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A model of sizing production buffer stocks based on the processes which take place in a furniture factory.

Master of Science Thesis in the Master's Program Supply Chain Management

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A MODEL OF SIZING PRODUCTION BUFFER STOCKS BASED ON THE PROCESSES WHICH TAKE PLACE IN A FURNITURE FACTORY

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Abstract

The problem investigated in this mater thesis dealt with production buffer stocks needed in the factory which produces furniture. The factory's strategy is make to stock and the production plans are based partly on forecasts and partly on the demand from the customers. Production buffer stocks correspond to work in process and are understood as stocks of the materials between the machines in the production process. The goal of setting buffer stocks was to optimize the production output of the factory. In order to define the optimal buffers the authors applied theory of constraints to this problem. A generic model was developed, which can be adapted in other factories. The major steps were defined, input data and the outcomes of the model. The final result is defined buffers for all the identified bottleneck resources.

Keywords:

Work in process (WIP), Theory of Constraints (TOC), manufacturing planning and control, bottleneck resources, buffer stocks, furniture factory

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Michal Furga

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Terms and abbreviations:

Available to promise (ATP)

Bill of material (BOM): a list of all raw materials, parts, intermediates, subassemblies required to construct, overhaul or repair something.

Bottleneck: department, facility, machine or resource already working at its full capacity and which, therefore, cannot handle any additional demand placed on it.

Buffer stocks: A supply of inputs held as a reserve to safeguard against unforeseen shortages or demands.

Computerized numerical control (CNC)

Customer order (CO)

Customer distribution centre (CDC)

Cycle time: the period required to complete one cycle of an operation or to complete a function, job, or task from the start to the end of a production process.

Distribution centre (DC)

Distribution order (DO)

Electronic data interchange (EDI)

Effectiveness: refers to the company's ability to adapt to and take advantage of opportunities that exist on the markets where it operates.

Information technology (IT)

Internal efficiency: is the capacity to be efficient during operational activities within the framework of existing resources and products (ability to produce a satisfactory result).

Lot size: number of items of the same type in a lot.

Make to stock (MTS)

Manufacturing order (MO)

Manufacturing planning and control (MPC)

Master production scheduling (MPS): translating a business plan into a comprehensive product manufacturing schedule that covers what is to be assembled or made, when, with what materials and the budget required.

Medium density fibreboard (MDF)

Order fulfillment process: sequence of steps involved in processing an order to the satisfaction of the customer and all the necessary changes made in the inventory records.

Overall equipment effectiveness (OEE): is a measure that gives a complete picture of how effectively a production process is running. It includes all losses - not only how many products were produced but also how much the potential output was limited due to a lower speed or poor quality. OEE is a comparison between a non-defective output and a maximum output i.e. the **name plate capacity (NPC)** during a running time. The losses limit a non-defective output and the reasons for not producing an expected amount of products are strictly related to these losses.

Service level: according to the IKEA concept it is a ratio between the number of stores which would like to keep a product in stock and the number of stores which in fact have a product in stock.

Statistical process control (SPC)

Strengths, weaknesses, opportunities, threats (SWOT)

Supply chain management (SCM)

Swedwood way of production (SWOP)

Takt time: adjustable time unit used in lean production to synchronize the rate of production with the rate of demand. Computed by dividing available production time by the number of items to be produced. Takt time provides a precise rhythm to run an entire process sequence that maximizes efficiency whereas minimizing wastes.

TIMWOODS: a concept used internally in Swedwood and can be understood as unnecessary: transportation, inventory, motion or movement, waiting time, overproduction, over processing, defects or waste of human potential.

Theory of constraints (TOC): is a concept which focuses on managing flows by focusing on bottleneck resources. The chain is as strong as its weakest link. There are five main steps which should be followed in sequence: identify a constrained resource, maximally exploit the constraint, subordinate other processes, elevate the constraint and repeat all the above steps.

Vendor management inventory (VMI)

Work in process (WIP): refers to goods which are under refinement in or between a sequence of value-adding resources.

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1. Introduction

This chapter provides the general background for the master thesis, the problem analysis and breakdown of the main research question. The main area in focus is presented as well as project's goals and limitations. The chapter also gives an outline of the company profile.

1.1. Background

1.1.1. Situation

The Swedwood Group is an industrial group within the IKEA Group of companies. Swedwood has more than 40 production units and offices in ten countries on three continents (Europe, North America and Asia). The head office of Swedwood is placed in Ängelholm, Sweden.

In the late 1980s and at the beginning of 1990s there was an increasing demand within IKEA for supply of furniture. That was the starting point which decided about setting up the Swedwood Group. The main task is to ensure production capacity of wood based furniture. This is accomplished by establishing and operating sawmills, component and furniture production units strategically located relative to consumer markets or raw materials suppliers.

The three main business sectors the company operates in are:

- board on frame: specializes in manufacturing sandwich construction furniture such as tables, cupboards, shelves, beds and chests of drawers.
- flat line: is organized in two business areas:
    - foil & pigment (this area produces kitchen cabinets and fronts, wardrobes, etc.).
    - veneer (this area produces office furniture, fronts for kitchen, cabinets and wardrobes, chest of drawers and book shelves).
- solid wood: this sector operates with products made of solid wood.

Figure 1. Example of the final product from the flat line sector; Duvbo kitchen fronts.

The strategy of Swedwood is to ensure cost-effectiveness by integrating the whole supply chain.

Continuous growth requires not only an increasing utilization of production units, infrastructure and reduced time of return on investments made but also investments in new machinery and production units.

Swedwood Way of Production (SWOP) is a specially dedicated organization unit within Swedwood. The unit's scope was reorganized recently and the main focus is to incorporate Lean methodologies into Swedwood operations and improve the company's operations. The Lean production is a disciplined method for integrating of a product design, production, supply network, distribution, marketing, economy systems and management (Medbo, 2010).

One of the objectives of SWOP is to facilitate the dimensioning of work in process (WIP) inventory and also increasing the utilization rate of machinery in order to increase the general output of the factories.

Furthermore, the lean philosophy stresses waste elimination in order to maximally increase the product's quality for the customer. In Swedwood wastes are called TIMWOODS which can be defined as: unnecessary transportation, inventory, motion or movement, waiting time, overproduction, over processing, defects and last but not least skills not used; in other words wasting the human potential.

The factory in Älmhult, which is in main focus, is the third biggest unit of Swedwood within the flat line sector. In the fiscal year 2010/2011 there was 335 people employed. The total production means amount to almost 27 different machines and yearly almost seven million articles of different types are produced. The annual turnover for the fiscal year 2010/2011 is estimated at approximately 61 million EUR.

The bill of material (BOM), which is a list of all raw materials and parts required to construct a final product, equals from one to three levels. The main products are different types of kitchen fronts, solid flat fronts, milled fronts, frame doors with fillings and doors with glass fillings. Despite of relatively few finished product types a big complication is that every range of products consists of around 40 different variants of fronts of the European sizes and about the same number of North America sizes; everything from small drawer fronts, cupboard doors and doors with glass fillings, to the largest cabinet cover panels.

The number of operations in the production process varies depending on the article type and amounts from minimum seven to maximum 13 operations performed in sequence.

The production environment is push oriented. Push characteristic of materials management, means that manufacturing and materials movement takes place without the consuming unit authorizing the activities, i.e. they have been initiated by supplying unit itself or by a central planning unit in the form of plans or direct orders (Jonsson & Mattsson, 2009).

The layout of the factory is oriented toward the flows of the products where three main flows can be distinguished. However, this is a recent change. Previously the factory was divided into three main departments: the machining department, lacquering department and assembly and packaging department (refer to the Figure 19). The change into flows orientation was made to facilitate products tracing and also better information sharing between subsequent machines.

All the products are produced based on medium density fibreboard (MDF) made of wooden fibres. Beside MDF other raw materials being used are polyester paints in the lacquering processes, glass used for glass doors, fillings which are packed with finished products and packaging materials used to pack 'flat packages'.

Demand for the products is driven by the requests for the products from the distribution centre (DC) and by the forecasts from IKEA. All documentation is transferred electronically through electronic data interchange (EDI) system. In order to stay responsive towards customers and to balance the effects of sudden changes in the demand IKEA maintains finished goods stock which means that Swedwood is producing in make to stock (MTS) environment.

1.1.2. Complications

In effect of a steadily increasing demand for Swedwood's products a need arose for an increased utilization of the available equipment and also for investments in new facilities and machinery. The general idea is to be able to produce more products in a shorter time and of a better quality.

However, some of the existing factories are quite old which means they were not originally designed for such large production volumes as nowadays. Hence, investments in new machines obviously increase the production capacity but at the same time limit the unoccupied space within the facilities; space demand for raw materials increases and a change in the flow's design is required.

Nowadays Swedwood does not trace the influence of new investments on the utilization rate of the already existing equipment.

The utilization rate of machinery is indicated by the overall equipment effectiveness (OEE) factor. In an ideal situation a machine would produce 100% of the time available at 100% capacity with an output of 100% good quality. At the moment different time losses have the highest impact on lowering the OEE factor. Moreover, new machinery that consumes available space can even increase these time losses since less space for buffers is available.

The buffer space needed between subsequent machines results from different OEE factors and different cycle times. Moreover, the machine cycle time changes depending on what type of article is produced. Hence, the sequence mix of articles which is run plays a crucial role. Nowadays there are no fixed production mixes which cause that different machines can become a bottleneck in the production flow.

In response to continuously changing customer requirements products are manufactured in relatively small batches instead of being mass produced. It is done to be able to fulfil demanded variety of features. Nonetheless, batches of the articles are also used in order to reduce the time needed for setting up a machine when the production of a specific article is changed. An ideal situation would be to have no set-up times and have one piece flow. However, at the present time the batch sizes are established on an empirical base and are usually the multiple numbers of the products which can fit one block. The forecast from IKEA and the received distribution orders (DO) for a specific week determine the actual lot sizes used for production. Different batch sizes and possible sequence mix causes that the needed buffer space can vary significantly from day to day.

Beside the time losses which influence the OEE factor most significantly there are also quality losses. Quality losses differ for each machine and are likely to vary from day-to-day. The biggest quality losses exist on the lacquering machines and in the packaging department where the final quality inspection is made and faulty products are detected. Articles from the quality losses can be scraped or re-worked. When the decision is made to do a re-work the sequence of materials produced is influenced and buffers needed as well.

It has been recognised there is a lack of general planning principles, business rules and standardized way of working which results in such low utilization rate of equipment and high work in process.

1.2.Research question

The main question triggering this project was:

"How the production flow in Swedwood factory in Älmhult can be optimized?"

However, the scope of the project has been narrowed due to the complexity of the main problem specified in the research question. There are several alternatives which could be researched. This project focuses on one of these alternatives.

The breakdown of the main question and areas in focus are showed in the problem breakdown section.

1.2.1. Problem breakdown

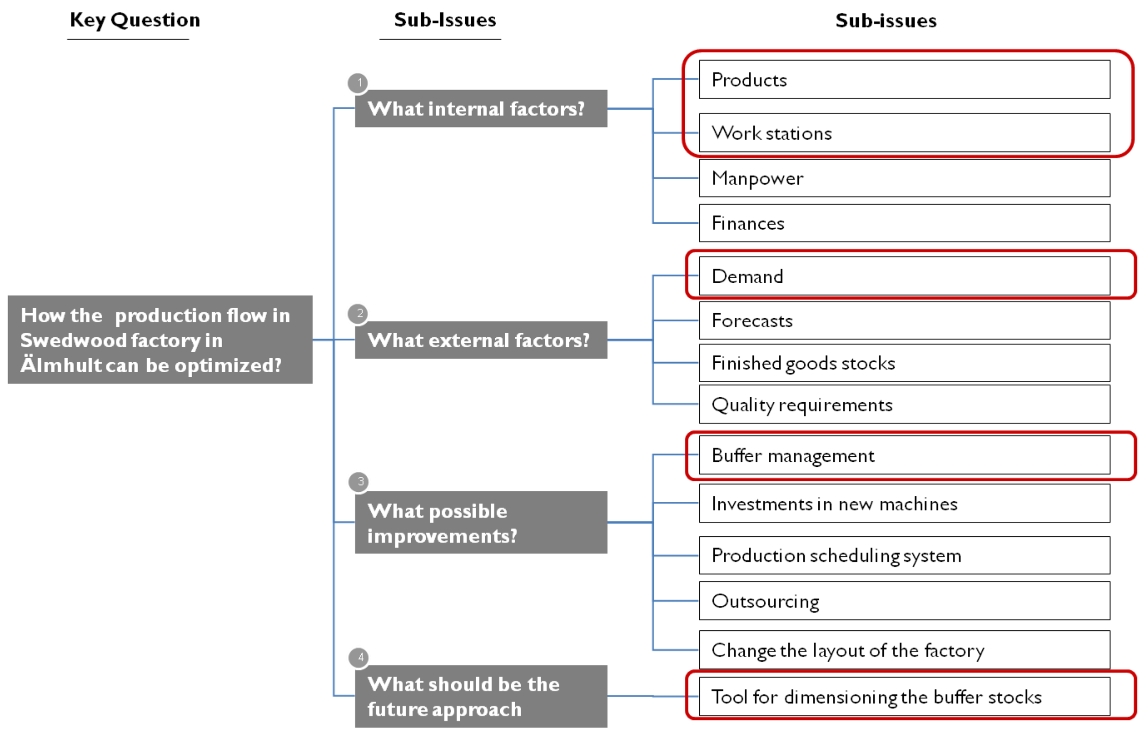

Figure 2. Issue tree.

The issue tree method has been used to define the main problem and specify the scope of this project. Several sub-sections have been identified in order to organize the project in a logical way and to categorize the specified issues into these sections. The further part of the report was organized according to the structure of the issue tree.

The main question specified above triggers this project. Further division into four main sub-sections was performed: internal factors, external factors, possible alternatives and the future approach. Identification of internal factors constraining present flow was done with help of fishbone diagram (refer to appendix 3). The main attention was paid to information about products and work stations. The factors on which the researchers have focused are marked with additional outline. However, it does not mean that other factors were not taken into account. The researchers were aware of their influence but due impossibility of affecting them within reasonable period of time they were just taken for granted in this project.

Development alternative was selected with an agreement of the stakeholders. It was decided that buffer management tool can bring the best results within given resources and timeframe. However, the scope of the project had to be narrowed due to several possible alternatives which could help to resolve the problem (refer to issue tree sub issue 3).

1.3.Project goals

The main goal of the project was to develop a generic model which would help to increase the production flow. The improved flow would be achieved by determining the optimal size of the buffer stocks between the processes. The optimizing criterion was to increase the efficiency of those machines which are the bottlenecks. The efficiency was improved by lowering the time losses through optimisation of inter-stage buffer sizes. Creating buffers is not the goal itself and should be compared against the tied up capital.

These improvements will in turn affect the whole production process. The goal is to make it more smooth, uninterrupted and also foresee the potential bottlenecks.

1.4.Other benefits

As mentioned above the goal of the project is to increase the production output of the factory and hence raise the revenues - a very quantitative factor. However, there are several other advantages which are more qualitative since they cannot be measured easily. Some of them are as follows:

- Identification of factors which influence the needed size of buffer stocks and indication how they can be improved.
- Creation of a simple generic model which determines the size of buffer stocks in the investigated factory.
- An algorithm describing the essential data, way of collecting and applying data into the developed model.

1.5.Scope and limitations

The project has several limitations. First of all the main research question was narrowed to one of the possible improvement alternatives. Secondly, the model was developed and tested based on data collected from a single factory. Reliability of data taken from the system can be questioned due to human factor which could cause some errors while data were registered into the system. Those data may not be representative for the whole company.

Only Swedwood factories were analyzed which implies that the model does not have to be applicable to any other than the furniture industry. Moreover, applicability of the model is limited only to factories of this single producer.

2. Methodology

In this chapter the general research process, the methodologies applied and way of gathering data in the thesis are described. Furthermore, the project plan with description of different phases is presented. The aspects of validity and reliability are discussed and how researchers tried to achieve high level of these factors. At the end the issue of generalization of the developed model is discussed.

2.1.Research process

The key to selecting the best methodology for any research project is recognizing the available methodologies and understanding their relative strengths and weaknesses (Jenkins, 1985). In his paper the author states that there is a fundamental research process, and that it is applicable to all research. Each step in this process is necessary in all research projects. Quality of the research is affected by extent to which a researcher complies to these steps. Skipping any step can seriously limit the study. Worth underlining is that research objective is developed in one step of the research process and the research methodology is selected in the next step in that process.

The basic outline of the steps in a research process is presented in the Figure 3 below. A sequential application of these steps through a research process would be an over-simplification. The feedback loops from each of the steps to any previous step illustrate the true iterative nature of the research process (Jenkins, 1985).

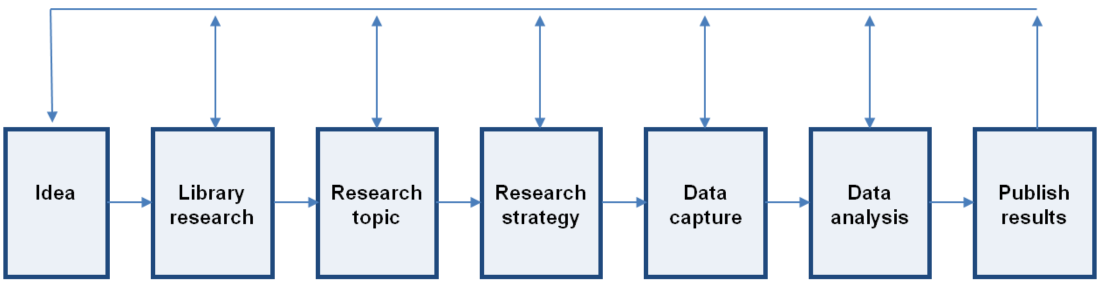

Figure 3. Basic outline of the steps in a research process.

Furthermore, Jenkins (1985) states that definition of a research question is the most critical step in the research process while combination of different research methodologies can be appropriate for a project. Thus, in this project the research question was defined and broken down to sub-issues at a very beginning.

The plan dedicated for this project was created with compliance to the general steps in the research process. The project plan is illustrated in the

Figure 4.

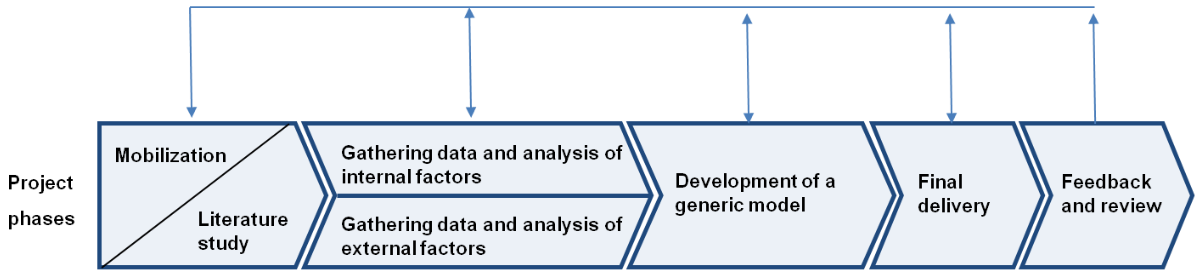

Figure 4. Project plan.

The plan of the project was basically divided into five main steps which were performed sequentially. However, the feedback loops were applied due to new information which have been gathered and analyzed during the research process. Description of the project's phases is presented below.

Mobilization and literature study

This phase complies with four first steps of a research process described by Jenkins. Having the general idea about the problem the primary literature study took place to obtain better understanding of the problem. After that the main research question was defined and broken down into sub-issues. At the end of the phase the research strategy was decided.

The goal of this phase was also to familiarize the researchers with the business type of the company and with the present situation. The scope and goals of the project were written down in the project directive and were accepted by the stakeholders.

Even though the most extensive literature studies were done during this phase it was somehow a continuous process throughout all project. Thanks to this it was possible to consider the existing solutions and problems in the furniture industry. It was decided that the theory of constraints (TOC) will be the most suitable means for solving the existing problem at Swedwood.

Gathering data and analysis of internal and external factors

Within this phase, which complies with fifth and sixth step of the research process, study visits in the production unit in Älmhult were performed. The main purpose was to get a better understanding of the problem. Project participants focused on collecting the required information and analyzing internal and external factors which affect the present situation. Main factors were identified and they were given special attention. At the end of this phase the improvement alternative was decided. Decision was supported by strengths, weaknesses, opportunities, threats (SWOT) analysis.

Altogether three visits lasting in total 8 days took place.

Development of the generic model for the chosen improvement alternative

This phase in the project overlaps with data analysis in the research process. The feasibility and effectiveness analysis of the chosen alternative was done firstly. When the stakeholders agreed to put effort in development of this alternative the researches spent time on developing the generic model for dimensioning the buffer stocks. The model was decided to be the most suitable method regarding given resources and time-frame.

Final delivery of the report

This phase comply with publishing results step in the research process. The model has been developed and the final version of the report has been written. Also a user manual how the model should be used has been created. The final presentation of the project was then prepared as well.

