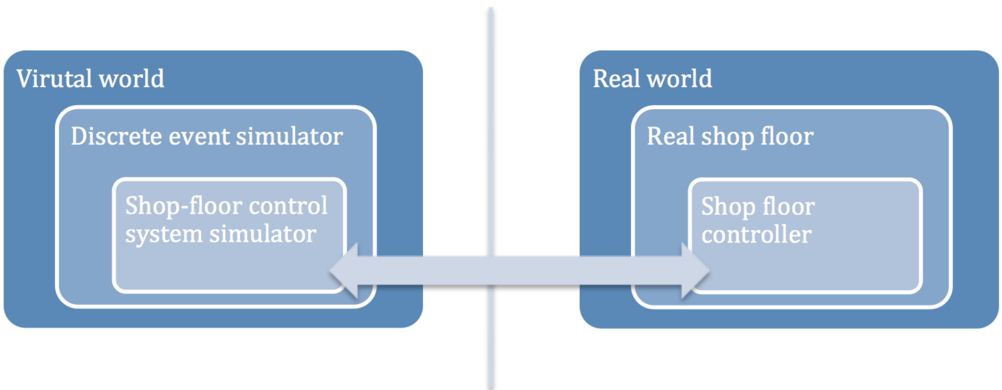

Figure 2.3: Link between virtual world (SFCS) and real world (SFC).

2.2.1 Real world to simulation model

The integration interfaces allow simulation models to access databases, spreadsheets and even external programming languages. To create, or update, a simulation model additional static- and dynamic information is needed (Son & Wysk 2001). Static information refers to shop floor layouts and resource information whilst dynamic information refers to product flow, arrival times and interaction between resources.

The article of Son & Wysk (2001) presents a structure to, based on the previous mentioned information and interfaces, automatically generate simulation models from the shop floor control system and the shop floor resource model by using a high level execution system and Ethernet communication to send/receive instructions- and confirmations messages between the simulation and the real world. A "simulation code-constructor" gets access to the master task schedule and process plans to generate simulation sequences based on "when", "where" and "for how long". However, the methodology requires in depth knowledge of computer science and included several limitation, e.g requirements on specific advanced software and single part flow. It aligns with the overview of Klingstam & Gullander (1999), which concludes that if the connection from the shop floor to the virtual model should develop, there is a need of more open system to allow software to communicate in a standardized way with hardware and other software systems.

More recent studies examines the usage of System Modeling Language (SysML) to generate or update code in order to shortened lead time for simulation studies. The article of Batarseh & McGinnis (2012) propose a model-driven approach using domain-specific semantics to create DES model from SysML. SysML is a graphical language and can be used to generate process plans while eliminating manual coding. In combination with access to databases, the stakeholders can specify problems on its own terms. When a production system is created in SysML, a translation to the simulation software can be largely automated using domain specific language (DSL) and a specific application model (McGinnis & Ustun 2009).

2.2.2 Simulation model to real world.

Similar to the link from the real world to the simulation model, the link from the simulation model to the real world lacks standardized tools for exportation and code generation. The article by Moore (2003) states that automatic code generation is a highly desirable feature but is generally only available to certain CNC machines and robot-systems. A general solution for design and off-line programming of manufacturing systems is not available. Instead, highly customised modules designed for specific solutions are used, especially for communication with manufacturing control systems, such as PLCs. Outside the DES area, there are literature exploring possibilities for SysML to integrate with PLC programs. An examples is the article of Schütz *et al.* (2013) which indicates that SysML diagrams has been successfully integrated environments for development of automation software following IEC61131-3, a leading standard programming language for PLC controllers. As stated in the previous chapter, successful case-studies has explored integration of SysML with DES. However, neither of the techniques seems to be standardized or available in large scale yet. Based on the situation consolidated from the literature there are reasons to believe that there is still a high level of manual work involved in exporting solutions from the simulation model to the real shop floor among most companies.

2.3 Discrete Event Simulation

> *"Simulation, to represent a system with another with the purpose to study its dynamical behavior or in a laboratory environment train the control of the system. The motivations for simulation can for example be: that the system is too complex for analytical analysis, not yet available, or too costly or dangerous..."* (Swedish national encyclopedia)

2.3.1 Fundamentals of Discrete Event Simulation

The power of Discrete Event Simulations (DES) is its ability to mimic the dynamics of a real dynamic system. The purpose of DES is to evaluate and understand the system, in order to provide possibilities to explore different strategies in the system (Ingalls 1999). As Shannon (1998) states:

> *"...the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and /or evaluating various strategies for the operation of the system".*

DES has become a powerful tool to observe a real system behavior in operation. It allows experiments with direct contact and feedback, without interference in the real system. It is especially useful in situation when the real system is too complex or too expensive to manipulate directly (Shannon 1998).

2.3.2 System Definition/Components of System

Discrete Event Simulations is based on modulate a system which changes state variables only when events occurs. The state variables represents all the information to describe a real world system at a certain moment in time (Banks 2010).

In the development of discrete event simulation systems there are many different approaches. Through the years a basic structure has been developed. No matter how complex or advanced the system should be, it must contain certain key components.

The fundamentals to a DES includes entities, activities, events, resources, variables, timeline, random number generator (Ingalls 1999 and Banks 2010).

When the different components are in place it is important to develop the model neither too advanced or simple. Too advanced refers to when the detail-level are far greater than required and and the outcome becomes overly complex and expensive in time. Too simple model can result in misleading output and conclusions (Ingalls 1999). The model should always be designed with the objective in focus, rather then try to copy the real system to its last variable. Patows law states that 80% of the behavior can be expressed by 20% of components in a collection of entities (Shannon 1998), thus the problem designing a model is to find the vital key components and include them in the model.

2.3.3 Advantages and disadvantages of DES

Simulation is an appealing solution for the customer when it mimics the behavior of the system. The literature of Banks *et al.* (2010) and Shannon (1997) addresses several advantages and disadvantages, presented in the sections below.

2.3.3.1 Advantages of DES

DES can be a useful tool to explore new logics and ideas if it is used in its right manner. In many cases a good simulation study gives a good insight in the behavior of both logics and opportunities.

- New design, modeling, logic etc can be tested without the need of implementation or disturbance to the system.
- Simulation helps to find bottlenecks in material-, information- and production flow.
- Large time span can be simulated on a fraction of the actual time span.
- Design flaws are easy to detect when the model visualizes.
- Helps to highlight and visualize interaction between variables in a complex system.

2.3.3.2 Disadvantages of DES

Even though there are many advantages in DES; there are also several pitfalls and disadvantages to be aware of.

- To build a model, special training is required. If two model builders intends to build the same system their model will most likely be different even though they have some similarities.
- Reliable data is generally difficult and time consuming to find. Simulations can not compensate for bad management decisions or insufficient information.
- Simulation models are highly sensitive to input data quality. Corrupted output can provide appealing credibility.
- Human choices are difficult to modulate, especially when driven by events beyond the model's' restrictions.

2.3.4 Steps in a Simulation Study

There are many methodologies and approaches of how to carry out a simulation project. One of the most popular and frequently used is the one presented by Jerry Banks in his book *"Discrete-Event System Simulation"*. The model is a step-by-step guide to systematically carry out a project. Even though the model is aimed for DES, it is applicable in many simulation situations. Figure 2.4 illustrates Banks model.

2.3.4.1 Problem Formulation

One of the most fundamental step in all projects is to define the problem. Musselman (1993) states:

> *"Nothing is less productive than to find the right answer to the wrong problem."*

Due to Musselman (1993) and Banks (2005) a good problem formulation should clearly define the problem. It should be defined in a way that everyone involved (actors) understands the problem, and that the view of the problem is common among the actors involved. This including both external and internal customers, as well as the model-builder, project-leader etc. A problem formulation should also be able to generate measurable goals and clear delimitations of the project.

2.3.4.2 Setting the objectives/create a project plan

When the problem is formulated it is time to set the objectives and to create the project plan. The objectives should be formed to indicate the questions to be answered by the project. The objectives should demonstrate understanding of the assignment and be restricted enough to be carried out within the desired time period of the project.

