Adaptive Capacity through Complex Adaptive System

– A case study at Smurfit Kappa Sweden

Niclas Bodin
Filip Cronberg

Department of Packaging Logistics
Lund Institute of Technology
Box 118
S-223 62 Lund
Sweden

Department of Business Administration
School of Economics and Management
Box 7080
S-220 07 Lund
Sweden

Master Thesis at Technology Management – 133 /2006
ISSN 1651-0100
ISRN LUTVDG/TVTM--06/5133--SE

KFS i Lund AB
Lund 2006
Printed in Sweden

Abstract

Title: Adaptive Capacity through Complex Adaptive System – A case study at Smurfit Kappa Sweden

Authors: Niclas Bodin and Filip Cronberg

Supervisors: Carl-Henric Nilsson, Lund School of Economics and Management
Fredrik Nilsson, Division of Packaging Logistics, Lund Institute of Technology
Fredrik Dahlgren, Production Planning Manager, Smurfit Kappa Sweden

Problem: The corrugated board industry is highly affected by customer uncertainty, various demands and short delivery times. In combination with a complex multi-step production process managers have to be able to identify bottle-necks and gain knowledge and understanding of how different changes in process will affect the production output.

Purpose: The purpose of this master thesis is twofold, (1) to examine applicability of complexity theory through agent-based modelling on a production process (2) to identify improvement areas in order to increase the production output at SKS production site in Eslöv, by modelling and simulating the production process through an agent-based model.

Method: The chosen method of this study is a combination of a case study and a complex system approach. The empirical data was collected through interviews, observation and document studies which were analysed through an agent-based simulation model.

Conclusions: Through the holistic complex system approach and by iteratively exploring the SKS production process's components the authors were able to distinguished essential factors of the production process wherefrom the complexity emerged. The production process exhibited several internal complex properties whereby the authors consider that SKS production process can undoubtedly be consider as a Complex Adaptive Systems (CAS). By mapping and utilising agent-based modelling the complexity of the system could be transferred to an agent-based model. Through analysis of the agent-based model the authors identified and simulated four improvement areas which provide possibility of an increased capacity utilisation and production output. Based on the results the authors recommend a higher individual freedom for the machines and a greater interaction both within the company and with the customer.

Key words: Agent-based modelling, complex adaptive systems, complexity theory, production planning, supply chain, Smurfit Kappa Sweden

Preface

In early February the two authors took the train from Lund to Eslöv, heading for a meeting with the production management at Smurfit Kappa Sweden. The question of conducting a master thesis was answered with a *"Yes"* and from that point the journey within the corrugated board company started. The authors had no considerable experience from manufacturing of corrugated board packages but the situation today is different. The authors have been guided into an exiting and changeable business which has resulted in many interesting and memorable impressions.

We would like to direct special thanks to the supportive workers at Smurfit Kappa Sweden in Eslöv. We owe our supervisor, Fredrik Dahlgren, a lot gratitude for the time and support he sat aside for this project. Further, for the essential data required for this project we would like to thank Per Kvist for the time and effort he put in to it. Everyone, including all the other participating workers at SKS in Eslöv, has made a great contribution in improving the results of this thesis. Finally, we would like to thank Peeter Saarnak, the plant manager, who made this study possible in the first place.

We would also like to thank our supervisors at Lund Institute of Technology and School of Economics and Management. With the extensive knowledge within the world of complexity and agent-based modelling, Fredrik Nilsson has been a great resource at hand. Carl-Henric Nilsson has been of great help when it comes to objective feedback and critical reviews of our master thesis. He has also provided us with interesting and noteworthy angles which has come in hand during the process.

A special thanks to Magnus Loodberg who has been at help during the creation of our model.

Thanks to you all!

