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Discrete event simulation as a tool for workforce allocation

Master's thesis in Production Engineering

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Abstract

The purpose of this thesis is to evaluate how Discrete Event Simulation (DES) can be used as a decision support for production planning and workforce allocation which is tested at the case company, ABB Kabeldon. The focus of the thesis is to reduce the work in process (WIP) without reducing the productivity of the production system. To evaluate potential changes in the production system a DES model was built and different scenarios was tested. The results from the study shows that reducing the WIP with sustained productivity is not possible without other changes in the production system. The case study also shows that by reallocating the current workforce a reduced WIP was not achieved without also reducing the productivity of the production system. In the case study, tests were performed to investigate on which shift it is most beneficial to hire an extra operator during a peak demand. This was found out to be best to level out the amount of operators during the day. The conclusion from this thesis is that it is possible to use DES as a decision tool but it has some limitations. Using DES as a decision tool is better for long term strategic decisions than micro manging of the production system in the case study.

Keywords: DES, workforce allocation, WIP, flexible flow shop

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Anders Johansson & Tommy Krogell, Gothenburg, May 2015

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1
Introduction

This master thesis aims to evaluate if production planning and workforce allocation can be improved by using a discrete event simulation (DES) model. This is an approach that is not commonly used in the industry and DES as a decision support for workforce allocation and production planing is not widely discussed in literature. Therefore a case study will be conducted at ABB Kabeldon in Alingsås.

1.1 Background

Organizations are often expected to continuously cut costs, or increase the output with the existing resources. In a production facility, there are several factors that waste and tie up capital.
By using a simulation software, the dynamics of a system can relatively simple be simulated and different improvement ideas may be tested with small efforts (Banks, 2004, p.13). There are many strategies and factors to take into account while scheduling (Zandin & Maynard, 2001, ch.77).
Stayer et al. (2011) states that it is possible to make accurate decisions in a live production without affecting the system by using DES and also to conduct a sensitivity analysis to monitor different variables and their effect on the production system which provides a foundation for a sustainable future. In the literature there is a lack of research in the field of DES as a decision support for workforce allocation and therefore the study at the case company will focus on workforce allocation.

ABB Kabeldon produce cable accessories for 12-420 kV AC and DC transfer systems. The production layout is a flexible flow shop with multiple parallel compression molding machines and one injection molding machine unit as the main production machines considered in this report. The products is post processed in different shared resources and also vulcanized in an oven. All products also pass a testing area where different amounts of products can be tested simultaneously depending on the product type. The company does not have enough manpower to operate all machines at the same time.

Today the company produces orders after arrival time in roughly chronological order. If a product type is already in the production plan when a new order arrives, the orders are produced in the same batch if possible. The setup time between batches are considered long and the main machines has long throughput times. This factors are contributing factors to a low machine efficiency and high work in process (WIP).

The case study company wants to reduce the WIP without loosing productivity or making facility investments. Too high level of WIP is considered a huge cost and therefore the case study company considered it a problem the needs to be solved. The company have not recently tried to actively reduce the WIP as other projects has been prioritized higher.

This master thesis will use DES as a decision tool for workforce allocation to try reduce the WIP for the case study company.

1.2 Purpose

The purpose of this master thesis is to reduce the inventory costs, increase the throughput and improve the work environment in the manufacturing industry. It is necessary to improve these areas in order to ensure a sustainable development.

1.3 Aim

The aim of this master thesis project is to support the management at ABB Kabeldon to reduce the WIP without affecting the productivity. This should be done through evaluations of the allocation of workforce and outsourcing strategies.

1.4 Hypotheses

To be able to handle disturbances in the production Saadat et al. (2010) state that it is important to have the right person at the right place. Saadat et al. (2013) also states that efficient training of the operators and allocation of the workforce will increase the productivity in the long term. If efficient training and allocation of the workforce can increase the productivity it might be possible to reduce the WIP with the same productivity. According to Saadat et al. (2010) it is common in the industry to hire a temporary operator if there is a peak demand. Therefore the first two hypotheses is formulated as following:

- Training the operators to use all machines will reduce the WIP without reducing the productivity.
- To hire a temporary operator in the day shift instead of the afternoon or night shift during a peak demand results in higher productivity with retained WIP.

Momme (2002) states that outsourcing is a generally known and used manufacturing strategy. Lin and Ma (2012) states that material outsourcing gives a productivity gain because it is possible to focus on the part of the production that gives a competitive advantage. If an outsourcing of products gives a productivity gain it might be possible to reduce the WIP with the same throughput by outsourcing products rarely produced. That is the base for the third hypothesis.

- Outsourcing of low volume products will reduce the WIP without reducing the productivity.

1.5 Delimitations

Delimitations are made in this master thesis to narrow down the number of solutions because of the limited time.

- The master thesis will not focus on the designated High Voltage Direct Current (HVDC) part of the production.
- Due to the limited knowledge on how to develop high voltage products no changes in the products will be investigated, nor the production process.
- The solutions from the master thesis will not be implemented or tested in the factory during the project.
- The result from the master thesis is only applicable for the production in the project and will not be generalized or tested in other facilities.
- Time studies will not be performed due to the high number of variances, long lead times and irregular production schedule.
- The focus of the project will not be to produce a graphically correct model.

2
Literature review

This chapter includes a theoretic background that was used to choose the methodology and will serve as a knowledge base for the relevant areas in the report. The chapter will include previous studies on simulation and planning, production planning and workforce allocation, lean production, KPI and simulation.

2.1 Previous studies on simulation and planning

Naveh et al. (2007) studies workforce allocation with constraints programming (CP), which is found to be very appropriate for the problem. The main reasons behind the suitability is assigned to the ability of CP models to adapt to changes in the system (Naveh et al., 2007). It is also stressed that the successfulness of any automated modeling is highly dependent on accurate input data (Naveh et al., 2007).
Savino et al. (2014) also explores dynamic allocation in a production facility where the number of workstations exceeds the number of operators through a multi-agent system which is decentralized and is followed by a case study that proves the method successful while both reducing the WIP as well as increasing throughput.
Choon et al. (2013) states that DES makes it possible, without any disturbances in the system, for decisions makers to evaluate how effective different workforce allocation strategies are in a system of interest. The model used by Choon et al. (2013) shows that a proper allocation of the workforce that match the volume in the system could reduce the cycle time in a pharmacy.

2.2 Production planning and workforce allocation

Since the 1960s there have been noted a gap between the practice and theory of production scheduling and a reason for this is the difference in the perception between the humans and the systemized methodology of scheduling methods according to Hermann (2006, p.23).

Hermann (2006, p.91) states that the academic literature in production scheduling has been dominated by a problem solving perspective, which is a view where scheduling is a problem to be solved, the last 50 years. The perspective that is more valid for the production scheduler is the decision making perspective, which is that scheduling is a decision to be made, where the individual scheduler face many challenges every day to satisfy the requirements in an environment that constantly changes according to Hermann (2006, p.92). According to Pinedo (2009, p.3) production planning is done regularly for most production systems. Pinedo (2009, p.25) also states that workforce allocation is always necessary to be done while having fewer operators than resources that requires an operator. Many decisions about production planning is made ad-hoc by persons not seeing the whole picture and planning information that is shared during periodic meetings might be considered unreliable which creates a broken production scheduling system where many decision takers needs help according to Hermann (2006, p.20).

In a production system with a high variety of products, processes and amount of produced products a production scheduler can coordinate the production to minimize the production cost and increase the productivity (Hermann, 2006, p.94). The production scheduler can identify conflicts between resources, ensure that the raw material is ordered at the right time, control which job the shop should do, can foresee if delivery dates can be met and when the best time for preventive maintenance is (Hermann, 2006, p.94).

Hermann (2006, p.94) states 7 different key decisions that is made in a production schedule system:

- Releasing orders or tasks to production.
- Assigning resources to different tasks and orders.
- Reassigning resources from one task to another.
- Prioritizing orders or tasks that require the same resource.
- Sequencing production tasks.
- Decide when orders or tasks should begin and end.
- Interrupt orders or tasks that should be halted.

To improve a production scheduling, Hermann (2006, p.106) states that it is of most importance to think about the persons who do the scheduling, the decisions they make, the task they do and what information they share before thinking of investing in a new scheduling software or algorithms.
Rescheduling a production is the process of updating a current schedule to react to disruptions or other changes in the production and Hermann (2006, p.137) lists a number of possible disruptions such as:

- Arrival of a new urgent order.
- An order that gets cancelled or changed due date.
- Machines failure or other unavailability
- Delays in incoming material for the order.
- Poor quality that require rework or new production of parts.

- Incorrect assumptions about process time, setup time and other tasks.
- Absence of operators due to changes in work assignment or other absence.

Hermann (2006, p.140) states two different strategies for rescheduling, dynamic scheduling and predictive-reactive scheduling. Dynamic scheduling is a decentralized production control that send out jobs when necessary and only use the information available at that moment and an example of this is a Kanban system according to Hermann (2006, p.140). Predictive-reactive scheduling creates a production schedule and updates it when a disruption or event occur to minimize its impact on the production systems performance according to Hermann (2006, p.140). When a predictive-reactive scheduling system is in use Hermann (2006, p.141) states a few different methods that can be used as the scheduling strategy; right shift rescheduling, partial rescheduling and complete regeneration rescheduling. Dynamic scheduling is good to use in a manufacturing of high volume, low variants products that need to react quick on disruptions and uncertain events (Hermann, 2006, p.144). Predictive-reactive scheduling is most commonly used in manufacturing of high variances products and its success rate of handling disruptions and uncertain events depends on the ability of the scheduler (Hermann, 2006, p.144).

