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SCA Packaging

Simulation of possible customer demand scenarios at SCA Packaging, Järfälla

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Preface

This master's thesis marks the end of five years of studies for a master's degree in industrial engineering and management at Lund institute of technology.
We have gained a lot of experience and insights through this thesis and would like to thank the people that have helped us along the way and made this possible. We would like to send special thanks to Stefan Johansson, Lars Birgersson and Per Melin at SCA Packaging for their, highly appreciated, helpfulness. We would also like to thank our supervisor Mats Johnsson for being at hand and guiding us, from the beginning to the end of this project. Last but not least we would like to thank Magnus Viström at STFI Packforsk for introducing us to the subject of inline digital printing and giving us constructive feedback.

Lund, 2006-11-15

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Abstract

SCA Packaging Sweden wanted to evaluate what would happen to their production if their customer demand structure would change and chose to get this analysis done in the form of a master's thesis project by two engineering students from Lund institute of technology. The measures of performance were determined to be lead time, storage levels and capacity utilization in the machines.

More and more consumer products, especially food products, come in a wide range of variants, thus increasing the need of smaller production series. To change to production to produce smaller series of each product would strain the production lines and possibly lead to delays or a need for investment in new production capacity.

A simulation model of the SCA Packaging plant in Järfälla outside Stockholm was built using a software tool named AutoMod. This model was made bearing in mind that it should be easy to adapt to other plants for future analysis. By using all of the Järfälla plant's logged production data from 2005 the model could be tested and its performance compared to the performance of the real plant. Upcoming Market trends were used to develop realistic and relevant future demand patterns. These were realized in the simulation through three scenarios.

The Scenario II and III implies a demand pattern change where a share of the customer orders gets smaller but more frequent whereas Scenario I is based on historical data as a reference scenario. When running Scenario II and III, the machine time spent for activities such as machine setup, job processing and maintenance changes compared to Scenario I.

Summarizing machine running time and machine setup time for machine 724, 725, 730, 732, 734, 735 and 736 corresponded to a ratio of 27:10 for the base scenario. For Scenario III the same ratio became 7:4.

The storage levels are found to be fluctuating, but reasonable, as long as the production flow is undisturbed. The machines that become bottlenecks cause rocketing storage levels.

The lead time was measured as the time it takes from when the first pallet of unprocessed corrugated cardboard sheets of a certain job starts being processed in the first in order printing or conversion machine for that specific job, until all sheets on that job are loaded on pallets and ready for delivery.

The average weighted lead time for a job is 42 hours in Scenario I, 60 hours in Scenario II and 67 hours in Scenario III. These figures reflect the impact of the bottlenecks that occurred in the simulations.

The simulation model created in this master's thesis provides a solid platform that is easy to modify and expand in order to study other parts of similar plants than those related to the goals of this study. By being able to simulate the plants, SCA Packaging should be able to make more rational decisions regarding resource allocation, strategic planning and investments in new machinery.

Since the same data has been used both for validating the simulation and developing process data the model may be slightly biased. Some simplifications had to be made in the simulation model due to flaws in the production database such as excluding some production orders. Much care has been taken minimize the effects of this.

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1. Introduction

This chapter briefly describes why we did this report, for whom we did it, what the scope was and what the goals were.

1.1. Background

SCA Packaging (SCA) is expecting competition to grow tougher and tougher over the coming years. The current trend is that more and more variants of each consumer product is marketed, leading to a need to produce smaller batches of packaging material with customized print on each batch.[1] This development will strain the production lines, and increase the risk of bottlenecks to occur.[36] Hence, to stay competitive it is crucial to shorten lead times, lower costs and increase flexibility to meet customer demands.

Upcoming printing technologies such as inline digital printing has potential to enable customized print to be added to packages after the packages leave the corrugated cardboard plant (i.e. at the location where the packages are finally filled with product). For example, all variants of a product could come with the same basic print, covering most of the package, but have different logotypes added with digital printing technology to distinguish the products from each other. This approach would allow the corrugated cardboard plants to run larger series, leading to reduced strain on the production lines.[2]

It is in the company's interest to evaluate the effects of changes in demand structure in order to be better prepared for future market demands.

Until the day when digital printing is commonly available and has reached wide spread use, it may be advantageous for SCA to prepare for smaller batches to be produced in the existing production lines.[2]

Through contacts at the department of packaging logistics at Lund institute of technology and contacts at STFI-Packforsk a software-based simulation project was initiated. A decision was taken to fit this project into the boundaries of a master's thesis project for two students at Lund institute of technology.

The SCA Packaging plant in Järfälla outside Stockholm was chosen to be the subject of study for the simulation project.

In May, 2006, the authors of this report started the project by attending a meeting at the Järfälla plant.

1.2. Purpose

The stated purpose of this report is to evaluate the effects of possible changes in the customer demand pattern at SCA Packaging, Järfälla. The effects could for example be bottlenecks, changes in inventory levels, changes in capacity utilization levels or changes in lead times.

1.3. Objectives

The goal of the project is to present a report with relevant measures of performance relating to the performed simulation study analysis. The variability for each measure of performance should also be calculated. The measures of performance of interest are:

- lead time
- utilization of capacity

- inventory levels

1.4. Scope

Bearing in mind what the purpose and what the objectives are, a simulation model should be built to a correct level of detail.

Feeding very good in-data into a too simple model would produce unreliable results. Taking low quality data and feeding it into a model that is very close to the real-world system would also produce unreliable results and be a waste of time.

In order to start out with a correct level of detail when building the model, discussions with SCA regarding what data was available was held at the very beginning of the project and assumptions regarding what data was available was made.

It soon turned out that all required data had to be ordered from external IT-consultants, thus making the whole data gathering process very expensive for SCA and slow for us. After phone conversations with the IT-consultant at Sogeti it became obvious that the most powerful way of getting good in-data for our model would be for us to copy the database that the consultants are using and process it ourselves to create reports with the desired sets of data.

Looking back, we would not have been able to render good in-data without having access to the main database ourselves. To create the desired reports turned out to be much more time consuming than we could ever imagine, mainly due to low quality of the data in the database (unused data-fields, faulty entries and systematically erroneous reporting by the workers). After a few months' work we were forced to simplify parts of the model since it turned out that the data required for these parts of the model was not to be found in the KIWI-database. The extra work required in order to understand that certain data was really missing and could not be derived from related tables increased our workload and delayed the master's thesis.

Parts of the model are simplified as described in Chapter 5.

1.5. Target audience

This report is first and foremost targeted at the top level management at SCA Packaging with responsibility for strategic decisions regarding future product offerings and production capacity development

The simulation model is built to be flexible in order for others to be able to base future studies on similar plants on it. The language of choice throughout this project is English, making it accessible for an international crowd with interest in the results.

1.6. Outline

This chapter presents the outline of this report and gives a short description of each chapter's contents.

1.6.1. Introduction

This chapter briefly describes why we did this report, for whom we did it, what the scope was and what the goals were.

1.6.2. Methology

The methology used in this thesis and the reasons for choosing it is presented in this chapter. Alternative approaches are also presented here.

1.6.3. Theoretical frame of reference

This part of the report contains the applicable theories within the area of simulation studies.

1.6.4. Empirical studies

This part of the report presents the workflow at SCA Packaging, Järfälla. The most common working activities are also put into their context.

1.6.5. The simulation model

A presentation of the simulation model is given and abstractions are motivated. The main parts of the simulation model are described on a general level to make the model understandable to the reader.

1.6.6. Scenarios and customer data

This chapter contains information about the customers and their order patterns, making up the basis for scenario development.

1.6.7. Validation and simulation results

The simulation model validation is briefly explained and the simulation results are presented.

1.7. Glossary

Some common abbreviations and definitions used in this thesis are described in Table 1 below.

Table 1. Definitions used in this thesis with a short description

Definition	Description
AGV	Short for Automated Guided Vehicle
AutoMod	The simulation software used in this model.
Buffer levels	Sometimes used a definition of inventory levels.
Customer specification	A specification of all production details for a product. May have many jobs.
Internal setup	Setup time / machine preparations for a job requiring machine halt.
Job	Here defined as a production order
KIWI	The production planning system developed by KIWIPLAN NZ Ltd
MySQL	An open source SQL database.
Order	Here defined as a customer order.
PHP	Is a recursive acronym for PHP: Hypertext Preprocessor. Scripting language used mainly in the field of web development.
Run	Short for simulation model run
Run speed	Here defined as sheets/per second. Used for machines.
SQL	Short for Structured Query Language

1.8. Presentation of SCA Packaging[3]

1.8.1. SCA group

SCA Packaging Worldwide is a subsidiary company of the SCA Group. The SCA Group was founded in 1929 as a merger between several Swedish forestry companies.

SCA is a global consumer goods and paper company that develops, produces and markets personal care products, tissue, packaging solutions, publication papers and solid-wood products. SCA's annual sales of 2005 amounted to 96385 million SEK.

SCA is organized in four business areas:

- Personal care
- Tissue
- Packaging
- Forest products

The business area of Packaging represents 33% of the annual sales.

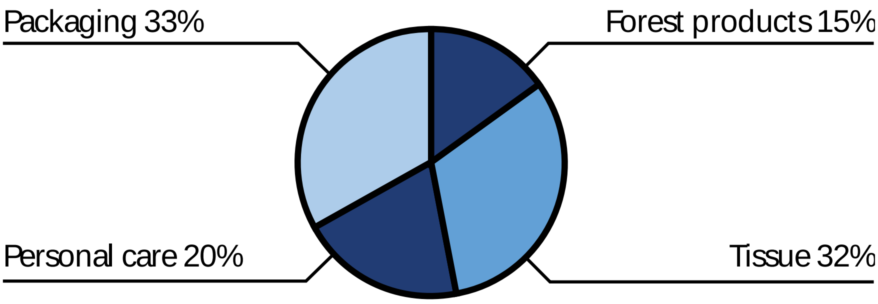

Figure 1. Share of the different areas of business for SCA Group

1.8.2. SCA Packaging

SCA Packaging is Europe's leading producer of customer-specific packaging solutions at some 260 locations in 25 countries. SCA Packaging has a market share of 14% and produce 5,1 billion square meters of corrugated cardboard each year.[4]

1.8.3. SCA Packaging Sweden

Every year SCA Packaging Sweden's corrugated cardboard-divisions altogether produce about 200 million square metres of corrugated cardboard and convert it to customer specific packages and display solutions with optional print.[5]

Products and services

The product portfolio covers not only conventional transport packaging but to an increasing extent also consumer and display packaging, customized protective packaging, packaging with advanced printing, service, heavy duty and industrial packaging.[6]

SCA Packaging Sweden is divided into four business areas, each one specializing in the production of a certain range of products: Wellförpackningar, Förpackningsservice, Cellplast/fiberpack and Display.

Wellförpackningar (corrugated cardboard packages)

Figure 2. An example of a product within Wellförpackningar

Wellförpackningar does high volume production of customized packages from corrugated cardboard. An example of such a product is found in Figure 2.

Förpackningsservice (packaging service)

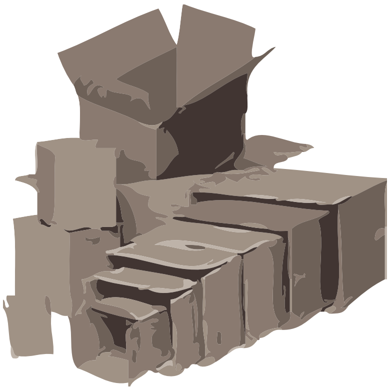

Figure 3. Illustrative picture of standard boxes from the Förpackningsservice business area

Förpackningsservice handles regional sales of standard boxes, see Figure 3 for examples. Some small series customization jobs are also done at the Förpackningsservice regional units.

Cellplast/fiberpack (cellular plastic/fiber packages)

Cellplast/fiberpack produces shock absorbing structures to be placed inside the primary package. These structures are typically made of molded cellular plastic or molded paper fiber. The main function is to prevent the package from collapsing when stacked and to protect and position the goods inside the package.

Display

Figure 4. Some examples of display solution made by the Display division

Within this business area customized display solutions are designed and produced. Display packaging similar to them in Figure 4 is designed to display and promote the products to consumers at the retailers. Furthermore, they should hold the primary packages during transport and handling.

1.8.4. SCA Packaging Sweden – the Järfälla plant

The plant is located in Järfälla outside Stockholm, Sweden. The four business areas are not represented on all plants. At the Järfälla plant the divisions Wellförpackningar and Förpackningsservice are represented.

2. Methodology

When conducting scientific research the choice of research methodology is important to render credible results. In this chapter we will introduce the reader to some common types of research methodology and also describe the method of our choice.

2.1. Scientific approaches

There are several more or less accepted scientific approaches to be found. Arbnor and Bjerke define three different approaches to research; the analytical approach, the systems approach, and the actor approach.[7]

2.1.1. The analytical approach

The analytical approach implies that the whole equals the sum of its parts, meaning that you can describe the whole if you can describe its parts. This assumption means that all problems may be broken down into smaller parts and solved individually, thus solving the original problem. Synergy effects and sub optimization are not possible to take into account with this approach. It is also important to understand that results coming from analytical research may never be influenced by the person conducting the research.[8]

2.1.2. The systems approach

The systems approach implies that the whole differs from the sum of its parts, assuming that you cannot fully describe the whole even though you can describe its parts. This assumption implies that all problems have to be analysed not only by investigating the parts making up the system but also by investigating the relations between the parts. The surrounding environment also has to be taken into account in order to be able to analyse and describe the problem in a good way. This type of approach generates results which are more specific for the current situation than results coming from research made with an analytical approach.[9]

2.1.3. The actors approach

The actors approach is even further away from the analytical approach, stating that the whole is best understood by understanding the social reality surrounding the parts. It is important to understand that results coming from research based on the actors approach is influenced by the researcher and his/hers perception of the studied system.[10]

2.1.4. The scientific approach used in this master's thesis

The system was broken down into smaller parts but these are however unusable on their own. The interaction of, and relations between the different parts causes the system to be highly complex. The method of breaking down the system into smaller parts represents an analytical approach. Since the parts can't be analyzed on their own they have to be considered in the context of a systems approach which is the main approach used in this thesis.

2.2. Research methods

Several research methods are available. The researcher should be aware of their individual strengths and weaknesses in order to know which one to choose.

2.2.1. Inductive and deductive methods

The two main approaches to building a theoretical foundation for the research are the inductive and the deductive approaches.

The principle of the inductive approach is to first collect data and then form theory and make conclusions based on this data. It is very important that the data is gathered in an un-biased way. One major weakness with this method is that it is almost impossible to get data that is totally un-biased. Another weakness is that the theoretical knowledge only includes what comes from the empirical study.

The deductive approach bases the theoretical foundation for the research on previously established theories. Once the theoretical foundation is established, it is tested through empirical studies and then analysed. The theoretical foundation will never be complete and each study will either weaken or strengthen previous theory. The main drawback of this approach is that theory that hasn't been developed earlier will be missed out and the researcher's hypothesis might become too vague.[11]

2.2.2. Qualitative and quantitative methods

There are two main methods to collect data, the qualitative and the quantitative methods.

When using quantitative methods data is collected and quantified in numbers. It is of major importance to gather the data in a structured and well planned way. If this is done, the results of the study can often be generalized and used for other, related, studies. A drawback of the quantitative method is that new information found during data collection is hard to fit into the already planned data gathering structure.[12]

When using qualitative methods focus lies on creating a holistic understanding of the studied system. Qualitative methods are often used when it is impossible to use quantitative methods. The most common way to gather qualitative data is through personal interviews. The major drawback is that the results of a study based on qualitative data are difficult to apply on other studies.[13]

2.2.3. Primary and secondary information

Primary information is information that is collected primarily for use in a specific study. Secondary information is information that was intended for use in one study but was later used for another study too. When using secondary information one has to be very observant on the quality and reliability of the information.[14]

2.2.4. The research method used in this master's thesis

Since we didn't have access to any previous simulation studies related to the same problem formulation we had to leave the deductive method behind and go for the inductive approach. By using the inductive approach to build a frame of reference for the simulation we reduced the risk of relying to biased information.

Qualitative methods were used to get the full picture and understand the internal processes and external environment of SCA Packaging, Järfälla. Quantitative methods were used to gather historical production data from the KIWI-database[15] for use in the development of the simulation model. Apart from relying to secondary sources of information like the KIWI-database, we have used primary sources of information such as our own video recordings from the plant and interviews with people from all levels at SCA Packaging.

2.3. Data collection

The methods of data collection depend on quantitative and qualitative targets and are also depending on the time frame and availability of information.

2.3.1. Interviews

Interviews are often used to collect data and information from people. The answers take into account the peoples' views, knowledge and opinions making the interviews applicable to most situations and most problems. Four common interview techniques are: personal interviews, telephone interviews, mail questionnaires and group questionnaires.[16]

Personal interviews make it possible to interpret body language and intonations. Telephone interviews make it possible to get quick answers using less time and resources. Questionnaires make it possible to gather large amounts of information in a very time efficient way.[17]

An interview can be more or less structured. It can be very well structured with given answer alternatives, or it can be completely open giving the respondent full freedom to discuss and answer like it was an everyday conversation. Structured interviews are best suited for quantitative analysis whilst free interviews are better suited for qualitative analysis.[18]

2.3.2. Literature studies

Literature is a great source of secondary information. Using secondary information involves the risk of relying on information that is not fully objective. Objectivity is hard to verify but one should be aware of the issue when searching for relevant information in literature.[14]

2.3.3. Validity and reliability

A high level of validity means that the research method measures what it is intended to measure and that nothing irrelevant affects the result. Validity is often about ensuring that the researcher has clearly defined what is to be measured and that the connection between theory and empirics is evident.[19]

A high level of reliability means that the measuring method is reliable and would provide the same result time after time. Reliability is often secured through repeated measurements. This can be difficult to accomplish when people are the source of measurement since they can learn and be influenced between the measurements.[20]

High validity requires high reliability but having a highly reliable measurement method doesn't ensure high validity.[21]

2.3.4. Data collection in this master's thesis

Data collection was initially done through interviews to get a throughout understanding of how the plant works, what products are produced, how they are made, who the customers are and how goods flows through the plant. Apart from audio recordings and notes from interviews we caught a lot of information on photo and video thus enabling us to review the different production processes and the information that is displayed to the factory workers on pallets labels and on computer terminals in detail at any given time during the rest of our work.

In order to get a better understanding of how simulation studies should be planned and carried out, we studied the AutoMod documentation and previous master's theses with simulation studies. We also studied various ISO standards regarding unit load carriers and naming conventions in order to interpret KIWI-data while defining the model logic.

Besides having relied on interviews and video recordings to determine the production flow, we relied a lot on historical production data. The use of historical data is a reliable method to determine the exact physical flow for each and every production order that has been produced during the last two years. Historical data also makes it possible to extract downtimes, working hours, customer specific data (stacking pattern, stacking height, whether to wrap the pallets in plastic etc.) etc. and makes it possible to calculate lead times.

We got the historical data from Sogeti AB which is the consulting firm in charge of the KIWI system at SCA Packaging. Sogeti sent us a CD with a 125 MB raw data file with all available production data from the last five hundred days. The database came in the form of an SQL database, thus we had to set up a MySQL server to look at the data and produce reports from it. By studying the numerous tables in the database we slowly managed to understand the naming conventions and the meaning of the data in each table and column.

After a while we had enough knowledge of the database to be able to answer some of our questions by looking at the data through complex SQL-queries. When additional logic was needed to answer our questions we used PHP-scripts to structure the SQL-queries. To be able to run PHP scripts we had to install a web server. We chose to use the open-source ‘Apache’ web server.

It is obvious that the designer of the database intended it to be able to store all kinds of data from all steps in the production but that the ones implementing the system at the plant did not make full use of the system. A lot of columns are empty of data and other columns simply miss data once in a while due to miss-use of the reporting routines at some of the terminals in the plant. Sometimes people have entered a digit to much or hit the wrong button when reporting production quantities etc. This makes it difficult to process the data and a lot of manual SQL work has to be done. Often it is possible to understand what the erroneous data should be replaced with by looking at historical data of similar orders but when the data related to an order was too bad we had to remove that order from the statistics.

More information on how to use MySQL, PHP and Apache can be found in commonly available literature, in each program’s help files (MySQL and Apache) or on the following internet addresses:

- http://www.w3schools.com/ 2006-10-15
- http://httpd.apache.org/ 2006-10-15

2.4. Composed workflow

This master’s thesis is conducted in the form of a case study.