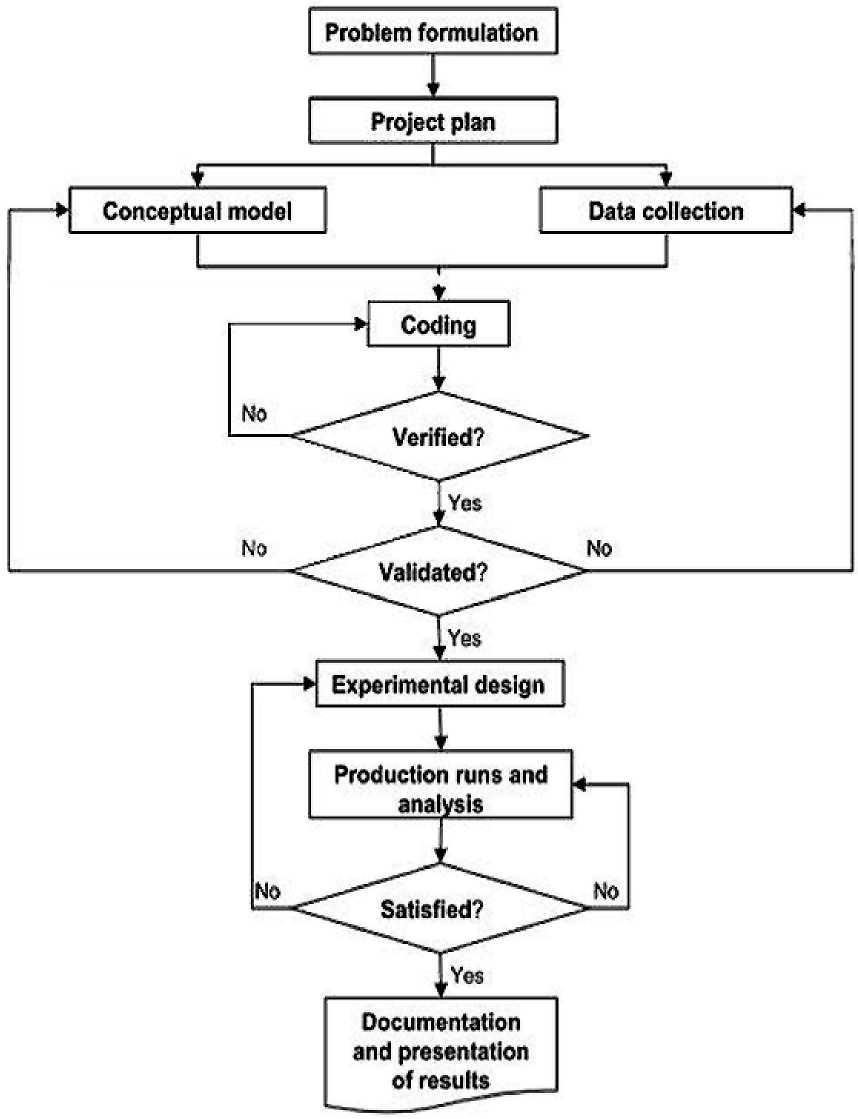

Figure 2.4: Banks model (2010).

2.3.4.3 Creating a Conceptual model and collecting data

The third step is to create a conceptual model of the system. The model is of simpler kind but should show all the logical connections. Typical examples are flowcharts, drawings or blueprint. Banks (2010) suggests that best way is to start out simple and build towards more complexity. He points out that there is no need to make the model overly complex, as long as the model can accomplished its purpose. However, there are several different ways to approach the same goal (Sturrock 2009). Two common approaches is *breadth first* and *depth first*. *Breadth first* starts with the lowest level of complexity throughout the entire/mayor part of the model, and then successively adds more complexity.

This gives the builder possibilities to in an early stage get feedback on the concept. While *depth first* focuses on separate/small areas with full complexity, while then adding more and more areas until the model is finished. This allows skilled and experienced builders the possibilities of prioritizing the important parts of the model, as well as in some cases “write off” parts of the model as “fully valid” in an early stage.

When creating the conceptual model, it is wise to use and involve the input from the model user. It serves a purpose to create a common understanding and it provides the model builder a base for detailed, more in depth knowledge about the real world model (Robinson 1997). Robinson (1997) also emphasizes the importance of the conceptual model being validated, since there is high possibilities of misinterpretations during the creation phase of the model. This due to that the aspects of the real world model can be expressed in both formal and informal ways. The formal ways is often printed down data; as in diagrams, charts or tables. The informal ways however are often fuzzier and based in elements or assumptions.

Due to Banks; in parallel with, and to support the development of the conceptual model, the data collection should begin. Good data is of essence and will have a large impact on how successful the project is. Data is needed for both creating and validating the model. (Sturrock *et al.* 2009). Robinson (1997) states that in most projects there are some data that is not accurate, not available or in the wrong format. The model builder should be critical towards the data and investigates the reliability and the consistency of the data before using it. When collecting data there are three main categories of data (Robinson & Bhatia 1995 and Skoogh & Johansson 2008) :

1. Data is available and needs to be extracted. Sources: Automatic data logging, documented measurements, maintenance logs, design/process specification documents etc.
2. Data in not available, but collectable. The data needs to be gathered. This could be done by time/video studies, interviews, frequency analysis etc.
3. Data is not available and not collectable. The data needs to be estimated. Methods for estimating data is interviews, using experts/focus groups, data from similar processes or using distributions that fits (for example with ExpertFIT etc...).

It the article by Skoogh & Johansson (2008), a ten step/ three questions methodology is presented. The aim of the methodology is to structure and link activities of data management, in order to reduce the overall data collection time and secure quality. The methodology is presented in figure 2.5.

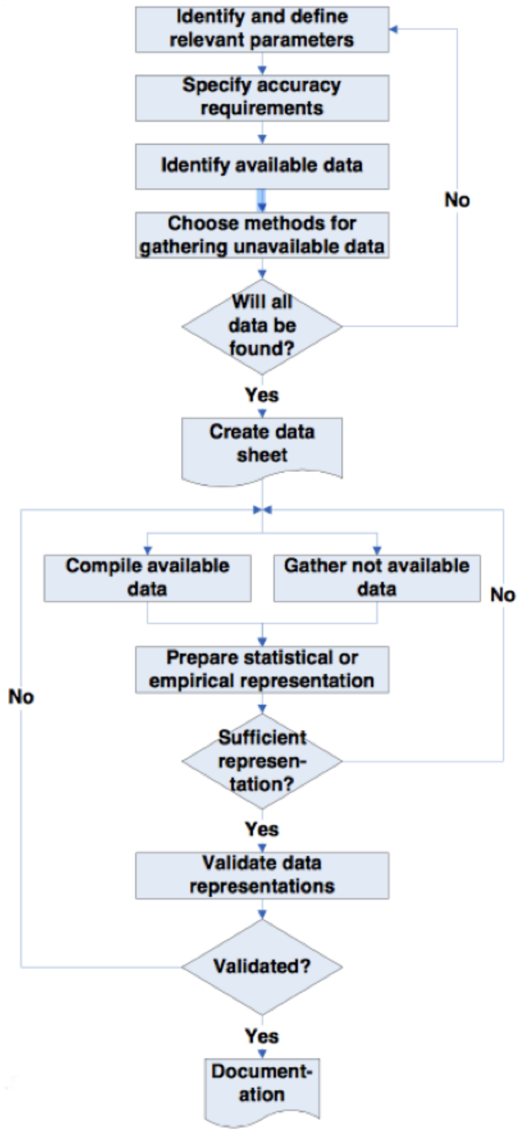

Figure 2.5: Methodology for input data management (Source: Skoogh & Johansson 2008).

2.3.4.4 Model translation and Coding

There are several pitfalls described in the literature regarding building and coding the model based on the conceptual model. Perhaps the most common mistake is to build the whole model, or large parts of the model, before verifying. The literature unanimously recommend to build and verify piece by piece. Similar to the concept model there are here two effective approaches in *breadth first* and *depth first*. *Breadth first* is referring to creating a larger, simple and low-level-of-detail model and systematically rise the level of complexity through. *Depth first* focus on creating smaller and high-level-of-detail parts and step by step thereby going through the model.

2.3.4.5 Verification and Validation

Verification of code a critical for a successful simulation project. Verification is often defined as *“ensuring that the computer program of the computerized model and its implementation are correct”* (Robinson 1997, p.53), which can be translated in to the question of *“are we building the model right?”*. Validation on the other hand is often defined as *“the process of ensuring that the model is sufficiently accurate for the purpose at hand”*, or simpler the question of *“are we building the right model?”* (Robinson 1997, p.53) and (Sargent 2010).

In the literature of Sargent (2010), Nidhra (2012) and Robinson(1997) there are several different types of verification and validations described. The four main approaches described as:

Conceptual model validation, which refers to determining if the conceptual model corresponds to its intended purpose. This by assuring that the theories and assumptions that is the foundation of the conceptual model are correct.

Data validation, which refers to ensuring that data is sufficient and accurate enough for building the model, validation of the model and to perform experimental runs with the model.

White-box validation (and verification), which refers to ensuring the components of the model corresponds to the component in the real world. White box testing therefore concerns only with the internal mechanisms of the model; such as control logic, data flow, units, timing etc.

Black box validation, which refers to ensuring that the overall model corresponds to the real world problem. Black box validation requires no knowledge or insight about that is in the model, it focuses only about input- and output performance.

Experimental validation, which refers to ensuring that the experiments provides result that is sufficient and accurate for the purpose of the study.

2.3.4.6 Experimental design

Experimental design concerns how to exploit, and experiment with the model to fully learn its behavior. This include model configuration and design of simulation runs; including length of runs, number of runs, decisions of actual experiments etc. Additionally, this part includes decisions about how to interpret the result/output of the simulation runs (Banks 2010 and Robinson & Bhatia 1995).