Saadat et al. (2010) states that the need for the right person at the right place at the right time doing the right job is important to respond quickly to any disturbance either caused by changed customer demand or other manufacturing environments factors. Saadat et al. (2013) states that to cross-train the operators is costly and therefore it has become unproductive to cross-train the whole workforce and thus it is important to find the optimum amount of cross-trained operators and skill level each operator needs. In the past most of the labour was permanent full-time employed, but to handle disturbances in the product demand it is becoming more common to hire temporary labour to handle a short period of higher demand according to Saadat et al. (2010).

While calculating the best production plan, the computing time grows fast when including more variables, which is why the problems often is solved by a heuristic technique (Hermann, 2006, p.154). Hermann (2006, p.145) states that to create a robust production schedule it is important to reduce the probability of something bad to occur and when something bad occurs, reduce the impact of that event.

Production planning relies on a combination of algorithms to allocate resources for the production to best suit the production goals (Pinedo, 2009, p.1). The production layout in the case study is a flexible flow shop, which is one of the most complex to plan according to Pinedo (2009, p.23) and Emmons and Vairaktarakis (2013, p.267) states that it is extremely difficult to theoretically analyze this environment. The scheduling is bound by different types of constraints, which Pinedo (2009, p.24-28) list as precedence, machine eligibility, workforce, routing, material handling, sequence dependent setup times and costs, preemptions, storage space and waiting time and transportation constraints as the main constraints.

2.3 Outsourcing

Outsourcing has for a long time been used to let companies focus on their core competence (Momme, 2002). Kobayashi-Hillary (2005, p.67) lists four general drivers that makes outsourcing attractive for companies:

- Political policies and stimulation.
- Globalisation and the knowledge economy.
- Technology.
- Corporate strategy.

Nordigården et al. (2014) states that there are two versions of mixed outsourcing strategies, major doers and major buyers. Major doers have a dominance of the production in house and complement with outsourcing, while major buyers outsource the majority of the production and have a complementary in house production (Nordigården et al., 2014). When in house production dominate, Nordigården et al. (2014) states these drivers:

- **Outsource to develop experience in how to outsource.** This is mainly to test how the company would react when outsourcing production to gain experience before larger outsourcing projects starts (Nordigården et al., 2014).
- **Outsource to complement the own in house production.** By using outsourcing to complement the own production it is possible to have a flexibility in the capacity and also in the workforce of the in house production (Nordigården et al., 2014).
- **Outsource to optimize the utilization of the capacity.** To outsource some of the products to ensure high utilization in the in house production and by this keeping the core competence (Nordigården et al., 2014).

Nordigården et al. (2014) also states these drivers for major buyers:

- **Avoiding lock in risks.** By not outsourcing all of the production the company avoiding the lock in risk which is the the company loses its ability to produce the products (Nordigården et al., 2014).
- **Use its in house production to benchmark for comparison and development of suppliers.** By keeping some of the production in house it is possible to benchmark the supplier and set clear performance goals (Nordigården et al., 2014).

The mixed outsourcing strategy with in house dominance allows the output to quickly be changed with the demand and also to improve the own company's in house manufacturing efficiency according to Nordigården et al. (2014).
By outsourcing some of the produced products it is possible to focus on the on the core products and in the long term increase the employee commitment, improve

the manufacturing performance and increase the competitiveness and profitability (Momme, 2002). When some of the product types are outsourced the product catalog become smaller, hence it becomes easier to cross train the operators due to the fewer number of products that needs to be taught how to produce. According to Nordigården et al. (2014) fluctuations in the demand or in partly uncontrollable in house factors such as workforce or machine, outsourcing could be a helpful tool to balance the production.

2.4 Lean Production

Lean production is a western adaption of Toyota Production System (TPS) which introduces a number of tools for efficient production, where some are applicable for the focus of this thesis.

SMED
Single Minute Exchange of Dice (SMED) is a tool belonging to the principles of Lean production. The goal is to eliminate waste during changeovers, resulting in shorter changeover times (Henry, 2013, ch.1). With long setup times, the machine is not utilized to its potential, as it cannot produce while down (Liker, 2004, ch.10). While reducing the setup times, the SMED principle differentiate between internal and external work, where the external is possible to perform while the machine is up (Henry, 2013, ch.6). On the contrary, internal work is needed to be done when the machine is down (Henry, 2013, ch.6). Liker (2004, ch.10) states that reduction of setup times is important to achieve a leveled production, that makes it possible to reduce the WIP in a production system. Singh and Khanduja (2010) states three steps that are performed in SMED. The first steps is by dividing the setup activities into external and internal activities and that the external activities are done when the production is still running according to Singh and Khanduja (2010). Step two are according to Singh and Khanduja (2010) trying to externalize the internal activities and that is mostly done by technical modifications in the setup process. The third step is trying to reduce the time each internal or external activity take by using industrial engineering tools to set a standard setup routine (Singh and Khanduja, 2010). Singh and Khanduja (2010) states that the first step reduce the setup time with 30 % to 50 %, the second step 75 % and the third step can reduce the setup time by 90 % of the original setup time.

Heijunka
The Heijunka principle is about leveling out the workload. Theoretically, a production system is best if there is no batching present at all (Liker, 2004, ch.10). However, if the setup times are not negligible, some sort of production batching is necessary. By only producing on customer order the risk of storing and owning unsold goods is reduced and therefore the inventory level is reduced according to Liker (2004, ch 10).

2.5 KPI

Key Performance Indicators (KPI) are a consistent way to follow the most critical performance of an organization (Parmenter, 2007). The ones that will be in focus for this thesis is listed below.

WIP
To have WIP is expensive as it ties up capital and storage space and should be kept at as low levels as possible (Pinedo, 2009, p.31). However, with high variance, long setup times and an irregular schedule, it is not always possible to achieve, thus forcing the production system to be designed to have a certain amount of WIP (Zandin & Manyard, 2001, ch.5.3.1). The size of the WIP is determined by a number of factors such as shift planing, lead time and batch size (Halevi, 2006, ch.5). The batch size corresponds to the level of WIP in two main ways, where one is that all products of the batch needs to be produced before the batch is sent further (Halevi, 2006, ch.5.1). The second effect is that if the company produce to storage, a larger batch size leads to more products on the shelf (Liker, 2004, ch.8). A smaller batch size corresponds to less WIP, but an exact relationship can be hard to establish (Halevi, 2006, ch.5.1).

Throughput
Fishman (2001, p.6) states that throughput is the number of produced products over a specific period of time. By measuring the throughput it is possible to decide if a change in a simulation model will affect the productivity and therefore increase the probability of a correct decision (Fishman, 2001, ch.1.6).

2.6 Simulation

A simulation model is an imitation of a real world process or system over a time period (Banks, 1998, p.3). By running the simulation over a period of time a artificial history for the system is created and from observation of that data it is possible to draw conclusions of how the represented real world system behaves according to Banks (1998, p.3).

The state of a DES model is changed in a discrete time point, which means that between speific events in the model, nothing happens (Banks, 2004, p.7). One of the main benefits of a DES model is that it, in contrast with many other models, has the ability to imitate the dynamic of a system (Ingalls, 2008). Muroyama et al. (2010) states that usage of DES to test a production system before it is built or used can significantly reduce the economical and environmental cost.

In any real life system, there is naturally occurring variations that are not possible to control, e.g. difference in order size (Banks, 2004, p.10). A statistical distribution is a way to represent these variations with a mathematical model.

2.6.1 Motivations for simulation

Zandin & Maynard (2001, ch.90) lists five main motivations to use simulation of the manufacturing system:

- An increase in global competition.
- Efforts in cost reduction.
- Improved decision making.
- Diagnose problems effective.
- Prediction and explanation capabilities.

An increase in global competition. With a market that is more and more global, the market share also commonly is increased and with this comes pressure to improve the manufacturing and supply chain continuously (Zandin & Maynard, 2001, ch.90). As this also creates a more complex production system while the room for error is decreased, simulation helps to determine the most efficient parameters (Zandin & Maynard, 2001, ch.90).

Efforts in cost reduction. Following the globalisation benefits, lean production has also increased in popularity since the eighties (Zandin & Maynard, 2001, ch.90). Lean production forces the company to increase production rates and flexibility, while reducing inventories, equipment and operators. (Liker, 2004). While designing a lean system, simulation provides a tool to control the robustness of the system (Zandin & Maynard, 2001, ch.90).

Improved Decision making. As many variables in a production system is not under control of the management, any changes in the production system may not be optimal (Zandin & Maynard, 2001, ch.90). Simulation is effective for managers to test the effects of any variable and therefore improve the decisions in areas such as product mix, scheduling and change the number of resources (Zandin & Maynard, 2001, ch.90).

Diagnose problems effective. Many tools to diagnose a problem in a production facility, such as root cause analysis or statistical techniques, requires either too much simplifications or is too complex to be explained in a convincing way to the management (Zandin & Maynard, 2001, ch.90). According to Zandin & Maynard (2001, ch.90), simulation can solve a problem with a suitable level of details and complexity, thus preserves a credibility of the results.

Prediction and explanation capabilities. More than predicting the behavior of a system, simulation can also gives the possibility for the user to understand the reasons behind the behavior (Zandin & Maynard, 2001, ch.90).