A case study is an empirical study that investigates a concurrent phenomenon in its actual context; in particular when the borderline between the phenomenon and the context isn’t obvious. The study is based on several sources of information where data collection and analysis is guided by theoretical assumptions.22

A case study is very time consuming and does not render generally applicable result but it is a very powerful method to gain better understanding in complex problems.23

During the simulation study the workflow suggested in 3.4 has been followed.

2.5. Criticisism of sources

Interviews are rarely un-biased. During the interviews situations occurred where personnel having different positions at SCA Packaging appeared to have different opinions about production details.

The KIWI database output can never be better than its input. Some logical errors have been identified during the collection process probably caused by poor system interface and/or lack of clear instructions of system use. Since numbers and data are usually typed in by hand such activities can also easily introduce errors.

By way of precautions any doubts concerning data reliability has been thoroughly examined and action has been taken. Examples of such actions are supplemental interviews and field observations to make sure errors are adjusted for or at least minimized.

3. Theoretical frame of reference

This chapter contains theory related to the simulation study. The simulation steps described here have been used throughout the master thesis.

3.1. Definition of simulation

A simulation study is an imitation of a real-world system over time. Running a simulation involves generating an artificial history of the system and observing that history to make conclusions concerning the real system being represented.

A simulation study is a powerful problem solving methodology that can be used to solve many real-world problems. Simulation is used to describe and analyze the behaviour of a system, ask questions about the real system and aid the design of real systems. You can model both existing and conceptual systems with a simulation study.[24]

3.2. Simulation methods[25]

There are four major simulation methods: the process-interaction method the event-scheduling method, the activity scanning method and the three-phase method.

In this study the process-interaction method was used since it is the one used by the AutoMod software that we were assigned to use for the simulation.

3.2.1. Process-interaction method

In this method, the computer program emulates the flow of an object through the system. The load moves as far as possible in the system until it is delayed, exits the system or enters an activity. When the load's movement is halted, the simulation clock advances to the time of the next movement of any load. This is the method that is used by the AutoMod software.

3.2.2. Event-scheduling method

In this method, the computer program advances time to the moment when something happens next and a new event starts. An event usually releases a resource and then reallocates available objects or entities by scheduling activities in which they can participate.

3.2.3. Activity scanning method

In this method, the computer program produces a simulation program composed of independent modules waiting to be executed. In the first phase, a fixed amount of time is advanced, or scanned. In phase two, the system is updated (if an event occurs). Activity scanning is similar to rule-based programming, i.e. if the specified condition is met, then a rule is executed.

3.2.4. Three-phase method

In this method, the computer program advances time until there is a state change in the system or until something happens next. The system is examined to determine all of the activity completions that occur at this time. The second phase is the release of the resources that have scheduled to end their activities at this time. The third phase is to start activities with consideration to the system's resource availability.

3.3. Advantages and disadvantages of simulation

3.3.1. Advantages

Simulation is a very powerful method for testing scenarios before and after they happen. This enables decision makers to analyse scenarios, get a good understanding of what is happening, why it happens and to answer questions like “What would happen if..”. This understanding facilitates decision making and cost savings are possible to achieve as real world experiments may be avoided. It is also possible to visualize the simulation over time, thereby making it easier to communicate the scenarios with employees and other decision makers.[26]

3.3.2. Disadvantages

Simulation studies should be used with caution since they are only approximations of the real-world system. Models created by two, equally skilled, individuals will probably be similar but they will never give exactly the same result.

The results are often difficult to analyze and should be well thought through before basing decisions on them.

No matter how skilled the person building the model is, it will require a lot of time in order to render reliable and useful results. Thus, this building phase can be a costly process. Clearly, it is important to know exactly what questions we want the model to answer and on what level of detail to build the model.[26]

3.4. The simulation workflow[27,28,29]

The steps followed in a simulation study have been suggested in several different sources of simulation literature such as for instance Law and Kelton in Simulation Modeling and Analysis (2000). However the theories and guidelines described originate from Banks, Carson, Nelson and Nicol (2000). Some concepts directly related to the AutoMod software have been gathered from Jerry Banks, Getting started with AutoMod (2004).

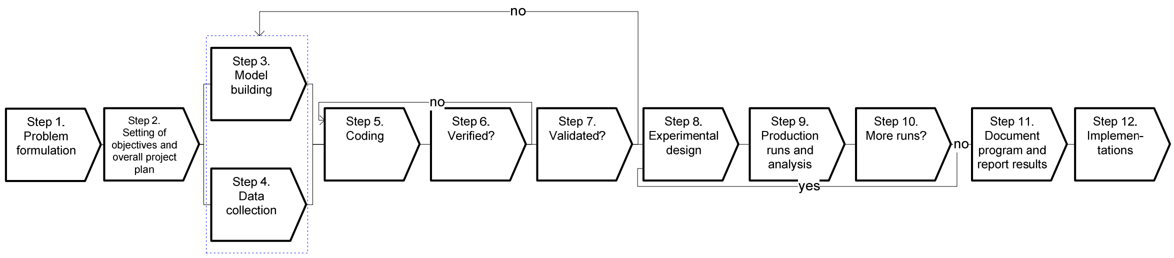

Figure 5. Schematic picture of the simulation workflow suggested by Banks, Carson, Nelson and Nicol (2000)

Figure 5 describes the recommended workflow for a simulation study. The “Verified?”, “Validated?”, and “More runs?” step may imply repeating one or many previous steps to ensure the simulation quality. A description of the steps follows.

3.4.1. Problem formulation

A simulation study always begins with a statement of the problem. The client (the one having the problem) and the simulation analyst have to make sure the problem is clearly communicated and understood by both parties. It’s recommended to let the simulation analyst set up some basic assumptions to be agreed on by the client.

Despite all precautions the defined problem formulation may have to be altered as the simulation study progresses due to unforeseen factors.

3.4.2. Setting of objectives and overall project plan

This step is to clarify which questions are to be answered through the simulation study. The questions are formulated as objectives and measures of performance are decided upon.

Given the simulation objectives and the timeframe an overall project plan is set.

3.4.3. Model building

The real world is in itself usually too complex to be perfectly imitated by a simulation model. A conceptual model is therefore to be developed with an appropriate level of detail. The conceptual model is essentially a series of mathematical and logical relationships binding model components together within a model structure.

A good way to go about is to begin by building a basic model and then expand it into a more and more detailed model until the desired level of detail is reached.

The following parts should be included in given order: material handling system, basic process system and resource cycles (downtimes, maintenance, shift schedules etc.). Finally special features may be added. It’s important here to keep the complexity of the model at a reasonable level. Giving too much attention to details takes a lot of extra time and may not necessarily result in better simulation results.

The client should be involved in the model building process not only to contribute with it’s expertise but also to get increased confidence in the model by taking part in discussion about assumptions and abstractions.

3.4.4. Data collection

A data requirements list should be submitted to the client. Since the requirements already have been discussed some of the necessary data should already have been gathered and prepared for the analyst

Numerical data should usually be delivered in an untreated format; i.e. derived measures such as for instance averages and sums should be avoided and instead be presented in its original, raw format.

The data collection process can progress parallel to the coding phase, which is also graphically illustrated in Figure 5.

3.4.5. Coding

The conceptual model developed in precedent steps is translated into a form understandable by the simulation environment such as for instance the AutoMod language for AutoMod.

3.4.6. Verified?

This step aims for a model that implements the conceptual model completely without technical flaws, software bugs or limitations. Verification is a continuous and iterative process which preferable takes place also when writing the code. The process is described in detail in 3.5.

3.4.7. Validated?

Validation is the determination if the simulation model for the purposes of the study can accurately substitute the real world system. A good way to perform model validation is to compare real world output with model output. This process is also performed repeatedly and is described further in 3.6.

3.4.8. Experimental design

Decisions have to be made concerning simulation runtime length, number of runs and initialization status. Such decisions are based upon experiments with the factors mentioned above.

3.4.9. Production runs and analysis

The simulation result is processed and analyzed with the measures of performance determined in step 3 in mind.

3.4.10. More runs?

When simulation results have been processed it's sometimes necessary to do some supplementary simulation runs to confirm the simulation outcome.

3.4.11. Document program and report results

If the model is supposed to be used again in the future the documentation of the model code has to be complete and easy to understand. Even if that is not the case proper documentation makes verification, validation and modification easier. A well documented project is more likely to gain higher confidence from the client.

The analysis of the results should be presented in a clear and concise report giving the client all significant factors measured, all evaluated alternatives and any potential recommendations or suggestions.

3.4.12. Implementation

A well performed simulation study following all steps rigorously may be a good basis for decisions concerning the earlier addressed problem. If that's the case the implementation is likely to be successful.

3.5. Verification[30,31]

The verification process is supposed to make sure the developed simulation model fulfils the requirements and specifications of the conceptual model. In the book Getting started with AutoMod by Brooks Automation, Inc. there are a number of guidelines to make the verification process progress as smooth as possible when developing simulation models in AutoMod. Some of them may seem like common sense but are briefly described below.

The model building should be designed top-down and with modularity in mind. It is advisable to start off with building a flow chart describing the concept model. Coding and commenting should be easy to understand without deep knowledge of the real-world or the concept model, implying that a lot of comments are added. Model logic should be reviewed by more than one person.

The units of all data should be carefully checked to avoid unintentional unit swapping such as for instance seconds appearing as hours which may cause the model to behave wrongly.

When building model components, the analyst's is advised to make sure the output seems reasonable to ensure resource handling and process functionality. Illogical actions or events may quickly be identified and corrected by carefully watching the model's animation.

3.6. Validation[31,32]

The validation process is supposed to determine how well the simulation model can substitute the real-world given the purposes of the simulation study. The methods to validate a simulation model are classified into either subjective or objective techniques.

Examples of subjective techniques are Face validation, Sensitivity analysis, Extreme-condition tests and Validation of conceptual model assumptions.

Two objective techniques are Validation input-output transformations and Validation using historical input data

3.6.1. Face validation

The conceptual model is presented to those who are knowledgeable about the real-world system. Such a confrontation can help identifying logical errors and assumptions and point out flaws in the model.

3.6.2. Sensitivity analysis

Input data is altered in such a way that a qualified prediction of the model behaviour can be made. The prediction should be in line with the simulation results.

3.6.3. Extreme condition tests

The model is run with parameters set to an extreme. The model behaviour should reflect the predicted circumstances but still behave according to predictions. The goal of this test is also to validate the model stability.

3.6.4. Validation of conceptual model assumptions

There are two conceptual model assumptions, structural assumptions and data assumptions.

Structural assumptions concern the operation of the real-world system. Since no one knows everything about every part of a system the parts of the model are validated one by one. Usually this can be done by discussions with appropriate personnel. For instance the machine operator would be of great help when validating the pallet flow in and out of a model machine process.

Data assumptions concerns simplification and assumptions about real-world data such as machine speed settings and inter-arrival times. The validation process for this type of assumptions could be made by examining the data and curve fit divergences.

3.6.5. Validation using historical input data

Historical input data is used to drive the model. The simulation outcome is thereafter compared to the real-world outcome and evaluated.

3.7. Stochastic processes

A stochastic process is a random process which evolves with time.33

Stochastic processes have been used to calculate random machine setup times and machine run speeds based on historical production data. We have considered using the following distributions and chosen the best one based on the real distributions found in historical production data.

3.7.1. Random variables[34]

A random variable is a mathematical object with two properties:

1. it has a set of possible values called range, set of states or sample space. This set can be continuous or discrete, and it can be one dimensional or multidimensional.

2. it has a probability distribution associated with this set. The probability distribution function assigns a positive, less than unity number to each element in the set of possible values.

The probability distribution function is normalized, i.e. given the set D of all possible values of random variable X' then: $\int_D P(X')dx' = 1$

3.7.2. The log-normal distribution

The log-normal distribution is the probability distribution of any random variable whose logarithm is normally distributed.[35]

A variable can be modelled as log-normal if it can be thought of as the multiplicative product of several small independent factors.[35]

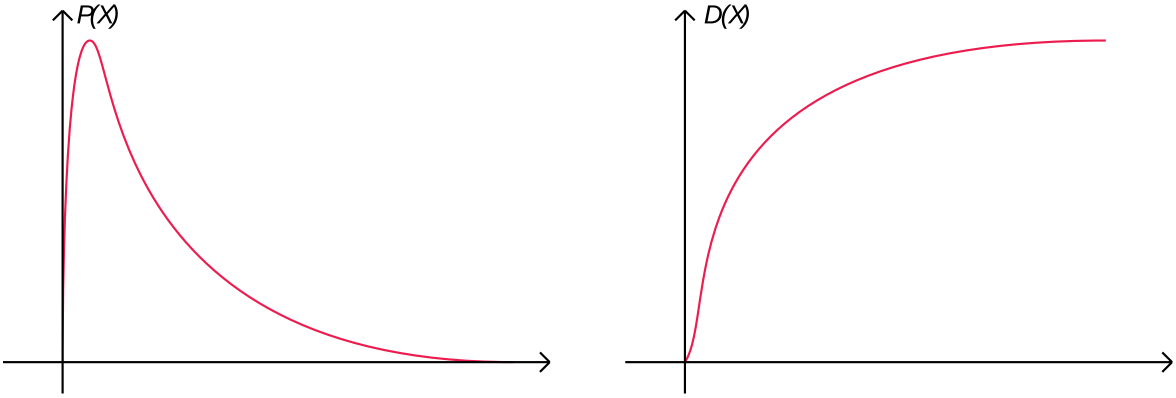

Figure 6. Typical look of the log-normal distribution

3.7.3. The normal distribution

A variable might me modelled as a normal distribution results if the variable is the sum of a large number of independent, identically-distributed variables.[35]

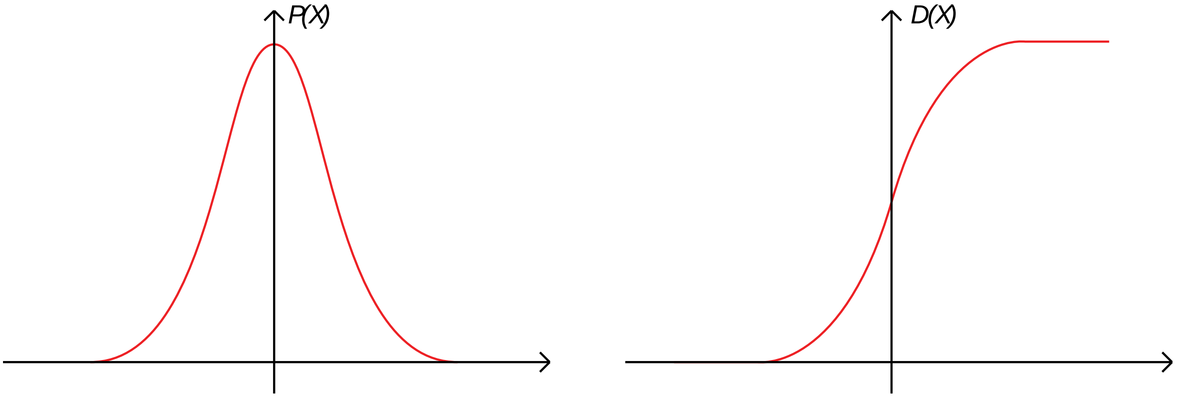

Figure 7. Typical look of the normal distribution

3.7.4. The triangular distribution

The triangular distribution is often as a description of a population for which there is only limited sample data, and especially where the relationship between variables is scarce. It is based on knowledge of the minimum- and maximum-values and a good guess of the modal value.

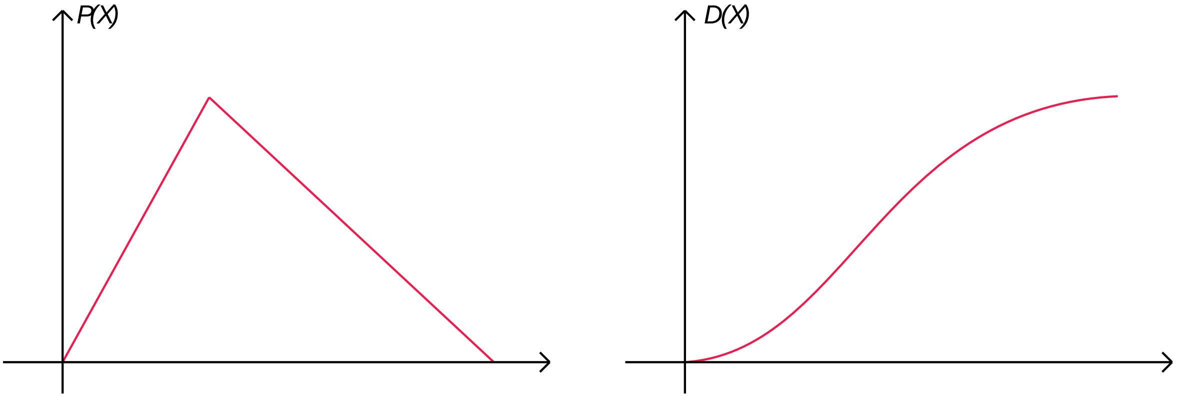

Figure 8. Typical look of the triangular distribution

4. Empirical studies

The simulation model is based on the real flow of goods and information in the plant. Theory can only give a very limited view on how the plant should work. To create a realistic model it is essential to interview people at all levels in the company and get a throughout understanding of the system. The input these people gave combined with the impressions observations of the flows in the factory is the foundation of this chapter.

4.1. Machine and process id

All machines and production processes in the plant have an identification number as explained in Table 2. How the machines are placed and the production flow is shown in Figure 20 in appendix.

Table 2. Machine and process id: s with descriptions

Machine/process id	Description
100	External material
110	Material taken from stock
120	Conditioning
610	Corrugated cardboard manufacturing machine
700	Loading unit shifting (change of pallet(s))
710	Sheet cutting machine using straight knives
724	Printing and conversion machine
725	Conversion machine
730	Printing and conversion machine
732	Conversion machine
734	Printing and conversion machine
735	Printing and conversion machine
736	4-color printing machine
780	Manual sheet processing (general)
789	Wrapping and strapping process.
790	Product storing and truck loading.

4.2. Understanding the processes at SCA Packaging, Järfälla

The production is mapped into a process chart as shown in Figure 46 found in appendix. A short description of processes and activities is given below.

4.2.1. Production of packages overview

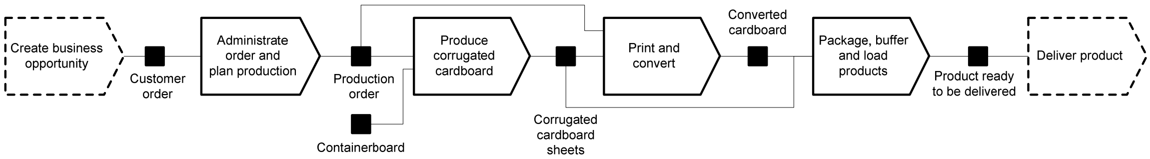

Figure 9. Basic processes overview

Figure 9 shows a simplified chart of the processes involved in producing and selling the corrugated cardboard products.

When making products out of corrugated cardboard you first of all need the raw material, the corrugated cardboard sheets. In the Järfälla plant these sheets are produced on site in machine 610. Machine 610 produces sheets of varying dimensions and flute types.

Once you have the sheets you need to consider if you want the package to have a printed surface or not. In order to print the sheet you need to process it through a machine with printing capabilities.

To shape the package you need to cut away certain parts of the cardboard sheet, this is done in a conversion machine. At SCA Packaging, Järfälla, there are two types of conversion machines, flat bed die cutters and rotary die cutters.[36]

Once the package is printed and shaped it has to be made ready for transport to the customer. The packages are transported through the plant and carried on trucks to the customers according to order specifications.[37]

The following chapters present the relevant processes one by one.