2.3.4.7 Production runs and analysis

The production runs are carried out based on the experimental design. Results from the runs are conducted and are to be analysed. The purpose of the analysis is to detect whether the objectives of the project has been fulfilled. If this is not the case more runs has to be carried out until satisfied (Banks 2010).

2.3.4.8 Documentation, Presentation and Evaluation

Finally the goal of the simulation study is to provide the stakeholders with the best possible information, to help take the best decisions possible. (Sturrock *et al* 2009). However, it importants recognise that the result of the simulation is always dependent on the quality of data and how “good” the reflection of the real world is. Simulation results is just one of many decision support. (Robinson & Bhatia 1995)

Documentation of the study can be divided into two sections: program- and progress documentation. Program documentation refers to the the documentation of programs, models and software to create an understanding of model and the work that was done. This especially regards studies where the model is to be handed over to other model-user(s); but also to create confidence and credibility of the results generated by the simulation model (Banks 2010).

Progress report refers to the the documentation of the project progress, as a “written history of the project” (Banks 2010). The progress report present the work that was done and the decisions that was made, chronologically. In complementary, Musselman (1993) suggest that the use of frequent progress report to let those who not take part on a daily basis get updated/be involved in the project. He suggest monthly reports. Further on this will lift possible misunderstandings, problems and other issues in an early phase of the project; minimizing any damages early on. Additionally it will create a deeper understanding of the final result, even though both Banks and Musselman stresses the importance of a clear and concise presentation of the result/analysis in the final report.

To ensure the understanding of the simulation model, additional evaluation could be practiced. A tool for qualitative evaluation is interviews. It is a useful technique to understand and map the participants experiences due to the possibilities to pursue detailed and in-depth information in the topic. McNamara (1999) states that interviews are particularly useful as follow ups on responses of less personal evaluation, eg. questionnaires, letter, presentations etc. There are generally three main types of interview-formats:

Open interview: Refers to an interview where no pre-determined questions are asked. The interviewees nature and priorities are in focus and the interview should stay as open and adaptable as possible. It Open Interview puts requirements on the interviewer to be adaptable and to “follow the flow” (Better Evaluation 2015).

Semi Structured interview: Refers to an interview with a agenda to collect information about with inte the same area or the same topics among all interviewees. The Semi Structured interview does provides a possibility to be more focused than the open interview, but still allows for some freedom (Gill *et al.* 2008).

Structured interviewed: Refers to interviews where all interviewees are asked the same questions. The Structured interview provides good possibilities to structure data from the interviews, especially in situations with a larger number of participants.

3

Methodology

To fulfill Objective 1 and Objective 2 a case-study was performed and complemented with a literature review. Study Objective 1 focuses on validation and verification of a new solution, realized in a DES model. Study Objective 2 concerns how to develop and export logic, as a result of a study. A slightly modified version of the methodology developed by Banks (2010) was used for the case-study, since it included several key parts. The methodology could be divided into four main phases: pre-study, model building, experimental design and simulation runs and documentation and reporting.

3.1 Pre-study

The pre-study was necessary to provide a throughout understanding of the new solution and the complexity surrounding it. The pre-study included the activities of problem formulation, conceptualization and literature review.

3.1.1 Problem formulation

Wellspect Healthcare uses E-beam radiation-chambers to sterilize their products in the end of the production line. Before entering the sterilization department the products are packed into boxes. The E-beam chambers then receives the boxes into three chambers where radiation is performed. Each chamber can be set to an individual radiation level since different products require different amount of radiation.

3.1.1.1 The current solution

Today´s transport solution is very sensitive to disruptions; problems in the chambers quickly causes limitations upstreams in the production flow, the current solution is illustrated in fiugre 3.1. The situation require the operators to unload the products to maintain the product flow to the chambers. The manual loading/unloading area is locally called *the square*. In the area each package is identified by QR code and checked whether the package has a designated destination for a radiation chamber. In case of "no assigned destination" the package is automatically unloaded and manually stacked. The event occurs if a package has a bad QR label, is damaged or has other disorder that makes the package unscannable. The local operator can manually assign a destination and load it back onto the conveyor.

At the time the package arrives to the E-Beam infeed it is scanned and delivered to one of the three conveyors that leads to the specific chamber. In case of scanning failure the package is discarded and ejected to a reject conveyor. When the package has been placed on the appropriate conveyor, it is transported to the respective chamber infeed. Here the QR code is again verified before accepted into the chamber. Thus, a reject conveyor slide exists also at each chamber infeed.

The existing layout creates unwanted drops in productivity as it is highly vulnerable to disturbances. If one radiation chamber becomes non functional for any possible reason, the products with destination to this chamber are moved to the reject slide. As the reject slide will fill up in approximately 30 seconds, products to the affected chamber will start block the main infeed to the radiation chambers generating a complete production stop.

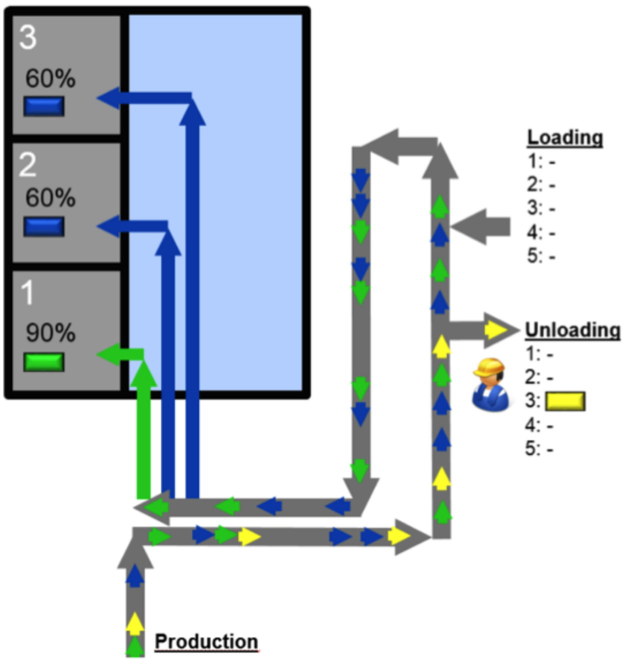

Figure 3.1: The current solution.

3.1.1.2 The new solution

Engineers at WellSpect has designed a new solution, see figure 3.2, for the transport into the radiation department. The main goal with the new solution is to decrease the sensitivity of disruptions in the production flow and to increase the utilization of the E-Beam chambers. In the E-Beam room a local conveyor transports the products on a rotation conveyor with three outlets feeding the respective radiation chamber. At each radiation chamber there should be a smaller ring buffer to avoid filling up of the conveyor in the E-Beam room. At each outlet the QR code must be verified.

When the conveyor in the E-Beam room is "full", or a package has no destination, the flow should instead be redirected to *the square* for buffering in batches or assignment of destination. At *the square* several new ring buffers are to be built up for automatic handling and separation of products. There should be a manual loading/unloading station where the operator can assign a destination to a product similar as today's principle. In order to keep track of the products, each ring buffer should be equipped with QR readers in order to have control of age (timestamp) and position of products in the system.

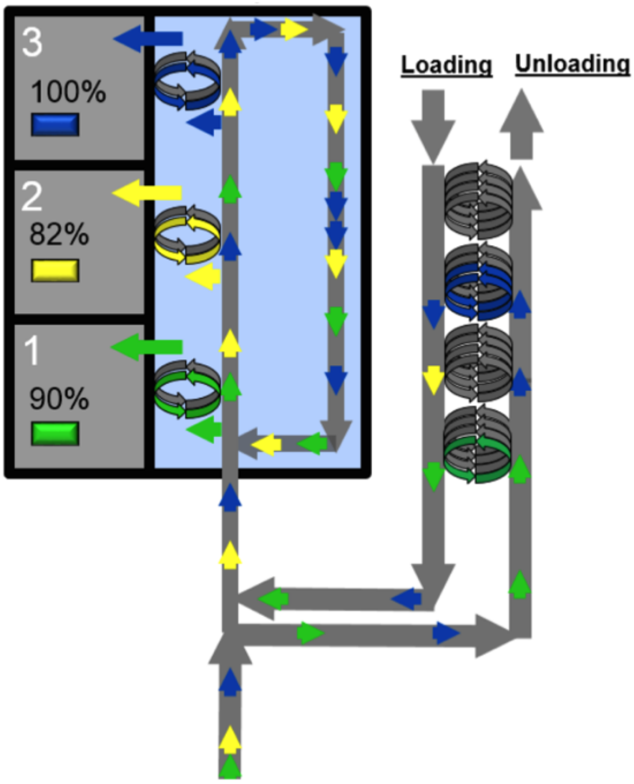

Figure 3.2: The new solution.