2.6.2 Advantages and disadvantages with simulation

Banks (2004, p.12) also lists several advantages and disadvantages with simulations, where the advantages are listed and the ones extra relevant for this thesis is further explained:

- Making correct choices by testing every aspect of a change.
- Compressing and expanding time, allowing fast analysis for a long time period or detailed analysis of a short period.
- Understanding the reasons behind certain behaviors in the system.
- Exploring possibilities of new methods and resources.
- Diagnosing problems in a complex environment.
- Identifying the cause of constraints in the system.
- Developing a understanding about how the system operates.
- Visualizing the plan to detect flaws.
- Building consensus for the decision making with an objective base.
- Preparing for a change in the system.
- Making investments that are well substantiated.
- Training the team offline, which can be much less expensive.
- Specifying requirements for a machine to achieve the goal.

Exploring possibilities of new methods and resources. When a model of the current state is developed, it is relatively easy to test the effects of a changed policy, procedure method without affecting the production system (Banks, 2004, p.13)

Building consensus for the decision making with an objective base. It is easy to compare the benefits and drawbacks of different solutions, allowing a team to conclude the most desirable result (Banks, 2004, p.13).

Making investments that are well substantiated. The cost for creating a simulation model could be only a fraction of the price of a redesign, a cost that is easily won if it prevents a modification on the system after installation, which is costly (Banks, 2004, p.13).

Some of the disadvantages with simulation can, according to Banks (2004, p.14), be:

- Model building requires training and experience.
- Simulation results might be hard to interpret correctly.
- Simulation modeling and analysis can be time-consuming and expensive.
- Simulation might be used inappropriately, when other engineering methods would be a better fit.

3
Method

This project relies heavily on computer aids, where AutoMod is the main application. AutoMod is a DES software which simulates a programmed model using discrete time steps.

3.1 Case study

The DES model was done in cooperation with the case company. Especially considering which products and resources to include in the simulation.

First step was to collect information about the production system and the products. Also, all process and handling times was collected through interviews and business system. The simulation model was not a perfect copy of the production system, as it was an abstract version of the reality and because the focus in the thesis was on workforce allocation and giving more emphasis on other aspects are non value adding.

3.2 Project approach

To collect the data needed to build a DES model interviewing of operators and managers was performed, existing production data was collected and also observed the production system to gather data to analyze. The data was converted into a format that are suitable for use within DES models. To be able to test different scenarios a DES model was built, verified and validated. The verification was to ensure that the model behaves as intended and the validation was to ensure it was a good representation of the production system. To find the best solution for the objectives several simulations was made to gather results that can be analyzed using a statistic tool.

3.3 Simulation of the production system

In this project AutoMod was a central tool and was used to create and simulate the DES model. The general steps to go trough while making a simulation study is described by Banks (2004, p.17) and shown in figure 3.1. The project followed these steps to create the approved DES model, which are more thoroughly described in this chapter.

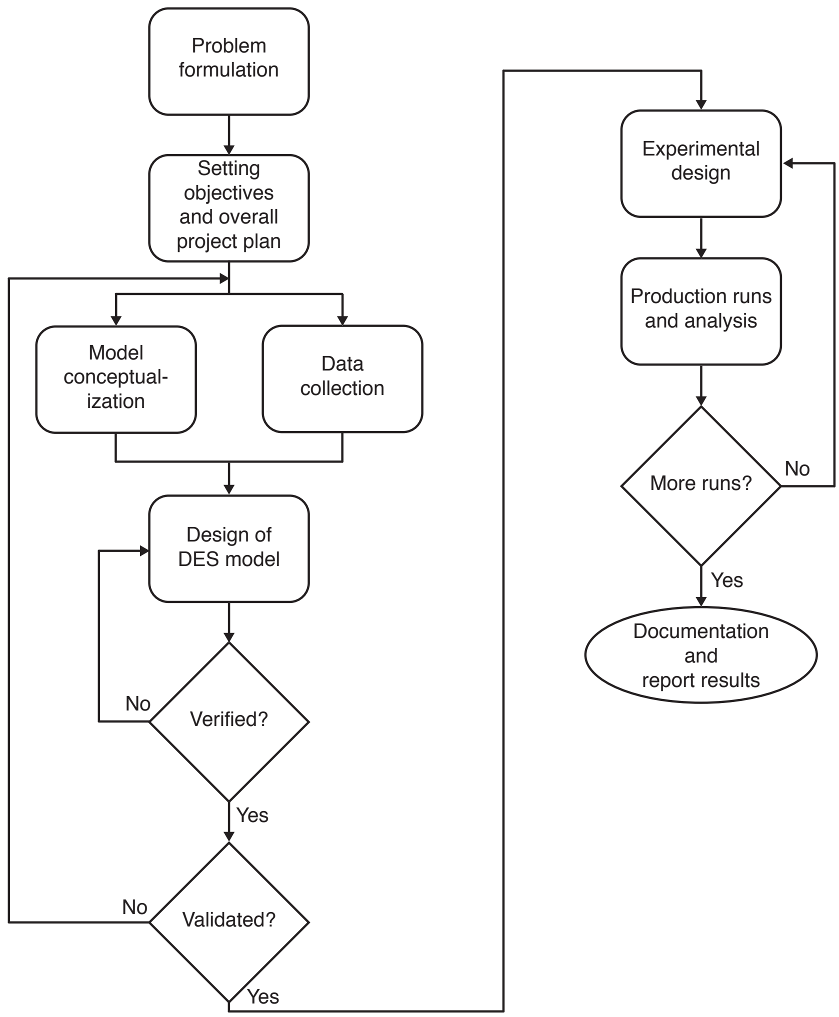

Figure 3.1: Steps in a simulation study inspired by Banks (2004).

3.3.1 Model conceptualization

A conceptual model is according to Banks (1998 p.15-17) a real world system with logical and mathematical relationship with the structure and components of the system it represents. The model conceptualization was made from information gained by observation and interviews with operators and managers. To fully understand the process it is important to have a close discussion with the managers and operators during the model conceptualization (Banks, 1998, p.23). At first a simple model was made and in our case that will be a flow chart to fully understand the logic between the different process in the production system. As the knowledge of the system increase the complexity of the model was increased as well.

3.3.2 Data collection

From the conceptual model a schedule for data needed was made. The data needed was collected from interviews, observations and logs that have been collected by the company.

Interviews
The interviews with the operators, scheduler and manager was intended both to gather an understanding of the production system, and also to gather what the interviewees considers be the main peculiarities of the production system. The interviews was semi-structured which is the most used interview format for qualitative research according to DiCicco-Bloom and Crabtree (2006). The semi-structured interview format is beneficial to use when the interviewer is unfamiliar with what to expect of the answers (Gillham, 2005, ch.10).

Observations
To deeply understand a production system it is important to go and see for your self according to Liker (2004, ch.18). By see the production system with your own eyes it makes it possible to understand and analyze the situations that happens in the production (Liker, 2004, ch.18). Therefore, in this master thesis a lot of time was spent on the production floor to thoroughly understand the production system. By observing many of the operations made by the operators a good understanding of the production system was obtained and used when the building of the DES model begin.

Collection of existing production data
All relevant and existing production data was gathered and also verified with the operators to ensure they are correct and accurate. The data was extracted from the case company's business system and then verified by cross checking it with the operator responsible for the operations the data covers. The data was converted into a format that are suitable for use within DES models. This was needed because the data from the business system was not directly compatible with the DES software, due to the different purposes for the data.

Data analysis
The data was analyzed using different tools to get data that can be applied to the DES model. When collecting data for a simulation model Banks (1998, p.59) states that it is common to mine for data that is collected for other purpose than building a simulation model. Banks (1998, p.59) also states six annoyances that can occur if the data is pre collected:

- The data is recorded in a non chronological order.
- The data is grouped in different intervals.
- The data is lacking precision and might be rounded to nearest integer.
- The samples could contain obvious faulty values.
- The data could be from more than one process without documentation.
- The data could represent a different real world process.

A data set that is pre collected might not have all of the above annoyances but Banks (1998, p.60) states that they occur so often that it is impossible not to be suspicious about the validity of and given data set. Banks (1998, p.60) also states that if it is the best available data it is important not to take the pre collected data too seriously.

Law and McComas (1999, p.261) states two common pitfalls when collecting data for simulation, the first is to replace a distribution by its mean and second is incorrect modeling of random machine downtime. Both pitfalls can lead to an inaccurate model and therefore it was important to always ensure that the data was valid.

3.3.3 Design of DES model

The DES model was converted from the conceptual model into a model that is recognized by AutoMod. To achieve a good DES model it was important that the model was simplified at the beginning to avoid hard to find errors in the model. All subsections was tested individually and when they work the subsections was combined.

3.3.4 Verification and validation

Verification, according to Law and Kelton (2000, p.697-698), means to determine that a model works as intended. There are numerous verification methods, where the ones used in the project is described in this chapter.

Verification methods

- **Numerical verification.** Do the necessary calculations manually and compare to the result from the program. Becomes impractical fast with growing applications in size (Jagdev et al., 1995).

- **Animation observation.** The simulation software's graphically visualizes the progress of the simulation to let the user analyze the behavior (Jagdev et al., 1995).

- **Tracing.** Run the simulation with a single load, to ease the observation of all the processes (Kleijnen, 1995).

- **Event validity.** Test specific events to evaluate that the behavior is as intended (Sargent, 1998). An example of such event is to force the buffers to reach their maximum capacity.

- **Extreme conditions.** Set the input to different specific values to evaluate how the model reacts to specific scenarios, e.g. zero products, constant rate and a infinite backlog of production orders (Jagdev et al., 1995).

- **Internal validity.** Run multiple simulations with the same input conditions and evaluate that the variance in output is kept at low levels (Sargent, 1998).

- **Operational graphics.** Comparing the production statistics and KPI's obtained in the simulations to historical data (Sargent, 1998).