Feedback and review of the project

This phase does not have equivalent in the research process steps defined by Jenkins. This additional time was spent on analyzing the feedback from the stakeholders and other participants of the final presentation. These comments were then included in the final report. The aim was to improve the quality of the final version of the project.

2.2.Research methodologies

Thirteen different research methodologies were identified by Jenkins (1985). This division was made on the basis of twelve categories containing a total of 24 dimensions. Of course each of these methods has its own strengths and weaknesses and a researcher must be aware of them to select the most appropriate method which answers the research question.

Furthermore, the author proposes an organization of these methods, from strongest to the weakest, basing on corresponding amount of control a researcher can have over the variables, the subjects and the experimental findings. According to this division math modelling is the strongest method while philosophical research is the weakest method which is adopted primarily for the generation of hypotheses. The research methods applied in the thesis were defined according to this division.

Researches decided to apply a combination of research methods in order to minimise tradeoffs in case of using only one specific method and to give the best possible answer for posted research question. Moreover, it was noticed that requirements for a research method varied during different project phases. The following research methods were used throughout the project.

Case study - using this methodology a particular subject, group of subjects or organization is observed by the researcher without intervening in any way. The case study attempts to capture and communicate the reality of a particular environment at a point in time (Jenkins, 1985).

Using this methodology the researchers were able to focus on the analysis of internal factors. Main focus was on internal data about products and machines. Some of the external factors were studied as well. Chosen production unit was decided to be representative for the whole sector in the company. Limitation to only one unit was done due to time restriction.

Math modelling – this methodology models the ‘real world’ and states the results as mathematical equations. It is a closed, deterministic system in which all of the independent and dependent variables are known and included in the model (Jenkins, 1985).

Even though not all independent and dependent variables were known, certain assumptions were made to be able to develop the model. The math modelling was applied when the generic model has been developed. Data which were gathered during site visits served as an input. The outcome was a model in which variables can be adjusted according to the situation in the production unit.

Group feedback analysis – by employing this methodology, groups of human subjects complete an objective instrument for testing of the researcher's initial hypothesis. Following the statistical analysis of the collected data, the data and the analysis are discussed with the subject group to obtain their subjective evaluation. The intent is to achieve a deeper analysis than that afforded by the statistical analysis alone. This methodology allows a re-evaluation of the original hypothesis (Jenkins, 1985).

The group feedback analysis was decided to be applied mainly to get the criticism on developed model and to improve its weak points. Thanks to comments from the end users of the model it was possible to improve the final version of the delivered tool.

2.3.Quantitative and qualitative methods

In their paper Vidich & Shapiro (1955) believe that certain research questions lead to more quantitative approaches, whereas other research questions are more suitable for qualitative methods. Although representing very different orientations, both approaches should be treated as being complementary.

In the quantitative research the statistical working and analysis method is applied. The main characteristic of this type of research is that the collected information can be interpreted into figures and quantities. Everything can be measured and valued numerically. It is crucial, however, to have measurable parameters.

At the other hand the qualitative research cannot be measured numerically. This method is suitable when specific characteristics are investigated or when certain problems have to be identified. The need for qualitative methods is great when interpretations in a theoretic context are made, when dealing with vague problems or when symbols are interpreted. When researching real life situations qualitative methods are of good use.

In his work Sieber (1973) articulated that because the both approaches, quantitative and qualitative, have inherent strengths and weaknesses, researchers should utilize the strengths of both techniques in order to better understand social phenomena. Furthermore, it was emphasized by Onwuegbuzie & Leech (2005) that relying only on one type of data (i.e. number or words) is extremely limiting.

In this master thesis a combination of these two methods has been used. The aim of using the qualitative method was to outline the background and precisely define what should be the input to the model. The quantitative method was used to develop an actual model for dimensioning the buffer stocks.

2.4.Data gathering

Data can be defined as a collection of facts or information. It can take many forms i.e. text, numbers, images, audio or video clips. Closely related term is information and is used interchangeably in this thesis. Furthermore, to be valuable data must have at least some of the following characteristics: data must be accessible, complete, flexible, reliable, simple verifiable, accurate, economical, relevant, secure, timely (Stefansson, 2010).

Data which have been used in this project derive from different sources. Majority of them have been collected during study visits in the factory. Interviews, empirical observations and Swedwood's periodical reports were the main sources. However, some data were also gathered through e-mails and through the phone conversations. Electronic means of communication were of great help when some doubts needed to be clarified. Collected information concerns mainly the production unit in Älmhult. However, during visits in the headquarters in Ängelholm researchers have learnt about some general concepts, i.e. SWOP, TIMWOODS, demand forecasting and production planning.

These methods of data gathering together with stakeholders were decided to be the most suitable for the task given. They provided a sufficient base knowledge for solving the problem.

Literature studies

Literature review establishes what research has been previously conducted and leads to refined, insightful questions about the problem (Soy, 1997). Furthermore, literature studies are seen as an efficient and economic way to gather much information within a short period of time. Taking this for granted the project has started with an extensive literature research in order to get a better understanding of the problem and also to look for existing solutions which could be applicable. However, it has to be mentioned that literature studies was an ongoing process through all time the project took place.

It has been found that many operational researchers tried to give a solution to the problem of determining the size of production buffers. Due to the complexity of these mathematical models their applicability is limited only to specific processes. Usually they are difficult to understand thus, their usefulness in real life is limited. Hence, it has been decided to go for an improvement alternative with an aim to develop a model which is specially dedicated to this particular problem.

Literature studies have helped the researches to widen knowledge about buffer management methods and also set the theoretical foundation before approaching the problem in details. After studying several concepts it has been decided that the most suitable will be TOC concept. Even though, the theory suggest specified steps they can be interpreted to specific problem.

The literature which was utilized in this project consist mainly of books about manufacturing planning and control (MPC), supply chain management (SCM) and internal corporate documents and handbooks. Beside that some literature about business process modelling, simulation and design has been studied in order to get better insight about structuring processes.

Interviews

Three main types of interviews can be distinguished: standardized, semi-standardized and non-standardizes. The standardized are very formal and structured in a certain way while non-standardized are unstructured, informal and allow for freedom during an interview. In his paper Bewley (2002) argues that the appropriate style of interviewing depends to some extent on the goal of the study. If the objective is to understand the shape of a general phenomenon with a view of formulating new theories, then the style should be less structured in the hope that the respondent will come up with unexpected descriptions and arguments.

During this project mainly semi-standardized type of interviews has been used. This allowed for a broader discussion on specific topics which were of particular interest. The other advantage was that additional and more than expected useful information has been obtained thanks to informal talks with the factory’s personnel and managers. Bewley (2002) stresses it is important to allow informants a great deal of freedom in any kind of an interview which is done. Furthermore, confining people to a fixed list of questions can be monotonous and exasperating. This in turn may lead to obtain unreliable data.

There were some cases where none-standardized interviews were performed. Despite of informal style of an interview there are always certain necessary background questions, such as the nature of a company and the informant's function within it which have to be asked (Bewley, 2002). This type of interviews allowed informants to speak freely about certain issues. It helped to get an objective view on certain problems.

Interviews in the production unit as well as in the headquarters were held with people assigned various responsibilities and representing different departments. Majority of the semi-standardized interviews were booked in advance whereas the non-standardized interviews took place when a specific need arose. When certain doubts after an interview emerged they were clarified during subsequent visits or through phone conversations and e-mails.

Observations

This method implies the collection of information by way of investigations own observation, without interviewing the responders (Rejendra Kumar, 2008). The production unit in Älmhult was visited three times. Intervals between subsequent visits were long enough so that researchers could analyse data gathered during each visit. However, in this project interviews were performed during the study visits. It was natural sequence of activities for the researchers to learn more about the things they have observed. Hence, very often empirical observations were naturally followed by interviews with personnel directly involved.

Empirical observations have been of great importance to understand the processes within the factory and perform the analysis. The visits gave the authors an opportunity to learn how production looks like in reality and what are the main obstacles which decrease the output of the factory. However, it has to be mentioned here that all authors' impressions are just their subjective point of view.

The employees and management staff in the production site were aware of the performed project. The production unit has been chosen in consultation with the project's supervisor. The chosen unit has been decided as representative for the whole sector and a good example to examine.

2.5.Validity and reliability

In any kind of a research project there are two primary criteria for evaluation of any measurement or observation made. These criteria assess whether the right things are measured (validity) and whether the same measurement process will yield to the same results (reliability).

Validity

The definition given by Ives et. al (1983) states that validity refers to the representativeness or sampling adequacy of the content of collected data. In other words validity refers to the extent what a researcher is measuring and what hopes to measure. A high validity level can be reached when data do not have any systematic errors and when all essential parameters have been taken into consideration. In the case of constructing a model the predicted result at the beginning of the study should align to certain extent with the final result. To achieve high validity the researches have kept in mind the main purpose of the study during whole time the project took place. The purpose was clearly communicated to the personnel so that they could speak frankly and relevant information could be collected.

Reliability

Ives et. al (1983) in their paper distinguishes two types of reliability: test – retest and amount of error in the measurement. Test – retest assess whether consistent results are obtained when a researcher administer the same measurement tool multiple times with an assumption that there has been no change in what was measured. This is seen as a really simple method of assessing reliability. Amount of error in the measurement can be assessed by using different tools for statistical process control (SPC). These tools however are seen as more advanced methods for tracking reliability and require certain knowledge about statistics processes. However, both types are concerned with questions of stability and consistency, whether the same measurement tool yield stable and consistent results when repeated over time.

In order to achieve high reliability in this project the researchers have contacted the most competent people from areas that were of interest. Furthermore, these people were informed in advance so that they had time to find and prepare required data. Test - retest reliability has been verified by sending out the report to involved people and checking that data were interpreted in the right way. Since, researches did not make the measurements themselves, they had to assume that collected numerical data did not contain significant errors. The assumption has been decided to be credible since numerical data were withdrawn directly from the enterprise resource planning (ERP) system. In case of knowing about existence of assignable cause distorting the data in the selected time interval the time interval was changed to one not containing assignable cause. If this action was not possible it was explicitly commented that the gathered data are affected by an assignable cause that is known and this was taken into consideration during results interpretation.

Comparison of validity and reliability

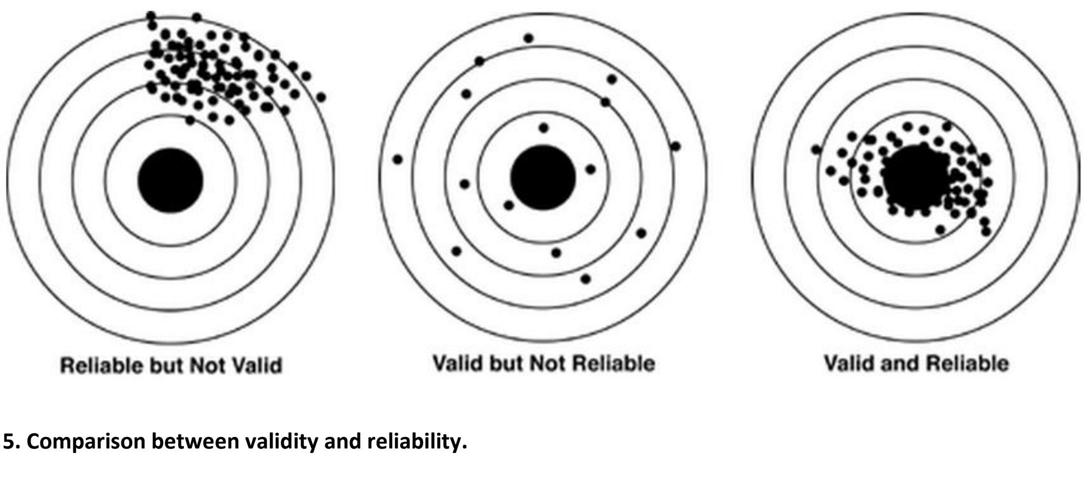

Figure 5. Comparison between validity and reliability.

The relationship between validity and reliability is presented on the Figure 5 above. Looking from the left side the first case is when a measure has high reliability but low validity. In other words a measurement that is consistent in getting bad information or consistent in missing the mark. In the second case one can have a relatively valid measurement but not reliable. Collected data are inconsistent and not on target, hence it is difficult to reach the target when measures are inaccurate. In the third case a measure has both high validity and high reliability. The results are consistent in repeated application and accurately reflect what researchers want to represent (ccnmtl.columbia.edu).

2.6.Generalisation

It may be possible for the researchers to arrive at generalisation i.e. to build a theory (Rejendra Kumar, 2008). Furthermore, in his paper the author states that the real value of research lies in its ability to arrive at certain extent of generalisation. During this project researchers kept in mind the generalisation of the developed model from the very beginning. From one hand it may seems difficult to arrive with generic model applicable in any of the company production units basing research only on one case study. From the other hand these production units are similar since they belong to the same company and several standards are the same. Thus, the assumption was made that if developed model works in the analyzed unit it will be easy to adapt in other facilities. However, the authors see implementation of the model as another stage of the project.

3. Theoretical framework

In this chapter the theoretical concepts, which were used in the thesis, are presented. Chapter starts with general description of manufacturing processes with more detailed description of different manufacturing strategies. Further the theory of constraints, main concept used in this thesis, is described and explained. At the end work in process and other type of inventories are presented.

3.1.Manufacturing processes

Manufacturing company

Somehow simplified, it can be stated that in every supply chain there is a flow of materials that starts at the company's suppliers and ends with its customers. However, the manufacturing company may be also considered as flows of money and information (Jonsson & Mattsson, 2009).

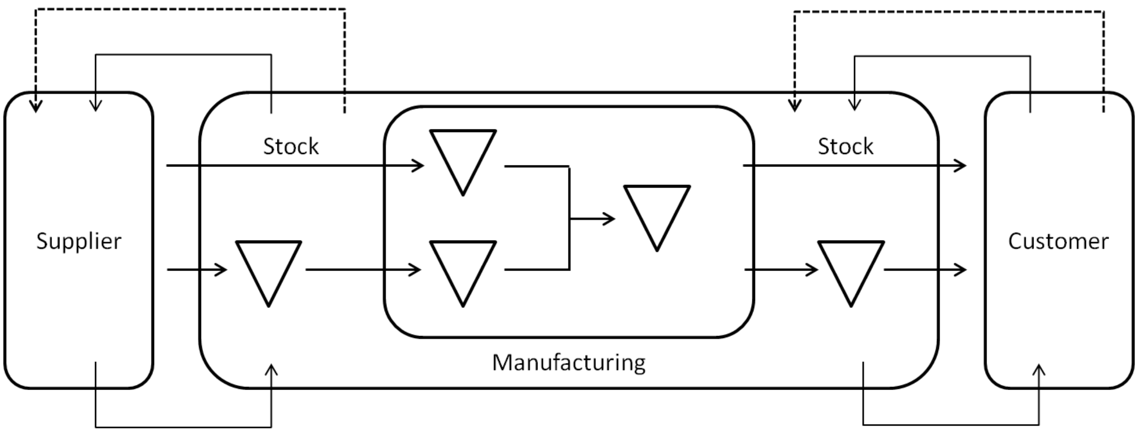

Figure 6. The manufacturing company as a flow of materials, information and money, source: Jonsson & Mattsson, 2009.

On the Figure 6 solid arrows indicate flows of material, narrow solid arrows flows of information and dotted arrows indicate monetary flow. As can be seen a chain usually starts with suppliers who are responsible for deliveries of raw materials and other components or semi-finished items needed for manufacturing processes. These deliveries are essential because without materials a factory is not able to produce. Hence, there are different strategies of purchasing materials either for direct usage or to stock for later usage. It has to emphasized that flow of materials is initiated by flow of information.

Purchased materials are processed during production process where value-adding activities take place. The result can be a finished product, or semi-finished product which serves for further production processes. In second case items may be either delivered to stock for later usage or can be directly consumed for end-product manufacturing or final assembly. On the other hand, finished products, can be manufactured either to stock for deliveries in future or according to customers' orders. In both cases flow of information is controlling the flow of materials.

When it comes to monetary flows they start on the customer side. Customers pay for delivered products and manufacturing unit in turns pay to suppliers for purchased goods. The differences in value of both these monetary flows consist of direct production costs and contributions to other costs and profits in the business. Monetary flows are also initiated by flows of information (Jonsson & Mattsson, 2009).

The concept of production

Production in general terms means a process in which goods and services are created through a combination of materials, work and capital (Jonsson & Mattsson, 2009). Consumption is the overall goal for all production; goods produced must be distributed in some way to allow consumption.

The manufacture of goods can be said to consist of a sequence of operations or value-adding activities. Raw materials are transformed during this process from a given to a desired state. Transformation can take place in five different ways:

- Transformation through division
- Transformation through combination
- Transformation through separations
- Transformation through shaping
- Transformation through adoption of properties

Manufacturing strategies

Manufacturing companies can be classified in different ways regarding the type of operations carried out. Jonsson & Mattsson (2009) in their book divide manufacturing companies according to extent to which their operations are customer-order initiated. Customer order point is defined as a position in product's bill of material from which the product has customer specific appearance and characteristics. Thus, delivery lead time to a customer has to be at least as long as the time it takes to complete manufacturing operation from this point onwards.

Customer order decoupling point is defined as the position in the bill of material from which material supply and value-added activities are customer order initiated (Jonsson & Mattsson, 2009). Thus, this point represents the moment in the bill of material at which material planning is not dependent on forecast. Therefore, before the decoupling point forecasts are determining needed material quantities and delivery dates.

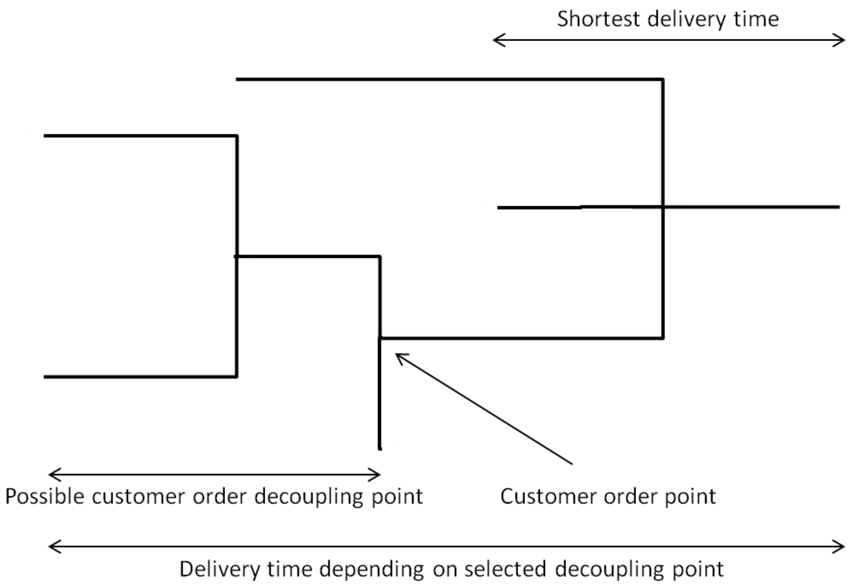

Figure 7. The connections between customer order point and the customer order decoupling point, source: Jonsson & Mattsson, 2009.

On the Figure 7 each horizontal line illustrates an item. The length of the lines illustrates lead times. Figure represents a connection between customer order point and customer order decoupling point. In reality in most cases these points are in the same place. Customer order decoupling point may lie before customer order point but never after this point.

The authors distinguished five different types of manufacturing strategies related to customer order decoupling point. These strategies can be seen on the Figure 8.

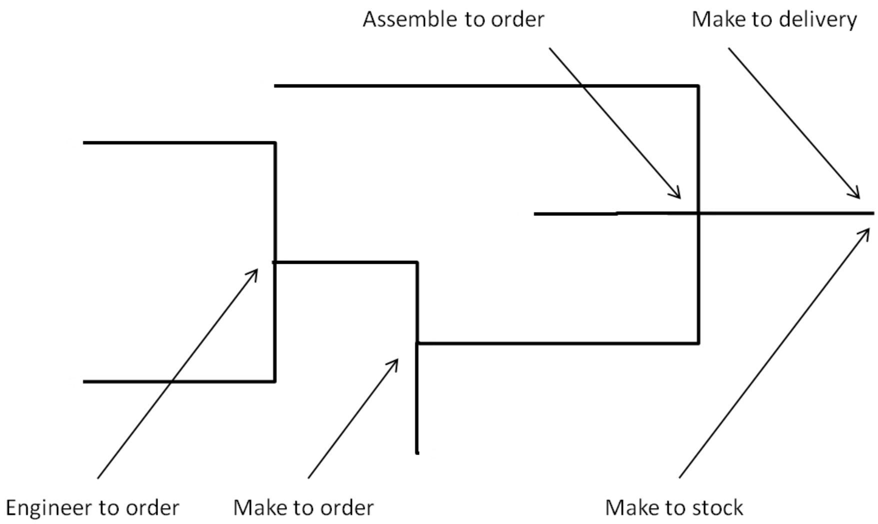

Figure 8. Position of customer order decoupling point for different types of company, source: Jonsson & Mattsson, 2009.