3.1.2 Conceptual model

A conceptual model of the new solution was created and visualized on large paper drawings to get a deeper understanding for the system and its complexity. The conceptual model was consolidated from a pre-made blueprint, an internal pre-study report by Furhammar/Wiig (2014) and interviews with production engineers at

Wellspect. The conceptual model was created and finished before the construction of the simulation model and the data collection.

3.1.3 Literature review

Throughout the entire pre-study phase literature was reviewed and a theoretical framework was constructed. Literature studies were carried out to get familiar with methodologies and softwares. Literature was mostly conducted via Google Scholar and Chalmers Summon 2.0. However, the course material from Simulation of Production Systems 2013 at Chalmers department of Product and Production Development was a contributing factor for direction of keywords to use.

3.2 Model building

After the pre-study, development of the simulation model took place. The simulation model aims to function as a representation of the new solution, in which control logics and experimental designs can be exploited. The model building involved the creation of a base model, which started with low level of complexity and gradually became more complex. Data collection and verification/validation was simultaneously carried out during the entire model building.

3.2.1 Base Model

The base model was built with a breadth first approach, defined as building a model with low level of detail and after stepwise verification more details and complexity are successively added. The approach allowed continuous feedback and validation from Wellspect throughout the creation of the model.

3.2.2 Data collection

The data collection was in large extent carried out in parallel with the model construction. It followed a modified version of the method described in chapter 2.3.4.3 and started with an identification of all relevant parameters and the accuracy needed.

To get an overview, data was categorised in three categories. Below is a simplified example of the outcome:

Category 1 - Available and collectable

- Downtimes: MTTR/MTTF/MTBF
- Lengths and dimensions of conveyor system
- Product variants
- Product volume
- Velocity of chambers
- Number of buffers and their capacity
- Location of qr-readers
- Location of switches/pushers
- Time until Chamber goes into standby mode

Category 2 - Not available, but collectable

- Length of chamber (calculated with category 1 - data)
- Cycle time of chamber (calculated with category 1 - data)
- Conveyor-speed

Category 3 - Not available, not collectable

- Cycle time for spiral buffers
- Unloading of products
- Time for switch between conveyor and buffer.

Once categorised, the data was collected. Different methods/programs was required to extract the data.

Lengths and dimensions of the conveyor system was given by blueprints/drawings in CAD-format and required manual work in CAD programs for extraction. It included positions of buffers, QR readers, switches and conveyor-belts. Buffer capacity was specified in the drawings as number of meters. The unit of meters was used in the entire simulation model to minimize the margin of error, since packages are in different lengths.

Downtimes and input flow of products was collected from the production monitor system and reviewed by the operators/production engineers with expertise and knowledge of the system. The review concern possible log errors and occurrence of undefined stops in the production monitoring system. Data was exported and processed (mainly formatted) into Microsoft Excel format on a standard form to fit the data-import process in the simulation software (Automod 12.4).

Cycle time and overall production time in the chambers was not immediately available, but calculated based on available data. The cycle time in the chambers was dependent on the speed of the chamber and the length of the boxes. The chamber uses different speed for different radiation doses. There are individual differences within each chamber, which is compensated with adding an extra, individual time factor in percentages. The margin of error for the different chamber-speeds was 1mm/min while the box-length had a margin of error of 0.1mm. This data was received from engineers with in the sterilization department. Moreover the length of the conveyor within the chambers was calculated with the formula:

$$Length = Time \ x \ Speed$$

The time for a product to travel through the entire chamber was measured with stopwatch.

The speed for the transport conveyor system was not available, but collectable through interviews with a supplier for the components. One standard speed was used during the entire development. Same supplier contributed with knowledge and data regarding the cycle time for the spiral buffer. The cycle time depends on the length and speed of the conveyor within the buffer. The time for a switch between conveyor and buffer was measured with stop watch from the current system which possessed a similar switch process.

To validate the performance of the new solution data of the manual unloading procedure was needed. Unfortunately, it was not available in the production monitoring system due to technical issues. An estimation of the manual unloading situation in the current solution was instead based on interviews with machine operators.

3.2.3 Verification / validation

Data was continuously revised and evaluated during the whole project to ensure enough accuracy and quality.

The verification of code was done by going through the code line by line. In complementary variables were used in different occasion to verify the function of a process. It helped greatly in terms of debugging of code and logical solutions. The simulation-model could be paused in special occasions to observe variables, attributes and products to have the right values and be in the right places at a certain point in time. Some variables became permanent in the model, others were fitted only for verification purposes.

Conveyors are used to transport products with a constant speed. Thus, there is a need of a good scalability in the model to receive correct "transport" times. Dimensions were checked against the real drawings and the simulation softwares' (Automod 12.4) grid/measurement tool was used to get the right distances and lengths within the model. In the conveyor system, all components (such as QR readers and switches) were checked independently (white box validation) to ensure it performed correspondingly to the conceptual model. The function of the buffers was validated by the supplier(s) during a visit. A short presentation of the simulation model graphically and explanation of the program provided the ground for the validation. A similar process was performed for the function of the chambers, which was validation by in-house technicians and production engineers. The process can be referred to as an open interview, which is further described in chapter 2.3.4.8.

The validation of the overall model performance (black box validation) was more complex since the system represented by the model currently does not exist. Nor are there any performance focus on output, since everything that goes into the model is coming out independently of how it travels in the system. The output-validation is only used to make sure no packages disappears along the way.

3.2.4 Development of control logic and rules

The development of control logic and rules followed the *breadth first* approach, described in chapter 2.2.5.3. When data was collected and a base model with low level of complexity was created, the development of the more complex control logic took place. The development was based on the lean principles of a pull system, instead of the push system which characterise the current solution. The foundation is the regulation of products on the rotation conveyor- and in the outer ring buffers based on limit values. It provides a first layer of rules based on pull principles.

Additionally, the ring buffers helped to solve the issue of ineffective usage of the chambers. The inner buffers were used to accumulate products to close the gap, which causes *unused production time* (further described in chapter 3.3). The outer ring buffers was used to control the flow into the conveyor belt. The option of buffering was placed as a second layer of regulation and control logic. It was initially used, and tested, with only one radiation dose as a one-dimensional regulation problem.

To make the regulation multidimensional, or being able to handle multiple radiation doses, a third layer of logics was developed to distribute capacity within the system. The logic was built to prioritise the larger radiation dose. Different rules was generated to let the system know the priority of different radiation doses.

Finally the simulation model was validated against the requirement specification from the internal report from Furhammar and Wiig (2014). The validation was done with continuous demonstration runs which generated feedback.

3.3 Performance validation and simulation runs

To validate the performance of the new solution, weekly comparison was used based on data directly from the production monitoring systems. The unit measured was in time, hours per week. The performance indicating times in both solutions was:

- Overall **downtime**, which refers to the downtime for all three chambers i hours over a week span.
- Active **production time**, which refers to the total time of which the chambers are performing radiation on products during a week.
- **Unused production time** (idle time), which refers to the time of which the chambers are running in full power, but without products.
- **Standby time**, the time of which the chambers has no products and therefore are able to go in to standby mode. The chambers are programmed to automatically enter standby mode when no products enters the chambers for 5 min.

The performance indicating times were selected in a dialog with WellSpect to facilitate comparison of before-and-after scenarios.

To evaluate how the new solution performed against the current solution, several test was formed. The aim of the tests was to generate an expected result of an upgrade to the new solution.

3.3.1 Head-to-Head Week tests

The new solution was compared to logged data of standby time, *unused production time*, *production time* and *downtimes* in order to detect how and if the new solution increased *standby time*. During the tests the *downtimes* and input products from logged production was taken directly from the production monitor system. This was used as input data in the simulation model, as a re-creation of the weeks, which generated new *standby times* and *unused production time*. Additionally, the data from the production monitor system worked as validation, since the model also generated *downtime* and *production time*. The tested weeks were chosen to represent a normal production situation over time. It included weeks of extra high production, weeks of an average production and weeks of extraordinary amount of machine-failure (e.g service-stops).

3.3.2 Unloading of products

To detect if the new solution reduces the amount of man-hours required to unload products due to overload in the system, data was collected of products manually unloaded every week in the simulated week-tests. Unfortunately, at WellSpect, data was not logged of the actual unloaded products for the tested weeks. To present an estimation of the improved unloading situation, data for a comparison was collected based on interviews with the operators responsible for handling the manual unloading.

3.3.3 Buffer capacity

Theoretical calculations on the capacity of the system was made to estimate how much production time the system swallow in terms of major breakdowns on the E-Beam chambers. This calculation was based on data collected from the production monitoring system and the specifications of the ring buffers.

3.3.4 Test without outer ring buffers

To examine the contribution of outer buffers to the overall result, test was conducted with products re-routed to the direct lane into the conveyor-belt, without entering the outer buffers. The re-route meant that the conveyor belt was used as buffers. When full; the products on the conveyors stopped the production, instead of being manually unloaded. The test was done to demonstrate benefits and the need of the outer buffers. The test was based on a representative week of production; data from the production monitoring system was, in the test, used in comparison purpose.