Validation
The validation process was to ensure that the model represents the real system as accurate as possible. As the behavior of a real life system depends on nearly infinite numbers of variables, a perfect model cannot be made, and the cost to build a better model rises fast, as figure 3.2 illustrates (Sargent, 1998). The model was validated by comparison with historical production data.

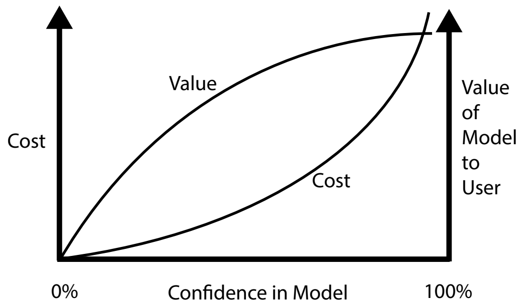

Figure 3.2: Model confidence inspired by Sargent (1998).

3.3.5 Experimental design

When the model has passed verification and validation, the next step was to design an experimental plan. Wu and Hamada (2009, ch.1.2) lists seven steps to take while planning and implement an experiment:

1. State objective.
2. Choose response.
3. Choose factors.
4. Design experimental plan.
5. Perform the experiment.
6. Analyze the data.
7. Draw conclusions.

How these steps was implemented in this case study is described in the following paragraphs.

State objective. The objective was stated to either answer the hypotheses directly or to gain a deeper understanding of the dynamics of the system.

Choose response. The response was chosen to get a understanding of the dynamics of the system and also to collect important data to answer the hypotheses. Responses was also chosen to monitor the WIP level.

Choose factors. The factors was chosen to be able to answer the stated hypotheses and to find variables that affects the WIP.

Design experimental plan. The length of the simulations was set to match the period of time there exists relevant production data, to ease comparisons between the model and the real production system. The number of runs was increased until a sufficient confidence level was reached without letting the simulation time be unreasonable long. The simulation had a warm up time to achieve a steady state before the start of measuring.

Perform the experiment. Before each real test begins a trial run was conducted to ensure that the factors and response behaves as expected. If the trial run was successful the full test simulation was run, otherwise the factors and responses was reviewed.

Analyze the data. The data from the simulation model was collected and analyzed. The data was visualized with graphs to ease interpretation of the results from the simulation.

Draw conclusions. From the visualized data conclusions was made to answer the stated hypotheses.

The experimental design was planned to ensure that the data collected from the DES simulation made it possible to answer the stated hypotheses of this master thesis.

3.3.6 Production runs and analysis

The simulations was run and simulation data was gathered when the experimental plan had been designed. The software AutoStat, which is integrated with AutoMod, is primarily used in this project to analyze the simulation results.

During the experiment phase, the simulation is required to be run a few times for each set of variables to obtain a higher significance (Krzywinski & Altman, 2013) with one or a few variable values changed to identify if a change makes the system perform better, worse or the same, and also to see when a resource converges.

3.3.7 Documentation and report results

The results from the production runs and analysis was converted to changes in percentage due to company confidentiality. Graphs of the output from the simulation model was also made to ease the understanding of the results. All of the codes written in the DES model was commented to easily understand how the model is built if there would be any further experiments or projects using the DES model in the future.

4
Results

This chapter presents the results and analyzes from the case study and answer the hypotheses asked in Introduction chapter 1.4. Due to confidentiality all numbers will be presented as changes in percentage.

4.1 Simulation model

The DES software that was used in the thesis is Automod. The facility is modelled with machines as resources, placed according to the most common product stream. The products, which are presented by loads, can in the model be moved freely across the resources, as not all products is manufactured using the manufacturing steps. Even though the runtime is not presented due to confidentiality, the logic of a generic model is illustrated in figure 4.1. The operators are represented as resources as well, but not presented graphically, as they are not bound to a physical location. The products are always kept in a certain queue, both in the resources and the storage between the resources. Batching of products during a production step is simulated, where applicable, by storing the number of batched products in one load and the other discarded. When a batched activity is finished, the model copies the number of loads stored in the one load to continue the manufacturing. The steps required for each product type are stored in tables and the production steps that are performed is stored in each load after the steps completed. All production times for each product are stored in tables and is read for the certain product step for the product. This way, the variables could easily be modified to study their effects on the production system.

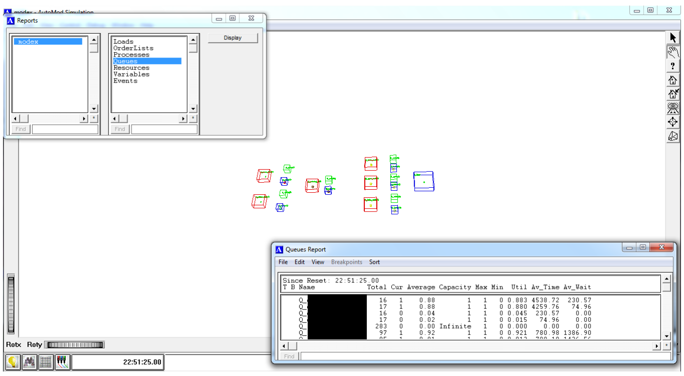

Figure 4.1: Generic Automod runtime.

4.2 Case study results

The production is separated into two areas; 1 and 2. Production area 1 (PA1) houses one injection molding machine while production area 2 (PA2) houses several compression molding machines. PA1 has significantly higher throughput and larger batch sizes than PA2 which is the reason behind the separation of the results. The production areas share common resources according to figure 4.2. The utilization for the shared resources is significantly lower than for the molding machines and therefore not further investigated. The testing areas is a resource also shared with the HVDC part of the factory. In combination with that it has low utilization it is therefore omitted from further investigations.

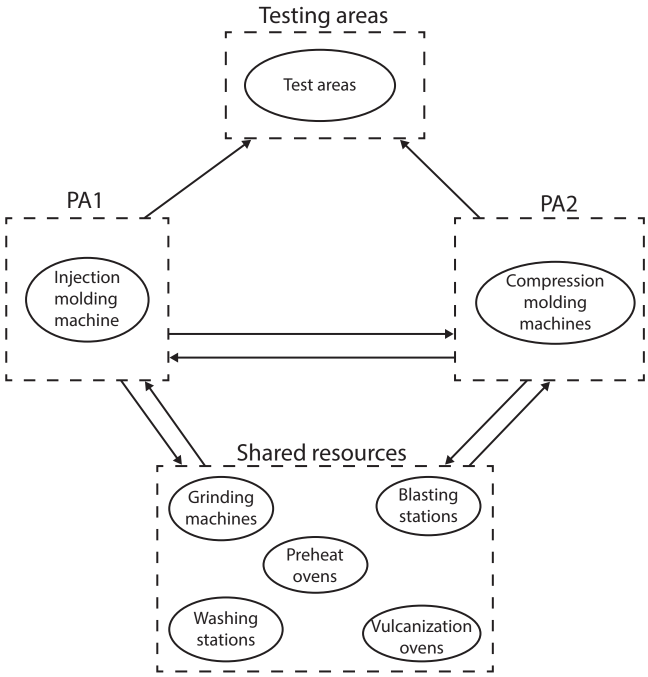

Figure 4.2: Schematic layout of the production system.

Today, the only machine in PA1 is operated by one operator (OP1), in three shifts from Monday to Friday afternoon. PA2 machines are operated by one operator (OP2) and one halftime (OP3) during day shift, two operators (OP4, OP5) during afternoon shift and one operator (OP6) during the night shift from Monday to Friday afternoon. The operators in PA1 and PA2 share resources for pre and post processing of some products. PA2 also have a dedicated operator (OP7) on a specific compression molding machine during daytime.

All runs are done for the equal of three years worth of production time. Simulations with one changing factor was done with 50 repetitions on each step, while the multiple factor graphs were done 20 times. In all cases the average result is presented, and the throughput changes is shown in percentage from the current state. The confidence levels shown are always at a level of 95 %.

In the model, the factors contributing most to the variance in the model is setup time and manual handling time. The machine time is very exact and most manual work exceeding setup time and manual handling time is done during the machine time. In the simulation model all machine downtime is excluded and that is based on the absence of data of this type. According to the interviews it happens rarely which makes it close to impossible to measure accurately during this case study. Due to simplifications in the model it is not possible to directly measure the WIP and therefore batch size is a substituted KPI for WIP. The simplifications where made due to lack of data and because of the complexity of the real production system with to many variable to mange within the time limit of the case study.

4.2.1 Experimental setup

The first experiment is setup to test how the production system is affected by changes in the batch size alone. The batch size is altered between ±50 % of its original value that differ depending on which product type that is produced. This interval makes it possible to see clear trends when changing the batch size. All succeeding experiments are tested against the batch size to investigate how they affect the WIP with the preserved throughput. The following test is conducted with a batch size changes from -50 % to +10 % and this is because the main interest in the study is to reduce the WIP.

The second experiment is designed to test the behavior of the system when OP7 is trained to operate all compression molding machines in PA2 and that the other operators in PA2 can operate the machine that OP7 previously was dedicated to. The second experiment also tests that OP1 can operate all compression molding machines in PA2 and that all operators in PA2 can operate the injection molding machine in PA1.

The third experiment test on which shift in PA2 it is most beneficial to hire a temporary operator if there should be a peak demand.

The fourth experiment tests the effects of outsourcing low volume products. The amount of outsourced products is determined on how often they have been produced in the past e.g. 2 % level outsource all products produced less times than 2 % of the total amount of productions orders. The outsourcing levels that are tested are from 0 % to 5 %.

The fifth experiment is to test how a reduction of setup time affect the production system. The setup time is reduced in three steps, 50 %, 75 % and 90 %.

A summary of the experimental setup is presented in table 4.1.