Engineer to order (ETO) characterize a company which produces according to specifications given by a customer. When an order is received from a customer all the processes like engineering, process planning, materials procurement and manufacturing take place. Since customer order decoupling point lies at very low level in the bill of material lead time is respectively long (Jonsson & Mattsson, 2009).

Make to order (MTO)manufacturing strategy is similar to ETO, but products are generally engineered and prepared for manufacture before customer orders are received (Jonsson & Mattsson, 2009). Therefore, some part of materials needed is purchased in advance according to forecast and some of the parts or semi-finished items are manufactured without a customer order. When a certain order is made then needed fabrication and assembly is performed. The decoupling point lies higher at the bill of material than in ETO type of company.

When assemble to order (ATO) strategy is applied all raw materials and components are produced in advance. Fabrication of manufactured items takes place without connection to specific customer orders (Jonsson & Mattsson, 2009). The features demanded by the customer are achieved through assembly of different variants of ready components. It is important to mention that applying this strategy all the components have to be standardized. Customer order decoupling point lies near the final product in a bill of materials.

Make to stock strategy represents the lowest degree of integration between production and customer orders. The products are completely known and specified on customer order receipt meaning that customer order decoupling point lies after the final level in the bill of material (Jonsson & Mattsson, 2009). In this type of companies finished products are kept in stock and are delivered to the customer. Thanks to that the lead time can be relative short. The manufacturing processes are initiated partly by forecast and partly by history of customer orders.

In the MTS type of companies there are standard products which are fully known at the time of order and are manufactured without requiring any orders from customers (Jonsson & Mattsson, 2009). The products manufactured are stocked and ready to ship when an order is made. When there are enough products in stock the shipments are immediate and delivery time is equal to time needed for transportation. However, there might be situations when there is shortage in stock. In these cases amount of delivery lead time exist which is prolonged by the time needed to manufacture the products. Customer service level is determined by whether an item is in stock or not (Vollmann et al., 2005). Furthermore, the authors stress that a key aspect of managing the finished goods inventory is to have product in right amount, in right time. However, it is also important to balance the level of inventory against the level of service level to the customer (Vollmann et al., 2005). By increasing inventory levels costs are also increasing mainly because of tied-up capital and warehousing costs. Thus, the challenge is to find a balance between the costs of inventory and the customer service level.

Jonsson and Mattsson (2009) introduced also categorization of mentioned above types of companies from material flow perspective. The division was made with respect to the stock points in the material flow. Stock points in different types of companies can be seen on the Figure 9.

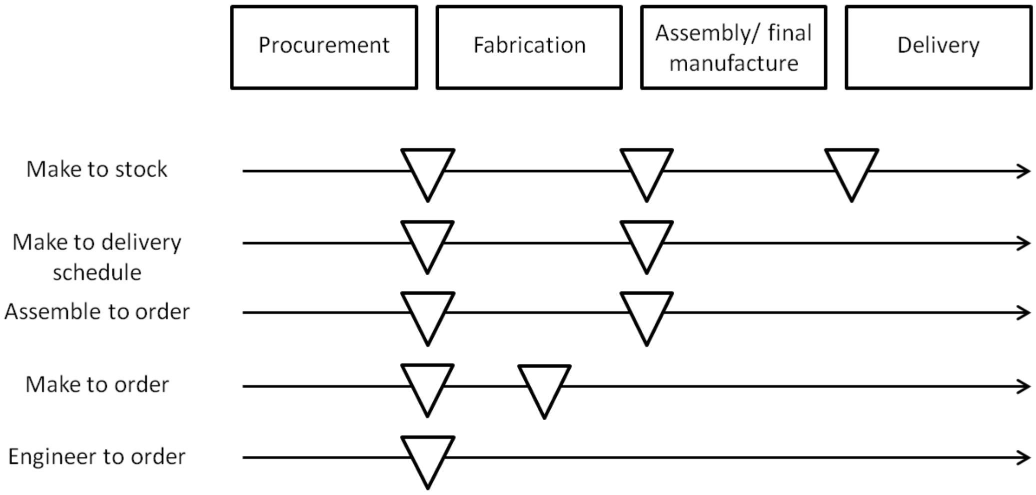

Figure 9. Stock points at different types of company, source: Jonsson & Mattsson, 2009.

Bill of material

Every manufactured item is produced through some kind of refinement of direct material. An item always consists of some other items. The relationship between the items is called bills of material (Jonsson & Mattsson, 2009). Therefore, it can be said that every product has its bill of material, which can be seen as a recipe how to construct particular product. Bill of material describes how it is composed of other items, and information about this is a precondition for being able to calculate its manufacturing cost and for estimating the requirements of raw materials and components needed in its manufacture (Jonsson & Mattsson, 2009).

In order to specify the bill of material it is necessary to know the items and what are the interrelationships of these items, which are creating the final product. An example can be a wooden table which consists of legs, tabletop, and screws. Tabletop may be built from several boards glued together. In the same way legs may be constructed. To describe these stages the terms one-level bills of material and indented bills of materials are used. A one-level bill of material contains information about direct items incorporated in a composite item (Jonsson & Mattsson, 2009). In the given example an information that a table consist of legs, tabletop and screws. An indented bill of material also shows which items are included at lower bill-of-material levels, i.e. it shows the complete structure of a composite item as far as the raw materials and/or purchased components (Jonsson & Mattsson, 2009).

Having the bill of material for a product it can be defined which bill of material level each incorporated item belongs to. This is expressed in the form of a level code, which states the structural level relative to the upper level of the product which the item is part of (Jonsson & Mattsson, 2009). The usual practice is to define the end product or semi-finished product as "level code 0" and a level which is below as "level code 1" etc. It is important to mention that this coding may work differently in different manufacturing units. It depends on the internal standards in a company.

Routing data

As described above bill of material provide information about the material content of a specific item. Routing file provides information about refinement of a product in the manufacturing process

(Jonsson & Mattsson, 2009). In the same manner as bill of material every product has ascribed the routing files, which provide information how and in what steps the manufacturing process takes place. Moreover, it also specifies what resources are needed.

Routing data has a number of very important areas of use within different units of material and production control (Jonsson & Mattsson, 2009). One of the areas is control over the product costing. Information included in the routing file allows to assess not only the material prices and material consumption but also resource consumption, which is usually translated into machine-hours or man-hours and can be directly transformed into monetary values.

Other of the areas is assessment of the capacity requirements of the resources. In the routing file it is defined how long time does it take to process one item on a particular resource. Therefore, it is a key condition for capacity requirement planning (Jonsson & Mattsson, 2009). When particular batch of products is demanded having the information from routing file it can be estimated when this batch can be delivered. Another area of use for routing data is in supplying information in the form of work descriptions and manufacturing instructions (Jonsson & Mattsson, 2009).

3.2.Theory of constraints TOC

Theory of constraints is an approach to consider capacity limitations when material flows are planned. The method is characterised by its focus on identifying and fully utilising bottlenecks along the material flow and subordinating the entire production system to these bottlenecks (Jonsson & Mattsson, 2009). The authors give a definition of a constraint which is everything that limits the performance of a system. The constraint can take one of the three forms: physical, market or policy. It can be said that a physical constraint exist when the demand on the resource is higher than its capacity. A market constraint have place when manufacturing system has overcapacity towards the demand on the market. Third type of constraint exists when the policies applied are constraining an output of the system.

TOC gives a definition that bottleneck is any resource whose capacity is equal or less than the required demand. Thus, they limit the general output of a plant. The fundamental principle of TOC system is that it focuses firstly on the bottlenecks. Orders are scheduled for bottlenecks firstly so that the throughput is maximised (Vollmann et al., 2005). Furthermore, as described by the authors, TOC gives some operational concepts for dealing with constraining situations. After a constraint is identified its importance has to be obvious for the whole plant so that the utilization is kept on as high level as possible. Buffers in front of the constraint, alternative routings for products or overtime are some methods which can be introduced to increase the utilization rate. The goal is to break a constraint and identify the next one. Vollmann et al. (2005) underline that continuous improvement is an integral part of the theory of constraints philosophy. The path for the improvement is directed to always follow the constraints.

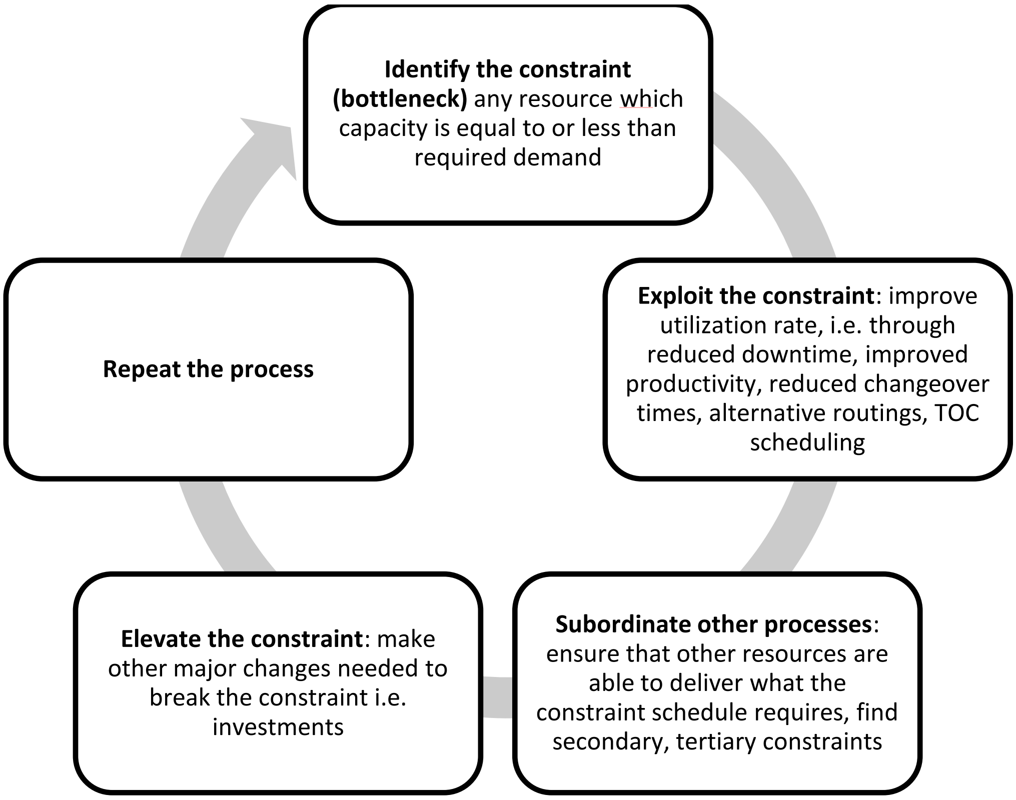

Figure 10. TOC steps

Theory of constraints approach is based on five steps process, which can be seen on the Figure 10 and are explained below.

Identify the constraint

Within this step it is necessary to identify which part of the system constitutes the weakest link and represents the constraint for the output of the system as a whole (Jonsson & Mattsson, 2009).

Exploit the constraint

When the constraints in the system were identified it has to be decided how to exploit them – how to achieve maximal efficiency within current setup. There are many ways how the constraint could be exploit and particular situation demand specific solution. Some of the examples may by reduction of downtime, moving maintenance to after work hours. A way to exploit a manufacturing resource is also to make sure that material necessary for the manufacturing process is always available, to avoid interruptions due to shortages, e.g. by keeping a buffer stock of material in front of the resource (Jonsson & Mattsson, 2009).

Subordinate other processes

The output of the production system is dependent on the capacity of the weakest link. The time which is lost on the constraint means a loss for the whole system. That is why other resources have to be subordinated to the constraint. Therefore, utilisation rate of other resources have to be synchronised with the constraint. Within this step it is important to understand that non-bottleneck resources may stay idle for some time. If non-bottleneck resources are not subordinated, the only outcome of them operating to full extent is increasing inventories and work in process (Jonsson & Mattsson, 2009).

Elevate the constraint

When exploiting and subordination of other processes did not result in enough capacity then additional capacity should be added to the system. It can take different form e.g. extra shift can be introduced, investment in new equipment or increased outsourcing of activities.

Repeat the process

When, by applying above steps, a constraint has been broken than the whole procedure has to be repeated. This step coincides with philosophy of continuous improvement.

3.3.Work in process

Flow, according to definition given by Jonsson & Mattsson (2009), generally means the movement of a material or an immaterial entity. However, in the logistics context it can be understood as movement of raw materials between different stages of refinement. Further the authors describe ideal flow as continuous movement of materials, including their refinement, from suppliers to customers. In reality it is impossible to achieve this kind of flow. Firstly materials have different speed in different parts of the chain. Secondly availability of machines may differ due to unplanned stop times. Thus, the primary function of inventory is to achieve decoupling points. Different sub-flows are decoupled from each other, partly due to discontinuity and partly to avoid the propagation of inevitable disruptions in one sub-flow to other sub-flows (Jonsson & Mattsson, 2009). In this sense inventories are inevitable part of the whole material flow system.

With regard to the position of a stock in the flow of materials different types of inventories can be distinguished: inventories of raw material and purchased components, inventories of semi-finished manufactured items, work in process and inventories of finished goods (Jonsson & Mattsson, 2009). The main role of inventories of raw materials, purchased components and semi-finished manufactured items is to decouple the production processes from the flow of inbound materials. Thanks to these inventories material requirements for production are assured.

Work in process refers to goods which are under refinement, in or between a sequence of value-adding resources (Jonsson & Mattsson, 2009). This can be seen as inventory which has somehow different role than the ones mentioned before. Work in process inventory decouples different steps within the production process. The adequate inventory level helps to close the gap between different rates of production in different parts of production system. Hence, production processes do not require the same production rate thereby they are independent when it comes to capacity. It is possible to limit the extent to which production disruptions extend to other steps of value-adding activities. In this respect, work in process can be seen as a buffer stock (Jonsson & Mattsson, 2009).

Finished goods inventories consist of stocks of goods that are completed and ready for sale (Jonsson & Mattsson, 2009). Here the role of the inventory is to decouple the production process from distribution and sales process. The goal is to be able to fulfil customer demands without delays. Figure 11 shows connections between material flows and different types of inventories.

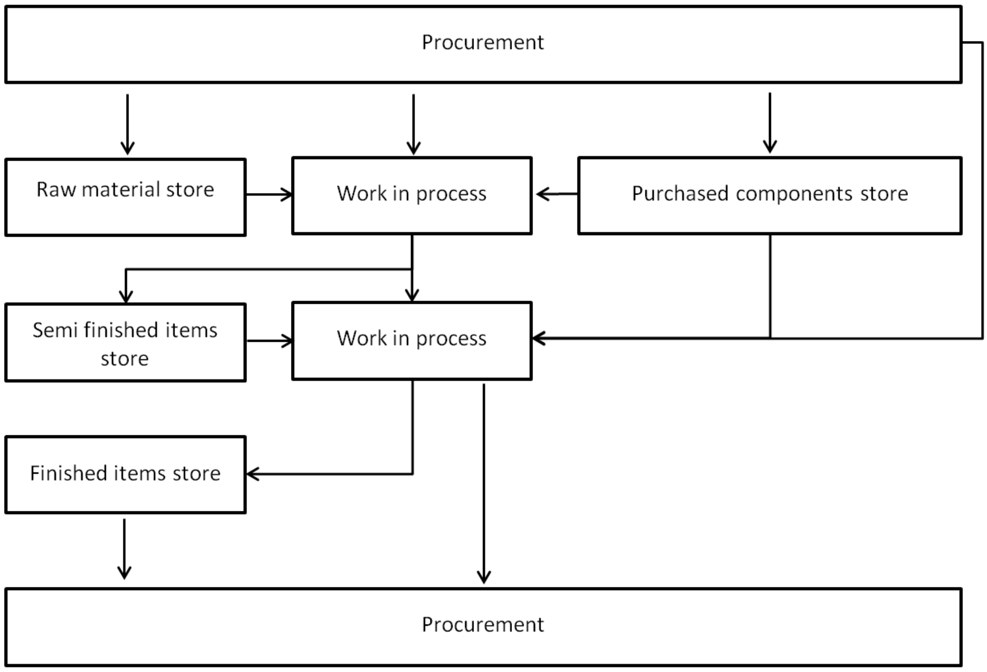

Figure 11. The connections between material flows and different types of inventories, source: Jonsson & Mattsson, 2009.

4. Empirical findings

In this chapter general findings and some results of initial analysis are presented. The findings described in this section concern mainly the analyzed production unit. However, some general facts are described as well. Chapter starts with general outline of the company and its role in the IKEA supply chain. Further findings about products and machines in the production unit are presented. The approach of production planning is described as well.

4.1.General information about the company

The Swedwood Group is an industrial group within the IKEA Group of companies. The company's place within the whole IKEA chain is presented in the Figure 12 below. The figure presents the value adding chain for the activities spanning from acquiring raw materials to selling to the end customer. Swedwood has responsibility for manufacturing processes in the three main sectors. As mentioned at the beginning of the thesis these three sectors are: solid wood, board on frame and flat line. The unit in Älmhult represents the flat line sector.

The role of Swedwood within this chain is significant because it represents the link where finished articles are produced. It means that the majority of value adding activities is performed there. Finished products must not only fulfil customer requirements when it comes to design and quality but they have to be available. That's why it is so crucial for the manufacturing unit to ensure proper capacity and output volumes when particular demand emerges. Hence, if one wants to improve performance of the whole supply chain major attention should be paid to the production units. IKEA is aware of this fact and this is the reason why a lot of effort and resources are put to continuously develop performance of the production facilities.

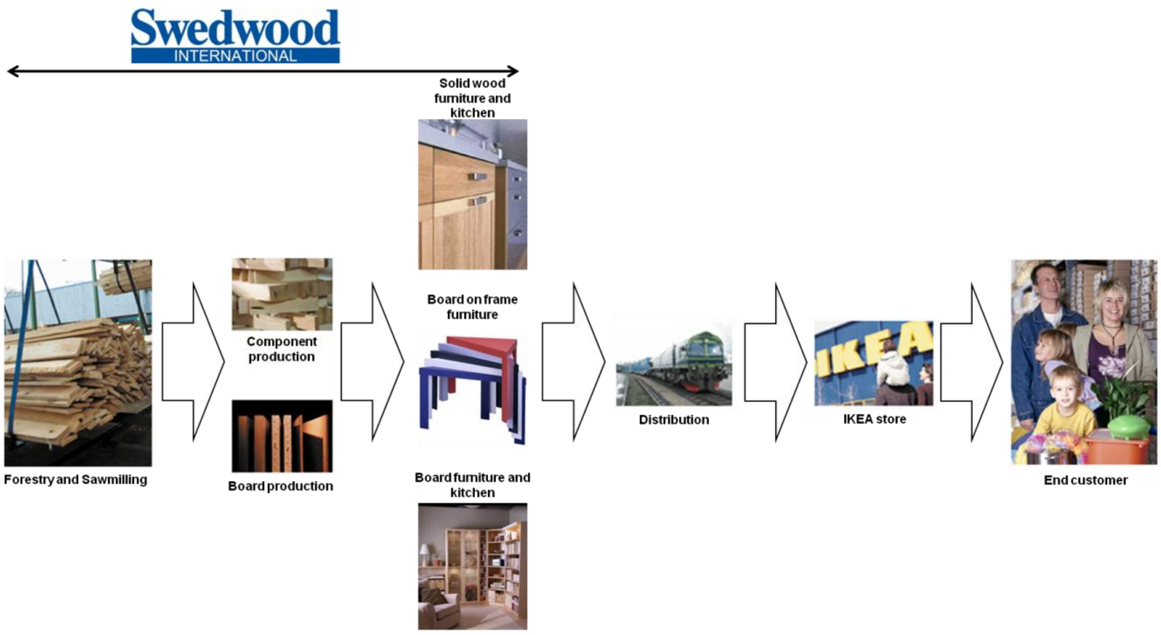

Figure 12. Swedwood role within the IKEA's group of companies.

The important characteristic of production facility in Älmhult is that it is located really close to one of IKEA's distribution centres. The relation will be described in details in the further section. The unit was purchased by Swedwood group in 1991 and was one of the first acquired units. Until recently it was the only unit within Swedwood group which has been producing this particular kind of articles.

Nowadays there is another unit in Portugal which produces similar articles. The main triggers for establishment of new production facility were increasing demand and sourcing strategy of IKEA which focuses on proximity and quick response towards the end customers.

Swedwood solely produce for IKEA. Since the kitchen fronts consist of many different products, the majority of them are delivered to distribution centres where they are merged for further transportation to the stores. The overall goal is to minimise transportation and fill the carriers as much as possible.

Facility in Älmhult produces different types of kitchen fronts, solid flat fronts, milled fronts, frame doors with fillings and glass doors. Every range of products consists of around 40 different fronts of European sizes and about the same number of North America sizes, everything from small drawer fronts, cupboard doors and glass doors, to the largest cabinet cover panels. The raw materials used for manufacturing are: MDF boards, polyester paints, glass and fillings. Three main departments can be distinguished within the facility: machining department, lacquering department, assembly and packaging department. The particular function of each department will be described in further section.