3.4 Documentation, presentation and communication of results

The result will be reported clearly and concisely in the final report, which according to Banks (2010) is important to make decision makers confident with the result from the study. Additionally the report provides detailed information for higher instants to gain understanding of the project, thus the report builds an information *bridge* between the model builders and the implementors, illustrated in figure 3.3.

Figure 3.3: The figure shows the *bridge*s' extend between simulation and customer where the arrows represents the communicated information.

3.4.1 Progress & program reporting

Following Musselman (1993) and (Banks 2010) advice of reporting on a continuous basis, feedback-meetings with both company and institution was held on regular basis. In the meetings the current situation was presented and discussed to elevate questions and problems in an early state to avoid damages later on in the project. The feedback meetings also provided project leaders and people with no day-to-day insight of the project with demonstrations of the simulation model and discussion seminars to create a "project knowledge-base" before the final reporting.

3.4.2 Final Result Documentation

The importance of good communication cannot be stressed enough (Musselman 1993). The results of the case study generated both empirical results, as well as rules and logics: which can be seen as a product of the development. It requires two different ways of communicating the result.

The data, generated from test results, was presented graphically. An already, within the company, used form for presentation was used to present the comparison in performance between the new solution and the current solution. The form, a staple diagram, focuses only on a before/after comparison of *downtime*, *standby time*, *unused production time* and *actual production time*. The form is used to present the performance of the system upwards, to managers and management; as well as to operators and engineers with a more daily insight to the system.

The logics and rules are exported via the *bridge*. It does not only target the superior management, but also external customers; such as suppliers and line builders. The *bridge* function is to connect the simulation model with the real world problem by translate the content of the simulation model and its program language sufficiently. The rules and logics of the system are presented literary in text format, explained in a pedagogical way the function and the ideas behind the solutions in order to create understanding of the system. In complementary purpose, pictures from the simulation model was used to provide better condition for learning (Eitel & Scheiter 2014). The pictures focuses on key features and details within the the model. A flow chart was used to visualize logic decisions. Layers-principles were used to demonstrate and present the hierarchy of the system rules . The layers generated a pyramid which due to Minto (2009) is a way to visualize the different decision-levels within the regulation.

3.4.3 Evaluation of bridge documentation and Implementation

When communication fails the model's credibility suffer, even when the model is properly designed. The implementation depends on how well the previous steps were followed. If the model user continuously been involved in the development of the model the chance for a successful transition increases. (Banks 2010).

As far as this report extends the implementation phase will not be completed due to the time frame of the project does not allow a longer study. However, evaluation from different receivers who reviewed the case-study report and presentation has been conducted.

The evaluation investigates to what extent the *bridge* works as it is intended to. The aim of evaluation is to elevate the amount of information which the receiver have embraced of the concept. The evaluation also indicates the functionality of the *bridge*. Consequently, evaluation needs to be aimed and received from different target groups. In this study 3 major target groups (management, users/operators and line builders/suppliers) were asked to leave feedback to evaluate the result based on semi structured interviews with the following topics:

- The understanding of conceptual difference between the new- and the current system.
- The understanding of technical difference between the new- and the current system.
- The understanding of logical difference between the new - and the current system.
- The demonstration (simulation) and its value to the understanding of the system.
- Presentation of data.
- Credibility of data.

4

Result and Analysis

The chapter present the result and analyses from the study. The first part is dedicated to Objective 1 and the second part is dedicated to Objective 2. Objective 1 concerns verification/validation and exploits how to compare and evaluate performance of the simulation model with data from a production monitoring system. Objective 2 concerns the export of the logic and rules which was generated from the simulation model. The result from the simulation study is communicated with a bridge, *which connects the simulation model and customers.*

4.1 Objective 1

> *"By using a Discrete Event Simulation model and logged data from a production monitoring system, identify the possibilities to compare and evaluate the performance of the new solution".*

To fulfill Objective 1, several simulation runs was performed with the goal to generate output data (time, products etc.). The output was directly or indirectly compared towards the data from the productions monitoring system.

4.1.1 Head-to-Head Week tests

The test was based on re-creation of actual weeks in production for comparison towards the data from the production monitor system. The aim of the tests was to identify the possibilities of reduction of *unused production time* in the E-Beam chambers. The result generated a difference in *unused production time* and *standby time*. For each week the left column presents the performance of today's conveyor solution and the right column presents the performance of the new solution. The staple diagram in figure 4.1 presents a direct comparison of a before/after scenario. The staple diagram indicates that the new solution has a generally lower amount of *unused production time* and a higher amount of *standby time* during all tested weeks.

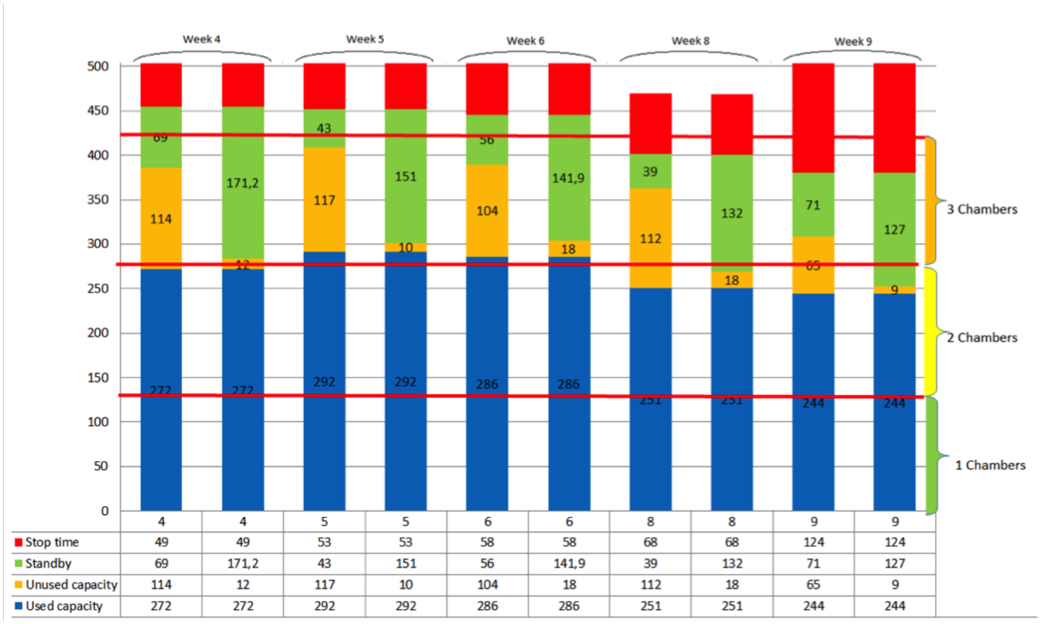

Figure 4.1: Head-to-Head Week tests, left column presents the performance of today and the right column presents performance from the new solution.

4.1.2 Unloading of products

The numbers of manually unloaded products was collected to identify the possibilities of reduction of products being unloaded on *the square*, due to system overload/failure. The data was collected during the simulation runs of the 5 weeks of head-to-head weeks test. Average value, median value, min value and max value provides a clear picture of the unloading situation during the tested weeks, illustrated in figure 4.2. The production monitor system does hold the equipment (hardware and software) necessary to collect comparison data, but unfortunately data was missing due to technical issues. Since data of manual unloading in practice was not collectable, an estimation was done. The estimation was based on interviews with the operators and relieved that, in today's solution, between 1000-3000 was manually unloaded every week. The table below presents a radical reduction of manually unloaded products, but it also indicate that the functions is still necessary.

	Average	Median	Min	Max
Unloaded products	130	98	11	278

Figure 4.2: Unloaded products generated from simulation runs with the new solution.

4.1.3 Buffer/System Capacity

Calculation of the theoretical limits of the system revealed a capacity of 324 meter (800 products) within buffers and conveyor belt, illustrated in figure 4.3. In tests, with all chambers down, the system provides 2 hours buffering before products continues to unloading. In tests with only one chamber working, the time before unloading is 5 hours based on the average input product flow of 144 meters/hour from the tested weeks and 89 meter/hour output per chamber. The calculation is based on data extracted from the production monitor system.

In practice this time varies depending on the variation of the input flow and the number of products that are already in the system. The static capacity does however function as a requirement specification for further projecting.

	Nr	Capacity meter	Capacity Products	Total meter	Total Products
Inner Ring Buffers	3	34	85	102	255
Outer Ring Buffers	4	45	110	180	440
Conveyor-belt	1	42	105	42	105
Total Capacity				324	800

Figure 4.3: Product capacity in different components of the system with a total capacity summation.

4.1.4 Test without outer ring buffers

To test the buffers sufficiency, a test with and without buffers was done, illustrated in figure 4.4. The outer ring buffers has an significant effect on the overall performance of the system. The simulation runs indicates that the outer ring buffers halves *unused production time*, compared to a system without outer ring buffers. The outer buffers largely contributes to control the product flow into the E-Beam chambers, which is a key part in converting *unused production time* into *standby time*.