4.2.2. Administrate orders and plan production

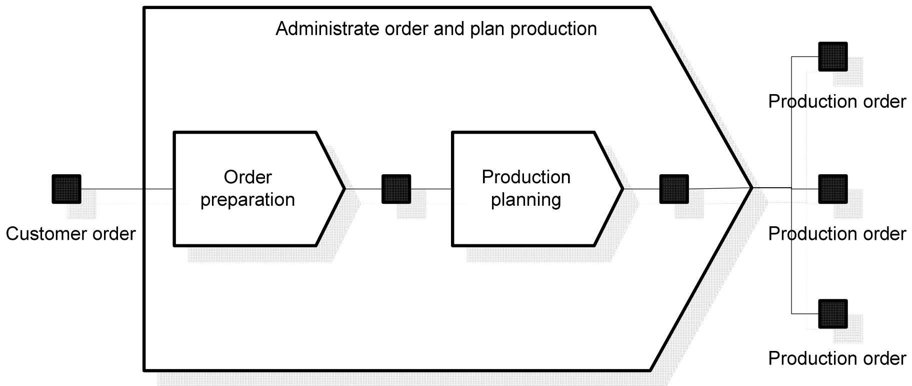

Figure 10. Picture of the administrate order and plan production process

The focus of this process is on delivering products on time and on planning the flow of goods in the plant in a way that maximizes the degree of utilization in the machines whilst minimizing costs caused by waste and machine setup.

At the Järfälla plant two persons work together in this process. They are supported by the KIWI-system and communicate mainly through KIWI. This work is done every morning and results in a list of what to produce, when to produce it and in what machine.[38]

KIWI presents a list of current customer orders and arranges them according to criteria of choice, commonly according to when KIWI suggests that the production has to start in order to have the product ready for delivery on time. This list is then manually altered in order to speed up urgent orders or to better utilize some or all of the production lines.

The production planning starts once the orders are prepared. The goal of the production planning is to schedule the daily production orders for all machines and make sure they have material on time.[39]

4.2.3. Produce corrugated cardboard

The production of corrugated cardboard (see Figure 11 below for an example) is done through a high speed process which combines several layers of paper into a material with planar outer surfaces (liners) and a wave shaped inner paper structure (flute).

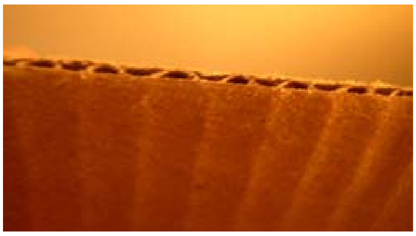

Figure 11. Corrugated cardboard

The production line is about fifty meters long, four meters high and five meters wide. In one end three large containerboard reels are loaded with the help of a customized fork lift, one reel for each layer of material.

Depending of what quality of corrugated cardboard the package requires machine 610 has to be set up differently and certain paper qualities has to be loaded. The production line has one *'wet end'* and one *'dry* end'. The containerboard is loaded into the wet end. From the rolls the machine feeds the paper into the first station that forms the inner wave shaped structure. The next station adds a thin layer of glue to the peaks and valleys of the flute and brings the liners in contact with the glue. Once this is done the corrugated cardboard is transferred through a station with moveable roller knives that cut the large produced sheet into proper widths according to production planning. The next station separates the different widths and cuts the corrugated cardboard to specified length. The second last step is to stack the corrugated cardboard sheets onto pallets for internal handling. Once the sheets are stacked on pallets the last step in the production of corrugated cardboard sheets is to let them dry for a specified amount of time. This period is called conditioning.

4.2.4. Print and convert

Once the level of moist in the sheets is correct the sheets are moved to one out of nine machines depending on printing demands and the complexity of the shape. During the preparation of the order it was decided through which machines the sheets are supposed to be processed. The truck-driver follows this on a screen and makes sure that each machine is loaded with sheets on time.

Machine 736 is dedicated solely to printing. It is an old machine and requires a lot of manual involvement.

Machine 730, 734, 735 and 724 have both printing and conversion capabilities. When machine 736 is used for printing conversion takes place in either machine 725 or the conversion part of machine 724. Also sometimes machine 725 is used instead of the conversion parts of the 734.

Material bound for transport to machine 724, 725 or 736 is handled by an automated guided vehicle (AGV). Goods handled by this AGV have to be processed by the de-palletizer opposite machine 724. Once a pallet is removed by the de-palletizer, it is transported by the truck-driver to a storage area for pallets close to machine 610.

Material bound for transport to machine 730, 734 or 735 is transported two one of two de-palletizers and the automatically transported by roller conveyor lines connected to each machine. Machine 730 has its own de-palletizer, 734 and 735 share one de-palletizer. The empty pallets are stacked by the truck-driver somewhere close to each de-palletizer. And then distributed to wherever they are needed when the truck-driver has time available.

Printing can be done with several colors or with only one color depending on choice of machine.

The printing machines use printing plates to add color to the corrugated cardboard. A printing plate is a plastic plate with a pattern of made up of peaks and valleys.

The peaks add colour to the cardboard. One printing plate is needed for every colour. The printing plates are made by Dynamic in Denmark. When an order is fully printed the plates are moved to an archive of plates and saved for future use.

4.2.5. Package, buffer and load products

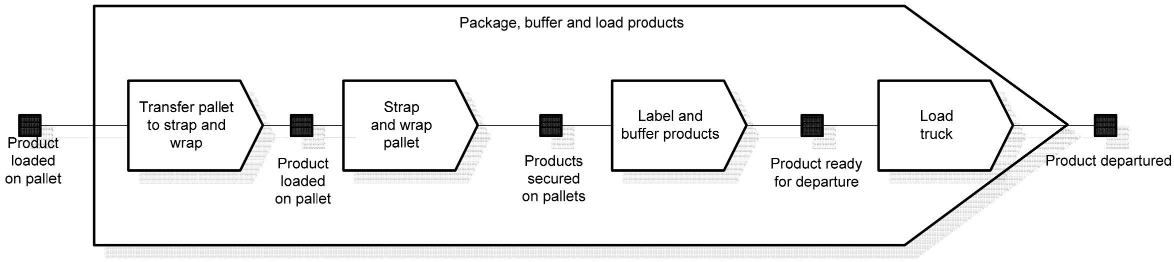

Figure 12. The package, buffer and load products process

Once the sheets are printed and converted they are ready for delivery according to customer demands. Some customers want their packages bundled in smaller units before stacking them on pallets. All orders are strapped and delivered on pallets. Some customers want extra protection for their packages and choose to have their orders wrapped in protective plastic film.

The physical flow of goods from the conversion lines to the loading bay is visualized in Figure 12. Once the packages are stacked on pallets after the conversion lines they are transported by roller conveyors to a large automatic transfer wagon. The transfer wagon transports the pallets to one of three roller conveyors based on the orientation of the pallet and what conversion machine it came from. The strapping machine only accepts pallets oriented with the short end facing forward when the pallet enters the machine, thus some pallets have to be rotated before strapping and wrapping. Pallet rotation is done automatically at one of the conveyor lines just before the strapping station.[40]

After being strapped a pallet goes though either of two wrapping machines depending on the size of the goods being wrapped.

4.3. The KIWI-database

The production control software used at SCA Packaging in Järfälla is called KIWI. Due to the complexity of the tool only information relevant for this particular report will be described here.

The system contains a database holding information regarding production and die cutters and stereos (tools). 500 days of production data history is available in the KIWI database.

KIWI uses date of delivery as planning basis and counts backwards deriving preceding operations' finishing times. When scheduling production orders the system aims to minimize setup-times and production waste. Situations can occur when the algorithms do not reach a feasible solution. The planning administrators then ease the default restrictions to reach a less optimal (but feasible) solution.

KIWI is not directly connected to the production machines; instead the machine operators act according to the order flow given by KIWI. Actual setup-time, starting time and similar events are manually reported back into the KIWI system at terminals close to each machine. Machine downtime and its causes are also manually reported into the KIWI system, thus making production problems traceable.

4.4. Working hours

Through interviews we found that the plant uses a two shift working schedule. The first shift starts at 6.00 in the morning and ends at 14.20. The second shift starts 14.20 and ends at 23.15.All shifts and breaks are reported by the workers and the data is stored in the KIWI database.

4.5. Machine setup times

Interviews with the machine operators show that the reported setup time only include internal setup activities. External setup activities are performed when the machine operators have time to spare. The operators do log those activities in any way.

When two consecutive production orders have the same tool and ink requirements, setup time is usually set to 0 for the second production order. However, since setup start and finishing time is manually entered for every order it is sometimes also logged as a minute or two depending on the operator's habits.

4.6. Job closing times

KIWI holds time data for activities related to finishing an order. That could be activities such as order administration, pallet refilling or machine area cleanup.

When a job has been setup and processed through a machine the operator can register a job closing time. Activities connected to the job closing procedure could be for instance cleaning, stereo washing and tool returns. This is different from setup time and not registered to specific jobs. For some machines job closing times isn't reported at all.

4.7. Machine processing times

Every machine and some of the production related processes have been given an identification number as listed in **Fel! Hittar inte referenskälla.**.

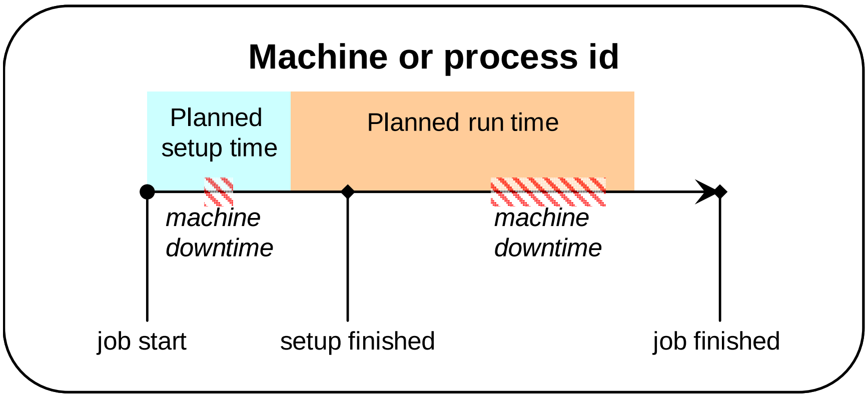

Figure 13. Machine processing time and its different time components

The job data is registered according to Figure 13. Every job has a planned setup time and a planned run speed from which the total planned job time can be derived.

Job start- and finish-times are registered with the number of sheets entering and exiting the machine/process. As the job is processed the setup time and possible downtime occurrences are registered. Downtime can occur one or many times both during the setup phase and during the run phase.

4.8. Machine downtimes

All machine downtimes are reported and stored in the KIWI database. Each downtime has a field for notes and by looking at those fields we have identified different type of downtimes, for instance: *electricity reparation, mechanical reparation, warped sheets, photographic cell adjustments and wrong linear quality*.

The causes and production impact of the downtimes mentioned above is correlated to stereos, die cutting tools, paper quality, number of processed sheets and to the order frequency.

4.9. Cleaning, “house-keeping” activities

When a working shift is finished the team sometimes performs cleaning activities. The amount of time needed for this is related to a specific machine, order types and number of orders started.

5. The simulation model

This chapter presents our approach when building the simulation model according to step three through twelve as described in Figure 5.

5.1. Initial modeling approach

The intention when building the model structure was to follow the process charts and process by process, task by task translate the real world into model logic. Every model process would then be named in accordance to the process chart. Part processes, activities and tasks would then follow the same naming pattern. Hereby the model logic would be almost self-explanatory accompanied with the process chart.

To follow these given guidelines would also make it easy to split the work into smaller manageable parts, modules, which could be developed independently. As the final step these modules would then be assembled into a full scale model describing the reality in accordance with the process charts.

5.2. Final modeling approach

The initial approach turned out not to be suitable for development with the AutoMod simulation software. Software stability limited the number of components and sub-models that could be used. Also the AutoMod software processing concept and logic writing style didn't fit well with the real world process oriented concepts.

Instead the model was built as two large blocks: one consisting of the machines and conveyor systems leading to the wrap and strap station and one consisting of forklifts and semi-finished product storage. The latter part handles goods flow control and model data input.

5.3. Target production flow

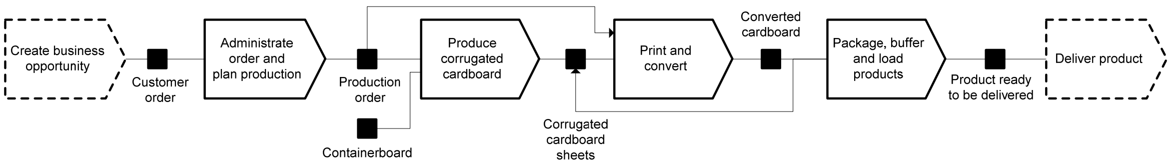

Figure 14. Basic process overview

The basic production process when making corrugated cardboard packages follows four main steps: *administrate order and plan production*, *produce corrugated cardboard*, *print and convert*, *package buffer and load products* as shown in Figure 14.

Once the basic production process was established the next step was to figure out exactly what routes through the factory different orders take and why they are scheduled that way. It turned out to be a complex task involving real time production planning with a lot of aspects to keep in mind and no strict rules to follow. Some abstractions and limitations had to be made.

5.3.1. Production processes

Administrate order and plan production process consists of many manual activities and requires interaction with the KIWI software planning routines. Sophisticated algorithms aiming for minimized level of waste in machine 610 is used. These are unfortunately within KIWI and thereby unusable for the simulation model. This, combined with a high level of dependency between the conversion machines planning process and the machine 610 (the machine producing corrugated cardboard) planning process, made the planning logic hard to fit in a simulation model developed within the frames a master thesis.

The *Produce corrugated cardboard* process was soon also realized to be of too high complexity. However, it was neither considered as a bottleneck today nor when introducing the proposed scenarios[39]. Therefore machine 610 was left out of the model. Instead material needed in the conversion processes was assumed to be made available for conversion according to historical KIWI production planning time stamps. This procedure also replaced the *Administrate order and plan production* process.

The *package, buffer and load products* process contains the wrap and strap station which is today considered as a major bottleneck due to capacity limits. The process consists of several manual activities and the production flow halts frequently due to problems with conveyors and wrapping stations.[40] Time measurements for the different activities performed within this process were used in the simulation model. The *package, buffer and load products* process and its simulation model implementation is discussed further in 7.1.

The activities following the wrap and strap stations are covered by an external company and wasn’t included in the model.

5.3.2. Planning

The conversion planning is based on status of running orders, available staff resources, machine operators experience, customer relationships and approximate tool changing times. The process is complex and involves real-time decisions. Since all factors with an impact on planning decisions could not be collected either through KIWI-data or interviews it was decided to make order scheduling rely on historical planning data only.

Orders with inconsistent, faulty or incongruous KIWI-data have been excluded from the model. The number of excluded ordered are less than 0,5 % of the total number of orders for year 2005.

5.3.3. Unit load carrier

As the corrugated cardboard is processed it is loaded on pallet of approximately 60 pallet constellations. An example of an odd constellation would be two EU-pallets nailed together lengthwise. Which sheets use what pallet type/combination is determined by customer specifications, sheets dimensions and the loading patterns that are established when creating the job specification. The machines may load one, two or three pallets simultaneously.

The KIWI data fields holding information about what pallets to use were not complete and the alternative, mapping customer orders and use of pallets through interviews wasn’t feasible within the timeframe of this thesis. Therefore, the pallet types were replaced by a generic pallet being able to load sheets of any size and in any patterns. The customer specifications were used to determine the quantity of sheets on each pallet. To make the machines loading behavior at least as good as in the real-world maximum simultaneous loading capacity per pallet was assumed. This has no impact on the machine performance but leads to more efficient use of the preceding conveyors.

5.4. Model structure

This chapter gives an overview of the final simulation model. First the process structure is described followed by a description of the underlying component transporting system and the data which manages the AutoMod events and processing flow

5.4.1. Process overview

The model structure and the processing flow are shown in Figure 15, a bigger version is shown in Figure 47 in Appendix. Order data is read from an imported data file. This process is represented by *Incoming jobs* in the figure. When the order has gone through the initial production step, which usually corresponds to machine 610 not included in the model, pallet objects are created through the process *P_realize*.

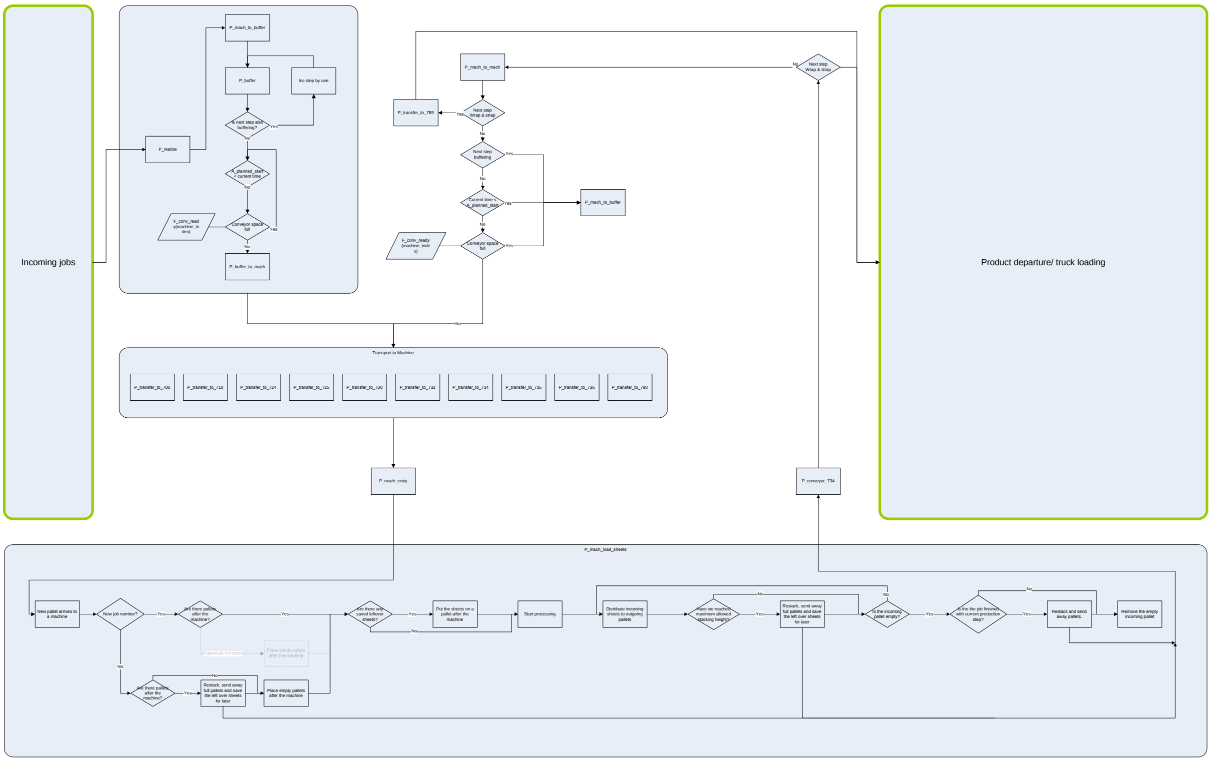

Figure 15. Simulation model overview

The process *P_mach_to_buffer* handles to transportation mechanism bringing an object from a machine to a storing location using appropriate method of transportation. The object is then sent to a process called *P_buffer* which buffers the sheets until the planned time of next machine processing step is reached. If, and only if the conveyor or machine entering buffer for the next machine has available capacity the object is sent to *P_buffer_to_mach*. Otherwise the object is put on a waiting list to be picked up whenever the machine entering buffer is ready.

The process *P_buffer_to_mach* forwards the pallet to the process in charge of arranging *Transport to Machine*. As the sheets arrive to the machines, they enter *P_mach_entry* which triggers machine setup up and other process related events. The sheets are then printed and/or cut in the machine.

When a pallet is ready to leave a machine the next processing step is determined. If next step is the wrap and strap process or the pallet is ready for delivery the pallet is sent directly to factory departing processes. Otherwise the pallet is sent back into production through *P_mach_to_mach*.

Due to machine logic when leaving machine 700, 710 and 780 another check is made to make sure the next step is not *wrap & strap* / *product ready for delivery*. If that's the case the pallet is sent to *P_transfer_to_789*.

The *P_mach_to_mach* process determines which machine is next and at what time the processing activity is scheduled. The process tries to send the pallet into the next machine processing step through *Transport to Machine* however, if necessary due to full conveyors or delayed scheduling, the pallets are sent back to *P_mach_to_buffer*.

5.4.2. Internal factory transports

There are two forklifts in the model, each of them governing the goods flow into separate sets of machines. The drivers are from now on defined as driver 1 and driver 2. Driver 1 is in charge of loading machine 730, 734 and 735 whereas driver 2 is in charge of loading 710, 724, 725, 732, 736, 780 and direct transports to the wrap and strap station.