Table 4.1: Experimental setup.

Experiment	**Changed factors**
Batch size	Batch size
Allocation of current workforce	Where the operators can work Batch size
Extra operator	Adding one extra operator on one of the shifts Batch size
Outsourcing	Outsourcing level Batch size
Setup time	Setup time Batch size

4.2.2 Batch size

As the batch size and WIP is linked to each other, the first experiment was to see how the batch size affects throughput in PA1 and PA2 respectively.
Figure 4.3 shows that PA1 has lower throughput with smaller batch sizes and that that the batch size is a big contributor to the throughput in PA1.

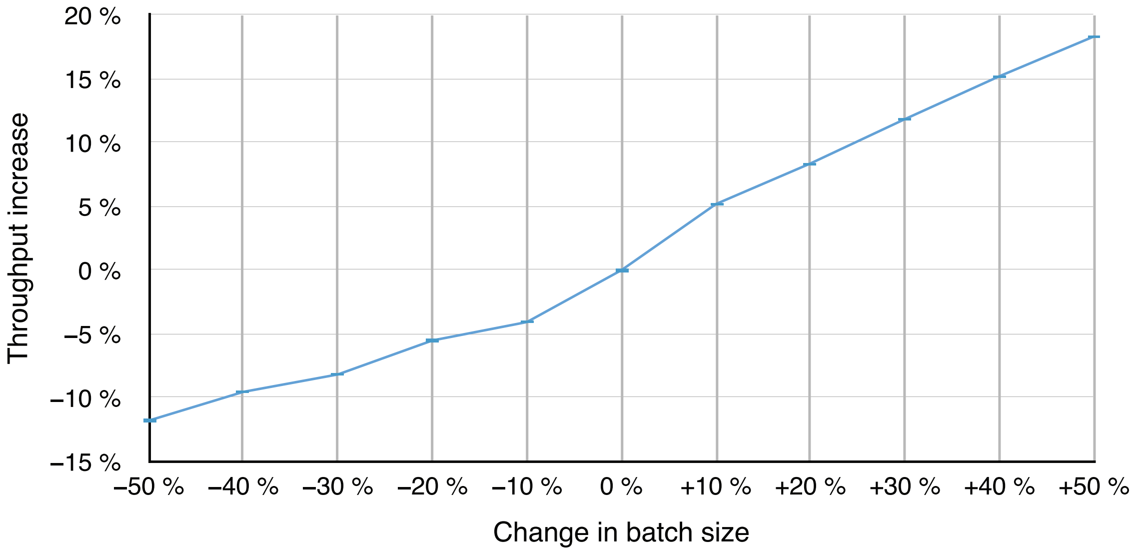

Figure 4.3: Batch size in PA1.

Figure 4.4 shows that the batch size has small impact on the throughput in PA2

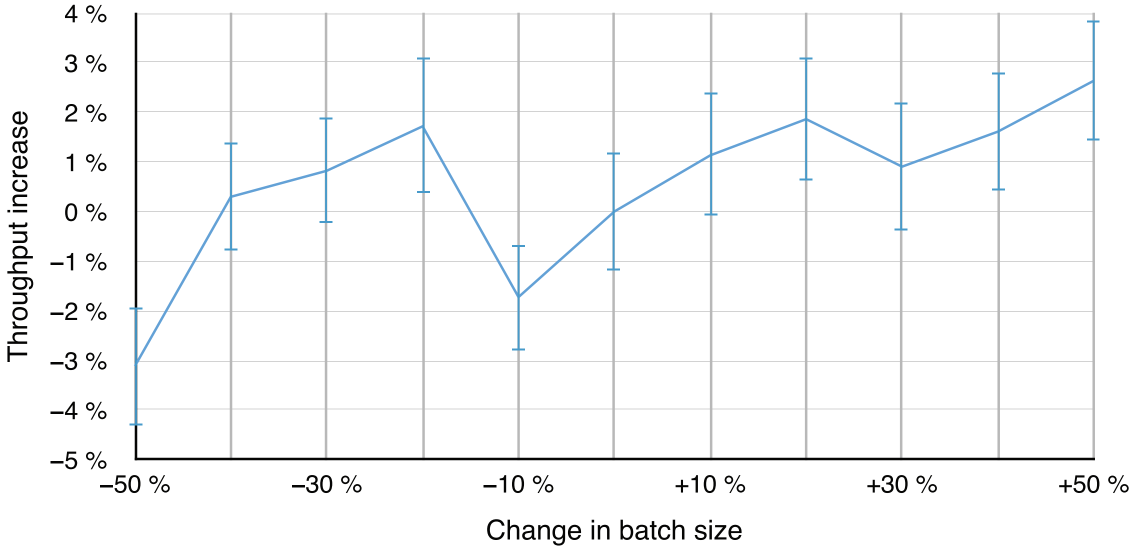

Figure 4.4: Batch size in PA2.

4.2.3 Allocation of current workforce

The allocation of the workforce is tested in two different variants which is that all operators in PA2 can work on all compression molding machines in PA2 and that all operators can work on all molding machines in both PA1 and PA2.

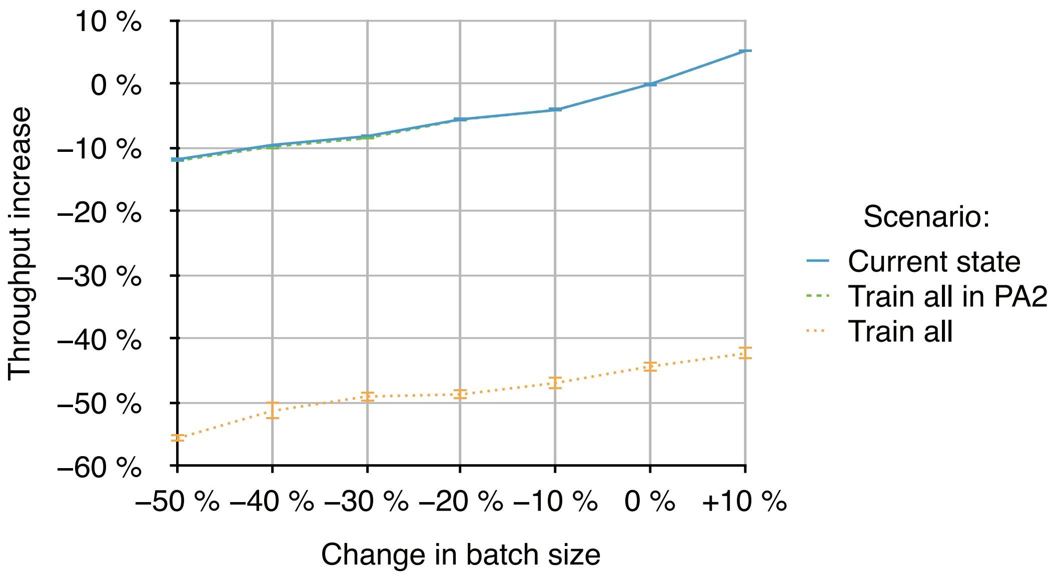

Figure 4.5: Batch size and allocation of operators in PA1.

As seen in figure 4.5 the current state and train all in PA2 shows the same result and that is because PA1 still have a dedicated operator in both scenario. When all operators is trained to work on all molding machines there are a huge decrease in throughput and the reason behind that is that PA1 no longer have a dedicated operator which leads to that the injection molding machine is not utilized as much as in the current state. From figure 4.5 it is also possible to see that while reducing the batch size the throughput decreases in all three scenarios.

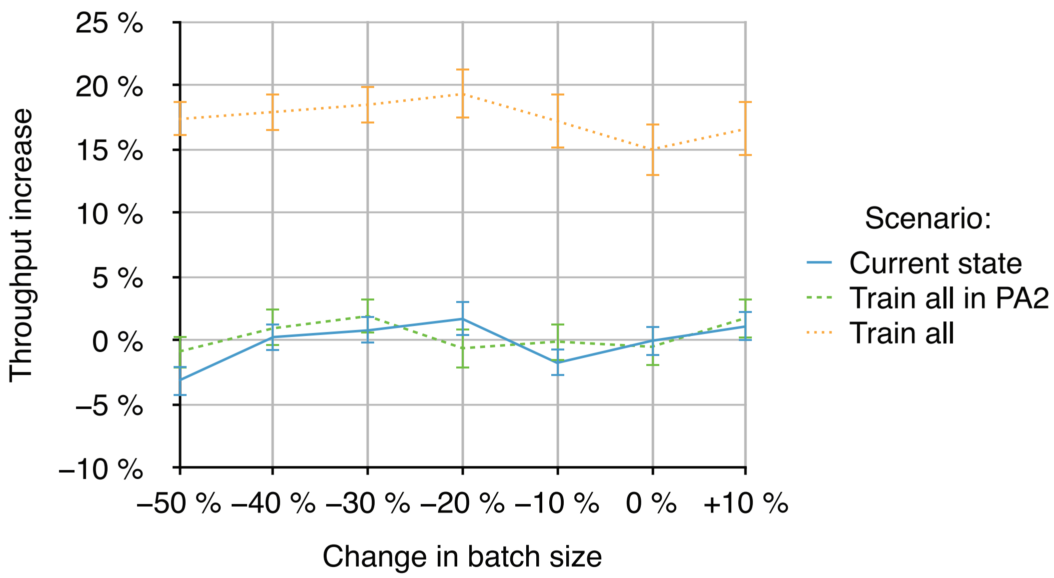

Figure 4.6: Batch size and allocation of operators in PA2.