Furthermore the outer buffers allows for a decrease in the need for manual unloading. Without the outer ring buffers the inner ring buffers and the conveyor-belt “can” act like buffers to avoid part of the manual unloading. It will however have an negative impact on the robustness of the whole system, due to blockage of the production flow.

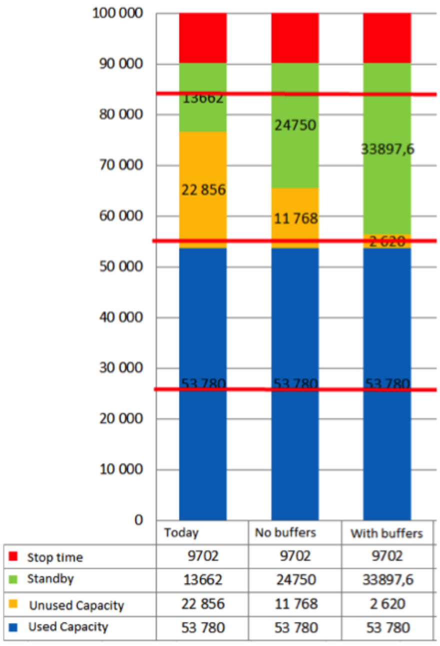

Figure 4.4: Comparison without buffer.

4.2 Objective 2

> *"By using a Discrete Event Simulation (DES) model of a given "new solution", develop and export computer logics to exploit the possibilities of a "bridge" between line builders and simulation/concept creators."*

To fulfill *Objective 2* a report of the case-study was constructed to present the result. The presentation aims to export the logics and rules of the simulation model. At last analysis and evaluation of the report is presented.

4.2.1 Explanation of simulation model and control-logics

The following chapter explains the function of the "new solution", the result of the development of system rules and control logic. This part also function as the *bridge* between the actual simulation model and the customer. In this case project leaders, superior management, consultants and future line builders (suppliers).

4.2.1.1 Layer principles

A pyramid of layers is used to give the reader an overall introduction of the model concept. The model is based on three layers of regulations and decisions, illustrated figure 4.5. The first layer functions as a foundation and concerns integrated pull principles in the layout. The second layer concerns buffering, which allows the system to run efficiently. The third layer concerns the complexity of dealing with multiple radiation doses.

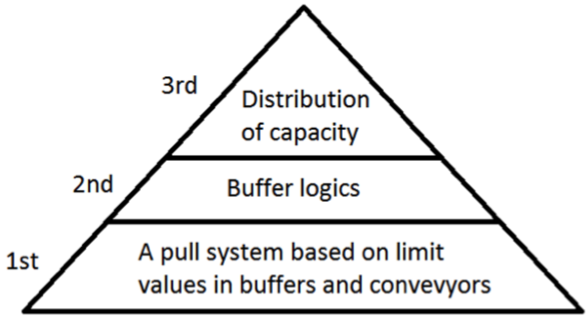

Figure 4.5: The pyramid of layers shows the complexity of regulations and decisions.

4.2.1.2 System-base and product flow, 1st layer

The model is based on a pull system, the model is illustrated in figure 4.6. The E-Beam chambers pulls products out of the inner ring buffers. The inner ring buffers pulls products of the conveyor-belt, to maintain a X number of meter within the ring buffer. The conveyor-belt provides the inner ring buffers with products, and maintains Y number of meter circulating on the conveyor-belt by pulling products from the outer ring buffers, which is located on the square. The outer ring buffers are fed products from production, on the highway.

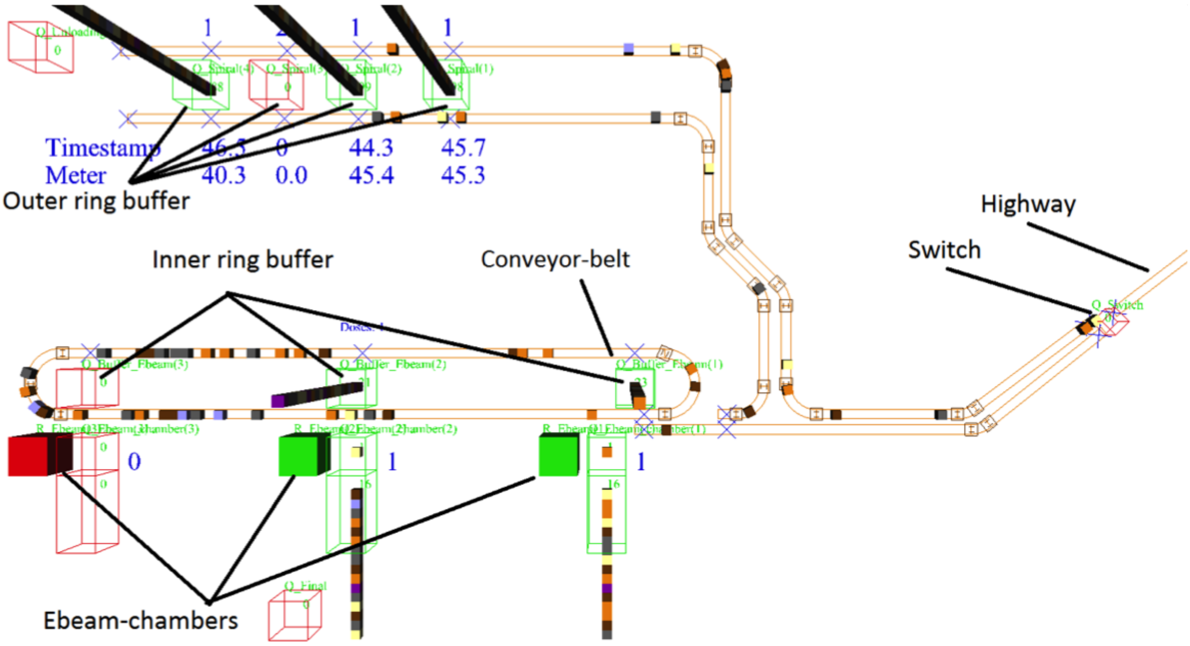

Figure 4.6: New solution simulation model.

To send products directly to the conveyor-belt without passing outer ring buffers, a switch is located on the highway to allow product with priority to get direct access to the chambers.

4.2.1.3 The regulation with in layout

The regulation of the flow includes several key features. First, the ability to control the meters in the inner ring buffers. QR reader are placed at the entrance and exit of each buffer. If the level in the buffer is below X numbers of meters and the product belongs to the right radiations dose, it is brought into the buffer from the conveyor-belt. Else it is to continue on the conveyor-belt.

The second key feature is the ability of control the number of meters on the conveyor-belt. This requires the control unit to count the meters between the inner- and the outer ring buffers. There is an individual regulation of each radiations does, not of the overall products on the conveyor-belt. When the number of meters of a radiation dose is below its limit value on the conveyor-belt, see figure 4.7, a product is pulled from the outer ring buffers.

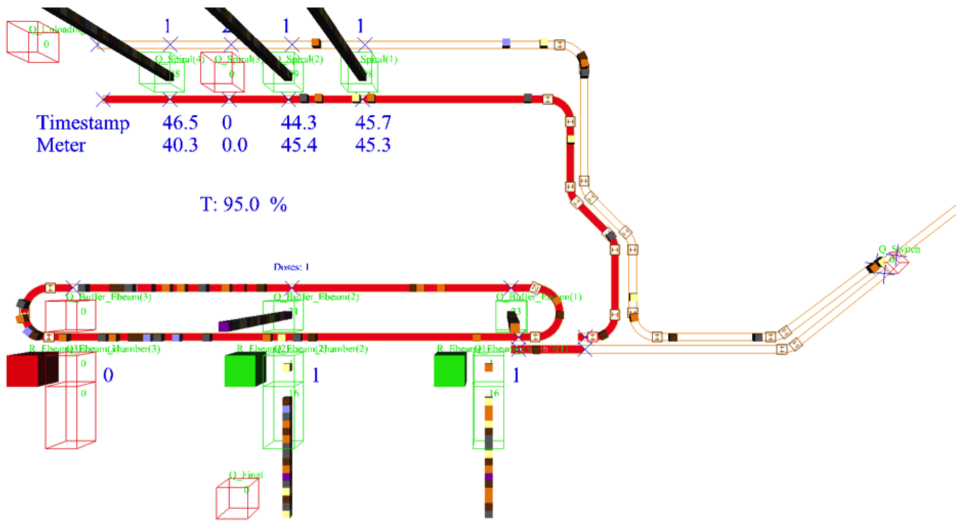

Figure 4.7: The red area of the conveyor-belt is affected by the limit value.

4.2.1.4 The outer ring buffers

The model uses four outer ring buffers (FIFO), illustrated in figure 4.8, to mix products with different radiation doses within the buffers. The key feature of the outer buffers is the QR readers, which allows the system to select the products it will let in and let the rest of the products proceed to the next buffer.