Within the company much attention is paid to working principles. Working principles are important because production is running almost 24 hours every day and there is no room for time losses. It is crucial to have standardized rules, clear targets and feedback on the results. Standardization is a foundation to be able to start an improvement process. Through standards the company establishes the processes to work in the same way all the time. When the processes are stable the next steps are taken toward challenging the processes improvement. However, continuous improvement is seen not only as taking the big steps from time to time but also as striving to does everything better on a daily basis. Therefore, Swedwood focuses very much on wastes elimination. The company's vision is that a good team reaches much further than individuals.

Quality policy for products within Swedwood has to comply to the rules set by IKEA. Hence, the most important is to have the 'right quality' meaning the quality which is demanded by the end customers. The warranty period for the majority of products manufactured in Älmhult is 25 years. It is relatively long time taking into account operating conditions in the kitchens. Therefore, the quality of products is continuously followed up and examined to ensure the required quality level. Data about any quality deviations are collected and analysed to identify the root cause and to take the fast actions which will eliminate the cause of a problem. It is extremely important due to the scale of the produced volumes. Even one day of faulty production may cause huge losses for the company.

4.2. Supply and demand chain

The general outline of the supply and demand chain for the manufacturing unit in Älmhult is presented on the Figure 13 below. All the articles manufactured in the unit are based on MDF board and this is the main product which is purchased by the unit. To be assured of a good quality and demanded quantity there are three different suppliers of MDF boards. Diversified sourcing is applied also to benchmark the quality of the materials and to prevent shortages in cases when one of the suppliers is not able to deliver. Beside MDF there are other materials which are purchased in big volumes. Packaging materials, mainly corrugated cardboard and foil, for creation IKEA famous 'flat packages'. Glass, clear or screen printed glass, serves for different types of glass doors. Special polyester paint is purchased in components and mixed in the lacquering process. The quality and stability of raw materials are extremely important to ensure the proper quality of finished products. Together with suppliers, Swedwood develops new processes and methods to identify and secure the raw material parameters critical for the production processes. The policy of raw materials in stock is directed by ‘lean’ concept and aims to achieve continuous flow of materials. Therefore, resources are kept in stock as short as possible and as a result required stock space is reduced considerably.

The majority of products are sent to IKEA distribution centre which is located just across the street. Frequent transports between these two units are not a problem since DC is operating 24 hours, seven days a week. Special truck can come any time when there is a request from the production unit. DC in Älmhult supplies local warehouses in many different places on different continents. Big part of volumes is sent to Germany - Dortmund. When there are enough products to load full truck they are shipped directly from the production unit to Dortmund. Several times a year there are shipments to USA, China and Russia. Deliveries to Japan take place twice a year.

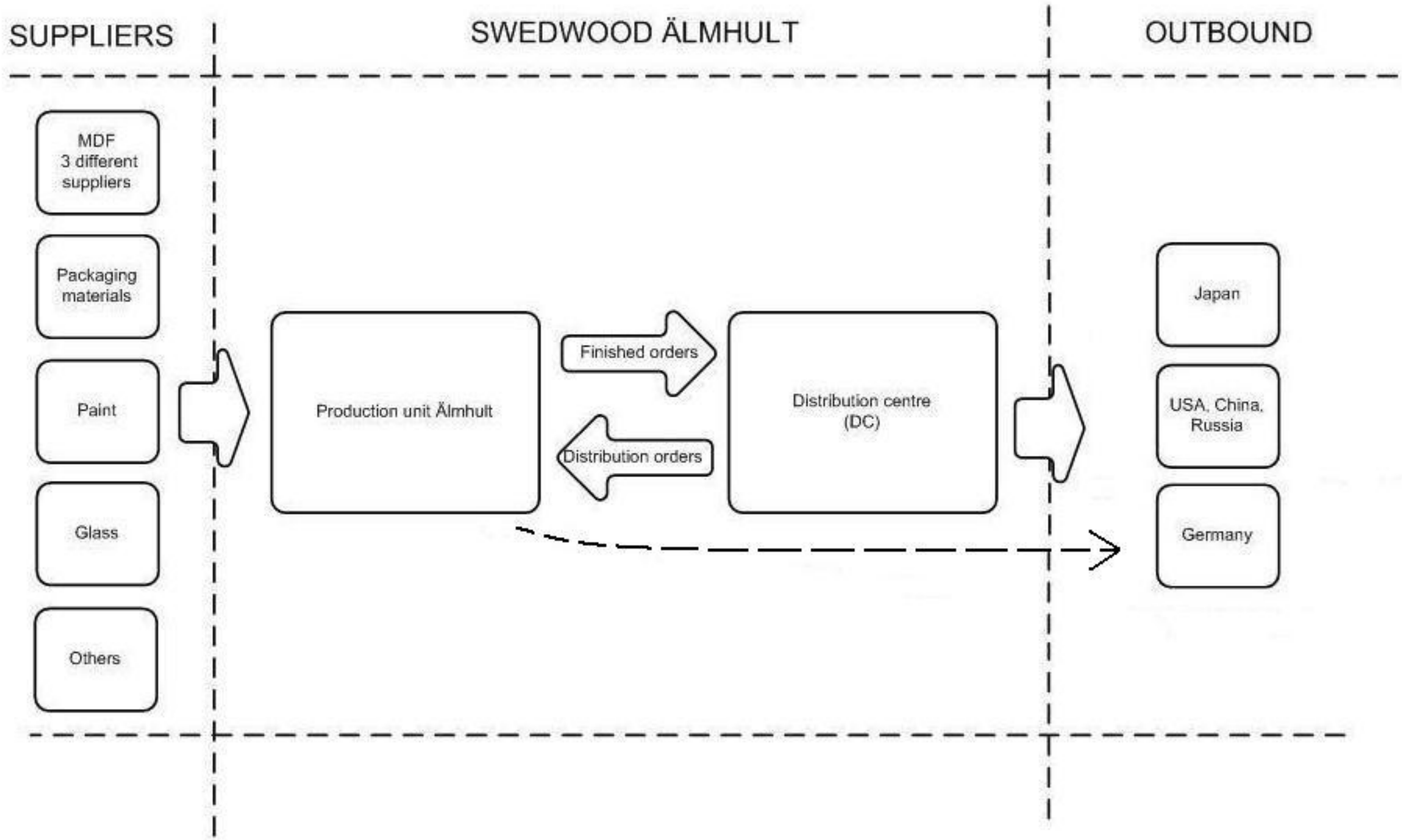

Figure 13. Supply and demand chain for Swedwood in Älmhult.

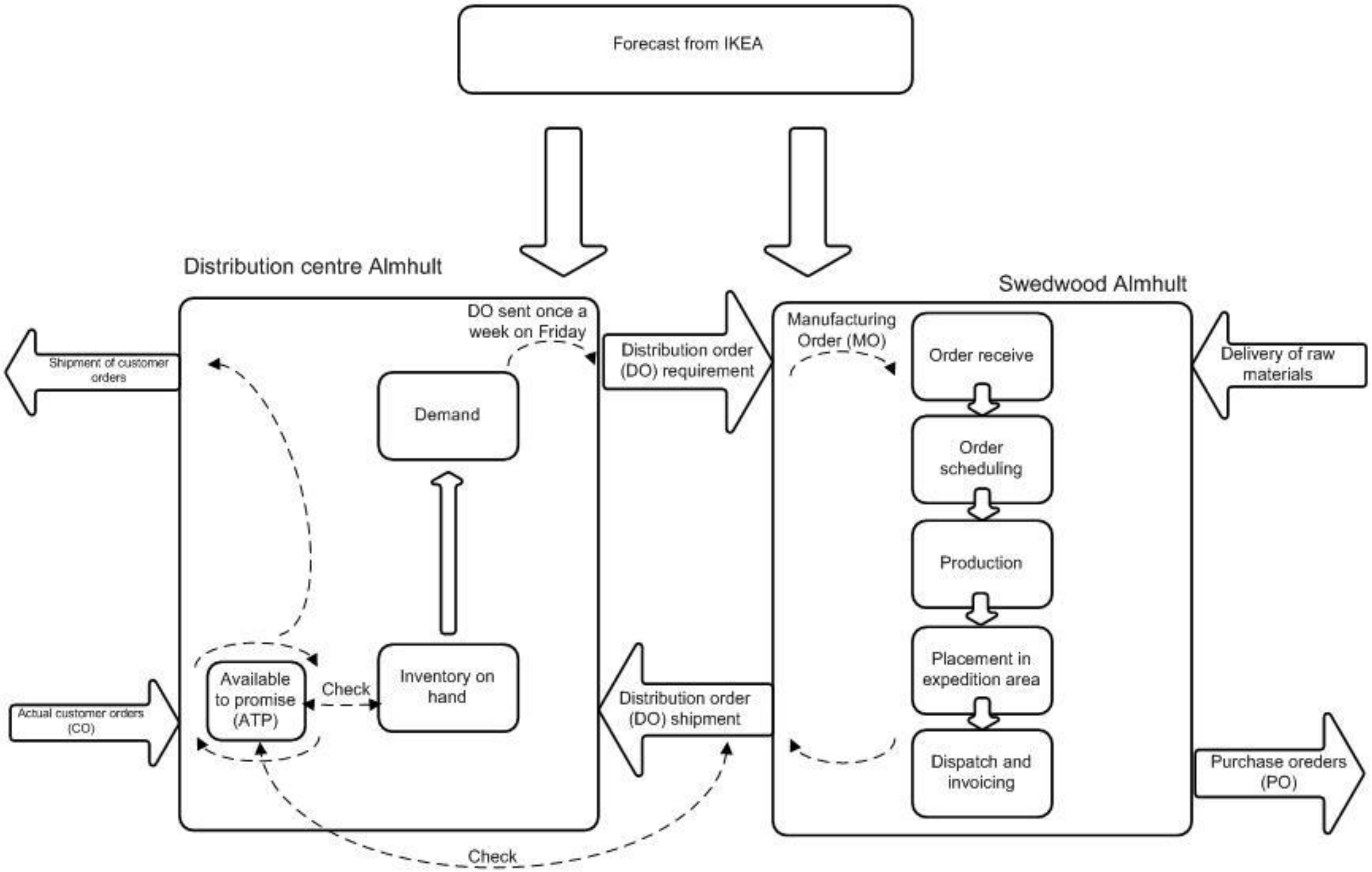

Figure 14. Material and orders flow between the factory and distribution centre.

4.3. Local scope of supply and demand chain

In the previous section overall scope of the supply and demand chain was presented. In this paragraph the relation between the production unit and the distribution centre in Älmhult will be described in details. The Figure 14 above illustrates this interaction.

The main triggers for production scheduling in a factory are distribution orders (DO) from DC and a forecast sent from IKEA. However, forecast from IKEA serves more for information purposes rather than detailed plan for scheduling the production. All documentation is transferred electronically through EDI.

DC receives both: forecast from IKEA and actual customer orders (CO) from local warehouses. Received orders are firstly checked if available to promise (ATP). During ATP process not only stock on hand is checked but also DO which might be on the way from the production unit. If required amount of products is in stock the products are taken and shipped instantly.

If items are not in stock neither in transit demand is created for the production facility in form of distribution order. To reduce amount of administrative work and consolidate the demand an accumulated distribution order is sent to the production unit once a week on Fridays. It is also done to decrease a risk of overproduction and to level off the production. Distribution orders are translated in the production facility into manufacturing orders (MO). MO schedule when certain type of article will be produced and in what batch. It also gives information to the DC when order is going to be ready for dispatch.

In order to simplify the order handling process and to enhance the information flow, recently a vendor management inventory (VMI) system was implemented. The system's role is to keep track of the stock levels in the distribution centre and to ensure that Swedwood products are available in the store at all the times. DC does not have to enter orders manually and Swedwood gets better visibility of the demands. The goal is to achieve more stable and even flow through the factory and at the same time create conditions for IKEA to keep higher service levels with lower stock levels.

4.4. Order fulfilment process

The order fulfilment process in the production unit can be defined as set of activities, which have to take place in sequence to fulfil the demand request for a certain product from distribution centre. The main activities are presented in the Figure 15.

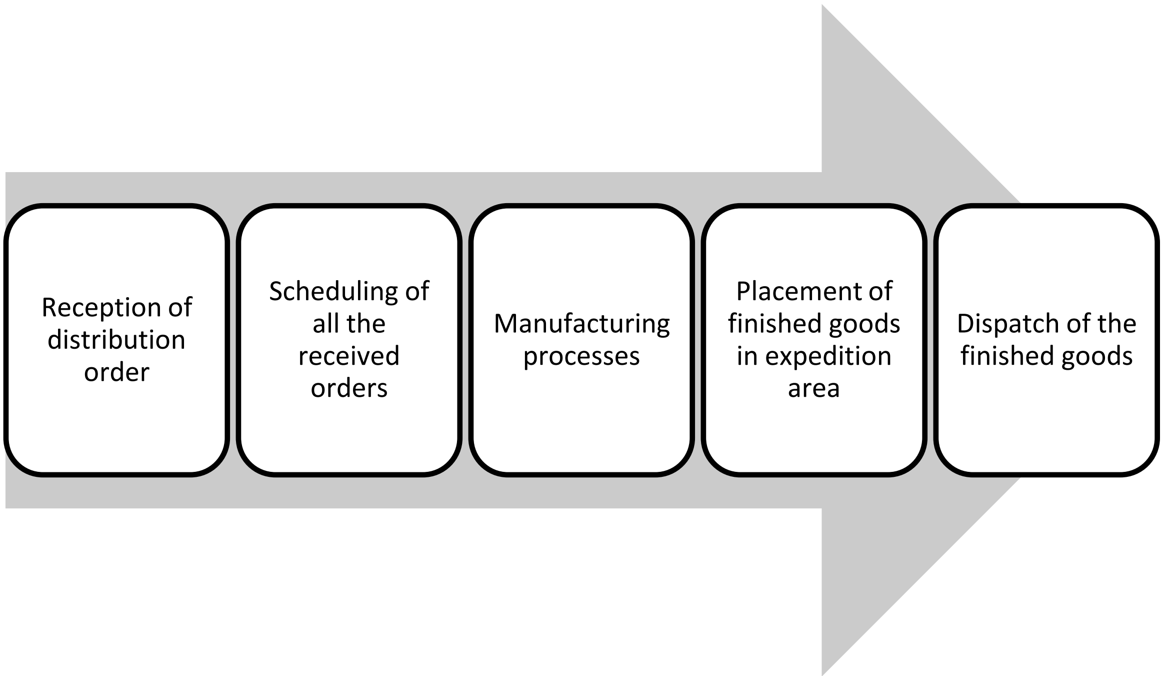

Figure 15. Order fulfilment process.

Once a week accumulated demand in form of a distribution order is received from the distribution centre. Orders are then translated into manufacturing orders and scheduled according to certain priority rules. Exact planning procedure is described in the next section. After that the manufacturing processes take place. The number of processes varies (from 7 to 13) for different articles and depends on the complexity of an article. The more complex an article the more processes it has to pass. Majority of value adding activities are performed during this step. After a product is finished and packaged it is placed in the expedition area. From there products are dispatched to a destination place.

4.5.Planning procedures

As described earlier accumulated distribution orders from DC are sent to production facility once a week on Fridays. Order sizes span from 500 to 3500 pieces depending on the article type. Beside this information, which is transferred by EDI, once every two weeks there are meetings between planners from DC and production unit. The aim of the meetings is to verify the master production plan for the factory. These meetings also enhance information sharing between actors and help to decide what should be a sequence of production. The sequence depends mainly on the level of safety stock, amount of customer orders for particular product and due dates for these orders. Another factor which influences the sequence is batch sizes. Batch size states about number of pieces of particular product in one batch in order to start production. Hence, if distribution order from DC does not fulfil this requirement the order is postponed until demand will be big enough (at least one batch size) to release manufacturing order.

The exact production sequence for the upcoming production week, which always starts on Mondays, is decided on Fridays. However, as presented on the Figure 16 below the planning period in the production unit in Älmhult embrace four weeks ahead. The level of details differs for every week.

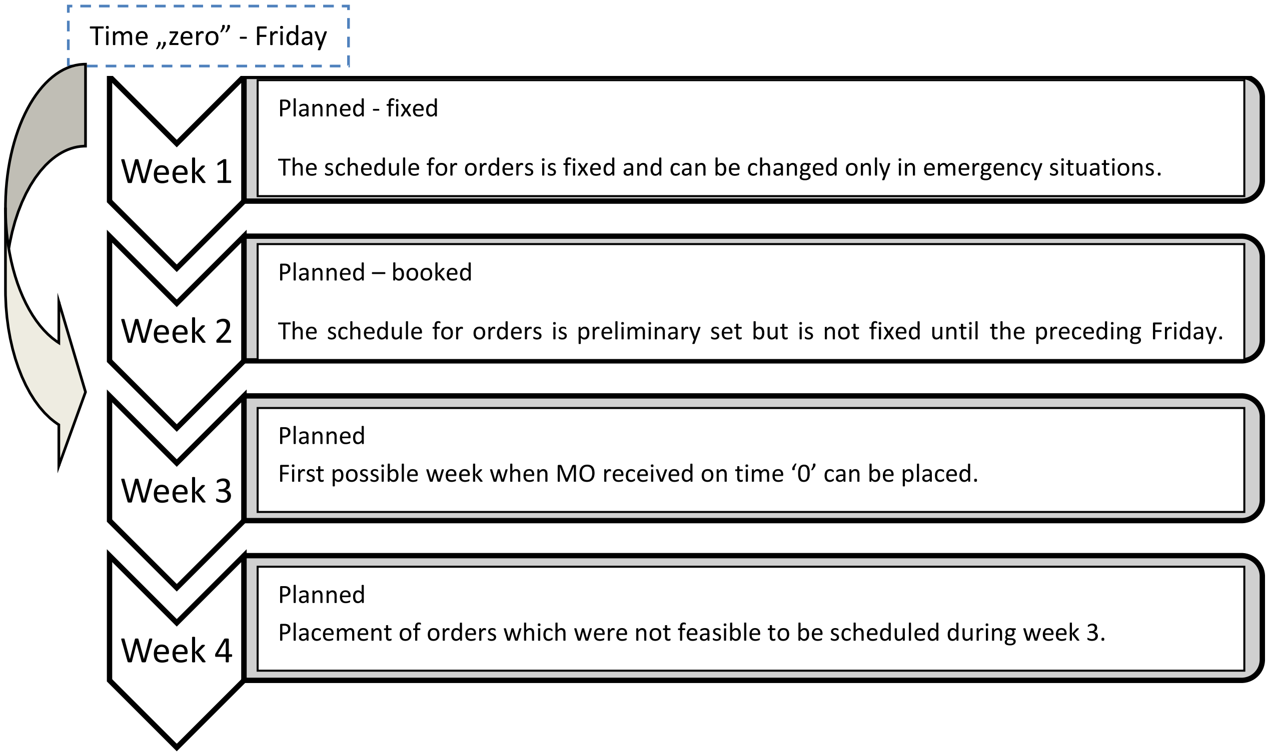

Figure 16. Planning procedure in the factory in Älmhult.

Assuming that the time "zero" is Friday, the day when accumulated DO is received from DC, the soonest possible week when currently received DO can be placed is the beginning of the week 3. The reason is that the initial schedule for the week 1 was already decided on Friday two weeks before time "zero" basing on DO which was received at that time. However, not until Friday time "zero" the exact schedule for the production week 1 is set. The main reason is to be able to respond to sudden or unexpected changes in demand. Hence, if any kind of such change occurs it is possible to place an order earlier. These situations are rare and the production plan for upcoming week 1 is fixed and usually cannot be changed. The other reason for change of the schedule in week 1 can be a situation when a machine in the production unit breaks or there is a shortage of raw material for a certain order.

In the same way the production week 2 is preliminary booked with orders which were received one week before time "zero". However, the schedule of the orders is not fixed until the Friday which precedes the production week 2. The logic for planning the production schedules follows the same manner continuously.

For the majority of products the production intervals amount from one to two weeks meaning that DO for particular product is released once every week or every two weeks. However, looking on the way back of DOs from production unit to the distribution centre they can be shipped any day during the week thanks to proximity of both units and lack of fixed schedules for inbound deliveries to DC.

4.6.Product data

Despite of relatively few finished product types there are over 400 types of articles which are produced in Älmhult. The reason of so wide range of articles is that each of finished product type has several size standards. All the produced articles in Älmhult can be divided into groups depending on the type of flow through the factory. Products with the same or almost the same flow are ascribed to the same product group. Figure 17 presents an annual demand for different product groups.