As seen in figure 4.6 the current state and train all in PA2 shows almost the same result over the different batch sizes and this is because that the dedicated operator for one of the compression molding machines in PA2 still works with a compression molding machine in PA2. When all operators is trained to work on all molding machines there are a quite large increase in throughput at all the different batch sizes and that is because the operator from PA1 now also can work in PA2. From figure 4.6 it is possible to see that the effects of reducing the batch size slightly affect the throughput.

The total throughput from the system, which is shown in figure 4.7, basically follow the trends seen for PA1, as the throughput is higher than in PA2.

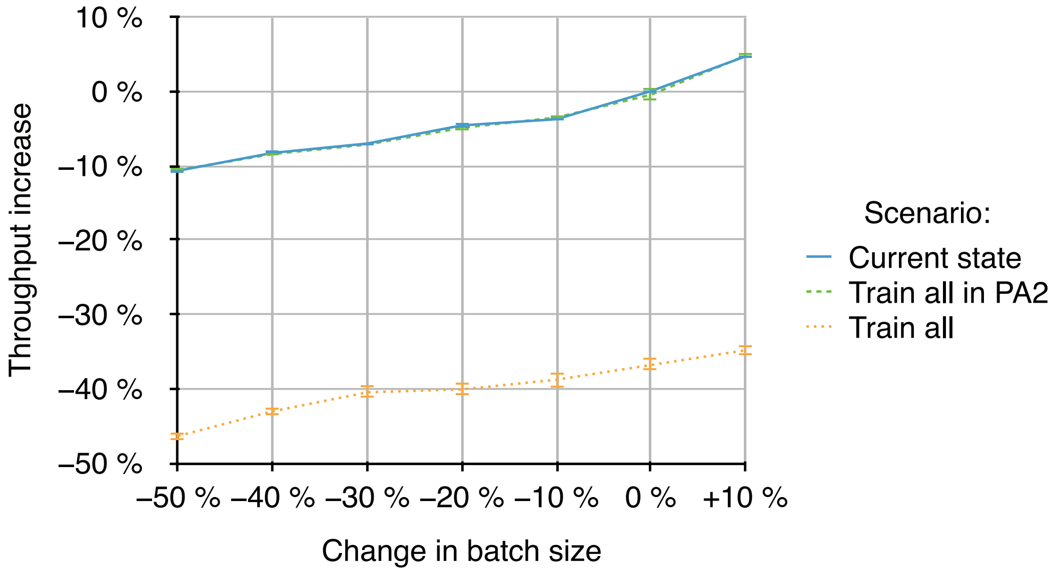

Figure 4.7: Batch size and allocation of operators in the total system.

4.2.4 Extra operator

Figure 4.8 shows in which shift it is most beneficial to hire a new operator if a peak demand will occur. PA1 is already fully staffed and therefore will the extra operator be placed in PA2. The reference point in figure 4.8 is 0 % change in batch size and extra operator on the day shift.

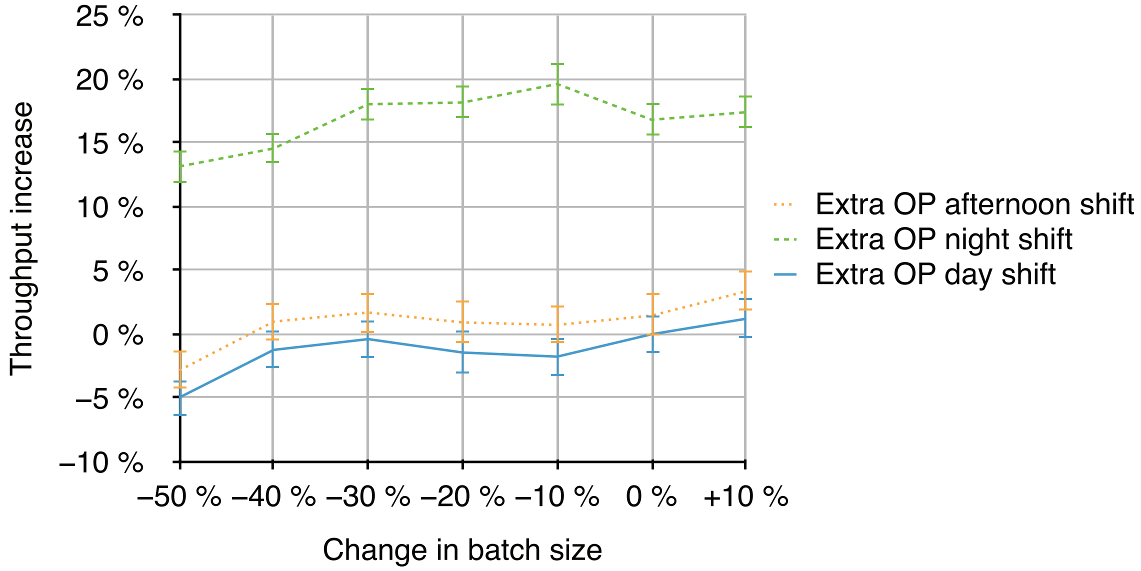

Figure 4.8: Extra operator in PA2.

As seen in figure 4.8 it is most beneficial to hire a new operator during the night shift independent of the batch size. Both the day and afternoon shift have more operators than the night shift in the current state and therefore it shows that it is most beneficial to level out the amount of operators during the day.

4.2.5 Outsourcing

The current state reference point is outsourced 0 % of the the products and batch size change of 0 %. The trend lines represent different level of outsourcing of low volume products.

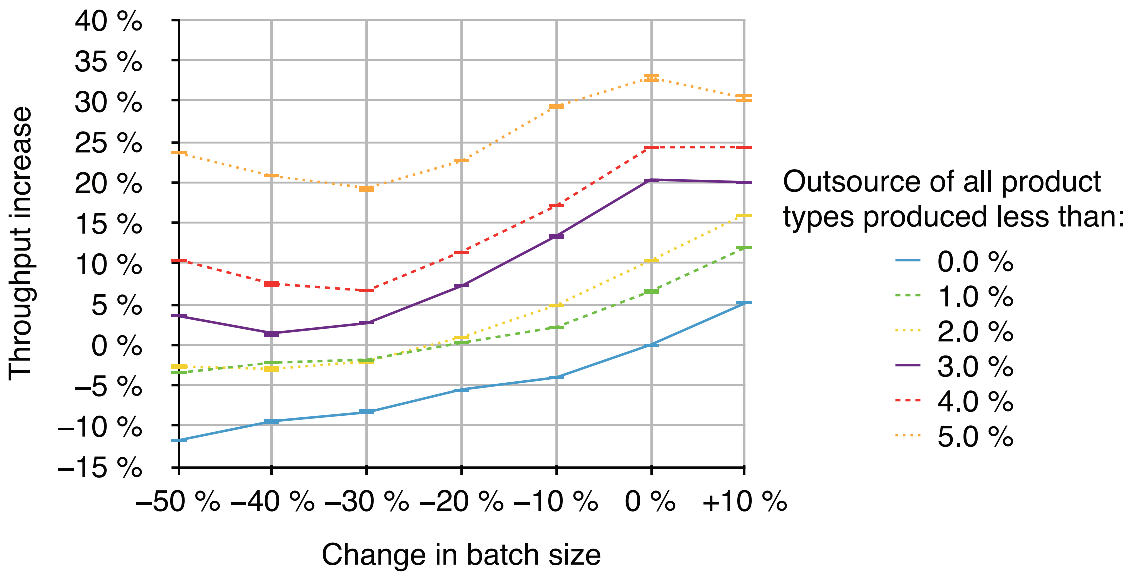

Figure 4.9: Outsourcing of low volume products in PA1.

As seen in figure 4.9 an increase of the amount of outsourced products increase the throughput. It is also possible to see that reducing the batch size with 20 % reduce the throughput but by also outsource products produced less than 1.0 % of the time will make it possible to keep the current throughput but with less WIP. If an increase in throughput is desired a higher level of outsourcing could make it possible.

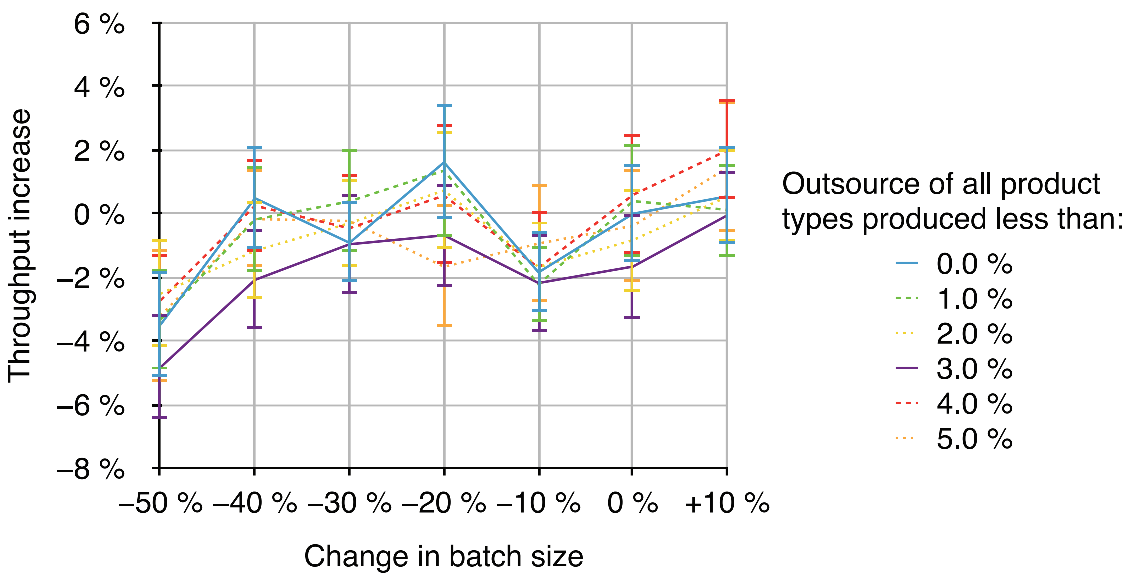

Figure 4.10: Outsourcing of low volume products in PA2.