When running tree different radiation doses, it is preferable to have one ring buffer for each radiation dose. The fourth ring buffers is an “open-for-everyone” type of buffer. Simulation runs shows that the fourth buffer is the key component to prevent products from manual unloading, especially when running active buffering with several radiation doses.

The control unit or the operators should be able to assign buffers to radiation doses. It is suggested that, to avoid manual unloading, the system should actively try to keep one buffer empty.

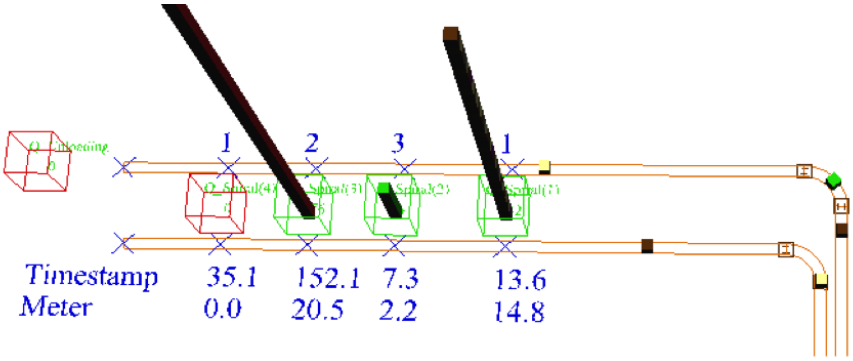

Figure 4.8: Shows the current radiation dose, the longest timestamp and the number of meters currently in the buffers.

4.2.1.5 The “Stack” list

When a product enters the outer ring buffers it is fed to a “stack”-list based on the products dose type. The “stack”-list keeps track of which product has been in the buffers the longest. It enables the system to send out products from several buffers in parallel, without changing the actual order of the products. It also helps the system to keep track of the products timestamps.

4.2.1.6 Buffering System, 2nd layer

The control logics is based on a buffering system. Since the input flow is varying enough to sometimes starve the E-Beam chambers, the idea is to buffer up products in the outer ring buffer and release in “dynamic-batches” to concentrate the use of the chambers. When the buffer levels are high enough the system releases products to the chambers. The system monitors the levels in the inner ring buffers. When the chamber starts to starve, the system cuts the product flow into the chamber. After 5 minutes the chamber automatically puts itself into standby mode if no products enters the chamber and the chamber is empty.

Consequently, the system could one chamber as the main chamber for a radiation dose. When capacity of an additional chamber is needed, when the outer buffer levels are “high”, the system opens the path into a secondary chamber. The main chamber is always located before the secondary chamber on the conveyor-belt. Thus, the secondary chamber will be starved, and go into standby, when its capacity is not needed. This provides for a dynamic buffering system which follows the variation in production. It actively minimizes *unused production time* and replaces it with *standby time*. The result is a more optimal use of the E-Beam chambers' radiation.

4.2.1.7 Multiple radiation doses, 3rd layer

There are several ways to handle multiple radiation doses. The simulated chamber-logic uses one "main" chamber for the largest radiation dose (high volume) and one secondary chamber with priority for the second largest radiation dose. The third chamber has priority of handle a third radiation dose. However, all chambers actively look for where extra capacity is needed (visualized in fig 4.9).

When an outer ring buffer (containing a radiation dose) reaches a limited value/level, capacity of the chambers is shifted to lower the levels in that buffer. If only the capacity of one chamber is needed, the "main" chamber for that dose switches over. "Conditions OK?" in the flowchart represents the conditions and priorities that needs to be fulfilled for a dose-shift to take place. These conditions could, for example, include decisions regarding the need for the capacity of the chamber elsewhere, timestamps, priority of doses or urgency of creating space in buffers etc. For each individual chamber shift-decision making the looks like:

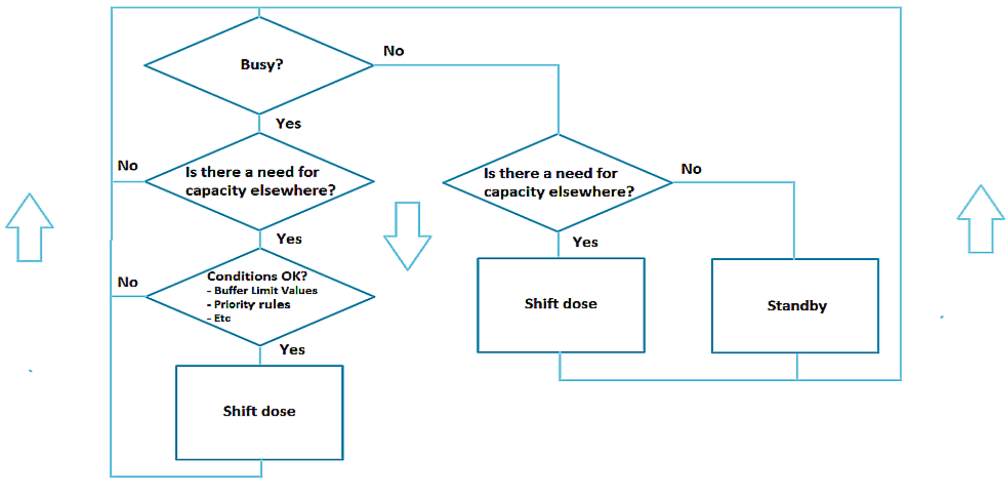

Figure 4.9: Chamber shift-decision flowchart.

If breakdowns occur the "ranking" of the chambers switch to always have a "main" chamber. When the system has only two chambers available complexity increases and focus shift from having generous buffering of product to pro-actively remove products from the buffers to create space in the buffers.

4.2.2 Analysis and evaluation of the bridge.

In figure 4.10 presents a summary of the result of the evaluation of the *bridge* documentation from the three target groups.

Topics/Groups	Management	Users/operators	Suppliers/Line build.
Understanding of conceptual differences	Showed a great understanding with the difference between push and pull systems	Showed understanding in their role with the system. Showed less understanding of the complexity of the buffer system	Understood the crucial part where competence is needed to build/implement the system
Understanding of technical differences	Showed understanding of the requirements in the components of the new solution.	No data.	Line builders from conveyor supplier showed detailed understanding of the technical requirements.
Understanding logical differences	Showed understanding of the logic behind buffering and product flow. Showed great understanding of the benefits of buffering.	No data.	No data.
Impressions of Demonstration	Helped the understanding of mainly the conceptual differences and buffering.	No data.	Helped the understanding of mainly the conceptual differences and buffering.
Presentation of results	Highlights the staple diagram over week-to-week test as very useful.	Can see the benefits and understand the result in practical matters.	No data.
Credibility of result	Misses data on unloading process, but generally sees the simulation results as credible.	Does not question the credibility. Not concerned about missing data of unloading since they possesses experience in the area.	No data.

Figure 4.10: Evaluation of the bridge documentation, based on semi structured interviews.

The implementation phase has recently begun and will extend the length of the Master Thesis project. The implementation will appear in three different phases. The first phase regards the *bridge* as a foundation for concept presentation upwards within the organisation. Thus the communication is aimed for the managers and management in both financial purposes and presentation purpose. The *bridge* has given the managers a clear picture of the benefits and drawbacks of the system. The evaluation of the documentation indicates that concept of the new solution was clearly understood; also by managers with limited knowledge of control system, production systems or lean principles. The *bridge* has given enough detail to for managers to decide on which suppliers and consultants to consider for the project.

The current phase of the implementation regards the *bridge* as a tool to present the solution for supplier as a project requirement specification for a budget quote. The *bridge* needs to provide a knowledge base, detailed enough to estimate the extent of the project and the practical implementation of the new solution. Since this phase has just begun there is so far a limited amount of feedback, especially from suppliers. However, feedback has been given from one possible supplier of conveyor system and buffers. The feedback was positive and allowed the supplier to make budget quotes.

The future phase is the actual line building and re-programming of the current PLC system. Here the *bridge* should be used as a guide of the rules and regulations for the system rather than provide a finished program. Since this phase has not begun there is so far no feedback.

5

Discussion

The chapter aims to further discuss and analyze the content of the study. The first part is dedicated to the project results, while the second part is dedicated to the project methodology.

5.1 Project Result

The design of experiments and simulation runs focused on comparing the the current- and the new solution against each other. The data from the production monitoring system represented the current solution whilst the simulation runs represented the new solution. The comparison showed that new solution has great improvement potential in terms of efficiency and cost savings. Firstly, there was high potential in energy-savings due to reduction of *unused production time*, which in large extent can be replaced by *standby time* due to active buffering. The comparison was presented with a stable diagram: a standard form, normally used to present the performance of the current solution. Positive evaluation results from semi structured interviews indicates that this was a powerful way of presenting the benefits of the new solutions, both to managers and operators. Secondly, the need for staff to monitor the square due to the manual unloading was heavily reduced. The unloading will require staff only when the system has an overload due to rare disturbance. Unfortunately the production monitoring system was not able to produce data for comparison purpose. Instead the comparison builds on interviews with the operators and measurements on an average production week. Evaluation results from semi structured interviews indicates that the credibility of the comparison suffer slightly from not having exact data to compare with. However, the operators with daily experience from working with the system are seen as high-credibility interview objects.