When a pallet becomes ready for machine loading it makes itself available for pick-up on machine specific order lists. These order lists are checked by the drivers whenever a transport job has been finished. The drivers determine which pallets is the most urgent by calculating current machine conveyor waiting time. The conveyor having the least time left until empty will be filled next if possible. They also prioritize pallets that may block the space where pallets leave the machine to prevent machine stops.

Since most machines requires the pallet to be removed before processing there is one de-palletizer before machine 730, one common for machine 734 and 735 and one common for machine 724, 725 and 736. Operators of the other machines may have to remove pallets manually.

Machine 700, 724, 725, 730, 732, 734, 735, 736 and 789 has one or more entering conveyor lines making buffering possible. Pallets leaving these machines are placed on outgoing conveyors where they are buffered until a forklift or an Automated Guided Vehicle (AGV) is picking them up.

The conveyors leading out from machine 724, 725, 730, 732, 734, 735 end up by an AGV which either transports the pallets to the wrap & strap station or transport them to a conveyor where they can be picked up by driver 1.

Sheets leaving 736, heading for machine 724 and 725, may be transported directly by an AGV if a conveyor is available thus easing the working burden of driver 2.

The drivers always place a pallet as close to the preceding machine, according to order plan, as possible. In those cases when the buffer location is full the pallet is placed at the second closest buffer location. This repeats until an empty spot is found.

5.4.3. Machine setup and processing time

When modelling machine setup time and processing speed either pure historical data or some stochastic approximation can be used. There are advantages and drawbacks with either approach. However, since the real-world production is fluctuating and in some respects randomized and since run speeds and setup times introduced in the new scenarios are not likely to be deterministic from historical data, the stochastic approach was chosen.

Run speeds and setup times correlate to different production factors. Examples of such factors are corrugated cardboard quality, machine type, number of colours used, type of cutting tool and stereos. Some of these are of higher influence concerning run speed and setup time than others. The job specification includes a complete set of such factors and was therefore chosen to be the basis for all processing times. Because a job specification usually includes many machines, that also had to be considered.

Machine run speed is based on the number of entering sheets being processed per second determined for each specification and machine. Machine setup time was determined by looking at the setup time distributions for each job specification at machine level. Subsequent jobs having the same job specification usually makes the setup time none-existing. This has been considered when deriving setup and run times.

In the Appendix some of the histogram plots used to determine the stochastic distribution of machine run speed and setup time are presented. Those included are general plots covering all jobs processed through the machine. The data was then reviewed on a job specification level for all machines.

Common for all machine run speed and setup time approximations is the fact that if only one valid (i.e. neither unrealistically low nor high) value has been registered in KIWI the approximations become pure historical data lacking the ability to fluctuate. All available data has been used when deriving machine speed and setup time not only data originating from year 2005.

When examining historical data for the machines they turned out have certain common characteristics. The distributions matching a certain machine were confirmed on a more detailed level before being applied on specific job specifications. The distribution fitting process for each machine is described below.

Machine 700

In real world the machine 700 hardly requires setup time. The KIWI data for this machine was therefore rather surprising. In respect of registering machine run- and setup-time the KIWI data for this machine had some serious quality flaws. Most machine runs were registered as either setup time or run time making either the run time unrealistically high or setup time unrealistically long.

In the simulation model context all run and setup times was instead considered as run time. Planned setup was then subtracted and used as setup time. A plot of historical run speeds is presented in Figure 21. The pattern shows great similarities to a log-normal distribution and was therefore modelled as such.

Those cases where setup time and run time were correctly registered seemed to have a setup time corresponding to a log-normal distribution. The used machine setup time varies between 3 and 10 minutes depending on order specification and has their means and standard deviation based on planned setup time.

Machine 710

As with machine 700, the reported machine run and setup time lacks crucial information of how much time is used setting up the machine and how much time is actually used for machine processing.

The same approach as for machine 700 has been used to approximate run speed and setup time, i.e. reported setup time and run time are both considered to be run time whereas planned setup time is the base for approximated setup time. A log-normal approximation is determined to suit machine run speed and setup time well.

As seen in Figure 22 the range of machine run speed is unrealistically high some of the specifications. This is also the reason for the apparent wide scale used in the plot. It is also unrealistically low for some orders which is probably explained by data registering errors.

Machine 724

The quality of the KIWI data of machine 724 is significantly higher for this machine compared to the ones for machine 700 and 710. Even though minor corrections had to be made to compensate for some low quantity orders, used for demo and/or tool testing purpose only, with unrealistic production run speeds most run speeds and setup time could be used unprocessed.

For comparison, a normal distribution is included in Figure 23. As seen, a normal distribution approximation would fit the real-world very bad. In addition, there is a probability for a value less than zero to occur. Negative machine run speeds are not valid. Similar fitting tests have been performed for all machines with possible stochastic distributions.

Machine 724 is determined to be modelled with log-normal run speed and setup time almost completely based on actual reported data to be viewed in Figure 23 and Figure 24.

Machine 725

As for machine 724 the registered KIWI-data is of relatively high quality, thus simplifying the data processing and reducing time needed for data reviewing.

The log-normal distribution fits both setup times and machine run speeds well and is therefore used in the model. The log-normal curves and histogram plots for this machine is found in Figure 25 and Figure 26.

Machine 730

As seen in Figure 28 there is an extensive use of 5 minutes rounding in machine setup time. This behaviour also appears when examining the reported setup times for other machines and distorts the setup time data. The outcome from a statistical point of view is a potentially higher standard deviation unless the setup time is very concentrated which commonly isn’t the case in this simulation study.

The log-normal approximation for setup times and machine run speeds is determined using Figure 27 and Figure 28 in combination with reviews of some single job specifications.

Machine 732

The same errors found in KIWI data for machine 700 and 710 is also found for machine 732 but to a more limited extent. Some run and setup times had to be adjusted to fit into a somewhat realistic context.

The setup times seems to have higher concentration than those of the log-normal distribution as seen in Figure 30. Those tendencies are limited and should not affect the model performance since the real-world time difference is usually counted within a couple of minutes. The machine run speed data suits a log-normal distribution well as seen in Figure 29.

Machine 734

When examining the setup times of machine 734 it is apparent that as significant number of jobs were registered as taking no time at all to perform. This could naturally be caused by manual typing errors but more importantly reflects the fact that setup time may not be needed if the same cutting/printing tools are used for subsequent jobs.

As shown in Figure 32 historical machine setup time has its peaks in intervals of 5 minutes. When distributing these to the surrounding bars the data fits the log-normal distribution well. That is also the case for machine 734 run speed as shown in Figure 31.

Machine 735

Figure 33 and Figure 34 describe the histogram plot of machine 735 historical machine run speed and setup time combined with a log-normal approximation curve. A log-normal distribution is chosen to model machine 735 run speeds and setup time.

Machine 736

The machine setup time is significantly higher for machine 736 compared to most other machines. It is explained by the involvement of many none-automated production activities and time consuming cleaning of printing plates. The KIWI data fits well to a log-normal distribution and as shown in Figure 35 and Figure 36.

Machine/process 780

Machine/process 780 consists of none-automated production activities. As with machine 700 and 710 either run or setup time is commonly reported. Planned setup time is therefore used for modelling the setup time needed.

Figure 38 presents the planned setup time with a log-normal curve on top. These two clearly differs and would not accurately represent the setup time at a first look. Taking a closer look however, it becomes obvious that the time scale is rather limited. To introduce some kind of real-world like randomization the log-normal distribution was chosen.

After examining specific job specifications it was confirmed that the derived approximations were realistic. Figure 37 describes the machine 780 run speeds and a plot of the best fitting log-normal distribution.

5.4.4. Machine downtime

General downtime

The large amount of factors influencing machine downtimes makes it difficult, close to impossible, to find a realistic algorithm to estimate downtimes. We have chosen to use plain historical data to determine when machines are down and to report what kind of downtime it is.

Job closing time

Job closing time is reported as described in 4.6. This data has been reported regularly for machine 724, 725, 734 and 735 and more sporadically (or sometimes none at all) for the other machines. The data belonging to the former group is therefore used whereas other data is ignored. The data plot for machine 735 and 734 showed similarities to a log-normal distribution. The times registered in KIWI for machine 724 and 725 was rounded to 5, 10 or 15 minutes.

Since the finishing procedures are similar for all four machines they are assumed to follow the patterns of 734 and 735. Finishing procedures belonging to the other machines are assumed to be included in, or has been included in the job runtimes.

Cleaning, house-keeping activities

Cleaning and other house-keeping activities have been logged in KIWI and are used in the model “as is”.

Machine downtime

Planned maintenance has been logged in KIWI and is used in the model “as is”.

5.5. AutoMod production import data

Relevant KIWI data is collected through extensive use of SQL-queries and the results are processed in PHP to format the data into a structure easily taken care of when imported into AutoMod. A long tab-separated text file holds the job information where every row describes a production step. This means one job usually consists of two or more rows to describe the production flow. An example of a job is shown in Table 3 below. Since the table is too wide to be presented and readable in its complete form it is broken down and explained column by column.

Table 3. AutoMod production import data (in its complete form)

job_number	spec_number	job_due_finish	series_number	series_quantity	job_quantity	machine_number	qty_per_unit_mach_out	die_number	number_out	print_number	planned_start_time	internal_setup_time	std_internal_setup_time	distr_internal_setup_time	external_setup_time	std_external_setup_time	run_speed	std_run_speed	distr_run_speed	unit_covering	
_76783A	7678301	11142480	1	10412	10412	610	425	0	1	0	10533660	0	0	0	0	0	0	0	0	S	S
_76783A	7678301	11142480	1	10412	10412	736	425	0	1	T2625	11373720	2036	1291.91598549606	logn	0	0	1.188951851	0.345757828298802	logn	S	S
_76783A	7678301	11142480	1	10412	20824	725	850	S5037	2	0	11391660	550	407.921561087423	logn	0	0	1.317529166	0.286788415734153	logn	S	S
_76783A	7678301	11142480	1	10412	20824	780	850	0	1	0	12382500	1330	2324.15576070108	logn	0	0	118.6762	161.863609682161	logn	S	S
_76783A	7678301	11142480	1	10412	20824	789	850	0	1	0	12381540	0	0	0	0	0	0	0	0	S	S
_76783A	7678301	11142480	1	10412	20824	790	850	0	1	0	12381540	0	0	0	0	0	0	0	0	S	S

The first column in Table 4 holds the job number which in itself is a key to determine production timeframe, quantity, customer name and number of series. It is followed by the specification number which is linked to a certain machine flow and machine processing and setup time.

The *job_due_finish* column tells us when the order is starting to be late, i.e. when the job has to be finished. If there are many series on an order the series number is given and corresponding quantity is given. In this example the series number is 1 and the *series_quantity* equals the job quantity for the first machine. This means only one series exists for this particular job. The *series_quantity* represents the number of sheets belonging to the specified series as the order enters the production. For a certain series the *series_quantity* is therefore constant.

As the sheets are being processed in machine 725 they are split into two leading to a job quantity twice the original amount. The last column tells what machines to use and in what order they are processed.

Table 4. AutoMod production import data (part I)

job_number	spec_number	job_due_finish	series_number	series_quantity	job_quantity	machine_number
_76783A	7678301	11142480	1	10412	10412	610
_76783A	7678301	11142480	1	10412	10412	736
_76783A	7678301	11142480	1	10412	20824	725
_76783A	7678301	11142480	1	10412	20824	780
_76783A	7678301	11142480	1	10412	20824	789
_76783A	7678301	11142480	1	10412	20824	790

The quantity to be loaded on each unit load carrier, such as pallets, is described in column *qty_per_unit_mach_out* in Table 5. Die and print number respectively identifies the die cutting tool and stereo tools in current machine. When a job passes through a machine containing a die cutter or a knife the number of sheets in usually does not equal the number of sheets out. Such events can be derived through the *number_out* column which tells AutoMod how many parts the sheets are split into. The number_out column affects the job quantity as described above. Information about the scheduled starting time for a specific job in a specific machine is held in *planned_start_time*.

Table 5. AutoMod production import data (part II)

qty_per_unit_mach_out	die_number	number_out	print_number	planned_start_time
425	0	1	0	10533660
425	0	1	T2625	11373720
850	S5037	2	0	11391660
850	0	1	0	12382500
850	0	1	0	12381540
850	0	1	0	12381540

The average internal setup time, standard deviation and its stochastic distribution is shown in Table 6. A zero value indicates either no time used or time not applicable for that production step.

Table 6. AutoMod production import data (part III)

internal_setup_time	std_internal_setup_time	distr_internal_setup_time
0	0	0
2036	1291.91598549606	logn
550	407.921561087423	logn
1330	2324.15576070108	logn
0	0	0
0	0	0

The Run speed in Table 7 below is described the same way as the internal setup time. The speed is given in number of sheets processed per second.

Table 7. AutoMod production import data (part IV)

run_speed	std_run_speed	distr_run_speed
0	0	0
1.188951851	0.345757828298802	logn
1.317529166	0.286788415734153	logn
118.6762	161.863609682161	logn
0	0	0
0	0	0

The last five columns shown in Table 8 holds information about the customers name, the type of unit covering such as for instance plastic film wrapping/strapping the customer prefers and the actual process start and finishing times. The two latter are mainly included to ease the model validation process. The column *sched_id* is used for error tracking.

Table 8. AutoMod production import data (last part)

unit_covering	kiwi_actual_start	kiwi_actual_finish	customer_name	sched_id
S S	10530480	10534860	KRAFT FOOD	43452
S S	11371980	11388000	KRAFT FOOD	43453
S S	11387640	11392380	KRAFT FOOD	43457
S S	11390400	11390460	KRAFT FOOD	43461
S S	11392740	11392740	KRAFT FOOD	43464
S S	11424480	11424480	KRAFT FOOD	43467

5.6. Order data exclusions

Logical errors do exist in the KIWI data. For instance some jobs have a planned starting time that is two years back in time, some jobs have none existing series numbers, job number, specification numbers, print number or die number.

Most errors could probably have been manually resolved but would have been very time-consuming since low-level searches and alterations were needed. Such order data has therefore been excluded from the model input data even though they may have belonged to the categories of interest according to the scenarios. Those jobs having a specification number with no valid machine production data (i.e. extremely unrealistic run speeds) have also been excluded from the simulation.

The excluded jobs make up less than 1 percent of the total number of jobs performed during 2005 and represents less than 0.5% of the total ordered quantity.

5.7. Verification of the simulation model

During the simulation model development the model fundaments were verified one by one through use of fictional order and tool data. Machine scheduling was tested to make internal material transports were handled according to our specifications. Commonly used coding standards were followed to ease debugging and increase readability.

Critical code logic was extensively reviewed to minimize logical errors.

6. Scenarios and customer order data

This chapter will cover the customer order pattern of year 2005 and relate it to the evaluated scenarios.

6.1. Customer order data 2005

The total produced quantity year 2005 at SCA Packaging Järfälla was approximately 75 million packages. Figure 16 shows the quantity share for all major customers. 8 customers represent half of the yearly production. However three of those are internal SCA Group customers. The commonly used 80/20 ratio could be applied saying 80% of the totally produced quantity is ordered by only 20% of the customer base.

The four biggest customers, in this report named customer 1, 2, 3 and 4 ordered 30 million packages altogether.

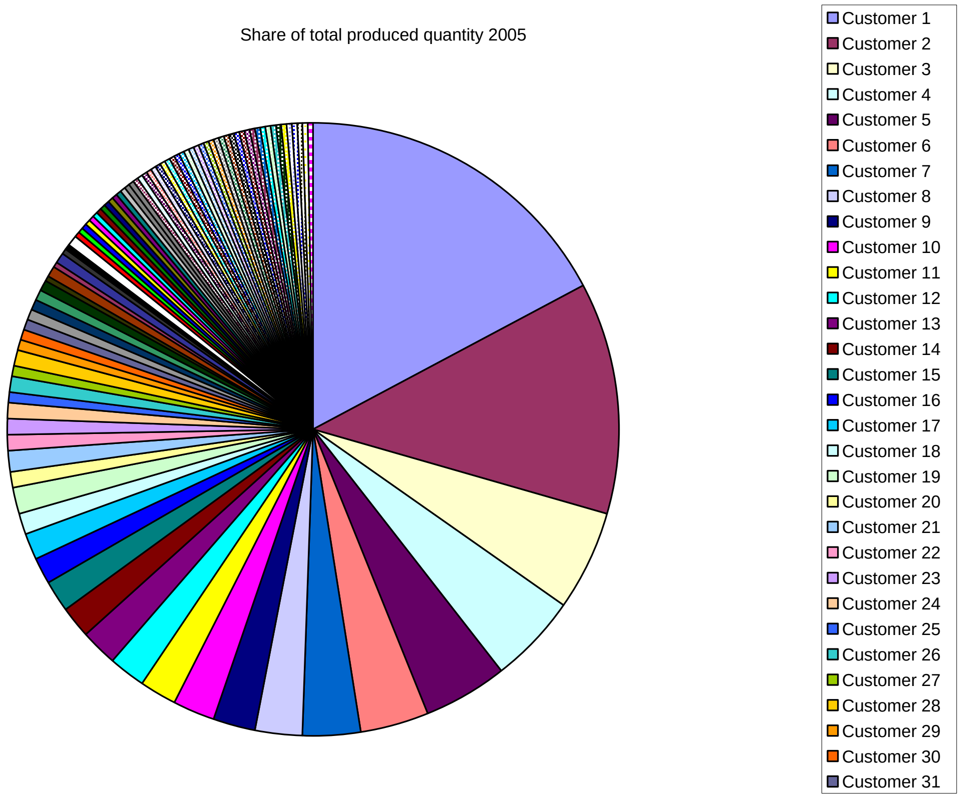

Figure 16. Each customer's share of the total produced quantity 2005

Figure 17 shows how the approximately 10 000 customer orders for 2005 were distributed over the bigger customers ordered by total number of orders placed during 2005. Like the quantity described above the top 8 customers has a share of 50%. The figure also tells us that the orders of M-real are significantly bigger than those of Spendrups who seems to order more frequently.

Interesting but well beyond the reach of this report is the fact that some of the quantity-wise smaller customers seems to have placed a large amount of orders, such as for instance the customer represented by the pink area to the left.

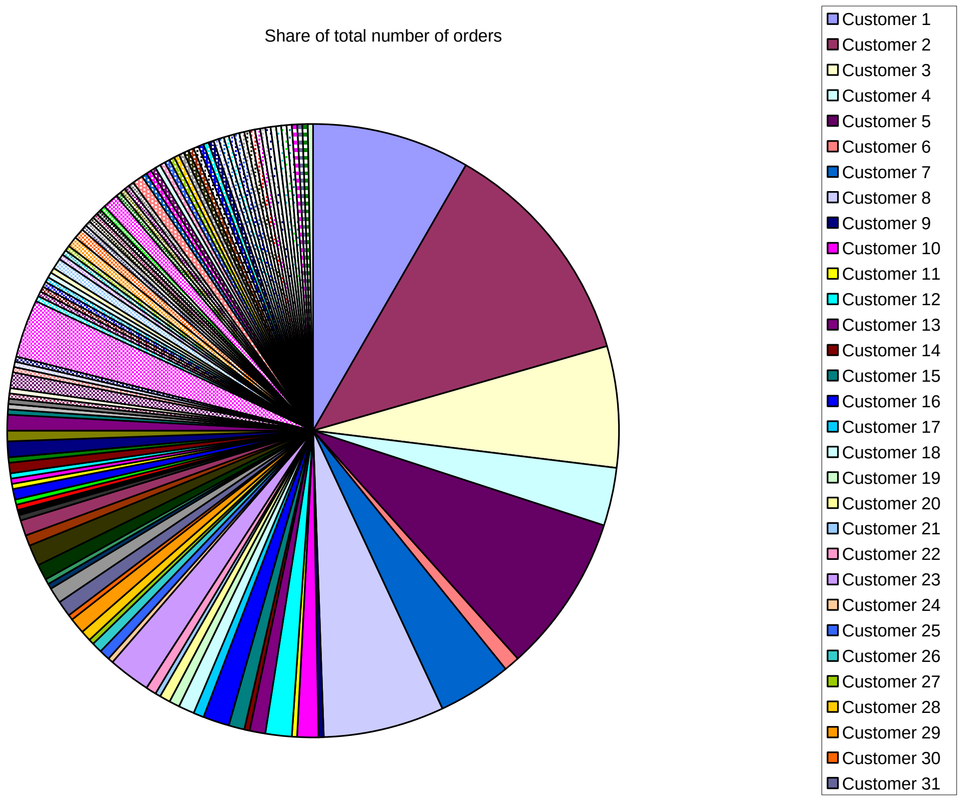

Figure 17. Each customer's share of the total number of produced orders 2005

6.1.1. Classification of customer orders

More than 2/3rds of the customer orders are repetitive and among these two categories of customer orders can be distinguished. The classification is made upon how many printing variants there exist for one particular conversion type. If there is only one printing variant for a corrugated cardboard package the order is defined as a Type I customer order. If many printing variants exists the order is classified as Type II.