Lund, May 2006

Niclas Bodin Filip Cronberg

Table of contents

1. Introduction ... 1
   - 1.1. Background ... 1
   - 1.2. Problem Definition ... 2
   - 1.3. Purpose ... 2
   - 1.4. Demarcations of the Study ... 3
   - 1.5. Target Audience ... 3
   - 1.6. Disposition ... 3
2. Methodology ... 7
   - 2.1. The choice of System Approach ... 7
   - 2.2. Case Study Approach ... 8
   - 2.3. Criticism of chosen Approach ... 15
   - 2.4. Reliability and Validity ... 16
3. Smurfit Kappa Group Overview ... 17
   - 3.1. What is Corrugated Board? ... 17
   - 3.2. The Packaging Company ... 18
   - 3.3. The Swedish Market ... 19
   - 3.4. Organisation ... 19
4. Theoretical Framework ... 21
   - 4.1. Complexity Theory ... 21
   - 4.2. Supply Chain Management ... 26
   - 4.3. Production Responsiveness and Vulnerability of Supply Chains ... 30
5. SKS in Eslöv – The Case Study ... 33
   - 5.1. SKS Internal Supply Chain ... 33
   - 5.2. Production ... 34
   - 5.3. Production Planning ... 36
   - 5.4. Stock ... 40
6. Applying Complexity to SKS Production ... 41
   - 6.1. The SKS Production in a Complexity Perspective ... 41
   - 6.2. Agents of SKS ... 42
   - 6.3. SKS in Eslöv as a Complex Adaptive System ... 43
   - 6.4. Synthesising Summary ... 47
   - 6.5. Improvement Identification ... 47
7. Creating the Model ... 53
   - 7.1. The Model ... 53
   - 7.2. Parameters ... 56
   - 7.3. The Graphical User Interface ... 61
   - 7.4. Model Assumptions and Limitations ... 63
8. Scenario Simulations ... 67
   - 8.1. Validation and Verification of Model ... 67
   - 8.2. The Scenarios ... 68
   - 8.3. Results of the Simulation ... 71
9. Analysis of Production CAS ... 75
   - 9.1. Scenario Analysis ... 75
   - 9.2. Suggestions of Improvements ... 78

9.3. What about ABM? 80
10. Conclusion 83
10.1. Criticism of Study 84
10.2. Further Research 84
11. References 87
11.1. Published Material 87
11.2. Interviews 89
11.3. Unpublished SKS Material 89
11.4. Electronic material 90
Appendix A 91

1. Introduction

This chapter is an introduction to the background and the purpose of the master thesis. Further the demarcations of the thesis will be discussed and finally the disposition of the thesis is presented.

1.1. Background

In today's competitive global marketplace, for the survival in any industry, manufacturing companies must simultaneously produce highly individualised and customer specific products in a short time at a lower cost. This implies that companies must master the balance between an efficient but limited mass production and an adaptable but expensive flexible production.[1]

The corrugated board market is a tough place to be. Customers order a large variety of boxes, each with specific demands on colours, printing and quality, with the expectation of a short delivery time. In combination with complex multi-stage production processes, uncertainty of customer behaviour and unscheduled production deviations, it is beyond doubt a challenge for the individual company.[2] Further, to complicate matters the corrugated board industry is characterised by a high overcapacity in the production which creates a highly competitive environment where factories must compete for their survival. The overcapacity on the market leads to a situation where customers are free to choose between suppliers – it is truly a buyer's market.[3] These industry characteristics and market demands are making production planning, scheduling, and control crucial in order to stay competitive in the market. Unfortunately these tasks also get even more complex to manage as complexity within the industry increases.

Smurfit Kappa Sweden (SKS) is one of the leading Nordic suppliers of efficient corrugated board packaging. SKS is a part of newly-merged Smurfit Kappa Group, a world leading packaging company that consists of several factories, sales offices and service centres situated in Sweden. The SKS production site in Eslöv produces a wide variety of package solutions with a flexible manufacturing process and can thereby swift and effectively respond to customer demand.

The SKS production site in Eslöv has a challenging task because of the broad range of articles and production capability. With this high manufacturing flexibility SKS has disclosed unutilised capacity in the production. The machine which produces corrugated board has an overcapacity in comparison to the following refining machines. This creates a bottle neck and thereby lowers the utilisation rate of the corrugated board machine. Through numerous improvements within the production SKS in Eslöv has sought to overcome the capacity issue and thereby increasing its output.