The second part of the study regards the export of the rules and logics behind the simulation model. The *bridge* has been used to focus the information from the simulation model to the customer. Undesired information acts as noise which detracts the receiver. Instead the receiver (customer) gets a information base from the *bridge* and can more effectively focus the information on implementation of the exported result.

To focus information, the *bridge* presents the rules and logics of the system in a literary and function-explaining way. It is complemented with visually explaining pictures, flow chart and text to highlight key features for a successful regulation. Based on the discussion in the literature of Banks (2010) and Musselman (1993), which concerns the differences in simulations and reality, the *bridge* leaves freedom of the technical solutions relatively open for the future programmers/line builders but clearly states the rules and requirements for both program and components. Musselman especially points out that:

> *"The models do not replace individual thought. The customer, in the end, must rule on the worth of a particular solution. The model cannot do this. Its purpose is to support the thought process, not to supplant it."*

The pyramid of layers (figure 4.5) is another example to visualize the model concept. The pyramid stresses the importance of using the pull principles as the base. The second layer refers to buffering as the main contributor to a more efficient system. The second layer can also represent a one dimensional side of regulation. When there is only one radiation dose the system work without the third layer. When adding multiple radiation dose the regulation becomes multi dimensional, a third layer on the pyramid. The regulation within the third layer has both manual or automatic solutions, but regardless it builds upon the founding layers underneath. It leaves freedom to the line builders without compromising the main concept.

Moreover, since the the *bridge* operate on a higher abstraction level it avoids many of the complex programming problems which occurs when exporting code from a simulation model direct to an implementation in real life. Languages/structure differences is such example. DES language uses event based programming (Banks 2010); in comparison of the practical implementation of code in micro controllers such as PLC, which generally uses ladder based programming (Richardson 2013), graphical or C/C++ code.

Without the *bridge* the simulation model becomes less available. The requirements of simulation knowledge becomes more apparent at the line builders and programmers. However, the case study is performed- and aimed at a medium-sized company. In larger companies that actively work with simulation in their production development procedures the project result may have had a different outcome due to different conditions and experiences in the field of simulation. One possible result of more extensive knowledge and integration of simulation, at both company and suppliers, would be a smaller "gap" between the simulation model developers and the line builders. Consequently the *bridge* then could loses some of its value.

So far in the discussion the focus has been on the *bridge* as a way of presenting and reporting the results and conclusions of the project. However, it has been evident that presenting and reporting not necessary only includes deliverable of a physical report, the *bridge*, but also benefits from additional demonstration of the simulation itself. The evaluation revealed a increased understanding of the concept and complicated/complex problems in the system when experienced demonstration of the simulation. This aligns with Shannon (1997), who highlight the simulations' graphical abilities as a major advantages. The *bridge* itself provide detailed knowledge and understanding about the system. It functions without the demonstration of simulations, but the addition increases its power further. Simulation however, functions alone as presentation and visualization, but misses the deeper understanding and the concrete connections to the shop floor. Thus there is no reason to exclude one or another; the simulation needs the *bridge* and the *bridge* needs the simulation.

Finally, chapter 2.2 in Theoretical Framework concerns the integration of simulation with the shop floor. The literature mainly focus on the a quicker creation of the actual simulation mode by eliminate manual work, such as coding and data management. Interestingly, the creation of the bridge, or the export of logics, required plenty manual work. To facilitate models-generation the combination of SysML and DES is currently explored. It is a relatively new technique with plenty of challenge to overcome. However, the technique is actively developed and hold great potential, especially since it by redirecting focus from code-writing both shortens lead times, but maybe more importantly have the potential to become more available to managers and decision makers in ways that traditional coding does not possesses. With the development of the SysML platforms, techniques to connect DES models with the PLC system is not far away. In fact, the article of Schütz *et al.* (2013) states that SysML diagrams has been integrated in an environment for development of automation software following IEC61131-3, which at the time was referred to as the leading standard programming language for PLC controllers. Since the connection between SysML and DES has been practiced, there are reasons to believe that the future holds interesting possibilities to use SysML to export code in a more time-efficient way from the DES model to the PLC controller.

5.2 Methodology

The case-study followed a modified version of Bank's methodology. The modifications were mainly consisting of adding a development phase for control logics. The development phase was also the main time consumer in the study. Input data from production monitoring system was used to verificate and validate the solution. However, it was received in the wrong format and required extensive formatting.

Moreover, collecting data was more complex than expected. Except for the formatting problems, complexity was added by the routines of having operators removing and adding products manually on the conveyor to compensate for the variation in input flow. The operators could add previously unloaded packages in a later section of the conveyor. This affected the order the packages enters the chamber, and thus the flow of input packages to the chambers. At first the products enter the chambers were used as the input flow. However, after the revision of the "routines" on unloading station, data of input flow was taken directly from the production logs from the machines within production.

This “non-official” routine also corrupted the data of how many packages that were unloaded. Counters at the manual unloading station was installed to get an estimation of the number of unloaded products during a representative week. But since the operators unloaded and loaded products on several random locations on the conveyor, the data was not exact enough. It lead to the usage of interviews to estimate the data of unloaded products.

During the model building phase the *breadth first*approach was of used. It fitted with the addition of the logic development phase. Firstly, the base model (the layout) was created. Secondly, the control logics was built up. The key feature was the possibility of using the input flow of product from real production in test purpose. Indata in combination with the base model allowed for a simulated test area to develop logic. This however revealed limitations and challenges in the software for creating a control logic which would suit a micro controller (PLC in this particular case).

Musselman (1993) discuss several pitfalls in a simulation study. One common issue is to “know when to stop”. The list of improvements is practically never-ending. Deadlines helped greatly in this case study to indicate when to stop, and was especially useful when planning the different stages of the study. The customer, in this case Wellspect, had an active role in the decision making regarding “when to stop”. Even though some phases might have been slightly over-worked, the study met the deadlines.

6

Conclusions and Recommendations for Further Work

The final chapter presents a summary of the results, analysis and discussion from previous chapters. The chapter examine each study objective independently. Additionally, the chapter present a recommendation for further studies; concerning the area of production monitoring systems and discrete event simulation.

The case-study has, by following a slightly modified version of Bank's' methodology for DES-studies, contributed in the development of the new solution and simultaneously brought answer to the two main study-objectives which was presented in chapter 1.3.

6.1 Objective 1

Study Objective 1 concerns the use of data from the production monitoring system and the possibilities to use it in comparison- and evaluation purpose. The study concludes that use of logged data from the production monitoring system has contributed significantly in development- and validation purposes. In the development phase data from the production monitoring system provided clear and valuable insight in what the system needed to handle and its constraints. Moreover, data was used in verification- and validation purpose during of the creation of the simulation model; where it was used to evaluate and validate product flow throughout the model, to ensure no packages were lost during the route by comparing input and output flow.

Data from the production monitoring system was used to evaluate- and test the performance of the new solution, compared to the current solution. The comparison generated data of how much *unused production time* that could be converted into *standby time*. The comparison was used to present the possibilities in energy-savings, which functions as support for financial calculation and highlights environmental benefits within the new solution. Additionally, data was used to present estimations of the systems theoretical limits in case of major disturbance. Further on, in a before/after-comparison, data was used to demonstrate the need for key components in the solution, such as the outer ring buffers or manual unloading.

6.2 Objective 2

Study Objective 2 concerns the development and the export of computer logic and rules for the new conveyor/transport solution. The result of the development process was a three layer control logic. The first layer represented the basic structure built on pull principles. The second layer concerned active buffering and the third layer concerned distribution of capacity. The rules and logic were exported with a *bridge*, to translate the solution in the simulation model to internal and external customers. An evaluation indicates that the *bridge* in the case study succeeded in decreasing the gap between the simulation model and the customer. However, as mention in the discussion; the case study provided good possibilities for a successful result due to the lack of previous simulation experience within the company and its suppliers.

6.3 Recommendation for Further Work

The study has started to exploit the use of data logged by production monitoring systems in validation purpose. The practical use of production monitoring system combined with DES relieves major improvement potential of further integration between the two interfaces in order to reduce time consumption. As Skoogh (2011) suggest in his research: a result of a more automated approach could generate a major reduction of time consumption in data management. This includes data collection for model construction; but also data collection in comparison purpose, and for the purpose of using the simulation model in future scenarios. Running the simulation model with real time data could be such a scenario. The authors of this thesis sees high potential of a more active the integration of production monitoring system in DES-projects and suggest more research to further exploit this area.

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