The biggest customers have a great share of repetitive Type II customer orders. These customers future demand pattern is a situation where they are likely increase the number of printing variants.

Some of the bigger type I customers today do some of their printing operation when filling the packages.[41]

6.2. The Scenarios

During the meeting with Mats Neymann[42] the basis for relevant scenarios were determined with respect to order quantities, present order patterns and size of customers. The scenarios are named I, II and III and are described below. They are all based on the year 2005.

6.2.1. Scenario I

This scenario represents the historical data as is and is used as a reference for determining the impact of the changes made in scenario II and scenario III. It has also been used to validate the simulation model.

This scenario implies around 10 000 jobs being fed into the simulation model started during the simulation period.

6.2.2. Scenario II

The four customers who have ordered the largest quantity during the year are changed according to an assumed future order pattern. These customers share of total ordered quantity 2005 is described in 6.1 above.

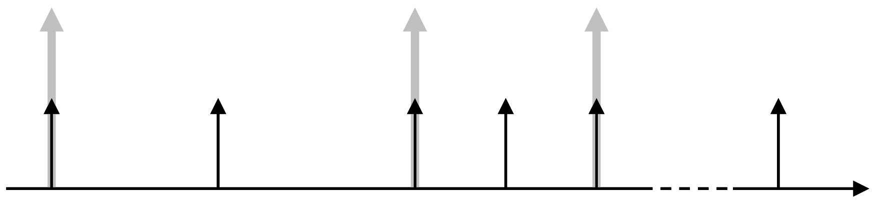

Figure 18. Job transformation for scenarios

The timeline in Figure 18 describes how jobs where transformed to represent scenario II. The arrows length measures the job quantity whereas the timeline positioning represents the job's planned starting time.

In the figure the grey arrows represent old jobs. In scenario II every job having a specific specification number is divided into two separate jobs shown as the thinner black arrows. They are given half of the original job quantity.

The time between two jobs (grey arrows) is cut in two and is used as offset for the second of the just created jobs. This leads to a situation as shown above where the black arrows represent new jobs replacing the old jobs represented by grey arrows. In those cases where a job specification number only holds one job the order data remains untouched.

Not only the job starting time is affected, all preceding production steps are planned with the same offset.

This scenario could be said to represent a situation where customers order more frequently but smaller quantities and/or a situation where Type II customer orders are changed into having more printing variants.

The scenario implies around 13 000 jobs being fed into the simulation model.

6.2.3. Scenario III

When splitting jobs according to the algorithm described in Scenario II some of the newly created jobs got quantities not being able to fill a full pallet. Splitting the customers orders further would therefore not be a realistic scenario. Instead the number of customer with changed demand pattern was increased. The 15 biggest customers were now assumed to order twice as often as before. These customers represent 2/3rds of the production year 2005.

This scenario implies around 20 000 jobs begin fed into the simulation model.

7. Validation and simulation results

Once the model was validated results could be generated through multiple simulation model runs. In this chapter the validation process and the simulations results is presented.

7.1. First simulation runs

The wrap and strap process was already known to be a bottleneck[43], which our first simulation runs confirmed. However, having this major bottleneck in the end of the production flow has impact on the other parts of the system. When the conveyor leading out from a machine gets full, due to a halt in the wrap and strap process, the machine can no longer process any sheets. A serious lock in this processing step may therefore lead to complete lock in most machines within a few hours.

Since this occurs in real world[40] this instinctively should be reflected in the simulation model. But since this problem is already known and such incidents may distort the runtime availability for the machines we decided to adjust the wrap and strap process to not cause major production locks. By removing that bottleneck flaws in previous production steps could more easily be discovered.

It was soon revealed that machine 734 was delaying the production flow significantly. The buffers to the machine 734 rose but the buffers to the other machines remained under control. This means the cause is not likely to be general seasonal changes in demand. When examining the machine data in KIWI further accumulated machine run and setup time for year 2005 turned out to be approximately 40 % higher than the available working hours. Keeping the machine 734 process on par with historical planning data based only on KIWI was therefore not possible especially since the flow of material into succeeding machines would also be affected since. The situation is likely a result of machine operators not reporting their working hours appropriately at the machine 734 or help has been received from operators working at the other machines.

The chosen solution for this dilemma would was to let machine 734 be attended by operators two shifts a day, Monday to Friday and 06.00 until 2315. A more realistic approximation of available working hours may have been developed but that would be beyond the scope of this thesis. The major consequence of this simplification is that holiday and or weekend working shifts is no longer available even if production scheduling assumes it. Some minor production delays are therefore to be expected. Naturally, the total amount of available machine time for machine 734 is overrated which also has to be considered when analyzing the results of the simulations.

7.2. Model validation

The customer demand patterns have a period of a year.[44] To include seasonal changes and their impact on production in the simulation model a full year ranging from January the 1st 2005 to December the 31st 2005 was chosen as simulation time. New order types and products are continuously introduced. Therefore machine processing data and simulation model time period cannot be separated. This in combination with the chosen simulation time length limits the validation process and may possibly make the validation results biased.

The first performed method of validation was to us feed the system from Scenario I, i.e. pure historical scheduling and order data. The number of pallets being finished was continuously measured and thereafter compared to real-world production output and evaluated. This analysis shows the total production capacity of the system and the comparison is presented in Figure 19.

The production performance of the model differs somewhat from the logged production. This can probably be explained by the newly generated processing and setup time and the simulation model lack of flexibility in the machine working hours. Decisions taken during whilst and before planned processing start concerning machine scheduling may also have contribute to the differences. Overall, the simulation model output seems to be quite close to real world output.

A sensitivity analysis was thereafter performed which is also shown in Figure 19. We chose machine run speed as a varying factor. To begin with, the machines in the simulation model were run with half of their speeds. After a few months of the simulation time the model inventory levels reached unrealistic heights causing the simulation model to exit. We consider a continued simulation under such circumstances to be irrelevant, therefore the corresponding plot ends after approximately 60 days. With the results from a worse performing simulation model in mind we continued the sensitivity analysis by increasing the original machine processing speed by two. We now should expect a model output higher than historical output, however, since machine scheduling is unaffected this now becomes the production bottleneck resulting in a production curve almost similar to the historical output.

The sensitivity test when machine run speed was divided by two may also be classified as an extreme conditions test due to the big impact of the system.

The historical output comparison and the sensitivity analysis show nothing unexpected. Some divergence is to be expected due to the introduced stochastic processes. Remaining discrepancies are explained above or by the simulation model approximations described in 7.1. However slightly biased we make the conclusion that the model is validated.

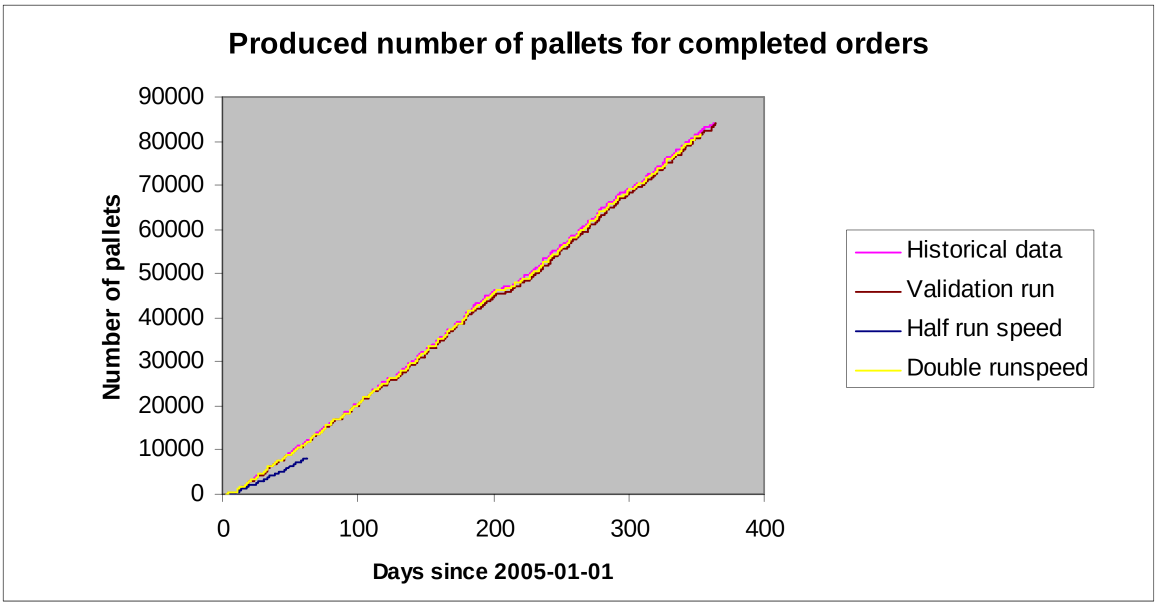

Figure 19. Model validation runs

7.3. Utilization of capacity

The utilization of capacity has been measured for each machine and scenario and the diagrams are found in appendix.

The measurements were performed using AutoStat. By running the simulation model numerous times the quality of the results can be statistically ensured. 7 simulation model runs were made for each scenario.

We assuming that the measured times is normally distributed. Then the results typically have a maximum margin of error of at most 0.3 % of the measured time using a 95 % confidence level. This is true for all machines except for machine 734 which has maximum margin of error of up to 2 % of the measured times, using the same confidence level. The machine 734 machine setup time and run time margin of error is however at 0.3 % of the measured time using a 95 % confidence level.

The machine 734 simplification described in 7.1 surely makes the machine idle time misleading. The focus when analysing the figures of this machine should be on machine run and setup time since the simplifications made do neither have any impact on time needed for setting up the machine nor running the machine.

Since machine downtime and operator working shifts are not affected in the scenarios these will only be considered once. The scenarios are discussed one by one.

7.3.1. Scenario I

As of today the machines are unattended on average 70% of the time with the exception of machine 734 which had the operator man-hours adjusted and therefore was not valid from this point of view. The total machine usage is presented in Figure 39 where 100% percent represents one year. By looking at the KIWI-data and summarizing the unattended time and the machine downtime you will realize that the machine is unable to process production orders for about 9 months a year.

The machine time with operator presence is presented in Figure 40. 100% in the figure represents the total machine operator attended time whereas the numbers on the bars corresponds to the percent of total time of the year the machine is in a particular state.

The measured states consist of *machine_running*, *machine_downtime*, *internal_setup* and *machine_idle*. The names are self-explanatory

In the ideal situation the machine would be used when operators are present and the machine would be used for machine run only i.e. processing of corrugated cardboard sheets. However, this is not commonly the case. A certain time is always needed for machine setup and machine halts do occur. This is usually considered when planning working shifts and production scheduling and this is causing the machine to be idle. What is interesting from the machine capacity utilization point of view is the proportion of the states as seen in Figure 40 and Figure 42.

Machine 724, 725 and 730 have a, in our view, more reasonable proportion of machine idle time whereas the operators working at machine 735, 736, 710, 700 and 780 has more than 15% idle time. Some or in some cases all of this superfluous idle time the workers may spend helping out at other machines.

Approximately 20% of the time with operators present is unavailable due to some kind of failure or maintenance activity.

Machine 700, 710, 780 and to some extent also 732's share of attended time needed for setup activities is low compared to the other machines. That is partly because of the nature of activities performed in the machines and partly due to flaws in the KIWI data as described in 5.4.3. These machines also have a lower relative share of machine downtime.

Machine 736 has a run/setup time ratio of 12:7 whereas machine 724 has a ratio of 18:4 which is significantly lower. These ratios commonly reflect the level of automation in the setup procedures but also point out possible areas of improvement. To use the machine as efficient as possible the aim is to lower the setup time as far as possible and maximize the time spent in the machine running state.

When summarizing the times for the bigger machines, i.e. 724, 725, 730, 732, 734, 735 and 736, the run/setup time ratio became 27:10.

7.3.2. Scenario II

Figure 41 shows the same diagram as Figure 39 but based on measurements from running scenario II. As mentioned before the share of total time in *unattended_machine* and *machine_downtime* state is exactly the same.

When comparing Figure 42 to Figure 40 they seem to be similar. The amount of time spent in machine running state is roughly the same with an exception for machine 725.

The setup times seem to be differing quite a bit for some of the machines. Machine 734 setup time has increased by 60%. Machine 724, 725, 736 got a setup time increase by 20%, 40% and 80% respectively which is a major change. The other machines' setup times didn't change significantly which is probably due to the production planning process. High volume orders are usually avoided in these machines.

Machine 725 could not handle incoming orders due to the many setups needed, thus explaining the low idle-time. The rest of the machines seem to be able to handle the raised number of setups introduced in the scenario.

The average machine run time/setup time ratio for the machines 724, 725, 730, 732, 734, 735 and 736 became 19:10

7.3.3. Scenario III

This scenario had a, machine utility-wise, not too surprising outcome. The machine state proportions are shown in Figure 43 and Figure 44.

All machines are now heavily affected due to a higher order frequency. For machine 736 and 734 the time needed for setup is now on the same level as the machine running time. Using scenario I for reference the setup times have increased with 80% and 70% respectively.

A difference to scenario II is that all machines are affected by the higher order frequency. Apart from the machines mentioned above the rest of them had a setup time increase of between 20% and 45% with machine 725 on the higher side.

The time in machine state idle time for machine 724 may be misleading since the machine actually became overloaded during the second half year.

When summarizing the setup time for machines 724, 725, 730, 732, 734, 735 and 736 and comparing it to the summarized machine running time you get a ratio of 7:4 which is far from ideal and also significantly worse than the base scenario which had a ratio of 27:10. There is a change between scenario II and III in this respect as well but not as severe.

7.4. Lead time

When we first started to look at the lead time we wanted to measure the time it takes from the moment a customer places an order until he/she receives it. However, this turned out to be impossible for us to measure since we excluded the production of corrugated cardboard and the order handling processes from the model. In our simulation runs the flow of material from machine 610 was kept very close to the historic flow, hence the dynamic of our system would never be good enough to measure the changes in lead times in a good way.

Our solution to this problem was to define another type of lead time that measures the time it takes from when a production order reaches its first machine until the whole production order is ready for delivery. By measuring the lead times, starting after the material for a production order is conditioned, we are able to measure the ‘production-lead time’ and compare with historic data.

The average weighted lead time for a job is 42 hours in Scenario I, 60 hours in Scenario II and 67 hours in Scenario III. Hence, the lead time seems to increase when changing the order frequencies according to Scenario II and III. The increase in lead time is caused by the bottlenecks that occur in some machines, by the increase in setup times and by the fact that many orders that were previously finished before the evening shift went off, in Scenario II and III is rather finished the day after, thus increasing the lead time with misleading night time.

7.5. Inventory levels

The model is made to be able to accurately measure and visualize the buffer levels in the plant.

The buffer levels in the simulation model are mainly depending on the incoming flow of material from the corrugated cardboard machine (610) and the outgoing flow of material through the printing and conversion machines.

The simulation model is driven by static parameters such as for instance working hours and machine scheduling. In real-world these are dynamic, at least to a certain degree. In case of high buffer levels in the factory some extra working shifts are likely introduced and machine scheduling is surely overseen to make sure the buffer levels are pressed down to a normal level. Such incidents cannot be handled appropriately in the simulation model which therefore limits the use of the model. The buffer levels may be viewed on a more general level with trends rather than exact momentary figures in focus and for this use it fulfils its purpose.

In the graph Figure 45 the buffer levels of the three scenarios are shown over one complete simulation period. The overall buffer level movements are almost same for all scenarios, but the amplitude seems to differ quite a bit. Also, Scenario II and III don’t recover as quickly to after production peaks as Scenario I does.

As can be seen, the buffer levels are similar the first three months, for short periods of time the buffer level of Scenario II and III is even lower than those of Scenario I. Thereafter the buffer levels slowly rises for Scenario II and III. Approximately five months into the simulation the lower graphs in Figure 45 makes a clear jump. This is mainly caused by the machine 725 not being able to handle the incoming jobs. Another month into the simulation yet another steep rise occurs for the buffer levels of Scenario II and III. The machine 725 is by this time definitely overloaded with work. Machine 724 now also has hit the roof. Whereas the relative buffer levels of Scenario II and III when compared to Scenario I don’t rise much for the last part of the simulation period they don’t get lower either. This is all due to lack of capacity in machine 724 and 725.

The impact of the last buffer level raise seems to be smaller for Scenario II than for Scenario III.

The average buffer levels for Scenario I, II and III are shown as dotted lines in the upper graph of Figure 45. But since some of the machines clearly become bottlenecks the average buffer levels are highly dependent on for how long the resource in question will remain overloaded. In real world a new working shift would probably be introduced. Similar behaviour cannot be accomplished in the simulation model meaning the exact values of the average buffer levels become more or less useless for deeper analysis. One thing can be stated though, and that is that during the time no real bottlenecks influences the system, the buffer levels don’t get dramatically affected by the different Scenarios.

The analysis clearly shows that machine 725 becomes a bottleneck when putting the system into pressure. During heavier loads 724 also constraints the simulation model throughput followed by 735 and 736. Because the working hours at machine 734 were overestimating the real world the effects of the scenario II and II hardly had any impact on those buffer level measures. But when concerning the discussions in 7.3 and examining the increased amount of time needed for setup machine 734 is also likely have big impact on buffer levels during heavy production load.

During the model development and during the simulation of the scenarios, we experienced the simulation model to be sensitive to fluctuations in machine load and changes in processing speed factors.

8. Future areas of research

As the model building progressed interesting areas of research, beyond the bounds of this thesis, were discovered. In this chapter some of these are described together with a brief overview of how to use the simulation model built in this thesis for future studies.

8.1. Research areas

Potential areas of interest related to this thesis can be classified into either statistical research or production logistical research.

8.1.1. Statistical research

The KIWI-database contains a lot of information surrounding customer order patterns, material and tools used, machine downtime and machine scheduling. Performing a deeper statistical analysis would probably raise questions about customer prioritization and pricing strategies. Deep analysis of such questions is a good way to find ways to increase the company competitiveness.

8.1.2. Production logistical research

When performing the research at the Järfälla plant we were confronted with some of the future challenges the plant was facing. These could probably be conducted within the frames of a thesis. For instance, machine downtime today exceeds one fourth of the total running time for most machined leading to an opportunity to increase the production with 25%. The reasons for the downtimes need to be clarified in order to develop possible and appropriate proactive solutions to reduce machine downtime.

If a new wrapping and strapping station were to be invested in its capacity limits and responses to a varying production load could easily be analyzed and evaluated through the use of simulation.

The issues raised in this thesis are probably of interest to other plants within the corrugated cardboard business. The model can be further generalized and applied to investigate similar concerns in the future.

8.2. How to use current model for future studies

This model was designed bearing in mind that it should be possible to use it when studying other factories in the future. The model fundaments such as machines and buffer and production flow logic are applicable wherever production information similar to KIWI data are to be found. We have made it easy to add or remove machines and storage areas in the model. When applying the code on a new factory the following things should be done:

1. Get a recent KIWI database dump.
2. Use PHP and MySQL to produce new in-data files.
3. Place the resources, queues and storage areas graphically in the model.
4. Name the resources, queues and storage areas according to naming conventions as seen in this AutoMod-model.
5. Adjust all performance parameters that are not depending on model input data(strap and wrap time, AGV speeds, truck driver speeds).

When running the model it is essential to study the flow of products in the factory and verify that the model has been correctly assembled. When something seems to go wrong in a machine the problem can most often be traced down by looking at queues, order lists, load attributes and resource statistics.

All orders that have been fully produced and made ready for transport are logged in a file named *finishedorders.txt*. By loading this file into Microsoft Excel it is possible to visualize the data and compare it with historical data and data from other runs, as seen in Figure 19. Every time a new run is initiated *finishedorders.txt* is overwritten and the old data lost, hence it is important to remember to save the file under another name after the run is complete.