---

[1] Baumgärtel (2000): p. 40
[2] Darley et al. (2004): p. 1
[3] Dahlgren, Fredrik. 2006-02-08

Though, in several cases, an improvement in one area of the production line has led to incomprehensible deteriorations in other areas. In combination with aspects of quality, lower waste, lead time, setup time and flow optimisation this creates a high non-linear complex situation. This further indicates that the problem may not be situated within the production line and requires a comprehensive view to identify and resolve the problem.

1.2. Problem Definition

In SKS's quest for increased capacity utilisation it is critical to identify the aspects with highest potential for increasing the utilisation. With a restricted budget and time SKS's primary problem may not be to choose what to do, but mainly choose what not to do. The desired output of this thesis is to help SKS to gain a comprehensive insight of the situation and identify improvement areas with most leverage.

SKS production in Eslöv is characterised as complex, not merely complicated, which imply that ordinary analysis are unable to identify how indirect-connected parts' actions may affect each other. Thus it is difficult to identify how different actions affect the total performance of the internal supply chain. Considering the complexity of SKS production and internal supply chain as well as the market demands it is important for managers to gain knowledge and understanding of how different changes in process will affect the production output. This identification is crucial in order to isolate which areas to focus SKS attention on.

Such identification can be accomplished through modelling and simulating the actual system with the use of complexity theory to incorporate a similar behaviour. The model may enlighten key improvement areas but demand extensive knowledge of the system itself.

Further, there is limited practical evidence of applying complexity theory on an empirical case study. However, the proposed solution of such a case cannot be effectively generalised for other complex systems but may be used as an analogical aid for simulations of similar systems. A way of applying the complexity theory on a real-life case is through agent-based modelling, a method which has gained attention through several previous studies. Although, the studies are providing applications of the method the case studied is never the same. Due to previous studies the quest for new applications with specific characteristics may provide new insights within the areas of complexity theory, supply chain management and agent-based modelling.

1.3. Purpose

This thesis has a twofold purpose, (1) a theoretical application of an empirical case and (2) a practical contribution to SKS's production. The purposes are as follows:

1. To explore the possibility of applying complexity theory on a production process through agent-based modelling. Hopefully this thesis will contribute

with new awareness for the process of analysing and controlling flexible internal supply chains.

2. To identify improvement areas within the production process in order to increase the production output at SKS production site in Eslöv, by modelling the production through an agent-based model. Further several scenario simulations of the model will distinguish the relative leverage of the identified improvements areas.

1.4. Demarcations of the Study

The scope of this study is limited to SKS production site in Eslöv and does not include other SKS production sites in Sweden or abroad. The study focuses on the process from when an order is placed to finished goods, which include order process, production planning, and production. The stock of raw material and finished goods are excluded because of their limited impact on the study as well as external supply chains.

Besides the empirical demarcations of the chosen production process activities there are also demarcations of the model developed in this study. A model is a simplification of reality which implies that minor real-time behaviour cannot be reflected. Thus, the authors believe that these minor behaviours will be reflected in a longer perspective with the use of historical data.

It should also be noted that the simulation model in this master thesis is built to match the specific conditions at SKS in Eslöv and should therefore not be used on other production sites with different characteristics.

1.5. Target Audience

The primary target audience for this master thesis is Smurfit Kappa Sweden's production management in Eslöv, to support their daily work and future development. The primary target audience also includes the supervisors from Lund Institute of Technology and School of Economics and Management, and fellow students at the Technology Management program, to whom this thesis hopefully will provide new knowledge and insights.

The secondary target audience of this master thesis is persons with an academic background and a genuine interest in supply chain management, production management or complexity theory. In this case the thesis can illustrate how these areas can help to explain and manage logistics and production systems within an organisation.