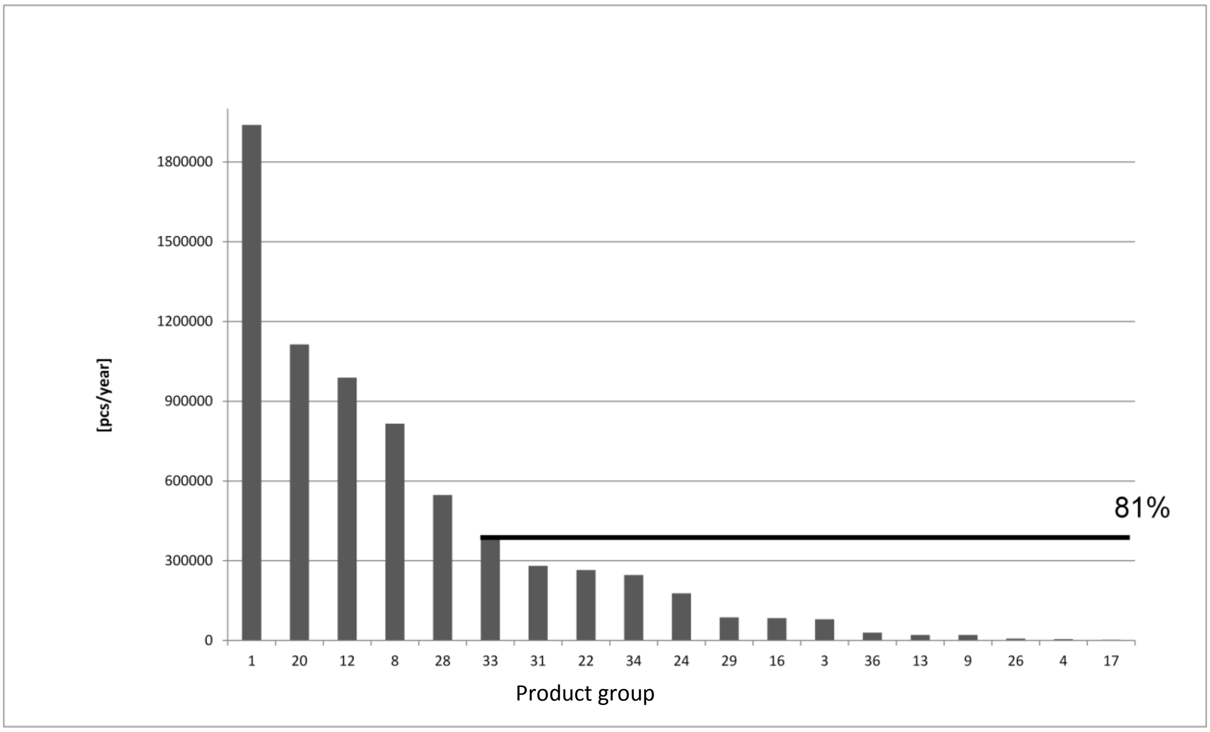

Figure 17. Forecasted demand for specific product groups.

It can be seen that out of 36 different product groups there are four major groups (1, 8, 12, 20, 28, 33) which constitute majority of the demand (approximately 81%). In total a forecast for the fiscal year 2010/2011 amounted to over 7 million articles. It illustrates the scale of the production.

Product service class

IKEA distinguishes five different service classes of products: S0, S1, S2, S3 and S4. Swedwood complies to this division. The S0 service class is the highest one and the products which are qualified in this class require a service level of 100%. It means that these products have to be always available - the safety stocks are kept on appropriately higher level. Service class S0 is used mainly for the products from kitchen segment. Hence, the products manufactured in Älmhult are qualified to this service class. The reason is that kitchens are sold as complete kits and all parts have to be in stock to be able to sell complete product to the end customer. The S1 service class requires 99% of service level, the S2 97%, the S3 95% and S4 90% of service level respectively.

These service classes are set on the basis of IKEA definition of service level for a product. Service level for a product is ratio between the number of stores which have particular product in stock and number of stores which would like to keep a product in stock.

Product's bill of materials (BOM)

Bill of materials can be defined as listing of all sub-assemblies, intermediaries, parts and raw materials that go into a parent assembly showing the quantity of each required to perform an assembly. Sometimes it is also called as product's structure (Jonsson & Mattsson, 2009).

Low complexity of the products manufactured in Älmhult causes that the bills of materials are simple. End product consists of small number of components. For majority of products sent to IKEA the BOM has just one level. It means that an article which is sold to IKEA is equal to production article and does not consist of more than one component which is transformed to have the final shape. However, there are also some products which have second and third level of BOM. If product consists of more than one component it is assembled just before the packaging stations. Example of products which have higher level of BOM are glass doors which consist of a frame and glass filling.

Routing of a product

The definition given by Jonsson & Mattsson (2009) states that routing is information which details the method of manufacturing of a particular item. It includes the operations to be performed, their sequence, the various work centres involved and the standards for set-up and run. As mentioned previously there are over 400 different articles produced in Älmhult and each product has its own routing file where all operations and their sequences are described in details. The file also contains information about cycle times on specific machine, dimensions of the article and bill of materials. Since there are so many articles they were divided into groups as described before.

Figure 18 below presents the routings for different product groups in Älmhult. On this figure machines are represented by bigger circles whereas product groups are depicted as smaller circles with group number inside. Arrows indicate the direction of the flow. If there is a loop it means that a product has to pass specific machine two or more times. Some of the products have to pass one operation up to six times. It happens mainly in the lacquering department where several layers of lacquer have to be applied. The aim of creating this graph was to facilitate tracking the order of operations through which specific product group has to pass.

There are three main machines where all the product can start: B44, B45 or A17. On these machines the major cutting and drilling operations are performed and they are automated. On the other side there are four packaging machines where products finish production process. Machines I61, I62-63 are automated while two other are operated by people. Each machine is adapted to different product sizes. On these machines the final quality by the employees is done. Products with defects are directed to be processed one more time. It may happen that whole batches are sent back to be re-worked.

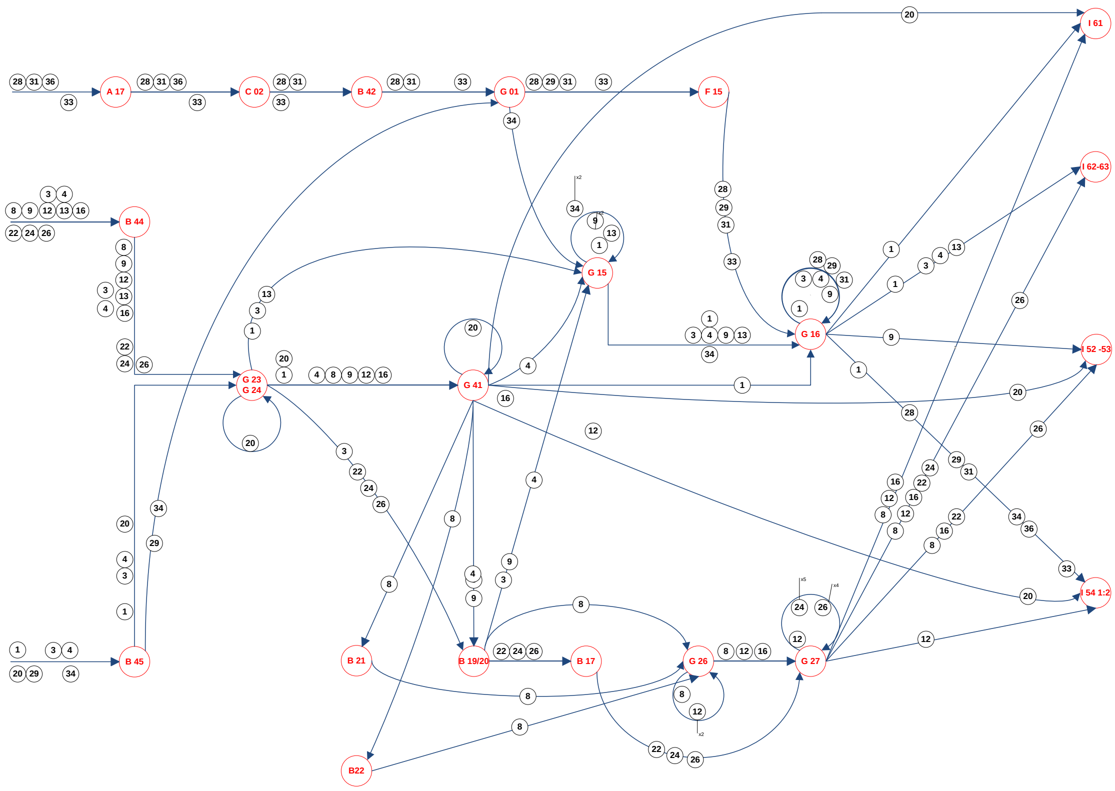

Figure 18. The net showing routing for each of the product group.

Batch sizes

Batch size can be seen as a unit of measure which states about number of pieces required in order to start production process. Nowadays batch sizes used in Älmhult are decided in many cases on empirical base. The aim of creating batch sizes is to maximise utilization of the machines.

Nr.	Swedwood article number	Description	Min. number of pieces	Max. number of pieces
1	AE002	APPLÅD	1650	1650
2	DE003	DUVBO	1400	1400
3	BL008	BIRKELAND	1050	12600
4	LE014	LIDINGÖ VITRIN	2200	4400
5	PF003	PERFEKT TÄCKSIDA	2400	4800
6	SN004	STÅT NA VIT	840	840

Table 1. Batch sizes for different product types.

There are two values for batch sizes: minimal and maximal. Demand for minimal number has to be fulfilled in order to start production of particular product. The maximal number of pieces per batch size is usually defined as multiple of minimal number of pieces per batch.

Products have different batch sizes. One of the issues which are taken into consideration when a batch size for an article is set is the space consumption. If a product consumes relatively big area on the conveyor belt the batch has to be adjusted so that enough space is left for other products. In the opposite situation the batch can be bigger.

Another issue are cycle times (in Swedwood term closely related to cycle time is name plate capacity (NPC); explained in section 4.9). If a product has relatively long cycle times the batch size cannot be too big. Otherwise it will cause that production of particular product will take too long time and production of other products will be belated.

One more factor influencing batch size is number of pieces which can be stacked on each other and create so called block. Number of pieces in one block depends on the thickness of an article. Moreover, there is a limit of maximal height in the production processes which cannot be exceeded due to specifications of the machines. Hence, basic batch size can consist of one or more blocks.

4.7.Machines

As mentioned at the beginning of the thesis the layout of the factory is oriented toward the flows of the products. However, this is a recent change. Previously the factory was divided into three main departments: the machining department, lacquering department and assembly and packaging department. The change into flows orientation was made to facilitate products tracing and also better information sharing between subsequent machines.

The Figure 19 below presents the layout of the factory. All the production processes start in the machining department, which can be seen on the right side of the figure. There MDF are processed and shaped to required dimensions. The warehouse with MDF is placed in the bottom right corner. Distances of materials movement are minimised due to proximity to machining department. The lacquering department can be seen in the middle marked with grey colour. Processes within this department are important because it is the place where all the jobs connected with putting paint or lacquer are done. Assembly and packaging department visible on the left side of the figure is a place where final assembly take place and where products are packaged. Another role of the department is final quality inspection before products leave the factory.

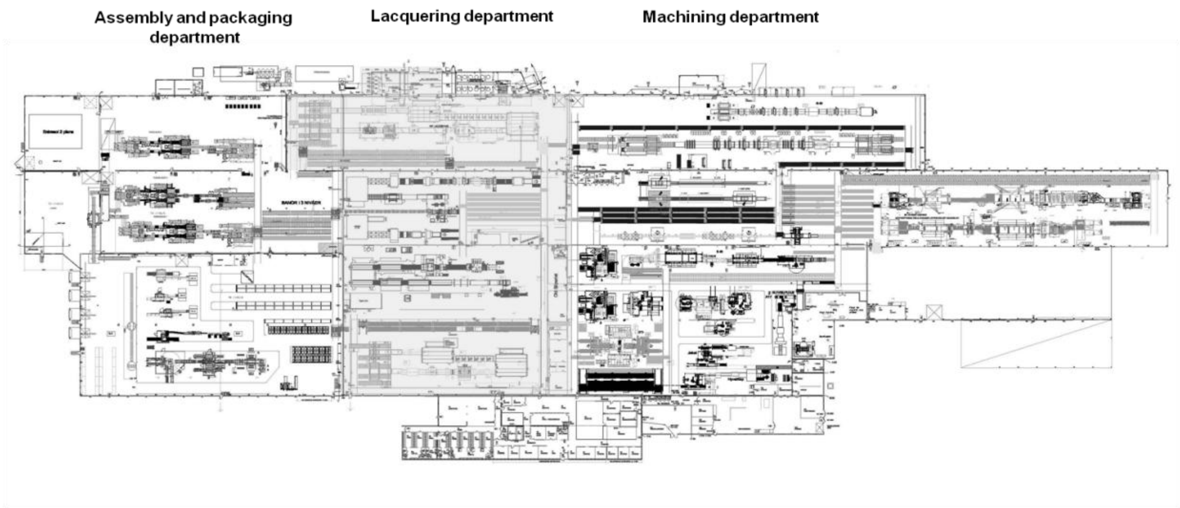

Figure 19. Organization of the production unit in Älmhult.

Machining department

Machining department processes the raw material, MDF, and shapes the fronts to a required form. The major types of machines which are utilized are described below:

- Double end tenoner: where edge and edge profiles are processed and created, hinge holes are drilled, longitudinal milling of grooves can be done as well.
- Computerized Numerical Control (CNC) machines: used for milling of more advanced front designs. The machines are equipped with tool exchange gear that can be loaded with up to 10 tools.
- Components: produced in a series of machines that split, cut, mill, sand, mould and drill the material.
- Mock-up workshop: where any type of front can be produced. This is a great advantage for IKEA when new products have to be developed.
- Feeding, stacking/un-stacking: performed automatically by robots in most of the machines.

Lacquering department

In this department all the jobs connected with putting lacquer or paint are done. A number of different production methods are used to ensure that all fronts get a surface of required quality. The lacquered surface is most important for the end product since it has to protect it from all the external factors.

- Edge spraying: fully automatic machine which assure the correct amount of paint is applied on every item.
- UV lacquering line: in a UV-line the paint is roller-coated onto smooth surfaces and drilled and cured instantly under ultraviolet light. The process is very effective and is finished within seconds. Product's surface can be immediately sand down and more layers of paint can be added without additional time losses.
- Spraying line: in a spraying line the paint is applied through rotating nozzles, which generate a very good surface even on patterned surfaces. A polyester paint that creates a very durable and even surface is used. The paint is dried and cured at around 100 Celsius degrees.
- Feeding, stacking/un-stacking: is made automatically by robots in most of the machines.

Assembly and packaging department

Famous IKEA's end product, the flat packages are produced in this department. There are a number of different packaging alternatives:

- Glass door assembly: where glass doors are inspected and nailed manually.
- Assembly line: where up to nine different components and fillings are fit together into, for instance, frame doors in an automatic assembly line.
- Packing machines: in the packing machines smaller products like drawer fronts and products with more than one product in each package are packed together.
- Packing robots: are packing the main parts of products together with fittings straight into the finished goods package; the flat package.
- Inspection of products front and back sides is done manually or with automatic vision system, defects products are stored out in the line before packaging.

There are 27 different machines on the shop floor. Beside machines there are several manual stations where different operations are performed i.e. assembly of glass into cabinets, some re-work operations. Set-up times are the average time needed for machine when settings have to be changed according to specific order. For some machines no set-up times exist since operation they perform is the same for all articles.

4.8.Stop times

Factory in Älmhult is equipped with a system to register stop times of the machines. The operators are supposed to assign the reason of a machine being idle to previously defined stop time category. There are eight general categories of stop time's reasons defined by the company:

- Flow problems: there was a problem on the input or output of the machines which stopped the flow.
- Category (not named) specified individually for every machine: this category of stop time precise for every machine subcategories connected with specific parts of the machines where the error was discovered. The reason of having this category is that each of the machines is unique and is build from different components.
- Scheduled maintenance or improvements: this category contains stop times which were planned in advance in order to install some improvements or perform the maintenance which was planned.
- Quality control or quality problem: stop time is assigned to this category if quality control is performed or the machine is idle and the operators are waiting for the decision if the quality of the products is approved or not.
- Downtime: this category contains stop times connected with the product change, colour change etc. Content of this category is highly related to set-up times (part of the stop times in this category can be explicitly categorized as set-up times).
- Lack of manpower: the line is standing still because there is lack of people who can operate the machine.
- Cleaning: the line is stopped to enable cleaning which was planned before.
- Others: everything which cannot be assigned to previous categories (e.g. fire alarms) is put here. Usually in case of using 'other' as a category broader explanation of the reason of the stop time is written as an extra comment.

All the categories can be expanded to several subcategories.

(Standard-Stop-Code Registering: internal procedure of Swedwood)

- Flow problems
- Specific to particular machine
- Scheduled maintenance & improvements
- Quality control or quality problems
- Dowtime
- Lack of manpower
- Cleaning
- Othes

Figure 20. Categories of stop times

All the stop times are registered into the database which is administered by information technology (IT) department. There is a possibility to export part of the data from the database into a report file. Exemplary table from a report can be seen on a Figure 21 below. In the given example the report was created for the machine B44. It can be seen that exact time is given when the break took place and how long it lasted. Furthermore, the reason of the stop is given by hand description and choosing suitable code of stop reason.

Machine	Machine hand description	Stop code description	Shift	Start time	Stop time [s]	Stop code
B44	ÖVRIGT	RAST	B44-3	2011-03-01 01:13:22	1204	B44.15.07
B44	PC52	INSTÄLLNING	B44-3	2011-03-01 02:38:32	440	B44.06.01
B44	ÖVRIGT	RAST	B44-3	2011-03-01 03:24:40	1004	B44.15.07
B44	PC52 setup	INSTÄLLNING	B44-1	2011-03-01 06:05:27	900	B44.06.01
B44	PC52	INSTÄLLNING	B44-1	2011-03-01 06:21:29	1310	B44.06.01

Figure 21. Stop times report file.

Reasons of the stop times are analysed in details in empirical analysis part of the report. The analysis will be performed only for the machines which were identified as bottleneck resources.

4.9.Name plate capacity – NPC

As described earlier in the text NPC is the abbreviation of Name Plate Capacity. For majority of the machines NPC is dimensioned in number of pieces which can be produced during one minute. However, for some of the machines more reliable number is amount of square meters produced during one minute. Recently in manufacturing unit in Älmhult the file called 'Capacity plan' was created. In the file NPC values are given for every article and every machine. The file contains the routings of the produced articles, forecasted yearly production mix and is supposed to be an aid for the planner for daily balancing of the factory.

Moreover, the file contains the maximal capacity of the machine when specific article is produced (what is the NPC of the given machine when particular product is refined). As said before the most commonly used unit is number of pieces per minute. NPC data from the 'Capacity plan' were used in the further calculations. Part of the 'Capacity plan' is depicted in the Figure 22 below.

5	Min./shift:	450	7,5
6	Shifts/FY when running 1-sh. Op.:	230	
7	Min./FY & Shift:	103 500	

B44 - Dubbeltapp

rm/min	32	m/min
dist b dogs	0,5	m
NPC	64	pcs/min
OEE:	49%	
Timeloss	50%	
Speed loss	0%	
Qloss:	2%	
Manning	1	op.'s

				Artikelnu Packen	Artikelnummer Produktion												
18	Flödes-id:	Beskrivning/Description	IKEA Art No.	Prod. Art no, (Pack)	Prod Art No, (Prod)	Längd/Length	Bredd/Width:	ek/Thicknes s:	Area/bit (/pcs)	= Sälj/Sales vol.	Antal Prod art./Sälj art.		NPC, (pcs/min)	Capacity$_{OEE}$, (pcs/min)	Capacity$_{OEE}$, (pcs/shift)	Belagd/Load - 1 shift:	Kommentar
19															5 233	207%	
20						mm	mm	mm	m2				10				
189	12	STÅT 60/125 APCN	10 187 974	SK029		1 245,0	595,5	19	0,74	612	1		15	7,4	3 308	0,1%	
190	12	STÅT 60/194	84 627 310	ST012		1 942,0	595,5	19	1,16	7 985	1		15	7,4	3 308	1,0%	
191	12	STÅT 60/194 APCN	80 187 975	SK012		1 942,0	595,5	19	1,16	572	1		15	7,4	3 308	0,1%	
192	3	STÅT 70 PAR/HÖRN VIT	40 041 715	ST026	ST xxx	694,0	300,0	19	0,21	26 674	1		22	10,8	4 851	2,4%	
193	4	STÅT 70 PAR/HÖRN VIT APCN	60 187 981	SK026	ST xxx	694,0	300,0	19	0,21	1 544	1		22	10,8	4 851	0,1%	
194	33	STÅT 80-1 LÅDFRONT	10 072 124	ST039		796,0	126,0	19	0,10	41 206	1						
195	33	STÅT 80-1 LÅDFRONT APCN	70 187 990	SK039		796,0	126,0	19	0,10	1 821	1						
196	12	STÅT 80-2 LÅDSATS VIT	00 072 134	ST050	ST541	796,0	254,0	19	0,20	37 248	1		25	12,3	5 513	2,9%	
197	12	Raden ovan - 2:a lådan			ST543	796,0	310,0	19	0,25	37 248	1		25	12,3	5 513	2,9%	
198	12	STÅT 80-2 LÅDSATS VIT APCN	00 187 984	SK050	SK541	796,0	254,0	19	0,20	1 944	1		25	12,3	5 513	0,2%	
199	12	Raden ovan - 2:a lådan			SK543	796,0	310,0	19	0,25	1 944	1		25	12,3	5 513	0,2%	
200	12	STÅT NA INBYGGN 1021X758	20 052 781	SN056		1 021,0	758,0	19	0,77	0	1		25	12,3	5 513	0,0%	

Figure 22. Capacity plan Excel file.