9. Conclusions

The Scenario II and III implies a demand pattern change where a share of the customer orders gets smaller but more frequent whereas Scenario I is based on historical data as a reference scenario. When running Scenario II and III, the machine time spent for activities such as machine setup, job processing and maintenance changes compared to Scenario I.

Summarizing the machine running time and machine setup time for machine 724, 725, 730, 732, 734, 735 and 736 corresponded to a ratio of 27:10 for the base scenario. For Scenario III the same ratio became 7:4.

The storage levels are found to be fluctuating, but reasonable, as long as the production flow is undisturbed. The machines that become bottlenecks cause rocketing storage levels.

The lead time was measured as the time it takes from when the first pallet of unprocessed corrugated cardboard sheets of a certain job starts being processed in the first in order printing or conversion machine for that specific job, until all sheets on that job are loaded on pallets and ready for delivery.

The average weighted lead time for a job is 42 hours in Scenario I, 60 hours in Scenario II and 67 hours in Scenario III. These figures reflect the impact of the bottlenecks that occurred in the simulations.

The simulation model created in this master’s thesis provides a solid platform that is easy to modify and expand in order to study other parts of similar plants than those related to the goals of this study. By being able to simulate the plants, SCA Packaging should be able to make more rational decisions regarding resource allocation, strategic planning and investments in new machinery.

Since the same data has been used both for validating the simulation and developing process data the model may be slightly biased. Some simplifications had to be made in the simulation model due to flaws in the production database such as excluding some production orders. Much care has been taken minimize the effects of this.

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38 Ann-Sofie Wennlund, SCA Packaging, Järfälla

39 Lars Birgersson, SCA Packaging, Järfälla

40 Claes-Göran Hedman, Production worker, Strapping and wrapping station, SCA Packaging, Järfälla

41 Mats Neyman, sales manager, SCA Packaging, Järfälla

42 Meeting 2006-09-06 at SCA Packaging Järfälla. Participants: Mats Neyman, Magnus Viström and Michael Eriksson Hultberg

43 Stefan Johansson, SCA Packaging, Järfälla

44 Meeting 2006-06-13 at SCA Packaging Jäfälla. Participants: Stefan Johansson, Lars Birgersson, Magnus Viström, Peter Stern and Michael Eriksson Hultberg