1.6. Disposition

The disposition given below presents a brief overview of the master thesis in order to clarify the thesis's structure and assist the reader. Most notable is that the analysis is divided into two phases, where the first analysis in Chapter 6 serve to create the agent-based model and identify improvement areas, which is further developed in the second analysis in Chapter 9. Within the second analysis a number of scenario simulations are performed to evaluate the impact of the improvement areas.

The master thesis consists of ten chapters which explain the process and result of the study at Smurfit Kappa Sweden.

Chapter 1 – Introduction

This chapter contains, with little surprise for the reader, the introduction of the study, which includes background, problem definition, purpose, demarcations, target audience and this disposition.

Chapter 2 – Methodology

The following chapter embarks on the journey to describe the chosen paradigmatic view and methodological approach of the thesis, and illustrate the preferred research methods and their consequences.

Chapter 3 – Smurfit Kappa Group Overview

Within the chapter is a short introduction of corrugated boards and Smurfit Kappa Group. The Swedish market of corrugated board and Smurfit Kappa Group's organisation is presented, in order to give full insight into the situation in which SKS production at Eslöv resides in.

Chapter 4 – Theoretical Framework

The chapter undertakes the task of presenting concise introductions to complexity theory, its characteristics and complex adaptive systems, as well as applicable knowledge of supply chain management, production planning and production responsiveness.

Chapter 5 – SKS in Eslöv

The chapter describes the internal supply chain within SKS in Eslöv, from order placement to finished goods. It also describes the work process of production and production planning, which creates the basis for the model.

Chapter 6 – Applying Complexity to SKS Production

As the title imply the chapter describes how the authors choose to structure and simplify the complexity in the production of SKS in Eslöv which constitute the first analysis of the master thesis. The agent-based model of the internal supply chain is described and the connections between the different elements. The analysis is concluded with an identification of improvement areas.

Chapter 7 – Creating the Model

The chapter describes the computer-based simulation model of the production at SKS in Eslöv, as well as the assumptions and limitations which applies in the simulation model.

Chapter 8 – Scenario Simulation

The chapter describes the validation and verification of the simulation model. It also presents the constructed scenarios for simulation to illuminate different aspects of historic operations and the future development of the production.

Chapter 9 – Analysis of Production CAS

The chapter analyses the constructed agent-based model and results from the scenarios, illustrating the advantages and disadvantages uncovered from the simulations. It also examines suggestions of how to improve the identified areas. The chapter is concluded by an analysis of the applicability of agent-based modelling.

Chapter 10 – Conclusion

The final conclusions are presented with the findings of the master thesis.

2. Methodology

In this chapter the paradigmatic view for this master thesis is described and discussed. Further the methodological approach of case study is explained, together with the effects on the study's procedures. Thereafter the processes of securing reliability and validity of the study are described and finally some self-criticism of the chosen approach is discussed.

2.1. The choice of System Approach

In the conceptual development of this master thesis the authors assume the theoretical approach of the system paradigm, as studying productions or logistics the concept of system approach is critical, as these areas are systems in themselves.[4]

Several definitions of a system exist where as one general definition is an entity of interrelated elements, where each element is connected to every other element, directly or indirectly. A fundamental principle of this paradigm is that the performance of the complete system is affected by each element in the system and each element's effect on the whole system relies on at least one other element.[5]

The paradigm proclaims that it is meaningless to deconstruct and examine individual parts of a system. Therefore the paradigm focuses on the system as a whole, as the whole differs from the sum of all parts.[6] Even when only a few parts of a system are studied the approach is concerned with total-system performance because there are some properties of systems that can only be handled satisfactorily from a holistic approach. These properties originate from the relationships between the parts of the systems, i.e. how parts interact and fit together.[7]

The system paradigm proclaims that knowledge of the study is dependent on the studied system and the concept of *multifinality*, a cause may have several alternative effects, and *equifinality*, alternative causes may have identical effects, applies within the system. This constrains the utilisation of the results from study to the studied situation and therefore it is primarily only an analogical aid to other similar systems.[8]