4.10. Overall equipment effectiveness – OEE

The utilization rate of machinery is indicated by the overall equipment effectiveness factor. In an ideal situation a machine would produce 100% of the time available at 100% capacity with an output of 100% good quality. OEE is a measure that gives a complete picture of how effectively a production process is running. It includes all losses - not only how many products were produced but also how much the potential output was limited due to a lower speed or poor quality. OEE is a comparison between a non-defective output and a maximum output i.e. the name plate capacity during a running time. The losses limit a non-defective output and the reasons for not producing an expected amount of products are strictly related to these losses.

4.11. Working days in the year

On average in the fiscal year there are 254 working days. However, due to some events which had place in the last fiscal year i.e. IKEA's change in the quality specification and roof collapse; the decision was made that there will be no holiday break in the fiscal year 2010/2011. Decision was made mainly to reduce the backlogs which occurred and to catch-up demand. Hence, in the fiscal year 2010/2011 number of working days was extended by 28 days. The total number of working days is equal to 282. This number was used in further calculations.

4.12. Shifts

There are five shifts working over the week. The reason is high demand therefore there is a need for equipment to run every day. The total number of working hours per month differs for each shift. This is due to existence of day, evening, night and weekend shifts.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Shift 1	X	x	x	x	x		
Shift 2	X	x	x	x	x		
Shift 3	X	x	x	x			
Shift 4					x	x	x
Shift 5					x	x	

Table 2. Shifts schedule in the factory in Älmhult.

Table 2 above presents on which specific days during the week each shift is working. Every shift has an appointed shift foreman. This person is responsible for coordination and controlling of activities during the shift. If something goes wrong workers are obligated to report firstly to this person.

There is a certain time assigned when shifts are changing. This overlapping of shifts was introduced so that workers have time to hand over responsibilities without stopping the production. This is especially important for machines which are utilized to high level.

In this thesis simplification was made to facilitate analysis. Calculation was made about the average available working time per day. The result was that on average there are 21 hours of available working time every day. Total working hours per year for each shift was summed up and divided by number of working days. Data were taken from the fiscal year 2010/2011. No sick leave levels were taken into consideration, neither absence. Also the assumption was made that there is no lack of manpower to operate specific machine if needed.

5. Generic model

This chapter presents a general introduction to the model. Firstly the general description is given and the results of SWOT analysis. After that the purpose of the model is described and different flow cases. The general steps of the model, input data and the main outcomes of the model are described as well.

5.1.Introduction to the model

The decision about improvement alternative to develop a generic model was made with agreement of the stakeholders. Researchers based the model on the theory of constraints concept. This framework for managing the flows with focus on bottleneck resources in the first place helped to develop the model in a structured way. The empirical analysis was performed in the excel software and is described in next section. The outcome is a spreadsheet developed in excel and manual how to perform all the steps in order to calculate needed buffer sizes.

Since, the objective was decided the researchers performed SWOT analysis to evaluate the strengths, weaknesses, opportunities and threats associated with development of this model. The results of the analysis are presented in the Figure 23.

Figure 23. SWOT analysis of a chosen improvement alternative.

The main strengths of the model are that it is easy to use, generic, can be applied in a short period of time and is developed in an excel software, which is already used in the company and workers are familiar with it. The main opportunity is that model can help to increase the flow by improving OEE of bottleneck resources. At the same time investments needed are on the low level. However, there were realized weaknesses like: need for periodical review, implementation of the model needed in the whole factory to give good results. The simulation of the model is needed before implementation which is time consuming. The main threat of the approach is that unreliable input data may result in the same or even lower performance of the production system. Hence, it is crucial for the model to have accurate and reliable input data. Despite of identified weaknesses and threats it was concluded that strengths and opportunities predominate.

Taking into account the outcomes of the analysis, given resources, time-frame and researcher's experience it was concluded that the model is right approach to optimize the production flow.

5.2.Purpose of the model

The purpose of the model was to find the size of the optimal inter-stage buffer between two subsequent machines. The adequate buffer had to be set to protect the machine from the input material starvation. Lack of input material can take place due to the fact that the feeding machine is not working for some reason. Having the optimal buffers from this perspective the flow through the factory is facilitated. In case of the bottleneck resources optimal buffers can be the factor which increases OEE and by that breaks the constraint which will lead to increased output of the factory.

Four basic flow cases, which are presented on the Figure 24, were distinguished for the purpose of the model.

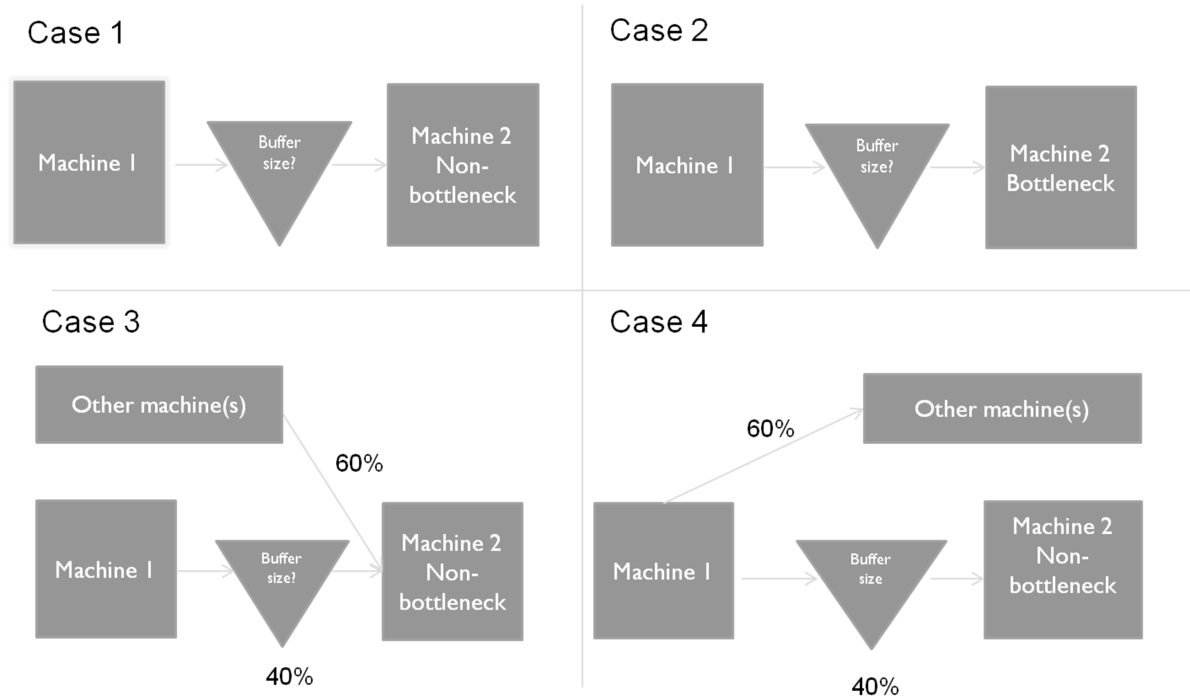

Figure 24. Flow cases Illustration.

Having defined these basic cases it was possible to depict all the production flow cases existing in the factory. Case 1 and case 2 present the situation when there is only one preceding resource before the machine for which the buffer is defined. In case 1 the consuming machine is not a bottleneck whereas in case 2 the consuming machine is a bottleneck resource.

Case 3 presents the situation when the consuming machine is fed by more than resource. Here two sub-cases can be distinguished: machine 2 in non-bottleneck resource and machine 2 is a bottleneck resource. Depending on the sub-case, case 3 has to be combined with case 1 or case 2.

Case 4 shows the situation where a consuming machine 2 is fed by resource which distributes its products to more than one machine. Here two sub-cases can be distinguished again: machine 2 is a bottleneck resource or machine 2 is non-bottleneck resource. Depending on the sub-case, case 4 has to be combined with case 1 or case 2.

5.3. Steps of the model

Three basic steps of the model can be distinguished. Each step consists of several actions which need to be taken. Figure 25 presents the basic steps of the model.

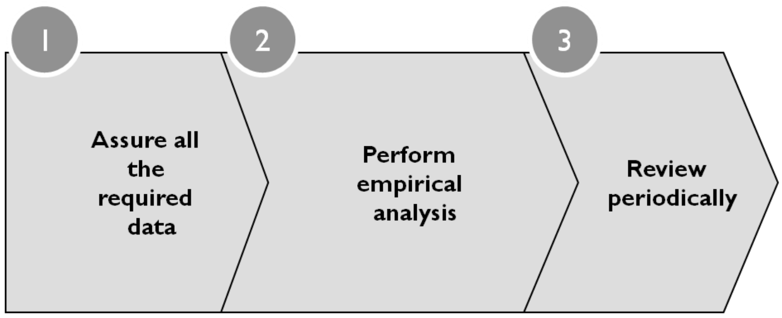

Figure 25. Basic steps of the model.

First step of the model before performing an analysis is to assure that all required data are available, reliable and accurate. Required input data to the model are defined in the next section.

Second step is to perform the empirical analysis. The description of the way how the analysis should be performed is presented in the chapter 6. Moreover, there was created a manual which guide the user step by step how to make the analysis. The result of the second step is defined buffer size in time unit for every machine.

Third step, which coincide with continuous improvement philosophy, is to review the model periodically. The time interval of the review can be decided freely by a user. However, it is recommended to do the review at least once a month.

Every buffer is dimensioned in time unit. Defined buffer in time unit has to correspond to the production time of consuming machine i.e. Figure 24 – case 1, if the buffer for the machine 2 was defined to 10 hours it means that there has to be enough pieces for the 10 hours of production time of machine 2.

The reason for dimensioning the buffer sizes in time unit is constantly changing production mixes in the factory. Fixed schedules of production mixes do not exist. Because of that it is not possible to predict what will be the production mix during specific day. Hence, having buffer dimensioned in a time unit it is always possible to translate it to current production mix.

5.4.Input to the model

All the required data for the model were firstly gathered during the visits in the production facility. The actual input data for the model were obtained through several transformations of these data. The input data to the model are presented in the Figure 26.

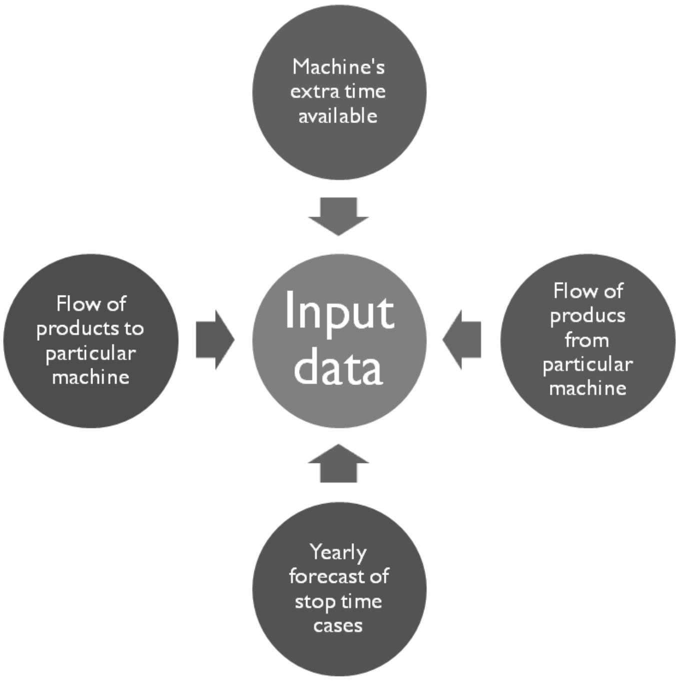

Figure 26. Input data to the model.

More detailed description of input data is presented in the following chapters:

- Machine's extra time available – presented in the chapter 6.3
- Yearly forecast of stop time cases – presented in the chapter 6.4
- Flow of products to particular machine – presented in the chapter 6.6
- Flow of products from particular machine – presented in the chapter 6.6

5.5.Output of the model

The main benefits of the model are presented on the Figure 27.

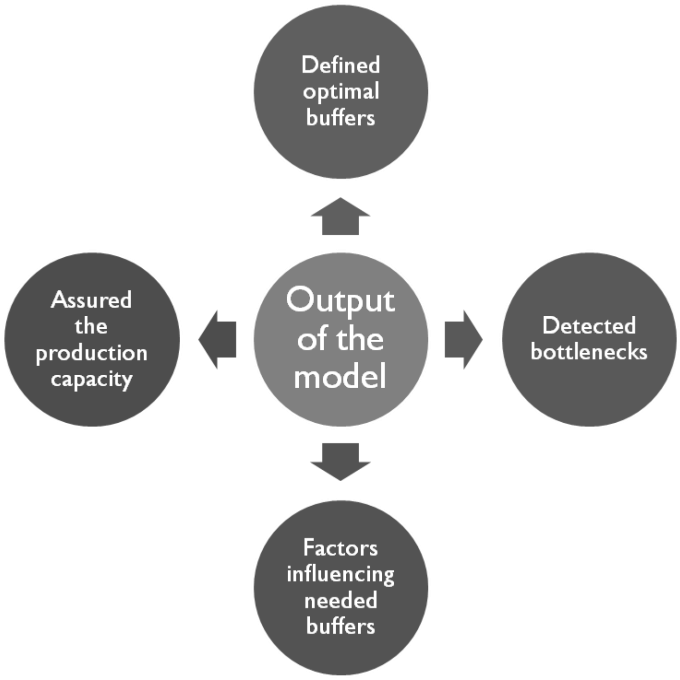

Figure 27. Output of the model.

The main benefit of the model was that optimal buffer for every machine was defined. The optimization was done from the perspective of facilitation forecasted production volumes and increasing OEE of bottleneck resources. Identification of bottleneck resources is another benefit of the model. Analysis of the stop time reasons helped to identify what are the main factors influencing needed buffers. Last but not least the model assures the production capacity for the demanded volumes. These benefits are further discussed in chapter 7 and chapter 8.

6. Empirical analysis

This chapter presents the way how the analysis of gathered data was performed in order to get input data for the model. Firstly the bottleneck resources are identified by checking the utilization rate of the machines. After that the results of analysis of stop times are presented and indicators for improvement. The incoming and outgoing ratios for every machine were calculated. At the end the results of different buffer settings is presented and the final buffer capacity for every machine.

6.1.Utilization rate of the machines

The utilization rate of a machine is defined here as a ratio of annual load on particular machine and annual available time on a machine.

This data was needed to be able to identify the bottleneck resources. Yearly demand for every machine was taken into account.

Calculation of the utilization rates and indication of the resources which are the bottlenecks is equivalent to the first step of the Theory of Constraints - identify the constraint.

Utilization rate of every machine was calculated in the following way:

'Annual available time of a machine' was calculated by multiplying all the available working days during the year and average number of working hours during a day. Then the result was multiplied by OEE of every machine. It was done to take into account all the stop times existing on particular machine. Used formula is presented below.

'Annual load of a machine' was calculated as a sum of the time required to produce all the articles passing through a particular machine. The result was divided by 60 to get the result in hours.

Data bout annual demand for a product was taken from the forecast for the year 2011. Hence, '*Annual number of pieces of a specific article produced'* was known.

6.2. Identification of the constraints

Having the utilization rates of the machines it was possible to identify which of the machines are the bottleneck resources on annual base. The resource is stated as a bottleneck when it is already operating at its full capacity (Vollmann et al., 2005). In other words if utilization rate of the machine is equal or higher than 100% then it is assumed to be a bottleneck.

Figure 28 shows five machines which capacity is exceeding 100%. These machines are: G24, B19/20, B17, I54 and Birkeland packing and these machines were identified as bottleneck resources. Birkeland packing is the machine that does not exists in Älmhult factory anymore so it was excluded from further analysis. Rest of the machines, which are utilized to a high level, do not have any extra available capacity. Thus, they are causing a loss for the whole system in case of being idle. The production capacity of the factory is equal to the weakest link – the output of a bottleneck resource. This time lost on the bottleneck cannot be recovered in any way. Hence, special attention should be paid to these resources and all efforts should be made to increase the available production time as much as possible.

The rest of the machines are the non-bottlenecks. Hence, they have some time during the year when they can stay idle and it will not cause a loss for the production system.

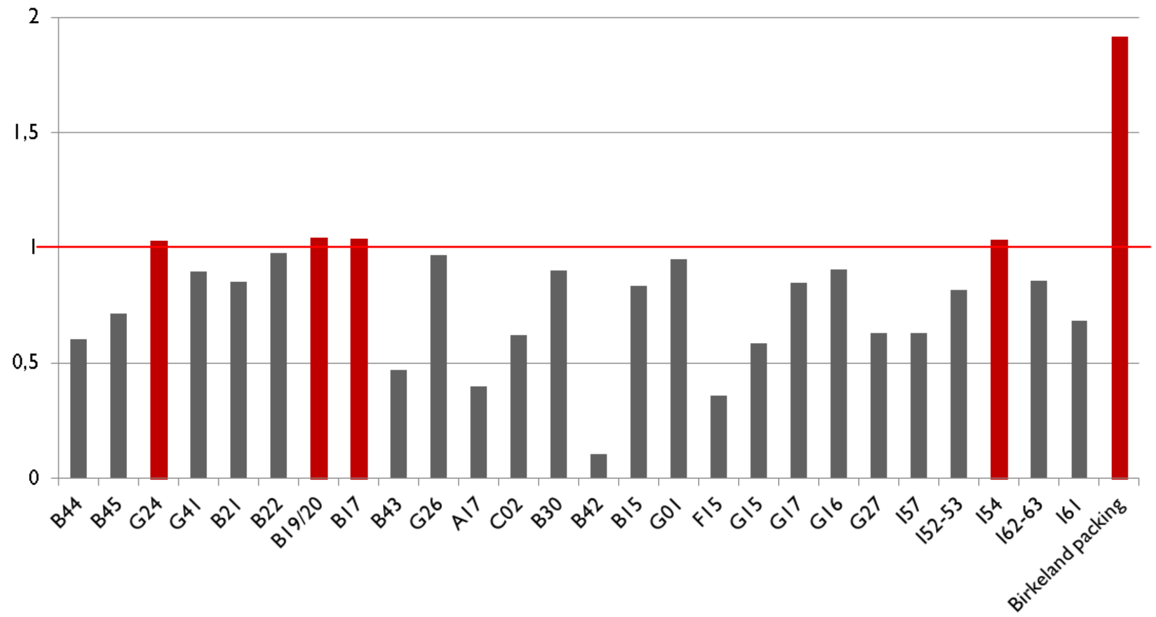

Figure 28. Utilization rate of the machines.

6.3. Machine's extra available time

Calculation of extra available time for every machine complies to the second and third step of TOC. It indicates that there is no extra available time for bottlenecks and to what extent they should be exploited. Furthermore, it is showed how much extra time other resources have which need to be subordinated to the bottlenecks.

As previously stated the bottlenecks are the resources with demand exceeding their available capacity. However, the production system consists also of non-bottleneck machines as well. Non-bottleneck resources have extra time available for the production since they are not operating at their full capacity. The situation is presented on the Figure 29.

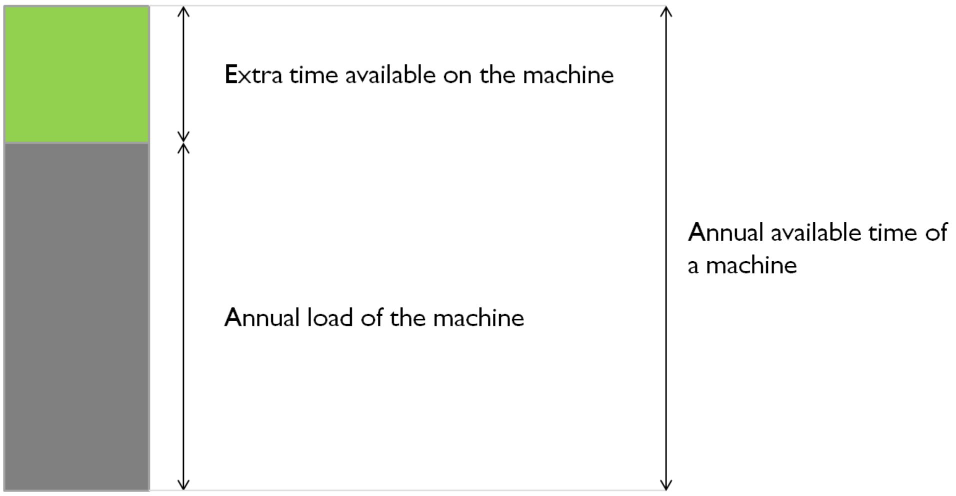

Figure 29. Machine's extra available time.

Jonsson & Mattsson (2009) stated that the machines should be idle during this extra available time because operating to extent higher than required causes only increase of inventories and work in process. Therefore, it is crucial to understand that there is nothing wrong if a machine stays idle in case when it is not a bottleneck resource.