Appendix A – Factory layout

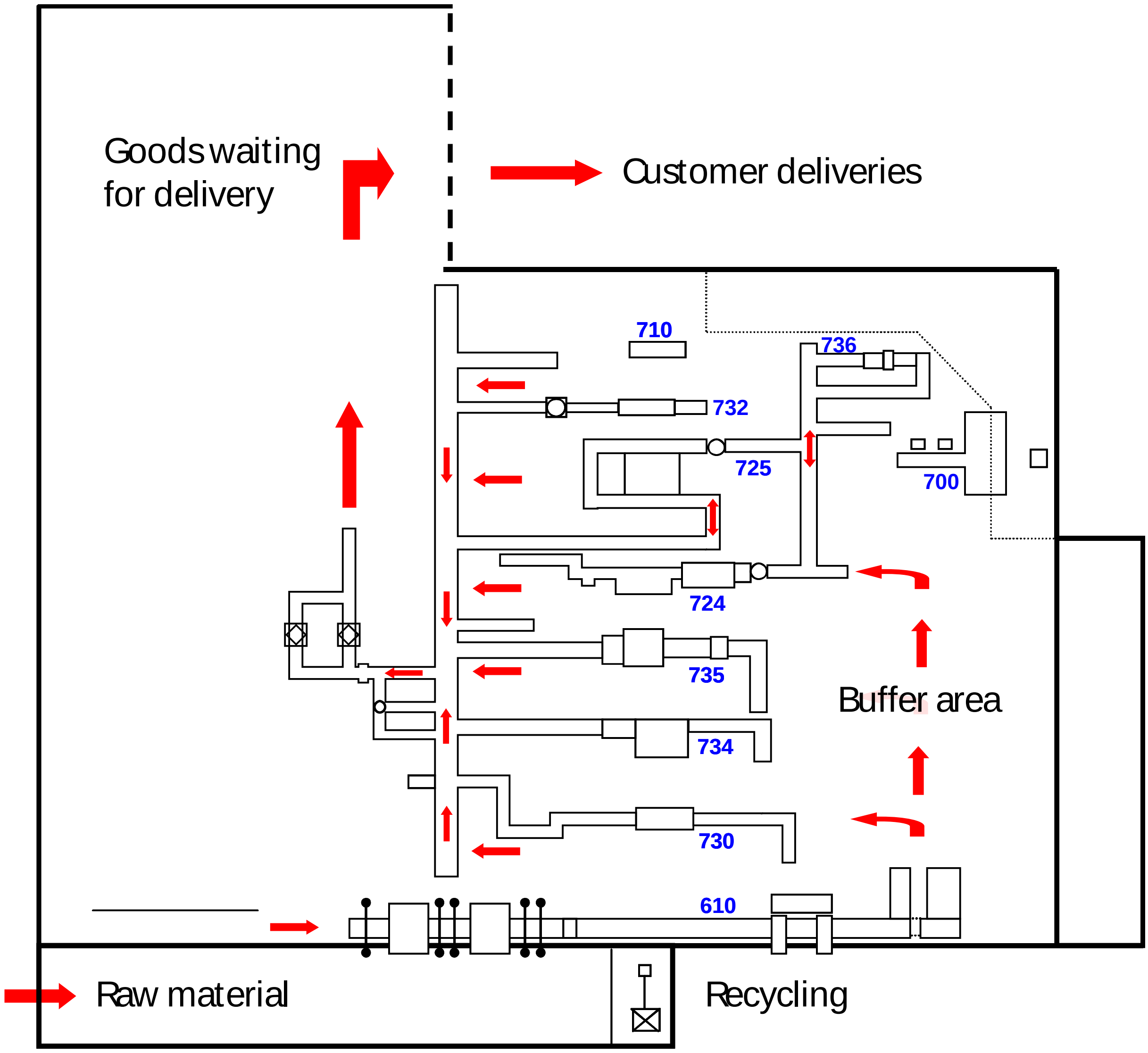

Figure 20. Factory layout of the SCA Packaging, Järfälla plant

Appendix B - Machine 700

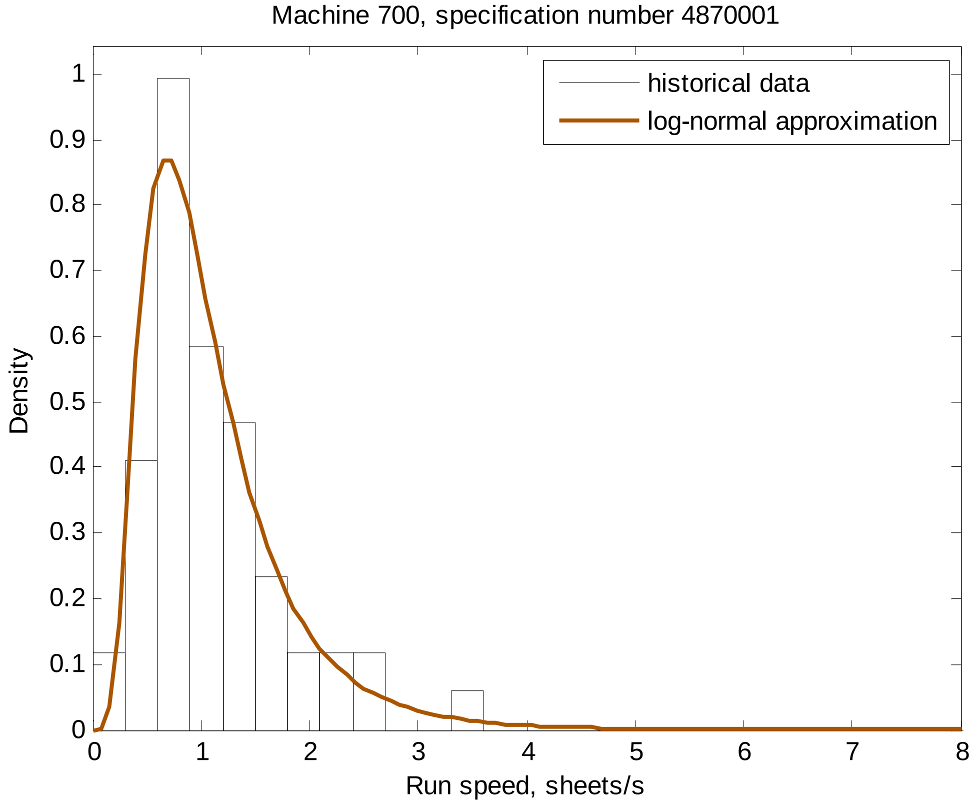

Figure 21. Run speed distribution - machine 700

Appendix C – Machine 710

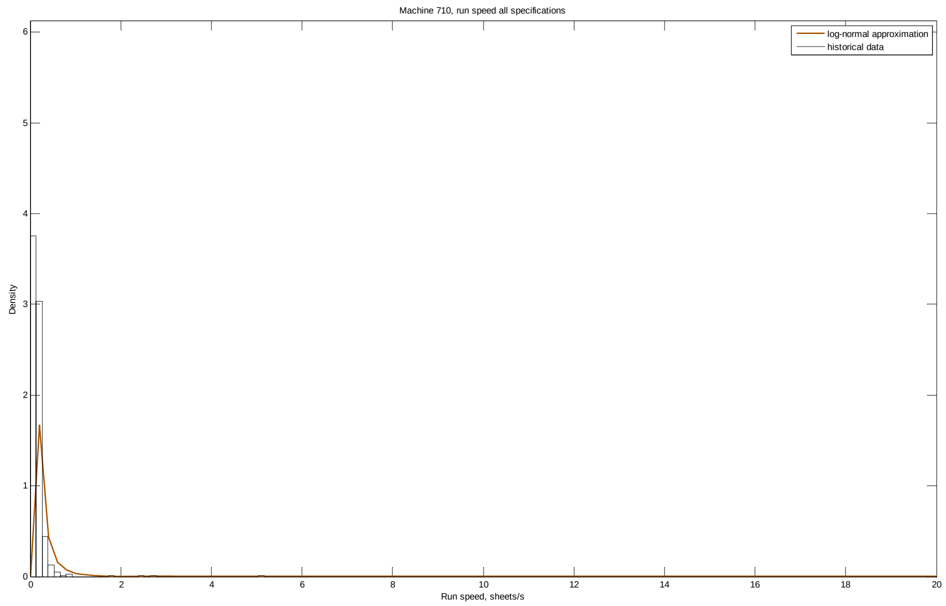

Figure 22. Run speed distribution - machine 710

Appendix D – Machine 724

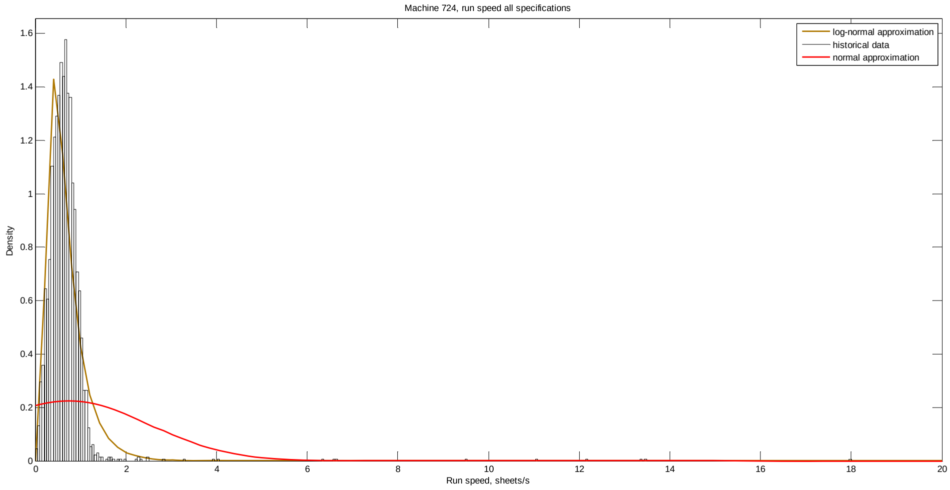

Figure 23. Run speed distribution - machine 724

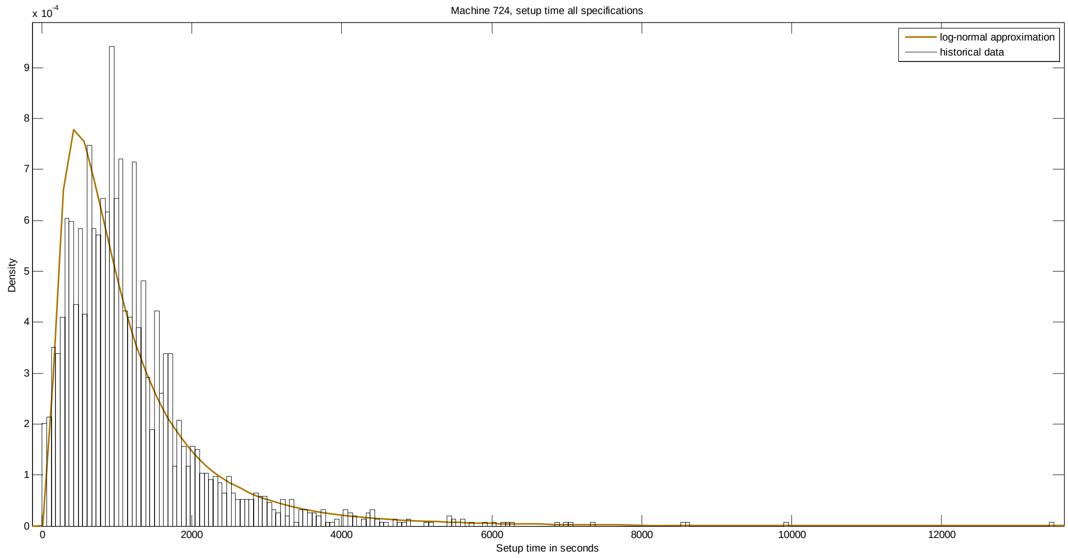

Figure 24. Setup time – machine 724

Appendix E – Machine 725

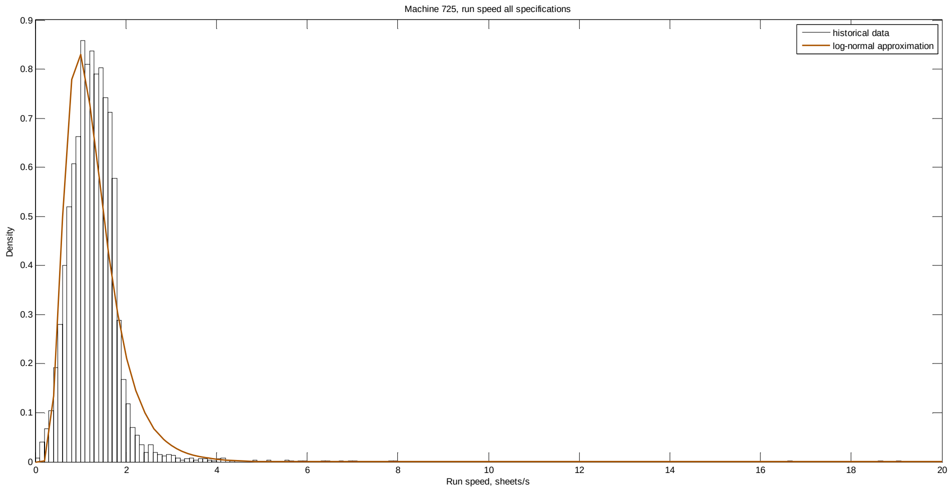

Figure 25. Run speed distribution - machine 725

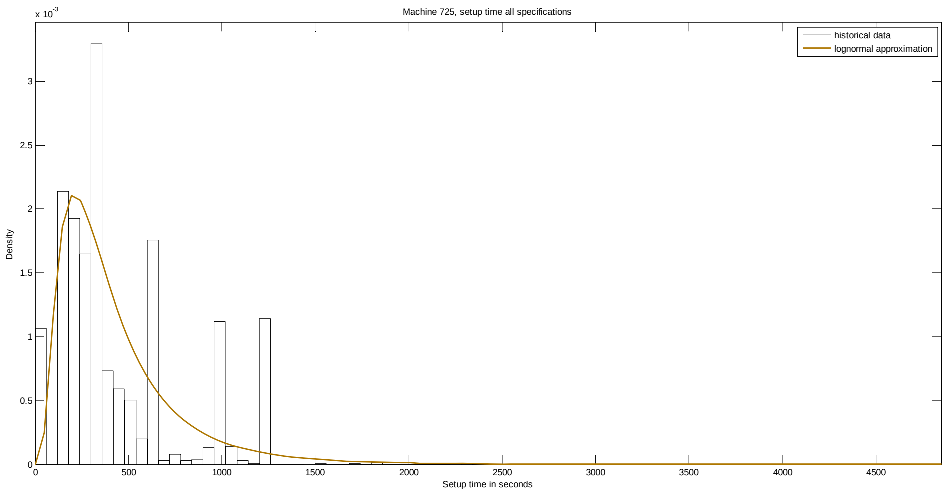

Figure 26. Setup time – machine 725

Appendix F – Machine 730

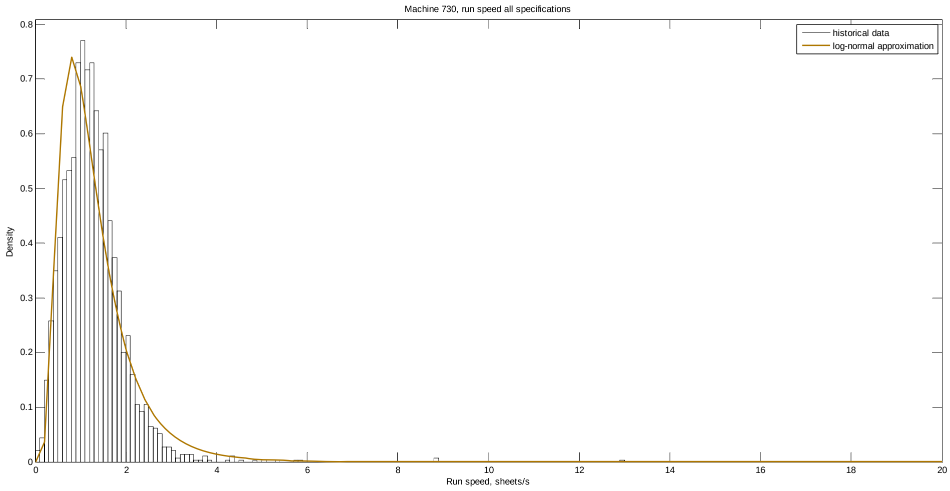

Figure 27. Run speed distribution - machine 730

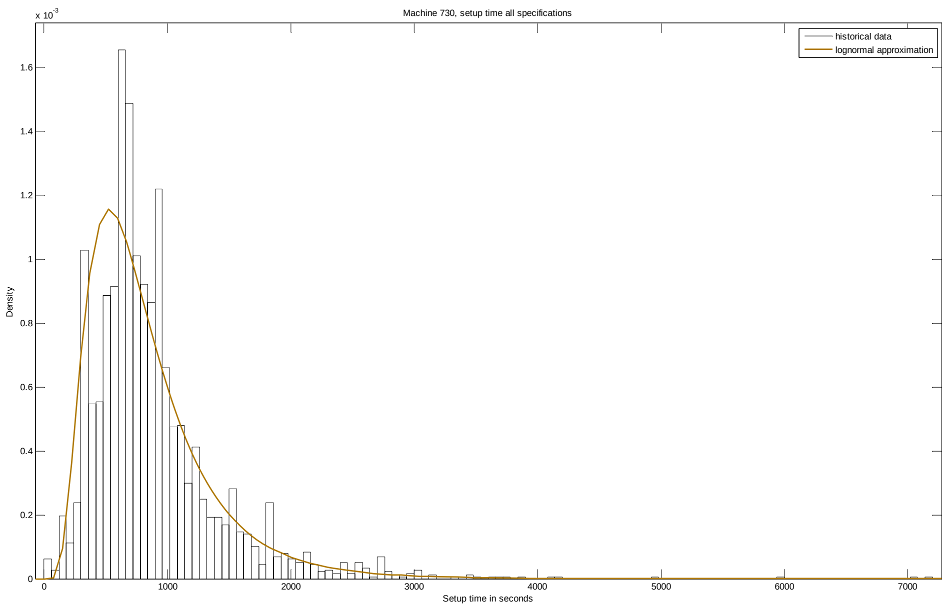

Figure 28. Setup time – machine 730

Appendix G – Machine 732

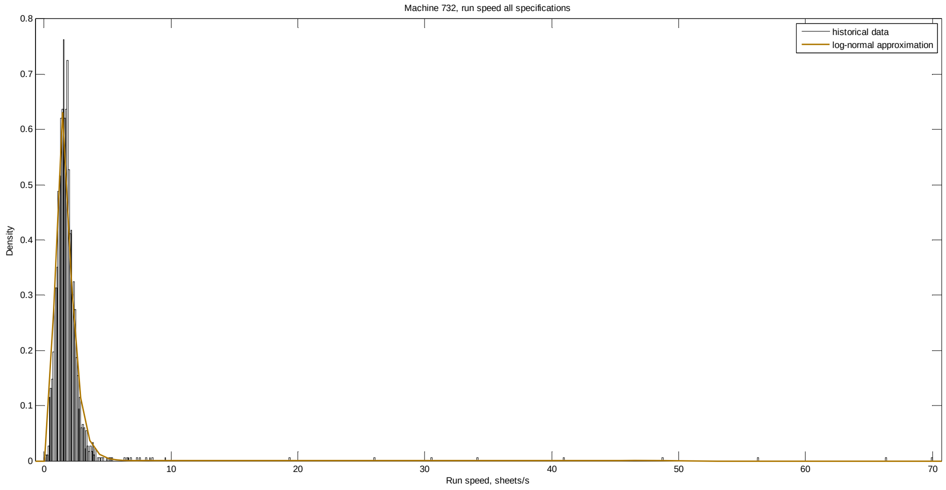

Figure 29. Run speed distribution – machine 732

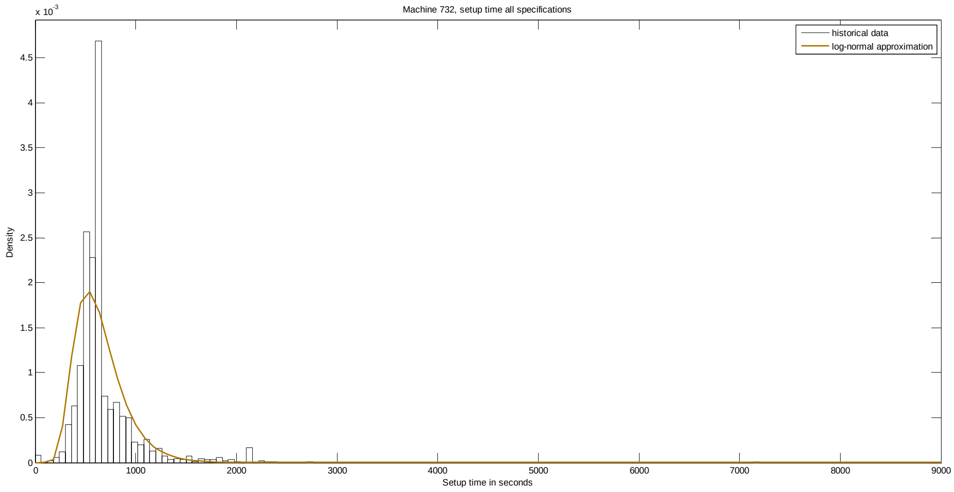

Figure 30. Setup time –machine 732

Appendix H – Machine 734

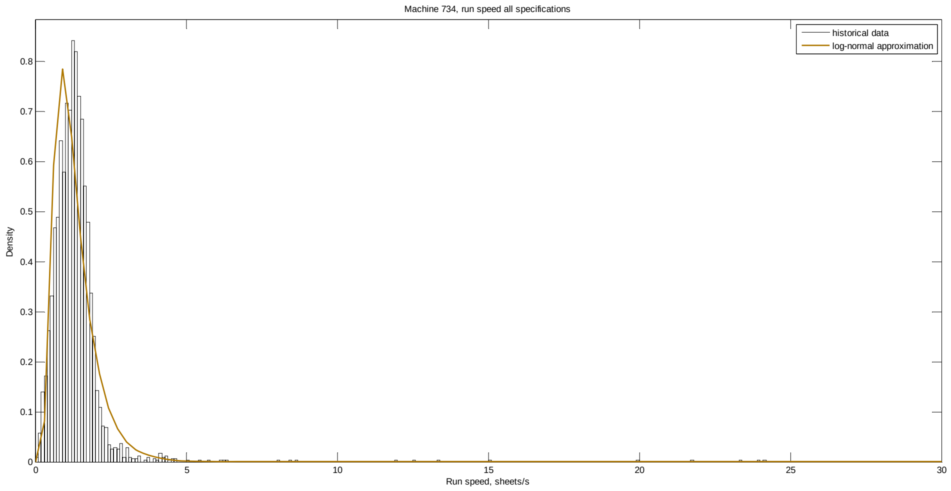

Figure 31. Run speed – machine 734

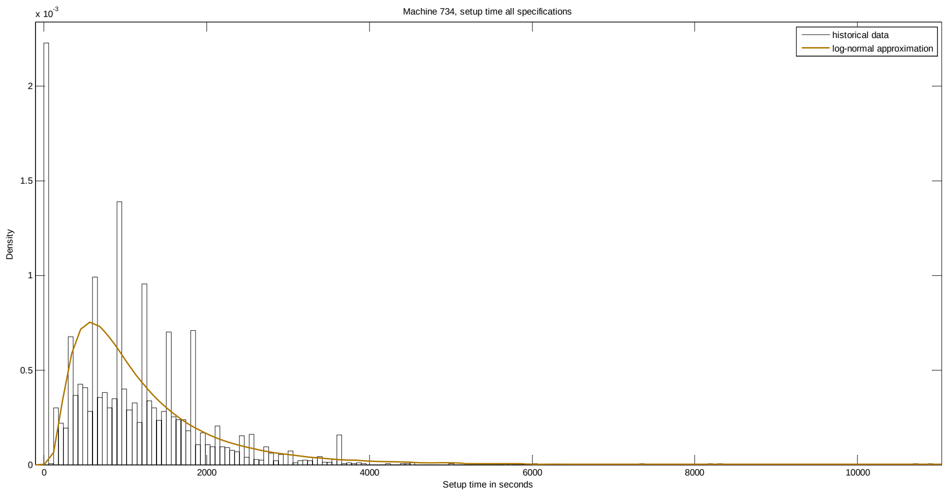

Figure 32. Setup time – machine 734

Appendix I – Machine 735

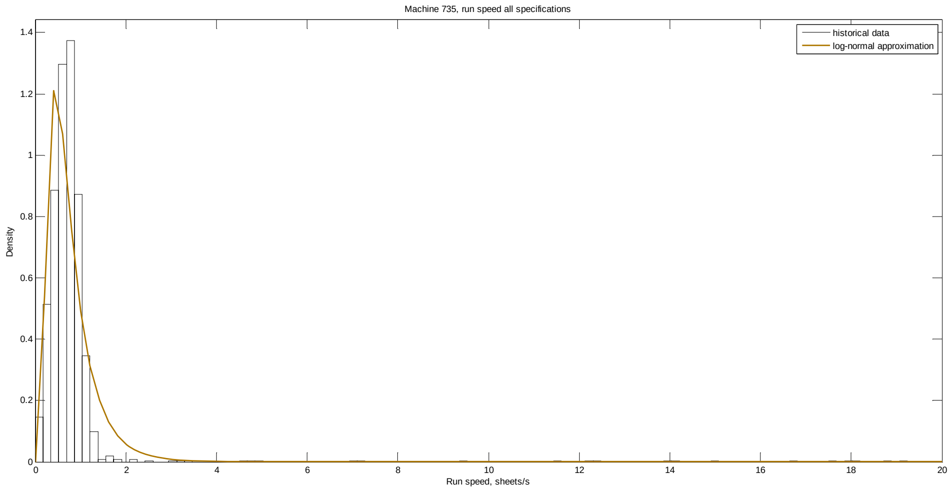

Figure 33. Run speed distribution – machine 735

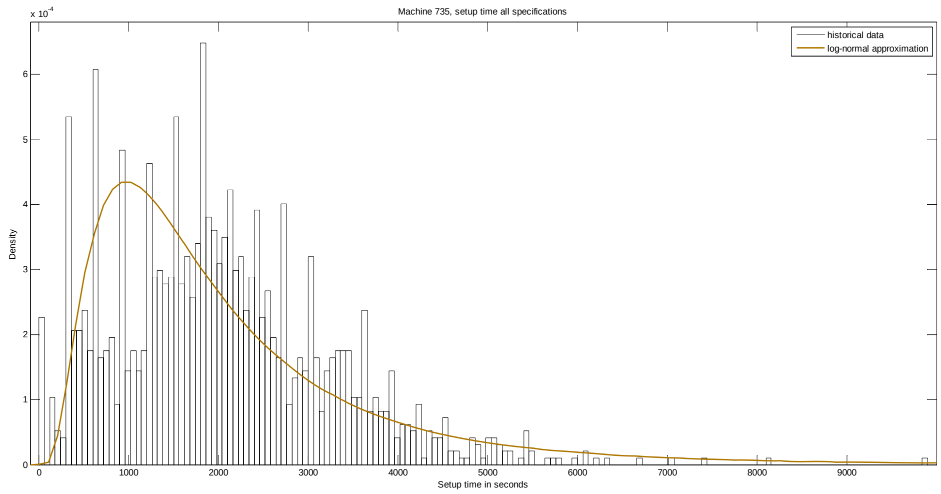