From figure 4.10 it is not possible to determine any relationship between the level of outsourced products, throughput and batch size.

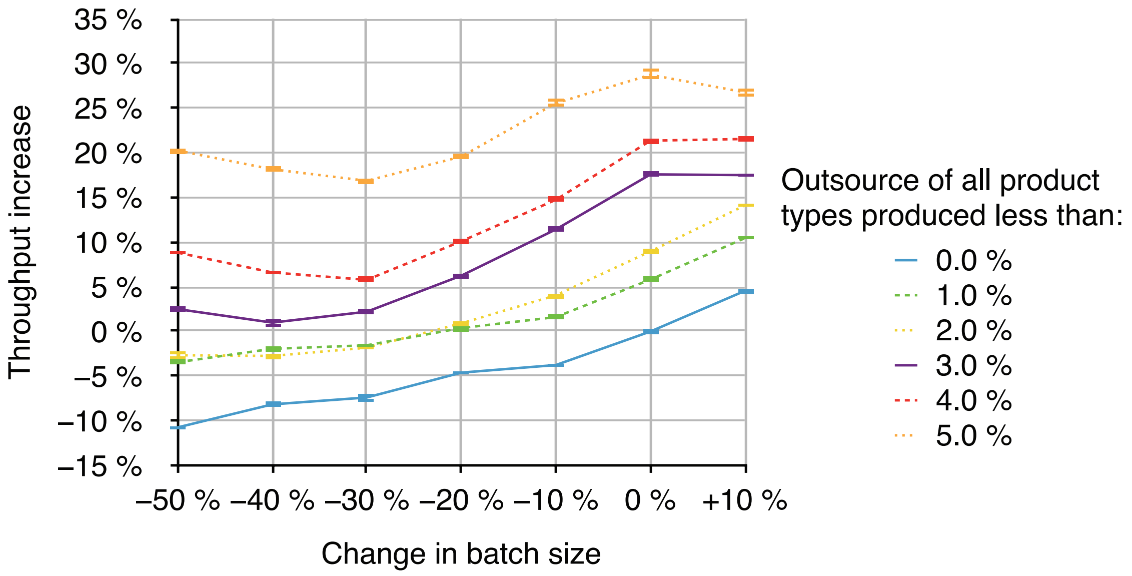

Figure 4.11: Outsourcing of low volume products in the total system.

Figure 4.11 shows the same trends as figure 4.9 because PA1 is the main contributor to the throughput in the system.

4.2.6 Setup time

A reduction of the setup time can make it possible to reduce the batch size and indirectly the WIP with preserved throughput.

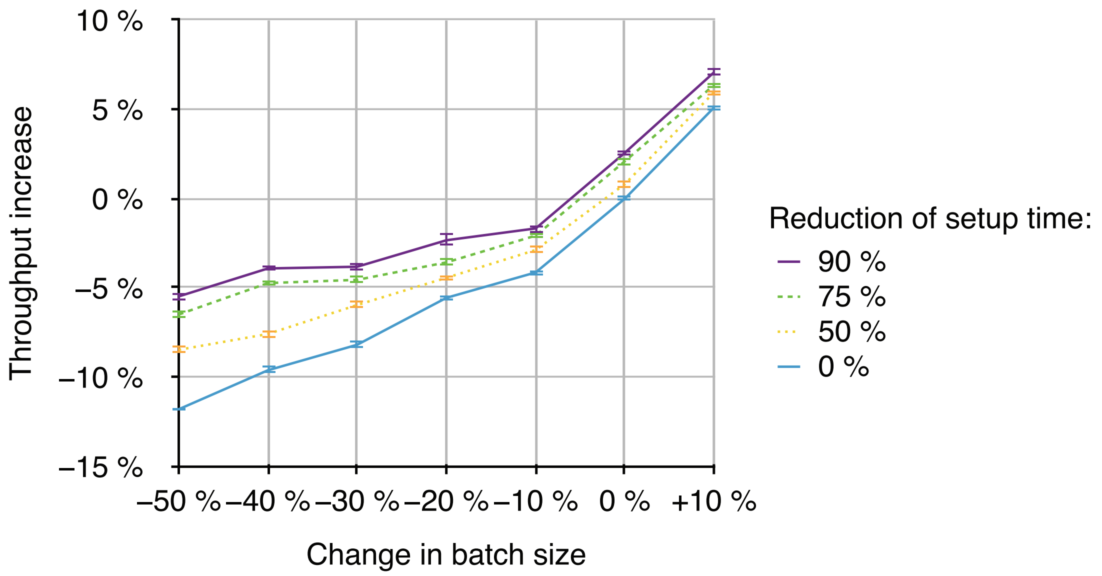

Figure 4.12: Reduction of setup time in PA1.

As shown in figure 4.12, a reduction of setup time has greater impact on the throughput if the batch size are smaller. By decreasing the batch size it is possible to compensate the loss in throughput in some way by also reduce the setup time.

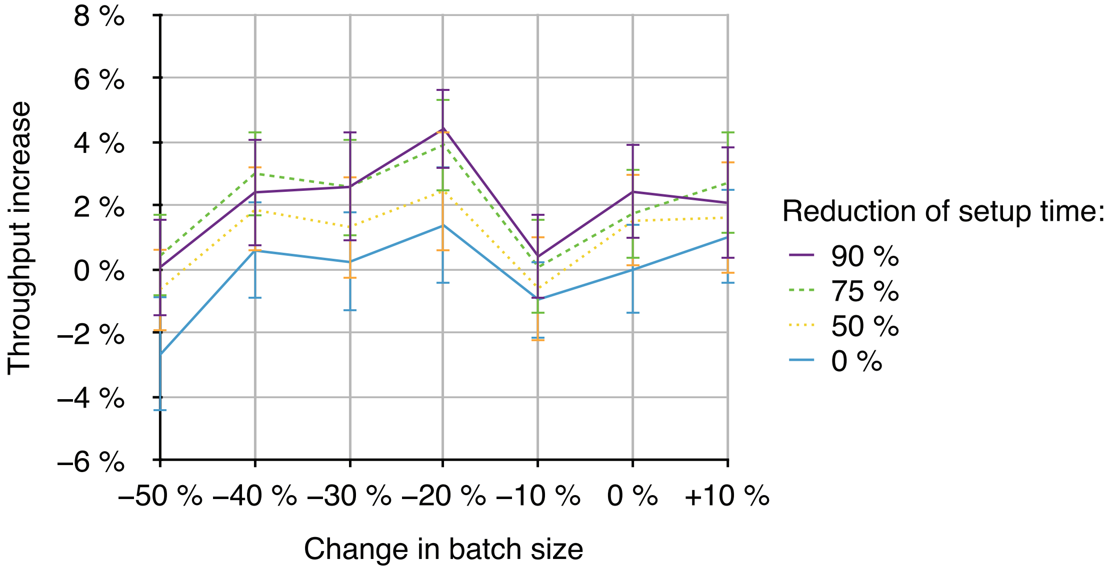

Figure 4.13: Reduction of setup time in PA2.

As shown in figure 4.13 a reduction in setup time might increase the throughput but it cannot be concluded with a confidence level of 95 %.

4.3 DES as decision support

By analyzing the output from the simulation model a basis for decisions are established. The figures in chapter 4.2 shows that by changing various factors in the simulation model it is possible to determine how they affect the production system. When different factors changes in the simulation the responses is also changed and observation of the responses shows that using DES as a decision support for workforce allocation is possible. This result could also be drawn from figure 4.7 and figure 4.8, where it possible to see that changes in the workforce allocation affects the WIP but not only in a positive way. The usages of DES as a decision tool for workforce allocation is however not without its limitations.

A limitation that was found in the case study when using DES as a decision support for workforce allocation is that it requires some extra adaption of the model before it is possible to use. The adaptions that was needed to be done was to create new custom scenarios for all of the different allocation options which would not have been needed if the DES model should not have been used for workforce allocation. Another limitation for DES as a decision support for workforce allocation is that the logic on how the operators should work, which machine and which product, could be tedious to program because there are no pre configured routines to handle workforce allocation. To use DES as a decision support for micro management the level of details needs to be higher and as shown in figure 4.4, figure 4.8, figure 4.6, figure 4.10 and figure 4.13 the error bars are relatively high in relation to the trends shown in the figures. The case study lack any further results in DES as a decision support for micro management due to difficulties program suitable model logic for the DES model and also due to the quality of input data.

It is also possible to use DES as decision support for production planing as shown in figure 4.11 where strategic outsourcing decisions is supported. By using DES as decision support for production planning it is possible to test and evaluate different strategic decisions before implement them in the real production system.

5
Discussion

This chapter discuss the result and method of the thesis and present the answer of the stated hypotheses. The effects on the sustainability aspects while using DES are also addressed.