Extra time available on the machine was calculated with the help of the following equation:

Annual available time of a machine was calculated already in previous section.

6.4. Stop times general analysis

This chapter complies to the second step of the theory of constraints. The analysis of the stop times allow to see if there is improvement potential for a particular machine.

For most of the machines the data from March, April and May were used. However, there were some machines were the registration of stop times was started only recently in comparison to the rest of the machines. There were days when the registration of stop times was not performed at all on some machines. In this case only available data were used.

As can be seen in the Table 3 daily stop times of the machines were divided in the intervals of 0,5 hour. Column named 'Cases' presents number of occurrences of stop time within the given interval. By dividing number of cases in the given interval by the total number of cases 'Frequency' was calculated. 'Yearly forecast of stop time cases' was calculated by multiplying 'Frequency' by number of working days in the year. Results for two of the machines are presented in the Table 3 below.

Machine's name	B44			B45		
Daily stop times interval [h]	Cases	Frequency	Yearly forecast of stop time cases	Cases	Frequency	Yearly forecast of stop time cases
0-0,5	0	0,00	0,00	0	0,00	0,00
0,5-1	0	0,00	0,00	0	0,00	0,00
1-1,5	0	0,00	0,00	0	0,00	0,00
1,5-2	0	0,00	0,00	0	0,00	0,00
2-2,5	2	0,02	6,20	1	0,01	3,10
2,5-3	4	0,04	12,40	1	0,01	3,10
3-3,5	3	0,03	9,30	2	0,02	6,20
3,5-4	2	0,02	6,20	1	0,01	3,10
4-4,5	3	0,03	9,30	5	0,05	15,49
...	...	...	...	...	...	...
23-23,5	0	0,00	0,00	0	0,00	0,00
23,5-24	0	0,00	0,00	0	0,00	0,00
Sum	91	1		91	1	

Table 3. General stop time analysis.

6.5.Analysis of the stop time reasons for the bottleneck resources

This chapter complies to the second step of the theory of constraints. The major reasons of stop times for bottleneck resources were analysed and potential room for improvements indicated.

Second step of TOC, exploit the constraint, state about increasing the uptime of a constraint (Jonsson & Mattsson, 2009). Data from the reports about stop times were used to perform the analysis and find the main reasons of stop times on bottleneck resources. Afterwards search for the areas of potential improvement was performed.

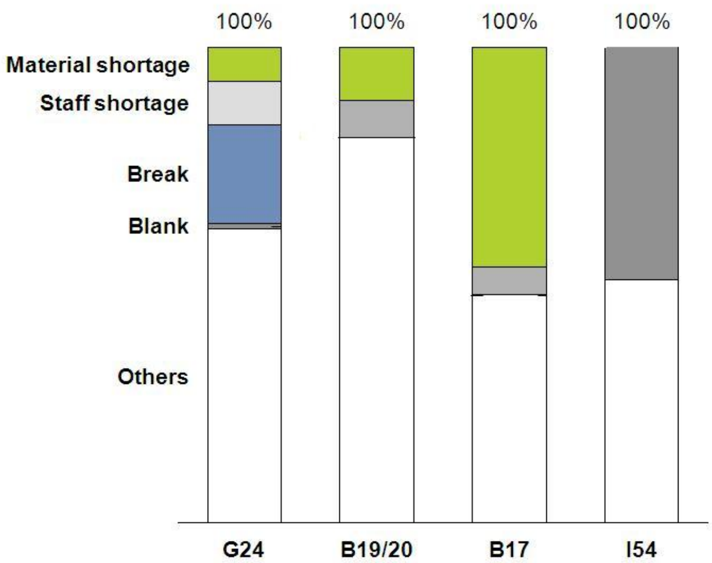

Figure 30. Analysis of stop times for the bottleneck resources.

Figure 30 presents analysis of the stop time reasons for the identified bottlenecks. Four major categories were distinguished which influenced the stop times in all bottlenecks: material shortage, staff shortage, break and blank. Within 'others' the reasons could be: specific to particular machine, scheduled maintenance and improvements, quality problem or quality control, downtime, cleaning.

G24

After the analysis of the stop time reasons for this machine the researchers noticed three possible areas of improvements.

First of all surprising is that breaks constitute high ratio of the total stop times. The data need to be revised and if the reporting reason is correct improvement action need to be taken immediately. This action could help to 'exploit the constraint' according to second step of TOC.

Secondly there is a problem with staff shortage. Hence, special attention should be paid to have always enough manpower to operate the machine. The operators should be also aware that their first priority task is to always operate the machine. The recommendation would be to train employees responsible for other machines how to operate G24.

The problems with material shortage (buffer problems) constitute also some part of total stop times. Hence, adequate buffers should eliminate this time loss. It is also recommended to revise the available size of the buffers in front of the machine.

Within other reasons there is as well room for improvement. Especially the time needed for cleaning and quality controls should be as short as possible.

B19/B20

Two major areas of improvement for this machine were found. Firstly, the problems with material shortage. This problem could be resolved by setting right buffers. Secondly, staff shortages should be minimised by providing enough manpower. The same as on the machine G24 the operators should be educated that this machine is a bottleneck resource and lost time on this machine causes loss for the whole system.

Within other reasons the stop times caused by the time needed for setting up a machine was significant. Thus, it should be considered to improve sequencing in order to minimise this time. Time needed for quality problems and controls was also considerable. Therefore, quality controls should be as short as possible.

B17

For this machine the buffer problems cause around half of stop times. Thus, this issue should be resolved on the first place. The buffers should be set and kept on appropriate level. By doing this the constraint could be exploited. Staff shortage constitutes significant part of stop times. Comparing to the problems with materials it is not much however, it should not be neglected and operators should be educated that it is a bottleneck resource.

Comparing to the rest of the bottleneck resources other reasons constitute relatively less stop times. Therefore, it is hard to indicate which particular reasons were the most significant. However, there is room for improvement in relation to: set-up times, cleaning and quality controls.

I54

Reporting of stop times on this machine was started recently. The categorization of the stop time reasons does not work in the correct way. Most of the stop times were categorized as short stops or others. The majority of the stop times were not categorized at all and the fields were left blank. There is no possibility to draw any conclusion for this machine. The recommendation is to improve the process of stop time categorization.

The main suggestion is that bottleneck machines should be prioritized during preventive maintenance and these jobs should be done in an efficient way. The time of quality inspection causing stoppage should be shortened as much as possible. Furthermore, adequate buffers should exist all the time to minimise stoppages related to material shortage.

The analysis of the stop times for rest of the machines was performed as well however, it is not presented in the report.

6.6.Product flow

Knowing the routing of products and total annual stop time for every machine it was necessary to know how the flow of the products between different machines looks like. Thus, the ratios were calculated of the incoming flows for every machine and outgoing flows from particular machine. This analysis shows what the interaction between specific machines is. This data serve as an input for calculation of needed buffer sizes.

Flow of products incoming to particular machine

Table 4 shows what ratio of total production time of particular machine is occupied by products incoming from preceding machines in the production system. The results should be red from the rows. Taking an example from the Table 4 it can be seen that the machine G24 is fed by two machines: B44 and B45. Products coming from machine B44 constitute 37,43% of the production time of the machine G24 whereas products coming from the machine B45 constitute 62,57% of the production time of the machine G24. Thus, it is known that buffer needed for the machine G24 is affected by two preceding machines. The results for other machines should be read in the same way. Production time is the total annual time which is required to produce all the articles passing through particular machine.

Flow of products outgoing from particular machine

Table 5 shows what ratio of the total production time of particular machine is needed to feed subsequent machines in the production system. The results should be red from columns. Taking an example from the Table 5 it can be seen that the machine B43 needs to use 69,27% of its production time to deliver products to the machine G26, 30,63% to the machine G15 and 0,11% to the machine I52-53. The results for other machines should be read in the same way.

to/from	B44	B45	G24	G41	B21	B22	B19/20	B17	B43	G26	A17	C02	B30	B42	B15	G01	F15	G15	G17	G16	G27	I57	I52-53	I54	I62-63	I61	Birkeland packing
B44																											
B45																											
G24	37,43%	62,57%																									
G41	0,09%	0,04%	99,87%																								
B21				100,00%																							
B22				76,53%	23,47%																						
B19/20	0,06%		62,13%	37,81%																							
B17				0,08%			99,92%																				
B43	0,15%			99,54%		0,03%	0,13%	0,14%																			
G26			1,26%	40,54%	7,40%	3,46%	13,87%		33,48%																		
A17																											
C02											100,00%																
B30											100,00%																
B42												100,00%															
B15												100,00%															
G01		6,32%											75,08%	18,60%													
F15																98,53%		1,47%									
G15			6,66%	0,14%			5,20%		18,95%	0,40%						68,12%	0,53%										
G17															42,30%			57,70%									
G16		0,03%		64,17%													21,35%	14,45%									
G27								50,60%		49,40%																	
I57																											
I52-53			0,27%	3,81%					0,25%	0,77%										3,43%	91,46%						
I54	0,49%			4,41%	5,46%	10,47%						1,60%								73,99%	3,35%		0,22%				
I62-63		0,00%		22,70%																39,21%	31,43%		6,65%				
I61				21,97%						0,00%										10,52%	3,29%		4,84%		89,37%		
Birkeland packing										15,78%								7,03%	61,16%			15,88%			0,15%		

Table 4. Flow of products to particular machine.

to /from	B44	B45	G24	G41	B21	B22	B19/20	B17	B43	G26	A17	C02	B30	B42	B15	G01	F15	G15	G17	G16	G27	I57	I52-53	I54	I62-63	I61	Birkeland packing
B44																											
B45																											
G24	99,36%	90,56%																									
G41	0,28%	0,08%	90,94%																								
B21				3,13%																							
B22				1,02%	7,60%																						
B19/20	0,02%		7,27%	5,73%																							
B17				0,00%			60,48%																				
B43	0,06%			15,29%		0,22%	0,22%	0,65%																			
G26			0,54%	10,95%	71,97%	38,22%	35,72%		69,27%																		
A17																											
C02											43,65%																
B30											56,35%																
B42												47,14%															
B15												52,02%															
G01		9,34%											100,00%	100,00%													
F15																19,57%		0,29%									
G15			1,21%	0,03%			3,57%		30,63%	0,06%						80,43%	1,47%										
G17															100,00%			50,34%									
G16		0,01%		21,43%													98,53%	38,27%									
G27								99,35%		72,34%																	
I57																											
I52-53			0,03%	0,67%					0,11%	0,23%										2,23%	35,42%						
I54	0,27%			0,53%	20,43%	61,56%						0,84%								24,64%	0,72%		0,57%				
I62-63		0,00%		24,70%																63,42%	61,53%		77,33%				
I61				16,51%						0,00%										9,71%	2,34%		22,10%		99,47%		
Birkeland packing										27,37%								11,09%	100,00%			100,00%			0,53%		

Table 5. Flow of the products from particular machine.

6.7. Effect of different buffer settings

This chapter presents what are the consequences of different buffer setting on a consuming machine. The exemplary cases are presented due to complexity of calculations in real cases.

Table 6 presents 'yearly forecast of stop time cases'. These calculations were performed already and were presented in chapter 6.4. The question was how much stop time of the consuming machine(s) will be caused by setting the buffer to the value of daily stop times interval of feeding machine.

It is unknown what exact values of stop times were within the defined interval. It is assumed that all the stop times within the interval were equal to right end of the interval i.e. for the interval 0-0,5 [h] it is assumed that all the stop times were equal to 0,5 [h]. This approximation was necessary to perform further analysis. However, the stop times intervals can be set according to the accuracy needs.

Machine's 2 accumulated stop time was calculated according to defined buffer capacity. The result was a sum of difference between right interval and the proposed buffer size multiplied by 'yearly forecast of stop time cases'. For instance in case of setting buffer to 2,5 hour it was forecasted that there are 12,4 cases during a year when the buffer will be too small by 0,5 hour (3-2,5) and 9,3 cases when buffer will be too small by 1 hour (3,5-2,5). Hence, the total stop time for the machine will amount to 15,5 [h] during a year. The situation is illustrated in highlighted row in Table 6.

Machine's name	**Machine 1 (feeding machine)**	**Buffer capacity [h]**	**Machine's 2 (consuming machine) stop time for given buffer capacity [h]**
Daily stop times interval [h]	**Yearly forecast of stop time cases**		
0-0,5	0	0,5	**71,3**=(3,5-0,5)*9,3+ (3-0,5)* 12,4+(2,5-0,5)*6,2+(2-0,5)*0+(1,5-0,5)*0+(1-0,5)*0
0,5-1	0	1	**57,35**=(3,5-1)*9,3+ (3-1)* 12,4+(2,5-1)*6,2+(2-1)*0+(1,5-1)*0
1-1,5	0	1,5	**43,4**=(3,5-1,5)*9,3+ (3-1,5)* 12,4+(2,5-1,5)*6,2+(2-1,5)*0
1,5-2	0	2	**29,45**=(3,5-2)*9,3+ (3-2)* 12,4+(2,5-2)*6,2+(2-2)*0
2-2,5	6,2	2,5	**15,5**=(3,5-2,5)*9,3+ (3-2,5)* 12,4
2,5-3	12,4	3	**4,65**=(3,5-3)*9,3
3-3,5	9,3	3,5	0

Table 6. Data and exemplary calculations.

From the presented example it is known what the consequences of different buffer settings are. However, it was just a general example. As showed in chapter 5.2 there are four basic flow cases which depict all the flow situations in the factory. Thus, in the further part these cases will be presented and discussed. Way of setting the optimal buffers is showed as well. Data used in the cases are exemplary and are simplified.

Case 1

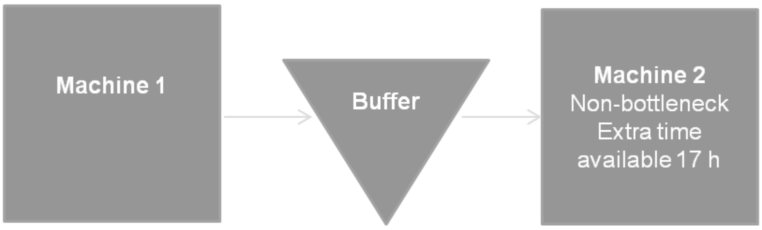

Figure 31. Flow - case 1.

In this case consuming machine 2 is a non-bottleneck resource hence, it has extra time available - time when it can stand idle without any consequences for the production system. Machine 2 is fed by one preceding machine. The buffer is set for machine 2.

Data necessary for calculations:

- Machine 1:
  - yearly forecasted number of stop time cases, Table 6
  - ratio of outgoing production volume from particular machine, Table 5
- Machine 2:
  - machine's extra time available – in this case 17 hours
  - ratio of incoming volumes to particular machine, Table 4

The consequences of setting buffer capacity to different sizes is presented in the Figure 32.

Machine's name	Machine 1	
Daily stop times interval [h]	Yearly forecast of stop time cases	Buffer capacity [h]
0-0,5	0	0,5[h]
0,5-1	0	1[h]
1-1,5	0	1,5[h]
1,5-2	0	2[h]
2-2,5	6,2	2,5[h]
2,5-3	12,4	3[h]
3-3,5	9,3	3,5[h]

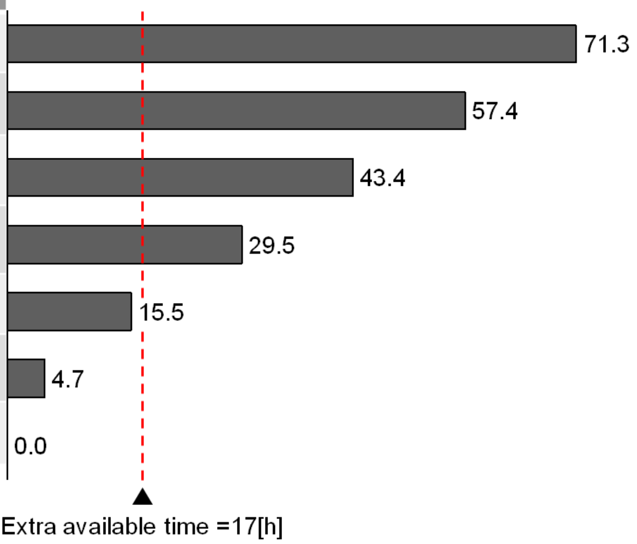

Figure 32. Buffer setting – case 1.

Extra available time of the machine states about the time that machine can stay idle during the year. Extra available time of the machine is compared to accumulated stop time according to different buffer capacity setting. If the total stop time exceeds the extra available time a machine becomes a bottleneck resource. The aim is to find the buffer capacity which causes shorter downtime of the machine 2 than its extra available time during the year. As can be seen in the Figure 32 the buffer capacity equals to 2,5 hours is the buffer which causes shorter accumulated stop time of the machine than its extra available time. Therefore, buffer set to 2,5 hours of production time of machine 2 is the optimal buffer size in this case.

Case 2

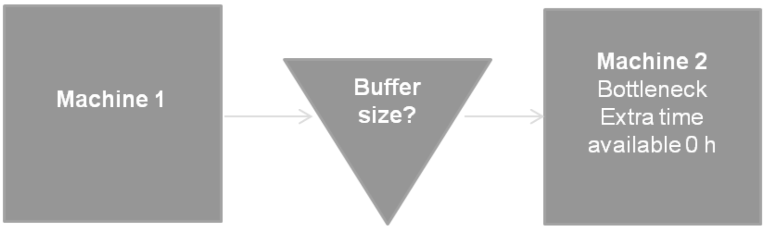

Figure 33. Flow – case 2.

In this case consuming machine 2 is a bottleneck resource and it does not have extra time available. This bottleneck resource is fed by one preceding machine. The buffer is set for machine 2.

Data necessary for calculations:

- Machine 1:
    - yearly forecasted number of stop time cases, Table 6
    - ratio of outgoing production volume from particular machine, Table 5
- Machine 2:
    - machine's extra time available – in this case 0 hours since, it is a bottleneck resource
    - ratio of incoming volumes to particular machine, Table 4

The consequences of setting buffer capacity to different sizes is presented in the Figure 34.

Machine's name	Machine 1	Buffer capacity [h]
Daily stop times interval [h]	Yearly forecast of stop time cases	
0-0,5	0	0,5[h]
0,5-1	0	1[h]
1-1,5	0	1,5[h]
1,5-2	0	2[h]
2-2,5	6,2	2,5[h]
2,5-3	12,4	3[h]
3-3,5	9,3	3,5[h]

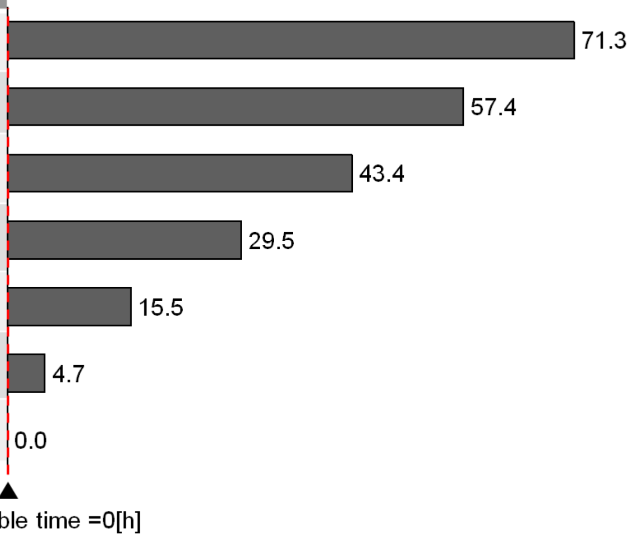

Figure 34. Buffer setting – case 2.

Machine 2 is a bottleneck resource and it does not have any extra available time. Hence, all the stop times should be avoided because the machine is already lacking of capacity. The machine cannot be stopped so the buffer capacity should big enough so that the machine is not stopped due to lack of input material. Hence, buffer size has to be set so that no stop time exist. The required buffer size is 3,5 hours. It means that the buffer in front of machine 2 should constantly include enough materials for 3,5 hours of production time for the machine 2.

Case 3

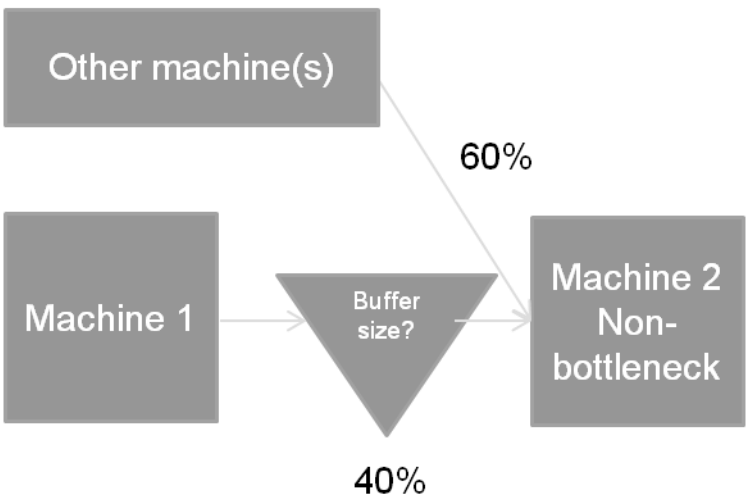

Figure 35. Flow – case 3.