Figure 34. Setup time – machine 735

Appendix J – Machine 736

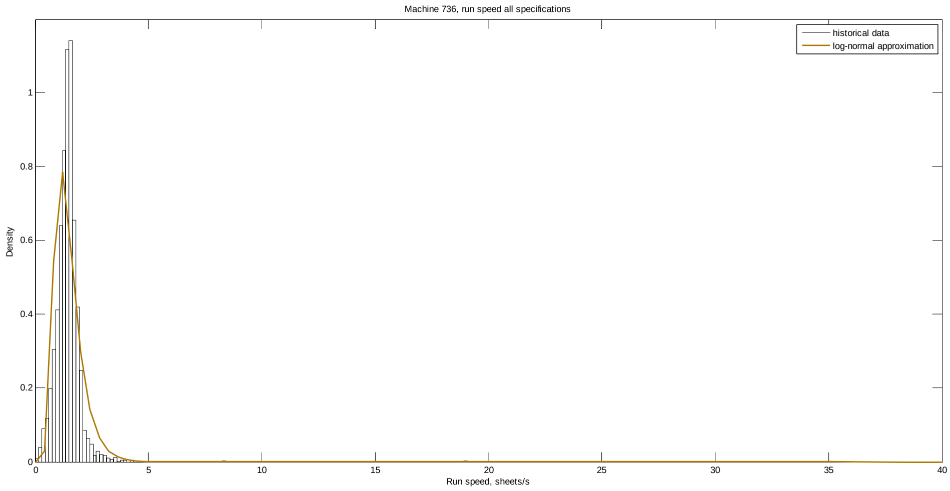

Figure 35. Run speed distribution - machine 736

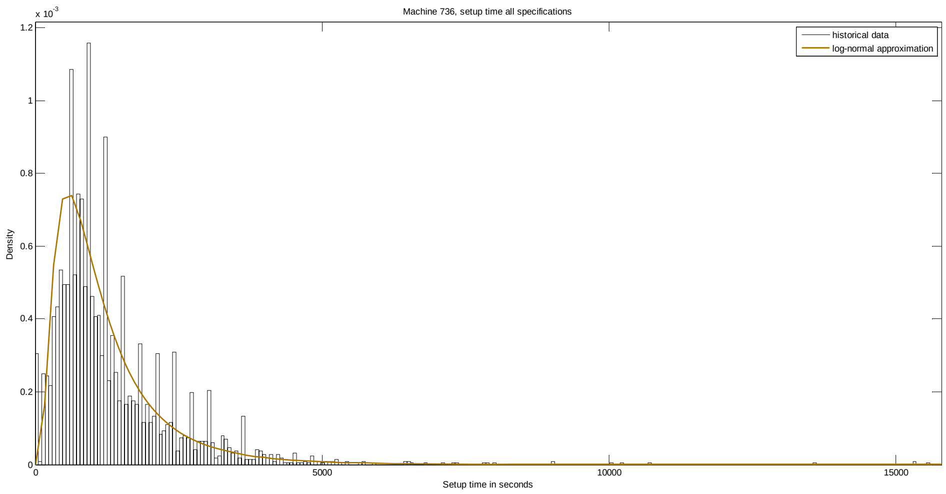

Figure 36. Setup time – machine 736

Appendix K – Machine 780

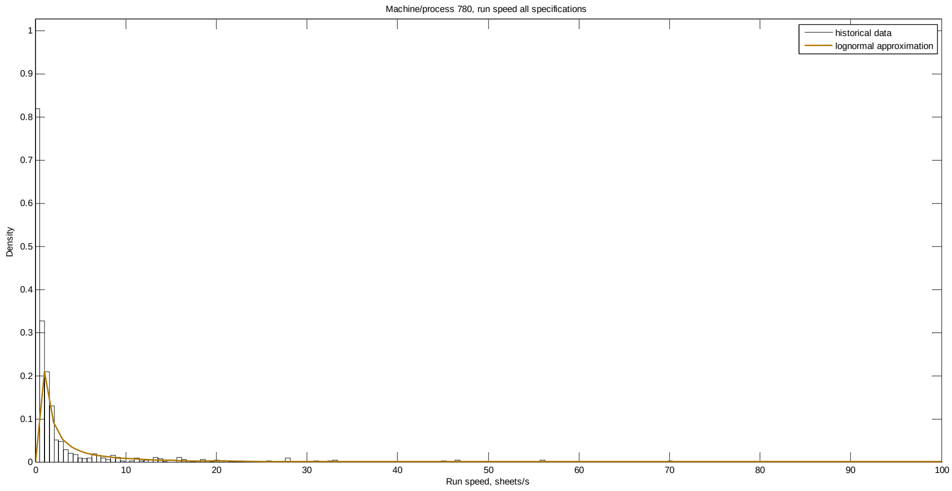

Figure 37. Run speed distribution - machine 780

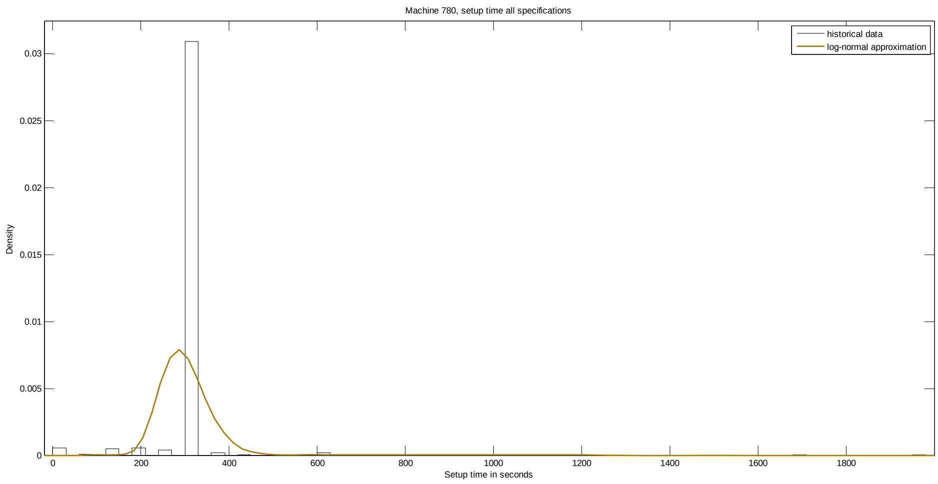

Figure 38. Setup time – machine 780

Appendix I – Machine state statistics, scenario I

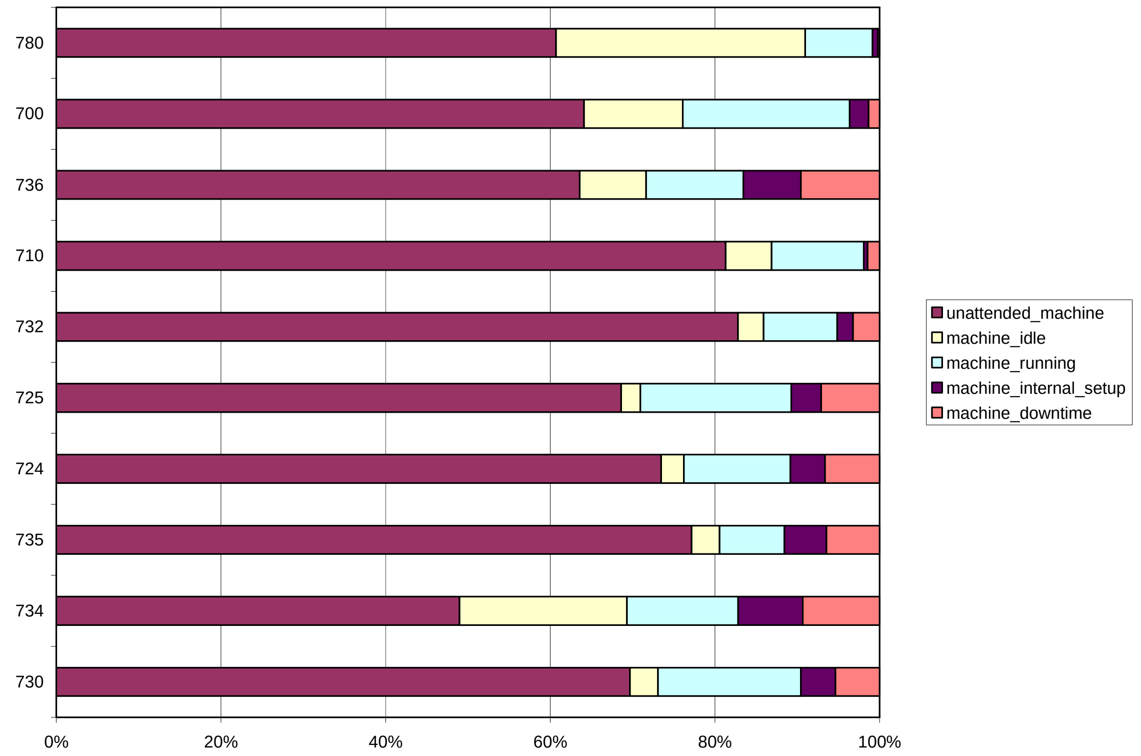

Figure 39. Machine states, scenario I

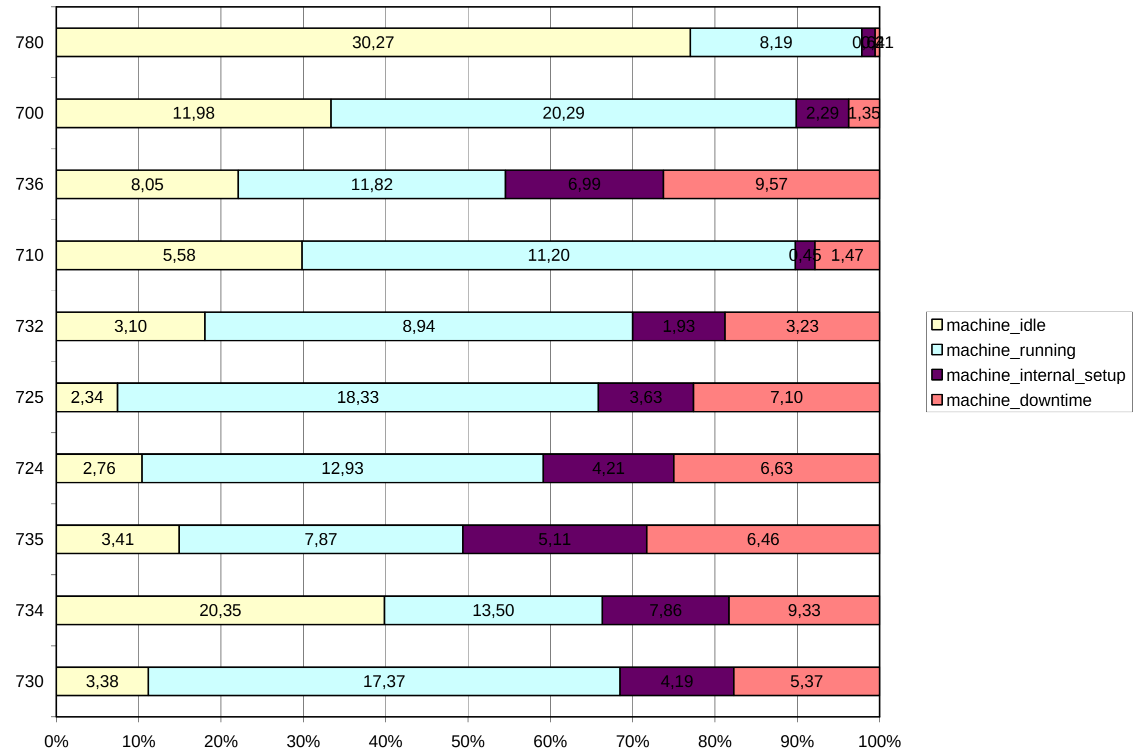

Figure 40. Machine states, attended time, scenario I

Appendix J – Machine state statistics, scenario II

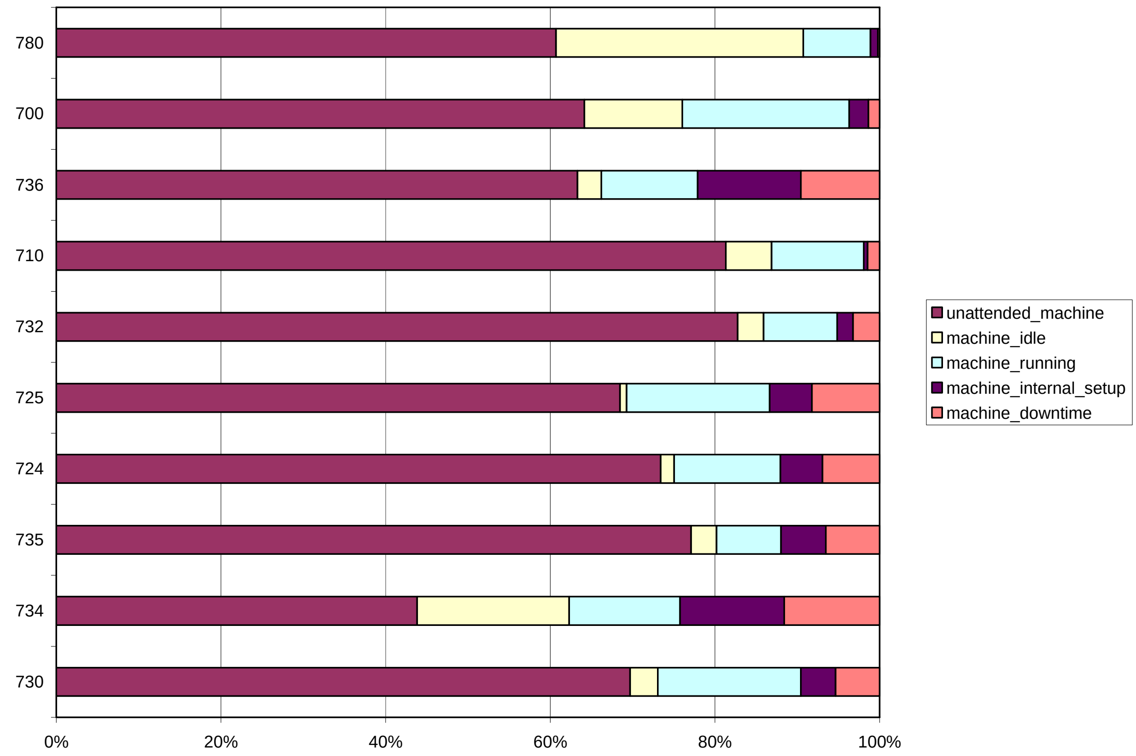

Figure 41. Machine states, scenario II

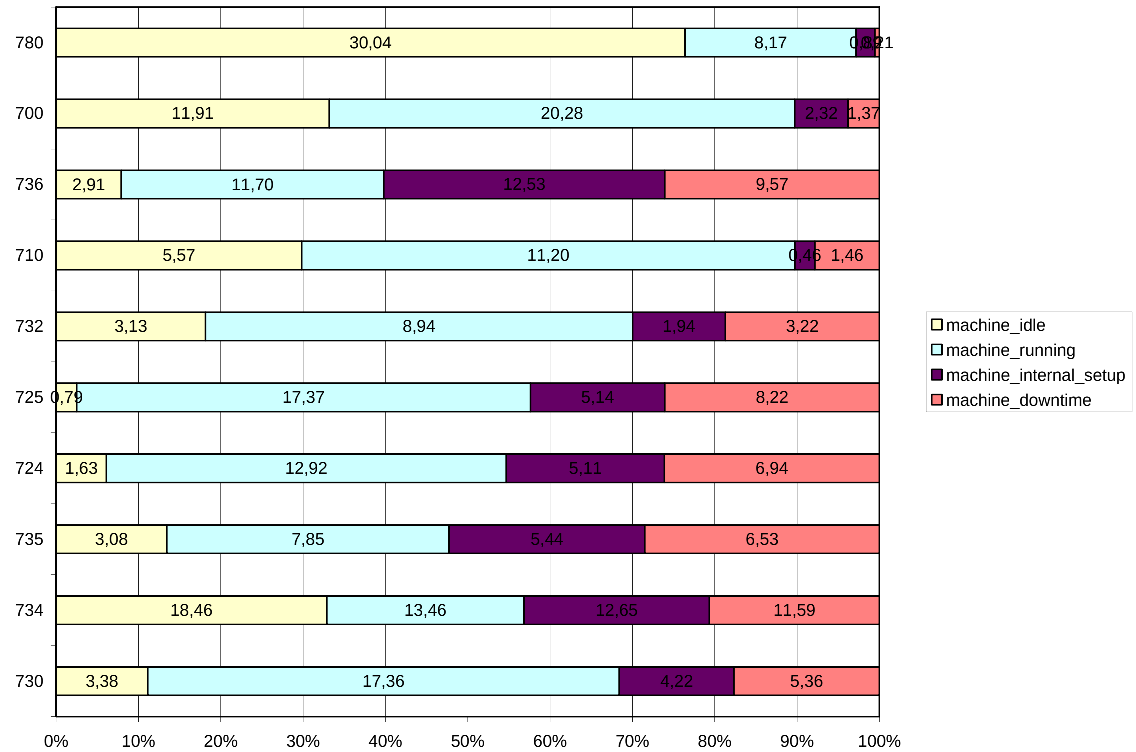

Figure 42. Machine states, attended time, scenario II

Appendix K – Machine state statistics, scenario III

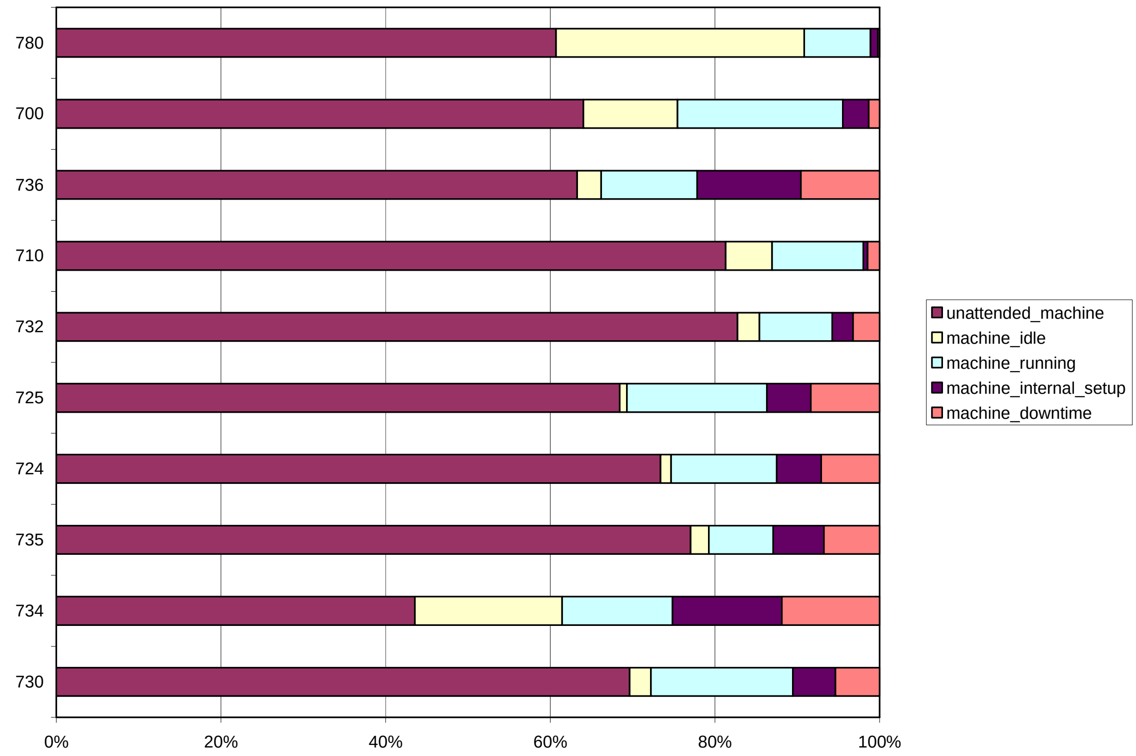

Figure 43. Machine states, scenario III

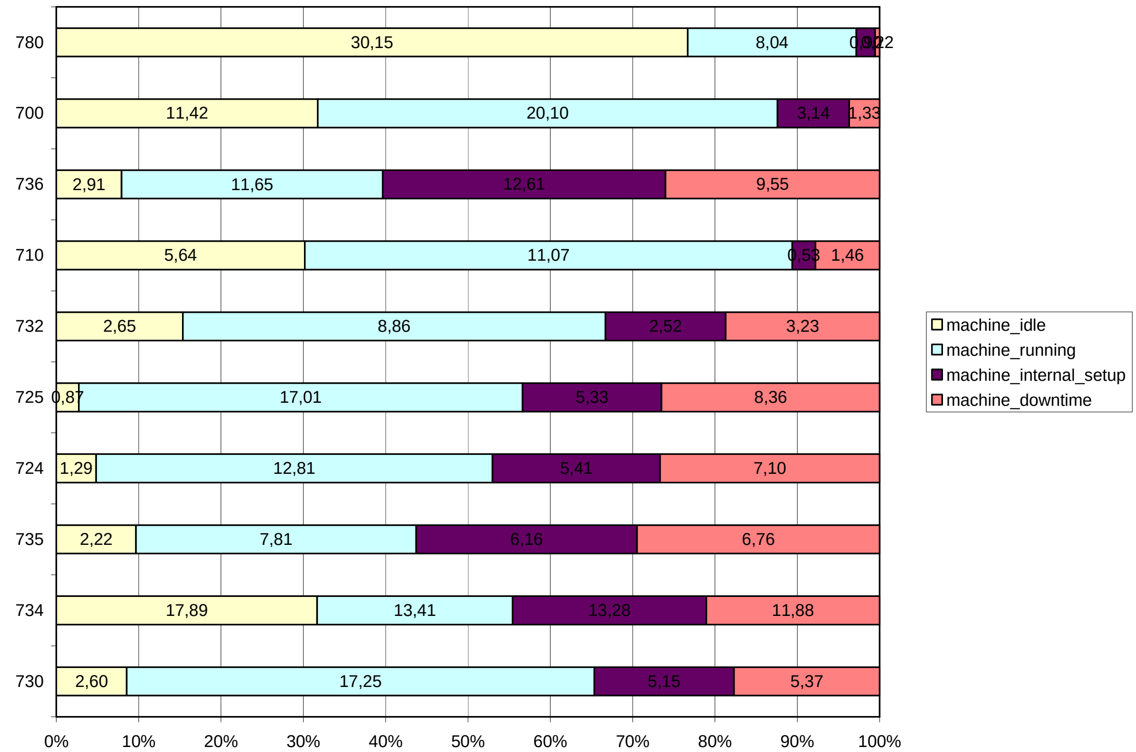

Figure 44. Machine states, attended time, scenario III

Appendix L – Buffer levels

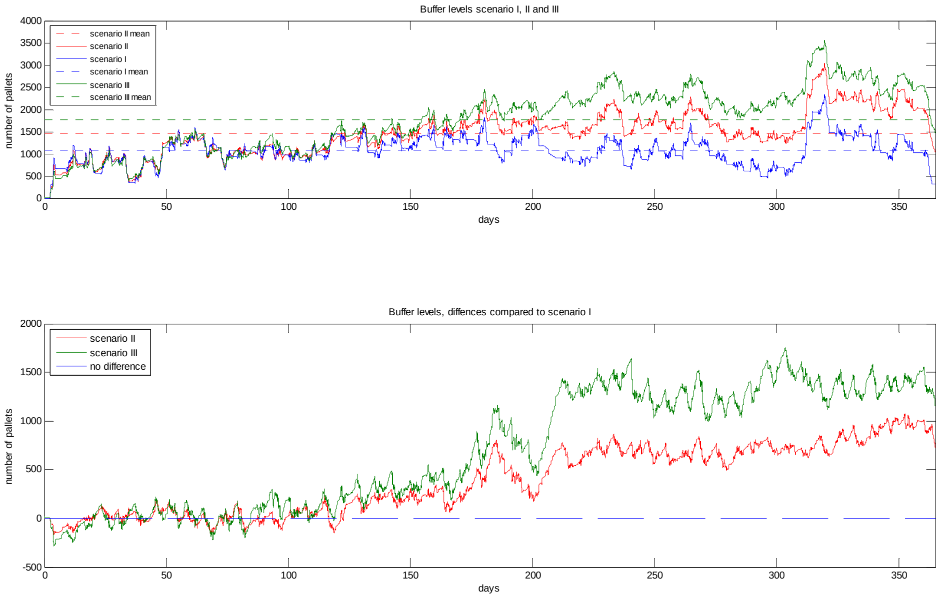

Figure 45. Total buffer levels, all scenarios

Appendix M – Process map, SCA Packaging, Järfälla

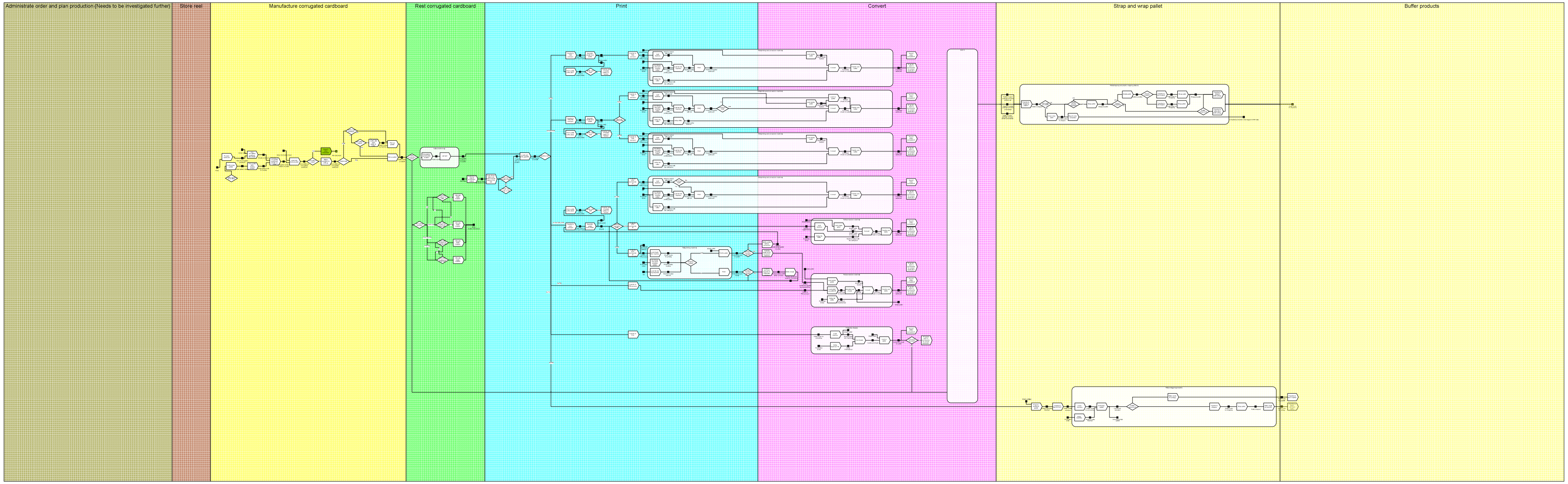

Figure 46. Process map, SCA Packaging, Järfälla

Appendix N – Simulation model overview

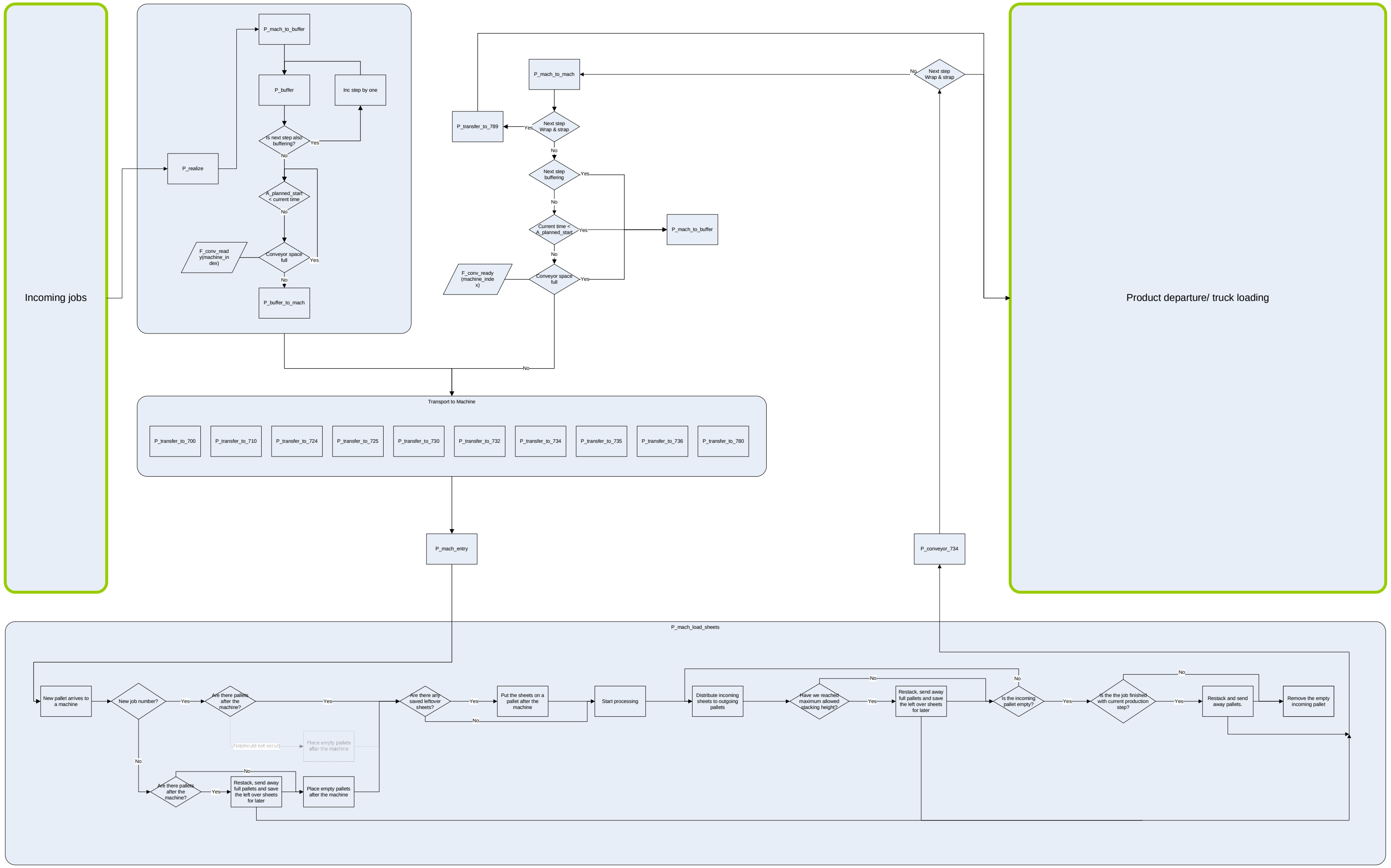

Figure 47. Simulation model overview