5.1 Results

A strength in this thesis is that even though one case study is done, both a high volume and low volume production system was studied. This makes it possible to make trends clearer and further see reasons for the behavior of the system. Some simplification regarding WIP were made due to cost and lack of relevant data. By using batch size as a KPI for WIP it is possible to determine that if the batch size is reduced, the WIP is also reduced but an exact relationship could not be determined in the case study.
Lowering the batch size gives less throughput in PA1 but for PA2 that already has quite small batch size a further reduction shows no impact in the throughput. To get the largest impact in the WIP level a reduction of the batch size should be done in PA1 because it has much higher volume and therefore more WIP that can be reduced. A reduction of batch size in PA2 could also be done to get a minor reduce in the WIP level. A reduction in setup time increases the throughput for PA1 and that is mainly because the time for producing products is increased. But for PA2 it is not possible to see any relationship between the setup time and throughput and that is probably because the operator could work on a different compression molding machine during the tool heat time that is the dominating factor of the setup.

The variations are quite low between the simulation runs, which suggests that the model is of good quality (Sargent, 1998). The throughput from the base model is higher than the historical data shows due to simplifications regarding stops and product variance. This is a expected behavior because the number of setups, stops and product variance are fewer in the model than in the reality but by converting the result to percentage it is possible to apply the result from the simulation in the actual production system. The exclusion of downtime should not be of importance due to the percentage conversion of the result and that the throughput in PA1 is almost strictly correlated with total up time. For PA2 the operators can work with other compression molding machines during any downtime. Even though the confidence levels in several of the results is shown to be high, the results itself can with this methods not be concluded to be as equal exact. The model has many simplifications due to the complexity of the system. However, the general trends should be correct as the results either shows a very strong change or no change at all.

5.1.1 Hypotheses

The hypotheses presented in chapter 1.4 are discussed in this section.

- Training the operators to use all machines will reduce the WIP without reducing the productivity.

This hypothesis, as seen in figure 4.7 where there is a significant decrease in throughput when OP1 and OP7 can work on all molding machines, can be rejected.

- To hire a temporary operator in the day shift instead of the afternoon or night shift during a peak demand results in a lower WIP with the same productivity.

This hypothesis is rejected. The batch size can be kept lower with the same throughput or higher throughput when hiring a extra operator on the night shift than during the day or afternoon shift in the production as seen in figure 4.8.

- Outsourcing of low volume products will reduce the WIP without reducing the productivity.

This hypothesis is accepted for this case study but it cannot be generalized because in PA2, outsourcing show no relationship with throughput and batch size.

Training operators to work on more machines had no positive effect for the throughput in the case study. The processing times is quite similar for all products in PA2, and the operators instead ends up working on another product without any gain for the total throughput. It can however be beneficial if the demand changes towards a specific product type but it is not economical justifiable to cross train the whole workforce, as Saadat et al. (2013) says it is costly. It was however found that the operator in PA1 should remain stationary at the machine and not work everywhere, as the throughput in PA1 declines drastically when an operator is absent. It makes no practical sense to train another parallel operator for PA1, as the single machine is made for one operator only.
To put in an extra operator to increase the throughput during periods with peak demand is ultimately an act of balancing out the work force as evenly as possible throughout the day. Only an extra operator during the night shift, which is less staffed than the day and afternoon shift, shows any improvements. This shows that the current staffing is at the best level during day time.
Outsourcing of low volume products was found to compensate for the loss in throughput when reducing the batch size in the case study. In PA2, there was seen no change in throughput in all the levels of outsourcing. Something that is not considered in the model, is that production tools that is rarely used may take longer time to set up for the operator due to the lack of practice. It should noted that it is not possible to continuously increase the outsourcing and keep the same increase in throughput as eventually, there will be no more products to produce.

5.1.2 DES as decision support

DES as a decision support for production planning is quite suitable for test long term strategies and overall management but might lack the micro managing possibilities, which may lead to a suboptimal solution without extensive and clever programming efforts. The lack of results for DES as a decision support for micro management in the case study could be due to the time constraint during the case study. By having more time a simulation model might be built to use for micro management but as cost increase with the time used to build the model it might not be suitable to use DES as a decision support for micro management. The usability for DES for long term strategic decisions seems high and by combining it with for example demand forecast, it is possible to investigate how many operators that is needed to reach the capacity for the expected demand. This is also true for the other direction of the demand, if there should be a decrease in demand it should be possible to investigate the correct amount of operators for that demand. By using DES it is also possible to see which factors that affects the system, how they affect the system and also to what extent they affect the system. This can be used when taking decisions on what areas to further investigate. By using DES for allocating the workforce it is possible to evaluate in some way on which machine the operator should work on and which product that should be produced at the moment. The usages of DES for workforce allocation might improve the work environment because of that the operators knows what to do and therefore the operator might feel less stressed. It might also reduce the stress or workload because it is known how much workload each operator will have and therefore it is possible to level the workload between the operators.

To use DES as a decision support for workforce allocation some extra code might need to be written and that perhaps extends the time needed to construct the model and also the time to run the model. This means that the cost to produce a DES model that can be used for workforce allocation decision support could exceed the financial gain of better workforce allocation. If the cost for construct the DES model for decision support exceeds the expected gain from using the DES model it is not recommended to use DES simulation for work force allocation. To use DES as a decision support it is preferable that the user has good knowledge in the DES software to be able to understand how to interpret the outcome of the simulation. If the person making a decision from a DES model without sufficient knowledge about the DES software and how the output is presented it might lead to a decision based on incorrect interpreted data.

To achieve a DES model with higher confidence in the case study it would be beneficial to use engineering methods, such as time studies, to collect more accurate data for the DES model. The level of accuracy in the collected data determine how accurate the DES model could be and also how accurate the output from the model is. To achieve a model with higher accuracy the cost of building the DES model and collecting the data for the model increases rapidly and might exceed the gain from the model. If the data has to low accuracy and it is not detected it might be possible to be lured into a false sense of security that the model has a higher accuracy than it has. This might lead to that decisions is made on the outputs from the DES model that is not consistent with the real production system. In order to get a more dynamic simulation a mathematical allocation algorithm could be used for the allocation of the operators in the DES model.

5.1.3 Production planning

If reducing the WIP is the main target for an organization, the study have found that it is possible reduce it with some strategic decisions or investments. The exact relationship between batch size and WIP could not be concluded in this study and therefore it is hard to measure the economical gain on reducing the batch size in the case study. To find the relationship between batch size and WIP in the case study the case study company must implement changes in batch size and measure the WIP to understand the relationship. To test changes in batch size in the real production to find the relationship with WIP might be costly and difficult to motivate for the organization. In PA2, the throughput were found to be independent from the batch size. On the contrary, in PA1 the throughput were found to have a almost linear relation with the batch size. To reduce the batch size in PA1 and also preserve the throughput other changes needs to be implemented for example reduced setup time or outsourcing of low volume products.

5.2 Methods

AutoMod might not be the best simulation tool for simulate a flexible flow shop production system. It is easy to let rare bugs persist long into the simulation because it is very time consuming to test all possible scenarios in a flexible flow shop production system, which may lead to faulty data.
A flexible flow shop production system with high variance in products, batch size and cycle time was with some simplifications possible to model in AutoMod, but to extract relevant and accurate data was found difficult. To collect data for the model in the case study, both quantitative and qualitative methods was used. The qualitative data was mainly collected through semi-structured interviews with managers and operators, while the quantitative data was extracted from the business system of the case study company. The quantitative data was verified during the conducted interviews where there was found that some of the data was old and invalid. However, previous production statistics was found to be accurate and was proven to be really useful during the building of the simulation model, as enough production statistics would have been hard to gather in the frame of the thesis.
The model was constructed in a way to minimize the run time of a simulation to be able to do more runs to get a higher certainties in the result from the model. By minimize the run time of a simulation it was also possible to test extreme values to verify as stated by Jagdev et al. (1995) that the model behaves as it should if it is pushed to its limits.
The model is mostly validated by comparing to previous production data, not actual behaviour of the components in the system. This may lead to a lower uncertainty in the results if too many factors are changed to extreme values.

5.3 Sustainability

The usage of DES decrease the need of modifying and testing in the real production environment which might lead to lower material and energy usage when implementing improvements. It may be lower costs while using a simulation model instead of trial and error in the real production environment, as stated by Muroyama et al. (2010). By using DES as a decision tool while allocating the workforce it is possible to analyze the workload for each of the operators and therefore reach a workload level that is acceptable both for the company and the operator before the tasks is carried out in the real system. The results from this thesis affect the economic part of sustainability by reducing the WIP that ties up capital.

6 Conclusion

This thesis presents that it is possible to use DES as a decision support but it might not be the best tool for all types of decisions that has to be made in a production system. It was found out that DES is better to use for long term strategic decisions rather than micro managing of a production system. This is based on that the DES model needs higher confidence that rapidly increase the cost to be able to support the decision accurately when micro managing a production system. DES can also be used to see how different factors affect the system and find which part of the production system that needs further investigation or improvements. The tests that have been performed on the model about workforce allocation has given clear results.

It was found that reallocation of the current workforce did not have a positive impact on the throughput and therefore could not be used as a tool for reducing the WIP. Instead, reallocation could, with caution, be used to meet a change in the demand toward other product types. The tests performed with an extra operator shows it is highly beneficial to even out the workforce during the day. That hiring a extra operator during the night shift could be done if there is a peak demand. This also shows that the case company already have a good level of operators during two of the three shifts on a day.

Reducing the WIP in this case study is possible with some strategic decisions. The case study shows that outsourcing of certain product types gives the ability to reduce the WIP through smaller batch sizes. It should be noted that only the high volume part of the examined system showed this response, so the positive results is highly dependent of the production system.

7

Future research

For further research in the area of this thesis and DES as a decision support the authors recommends these topics:

- Test DES as a decision tool in more variants of production systems, for example a line flow production system.
- Compare the suitability of DES with other tools for decision support in a production system.
- Investigate on how the results from a DES simulation can be transferred to decisions makers without knowledge of DES.

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