In this case consuming machine 2 is fed by more than one machine. Machine 2 can be either bottleneck or non-bottleneck resource. Depending on the situation this case has to be combined with case 1 or case 2. Additionally it is necessary to know the ratios of incoming volumes to machine 2 from other machines. The buffer is set for machine 2.

Data necessary for calculations:

- Machine 1:
  - yearly forecasted number of stop time cases, Table 6
  - ratio of outgoing production volumes from particular machine, Table 5

- Machine 2:
  - machine's extra time available – in this case 17 hours
  - ratio of incoming production volumes to particular machine, Table 4

- Other machine(s):
  - ratio of outgoing volumes from particular machine, Table 5

As shown in the Figure 35, 40% of the production volume of machine 2 is coming from machine 1 and 60 % from other machine(s). Extra available time of the machine 2 is divided proportionally between machine 1 and other machine(s). Therefore, extra available time of machine 2 assigned to flow from machine 1 is equal to 6,8 hours (40% of 17 h).

The next step is comparison between extra available time of machine 2 during the year assigned to flow from machine 1 (6,8 h) and machine's 2 accumulated stop time according to set buffer capacity. Total stop time cannot exceed calculated ratio of available extra time. As can be seen in the Table 6 buffer dimensioned to 1 hour results in machine's 2 stop time lower than 6,8 h (6,2 h). Thus, the optimal size of the buffer related to the flow volume from machine 1 is 1 hour. The calculation is done in the same way for the rest of incoming volumes to machine 2. The final buffer size is sum of these buffers.

Case 4

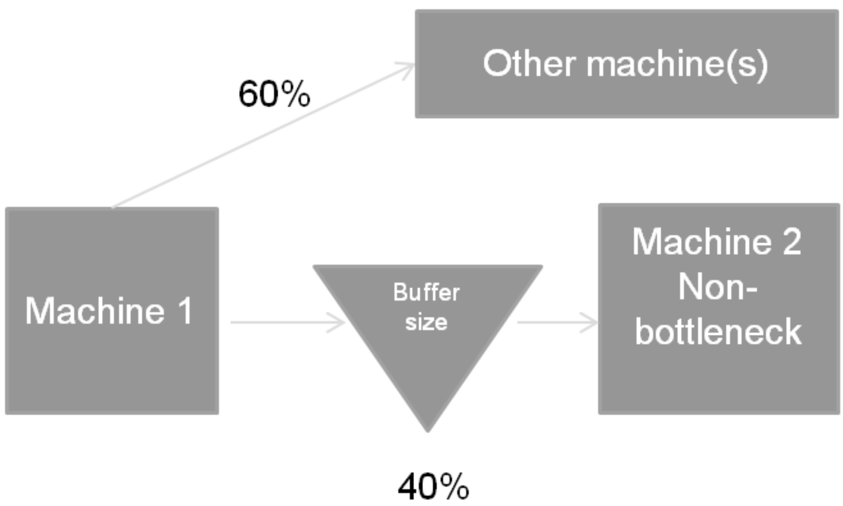

Figure 36.Flow - case 4.

In this case consuming machine 2 is fed by one machine. Machine 2 can be either a bottleneck or non-bottleneck resource and has to be related to case 1 or case 2. However, in this case machine's 1 flows are going to more than one resource. Hence, it is necessary to know the ratios of outgoing volumes from particular machine. These flows were presented in Table 5. The buffer is set for machine 2.

Data necessary for calculations:

- Machine 1:
    - yearly forecasted number of stop time cases, Table 6
    - ratio of production flows outgoing from particular machine, Table 5

- Machine 2:
    - machine's extra time available – in this case 17 hours
    - ratio of incoming production volumes to particular machine, Table 4

As shown in the Figure 36, 40 % of produced volumes by machine 1 are going to machine 2. 60% is going to other machines. From the perspective of machine 2 it is fed by one resource hence, 100% of incoming volumes are from machine 1.

Because of the fact that 40% of machine 1 production volume is feeding machine 2 the same share (40%) of the stop time of the machine 1 is affecting machine 2. Thus, values in the column 'buffer capacity' and 'Machine's 2 stop time for given buffer capacity' in the Table 6 were multiplied by 40%. Result is illustrated in the Table 7.

Machine's name	**Machine 1**	**Buffer capacity**	**Machine's 2 stop time for given buffer capacity**
Daily stop times interval [h]	**Yearly forecast of stop time cases**	**[h]**	**[h]**
0-0,5	0	**0,2**	28,52
0,5-1	0	**0,4**	22,94
1-1,5	0	**0,6**	17,36
1,5-2	0	**0,8**	11,78
2-2,5	6,2	**1**	6,2
2,5-3	12,4	**1,2**	1,86
3-3,5	9,3	**1,4**	0

Table 7. Influence of volumes ratios between machines on the buffer setting.

Data in Table 7 above are used for comparison of machine 2 extra time available during the year and machine's 2 accumulated stop time in case of set buffer capacity. In discussed case 4 buffer set to 0,8 hour of production time of machine 2 is the optimal value in this case. It results in machine 2 being idle (11,78 h) shorter than its extra available time during the year which is equal to 17 hours.

Above paragraphs presented four basic flow cases in the investigated production unit. By different combinations of these cases it is possible to model all the situations which can take place in the production facility and set the optimal buffer size.

6.8. Final result

Defined buffer sizes for the machines, which were identified as bottlenecks, are presented on the Figure 37.Figure 37

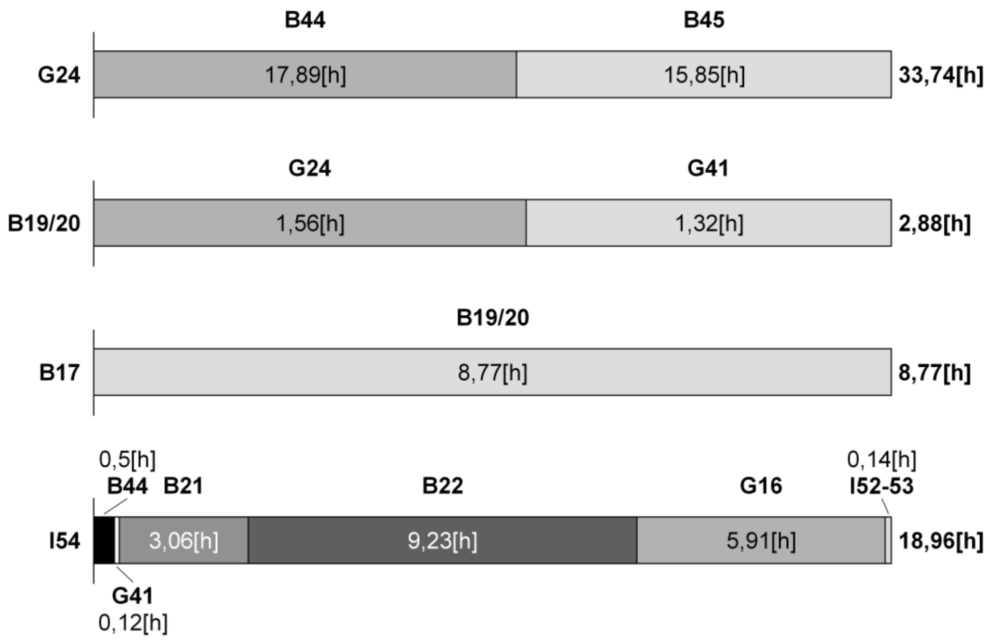

Figure 37. Defined buffer sizes for bottleneck resources.

The aim of defined buffers is to assure continuance of production by elimination of unplanned downtime for these machines. The results should be interpreted in a following way:

Machine G24

This machine is fed by two preceding machines B44 and B45. In order to assure that machine G24 will not be stopped due to downtime on the preceding machines the buffer in front has to contain enough material for 33,74 hours of production of machine G24. However, due to the fact that machine is fed by two machines the total buffer has to be split according to the flow ratios from each predecessor. Therefore, as can be seen on the Figure 37 machine B44 has to provide enough pieces for 17,89 hours of production time of the machine G24. In the same way machine B45 has to provide enough pieces for 15,85 hours of production time of the machine G24.

Machine B19/20

This machine is fed by two preceding machines G24 and G41. The same as in the previous machine there is a situation that the total buffer has to be build by two preceding machines. Machine G24 has to provide enough material to assure 1,56 hours of production time of the machine B19/20 and machine G41 has to provide enough material for 1,32 hours of production time of the machine B19/20. The total defined buffer equals to 2,88 hours of production time of the machine B19/20.

Machine B17

In this case the situation is simple. Machine B17 is fed only by one preceding resource B19/20. To assure the continuity of the production buffer has to contain enough pieces for 8,77 hours of the production time of machine B17.

Machine I54

Machine I54 is a packaging machine and due to that it has six predecessors. The total buffer required for this machine is equal to 18,96 hours of production time of this machine. In the same manner as in previous cases the buffer has to be built by preceding machines. The ratio from particular machine can be seen on the Figure 37.

Defined above buffers are based on the annual production demand and on the stop times taken from three months period. Therefore, they may not correspond to the present situation, which is dynamic. As described in chapter 4.5 Planning procedures the production plan span four weeks time. Therefore, the model should be reviewed periodically i.e. every second week and buffers should be adjusted to particular situation.

Moreover, it can be seen that some bottleneck resources are predecessors of other bottleneck resources i.e. G24 and B19/20. Thus, the elimination of the first bottleneck resource may cause that a following machine will require smaller buffer. This case also illustrates a dynamic situation in the production facility and a need for continuous control over needed buffers.

7. Discussion

This study tried to answer the question how the flow in the factory in Älmhult can be optimised. The outcome of the research is a generic model which gives dimensions of the required buffers in front of each machine. Buffers were dimensioned in time units so that they are universal and can be translated to any production mix. The model and proposed solution of the limited flow is based on the theory of constraints and was designed to be in line with strategic goal of the company - to work in the lean environment.

The first step to improve the flow in the factory was to calculate resource utilization. The discovery was made about existence of the bottleneck resources. Therefore, this part of the study can be associated with first step in the TOC approach – identify the constraint. Constraint is the weakest link in the system and hence it limits the output of the all system. Authors of this thesis strongly believe that the identified bottlenecks are of physical type because capacity in the manufacturing resource is less than the demand on product manufactured on the resource. For the purpose of the model extra available time for every resource was calculated. This time states about period when the resource can be idle and it will not affect the production flow. Obviously the bottleneck resources did not have any extra time and it was necessary to decrease stop times to lower the utilization rate of these resources.

Second step of TOC states about exploiting the constraint, which can be understood as finding the most efficient way to utilize discovered bottleneck resource within given configuration. The analysis of stop time reasons was performed for all the machines in the factory. Detailed analysis for bottlenecks allowed to identify the most common reasons of stop times and indicate the improvement potential for these resources. Several recommendations were made such as: avoidance of staff shortage, moving operators from non-bottleneck to bottleneck resources, prioritisation of preventive maintenance and shortening of quality inspections on bottleneck resources. It was also stressed that keeping track of stop time reasons should be performed to higher detail on resources without extra capacity. All the improvements proposed intended to increase the OEE factor of bottlenecks and by that decrease their utilization rate to keep it below its maximal capacity.

Developed model is capable to dimension needed buffers in front of every machine. Hence, having appropriate buffer a bottleneck resource is protected against any stop of a machine which is feeding bottleneck resource. However, to embrace whole production system it was necessary to dimension buffers also for resources which are not bottlenecks. The buffer for non-bottleneck resources was set to facilitate the flow and avoid the situation that the machine is stopped due to lack of input material. By doing that it was secured that other machines will not become new bottlenecks. Focus was on the flow through all the machines in order to assure that whole network of machines have enough material. This approach complies with third step of TOC which states about subordination of other resources to the bottlenecks. While there is lack of subordination of other resources to bottlenecks then the result are increased inventories and amount of work in process in the production facility. Since, Swedwood operates in lean environment and inventory is considered as a waste the model approach aligned to the company vision. Having non-bottleneck resources which are not subordinated to bottlenecks would cause increase of unnecessary WIP.

Authors of the thesis believe that by complying to three steps of TOC it is feasible to break to the constraints and improve the production flow in the factory. The hypothesis is based on the fact that currently demand placed on the bottleneck is only slightly higher than available capacity. However, in case of demand increase or available production time decrease there is possibility that fourth step of TOC – elevate the constraint – will have to be applied. In this case introduction of another shift should be done and if it is not feasible an investment in new machinery should be considered.

The fifth step of TOC states about repeating all the steps. In the case of this model buffers capacity have to be the subject of periodical review. Authors of the thesis are aware that there is interdependence of the OEE factor and buffer sizes. The size of the buffers can reduce or increase the sum of the stop times and therefore have influence on the OEE factor. Proposed improvements can help to break the current constraints but at the same time new bottleneck limiting the output can appear. Hence, there is a need to go back to the first step and repeat the whole process periodically. The fifth step of TOC is in line with continuous improvement philosophy which is a part of the lean philosophy. Breaking all the physical bottlenecks can cause that policy constraints would appear. However, author's opinion is that there is a low probability that the market will be a bottleneck since Swedwood produces for IKEA and the demand for their products is increasing year by year.

8. Conclusions and recommendations

The aim of this thesis was to examine methods which will allow flow optimisation in production facility in Älmhult. It was discovered that there are bottlenecks in the factory which are constraining the production flow. Methods to break the constraints were proposed. Model which is a tool to dimension buffers in front of the bottleneck and non-bottlenecks resources was developed.

Four bottleneck resources were identified. Detailed stop time reasons analysis allowed to give indicators how these stop times can be lowered. It was concluded that if the bottleneck cannot be broken with proposed improvement a new investment should be considered. Proposed improvement was a generic model which dimensions the needed buffers in front of every machine. The model was developed on a basis of TOC approach. It proves that used theory is suitable for resolving production flow problems.

Created model, besides dimensioning currently needed buffers, can also asses influence when investment in new machines is considered. However, then routing in the factory and other input data have to be updated and extended by a new machine. Moreover, assumptions about the stop times, NPC, OEE and other required input parameters should be made. The model can be used as a tool to show what will be the affection of the purchased machine on the current buffer stocks and what size of the buffer stocks will be required in front of new machine.

Size of the buffers in the proposed model was adapted to forecasted sales for fiscal year 2010/2011. However, by using forecast for the upcoming year it can be estimated what will be the future need in terms of the buffers. Beside that shorter span of time can be used which will increase the reliability of the defined buffers since production mix in shorter time is more precise.

During the visits in Älmhult researchers noticed current buffer space may not be enough for defined buffer sizes. Thus, the recommendation is a double tier conveyor (see Appendix 4, Figure 39). By implementation of this solution the problem with lack of space for buffers will be solved. Moreover, space for new machines will be provided. Another benefit of this solution is assured buffer capacity connected with regular increase of the production volumes.

Last but not least a good way to test the proposed model before applying it in reality is to use the simulation software to check the reliability of the results.

The recommendation for future work would be to investigate improvement potential when it comes to possible production schedules. The optimal batch sizes will be strongly connected to this topic as well.

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Swedwood internal reports, promotion materials, internal procedures

10. Appendix

Appendix 1 – List of interviewed people

Nr.	Name	Function	Location
1	Bjorn Andreasson	Quality inspector	Swedwood - Älmhult
2	Erik Edlund	Production leader	Swedwood - Älmhult
3	Franc Gselman	Technical manager	Swedwood - Älmhult
4	Fredrik Olsson	SWOP	Swedwood - Älmhult
5	Fredrik Sagerstrom	Logistics	Swedwood - Ängelholm
6	Hans Gullstrand	Maintenance coordinator	Swedwood - Älmhult
7	Jan Stiernkvist	Shift leader	Swedwood - Älmhult
8	Leif Johansson	Logistics	Swedwood - Älmhult
9	Lena Skinnar	Finances	Swedwood - Älmhult
10	Magnus Smedmark	SWOP	Swedwood - Ängelholm
11	Mikael Frisk	Shift leader	Swedwood - Älmhult
12	Nils Vikdahl	Production manager	Swedwood - Älmhult
13	Thomas Nyquist	Production leader	Swedwood - Älmhult
14	Ulf Johansson	Maintenance manager	Swedwood - Älmhult

Table 8. List of interviewed people.

Appendix 2 – List of questions used for interviews

General information

- What is your role in the company?
- What are your main areas of responsibilities?

Products related questions

- How many products do you produce?
- What are the volumes of these products?
- What kind of products are you responsible for?
- What are the main characteristics of these products?
- What are the cycle times on different machines?
- What raw materials are used for production?
- What is the routing of these products?
- What are the batch sizes?
- What is the bill of material?
- How the final assembly is done?
- What is the planning procedure for a product?
- What are quality losses for this product?

Production related questions

- Which work stations you are responsible for?
- How many people are working on this station during one shift?
- How many shifts are working on this machine?
- What is the capacity of this machine?
- What are the main problems with this machine?
- How the maintenance is planned for this machine?
- What do you do when machine is stopped or broken?
- What is the capacity of the buffer in front and after the machine?
- Do you consider this machine as a bottleneck?

Appendix 3 – Fishbone diagram

The diagram served as an input to construct an issue tree at the beginning of the project. In later phase it was helpful to determine what data were needed for the model.

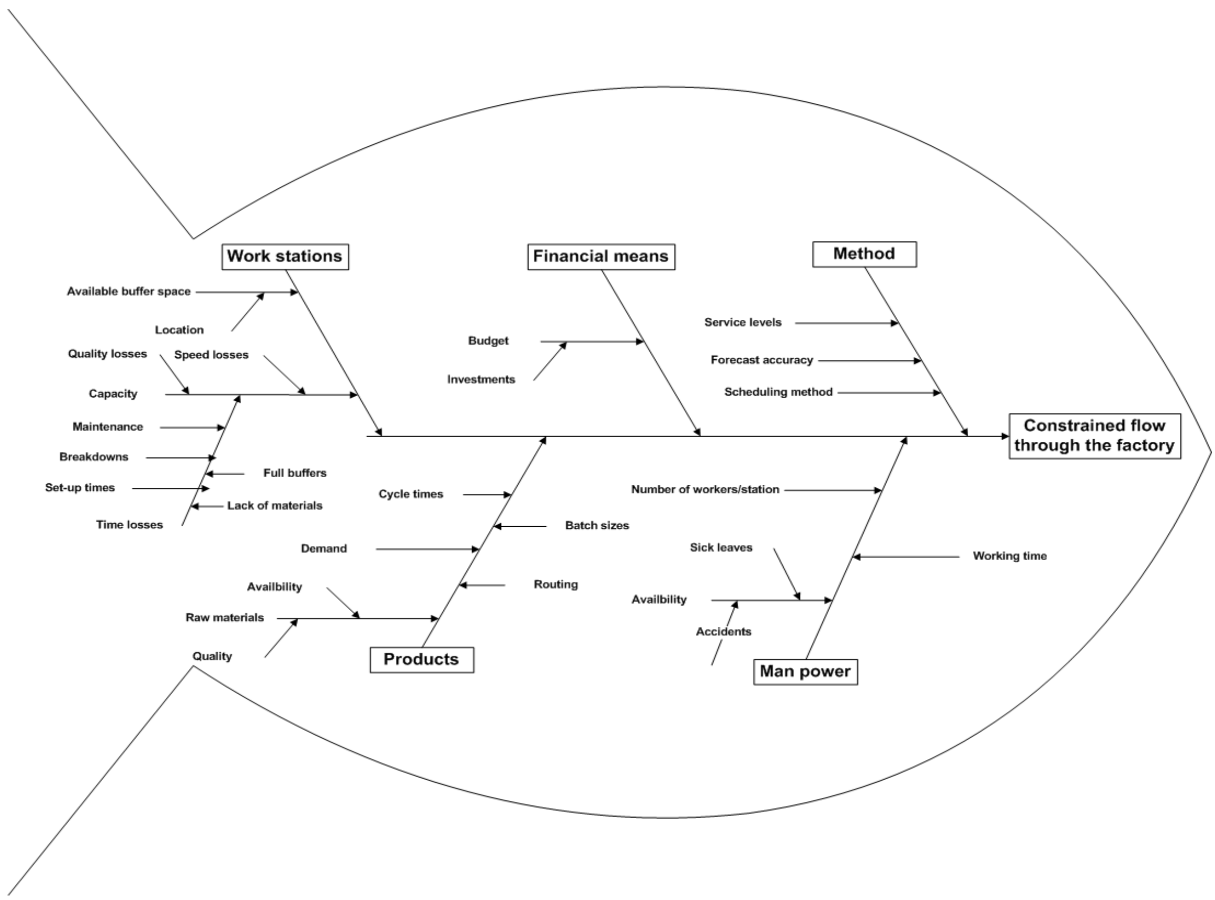

Figure 38. Fishbone diagram.

Appendix 4 – Illustration of double tier conveyors application in the furniture industry.

Figure 39. Double tier conveyors (andrews-automation.com)