For this master thesis the authors also chose to expand their paradigmatic system approach with complexity theory system. The complexity theory will be described in fuller detail further on in the thesis, but as Nilsson describe the paradigmatic view of system approach and complexity theory are closely related, but differ in various aspects. The main differences are divided into three categories:[9]

[4] Lambert, Stock & Ellram (1998): p. 43
[5] Ackoff (1971): p. 662
[6] Bjerke (1981): p. 7
[7] Ackoff (1971) p. 661
[8] Arbnor & Bjerke (1994): p. 82-85
[9] Nilsson (2005): p. 233-235, 241

- Structural
- Behavioural
- Time-related

2.1.1. Structural

A difference between system theory and complexity theory is their view on structure. As systems theorists' view that *"structure drives behaviour"*, complexity theorists also state the paradoxical view of that *"behaviour creates structure"*. The system approach works well in a static context, but as time is directional, structure will change. Thus the authors study the production process at SKS in Eslöv as a changing system where its continuous evolution has been taken into account. [10]

2.1.2. Behavioural

The view of how complexity emerges constitutes another difference, whereas system theory states that it arises as a cause of how many parts and interactions are present, seen from a holistic view. This makes the system difficult to comprehend, i.e. complicated, not a complex system. Complexity theorists argue that complexity emerges from the self-organising processes by interacting parts which follow a set of simple rules.[11]

In the question of designability the system theory states that the observer is able to control the behaviour of the system and direct it towards a goal. The authors agree with the view of complexity theory where behaviour is far more spontaneous and only controllable through simple rules on an individual level.[12]

2.1.3. Time-related

In accordance with the system theory's beliefs of designability it focuses on problem-solving and altering of specific behaviours with the purpose of reaching an optimal future state. The complexity theory state that it is improbable to predict the future and as Choi, Dooley and Rungtusanatham state *"in a complex system, it is often true that the only way to predict how a system will behave in the future is to wait literally for the future to unfold"*[13]. Complexity theory focuses on helping practitioners to cope with uncertainty instead of trying to remove it.[14]

2.2. Case Study Approach

Since this master thesis has the intention to take a holistic view of a real-life process a case study approach was taken. A case study is a commonly used research strategy for testing or generating a theory and allows the investigator to retain the holistic and

[10] Nilsson (2005): p. 242-243
[11] Nilsson (2005): p. 244
[12] Nilsson (2005): p. 244-245
[13] Choi, Dooley & Rungtusanatham, (2001): p. 356
[14] Nilsson (2005): p. 247-248

meaningful characteristics of real-life events[15]. As Patton et al. and Drake et al. define it *"a case study is an empirical inquiry that investigates a contemporary phenomenon within a real-life context where the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used"*.[16] Case study research investigates predefined phenomena but does not involve explicit control or manipulation of variables[17].

In order to reach the objectives of this master thesis both qualitative and quantitative data will be used. A case study makes this possible as it is combining data collection methods such as archives, interviews, questionnaires and observations.[18] Case studies can also be successfully combined with a simulation method in order to use quantitative data and more thoroughly investigate the case.[19] In this study the qualitative data is used to build up a conceptual agent-based model in order to gain an understanding of the system studied. A computerised simulation model, based on quantitative production data and the agent-based model, is then implemented to penetrate the real behaviour and provide a deeper understanding of the production system.

The case study approach is very useful when examination and understanding of the context is important, and when the understanding of why a phenomenon occurs is limited.[20] To gain the maximum outcome of the case study approach and a thorough understanding the authors choose to adopt a case study roadmap divided in five steps. A roadmap provides a clear vision of what actions need to be undertaken in order to accomplish a well performed case study. The five steps of the case study roadmap are as follows:[21]

1. Determine the objective of study
2. Select the case
3. Build initial theory through a literature review
4. Collecting and organising the data gathering
5. Analysing the data and reaching conclusions

Below the case study working process is described through this five step roadmap, which has been modified from its original design to suit the study at SKS.

2.2.1. Determine the Objective of Study

The topic of this study was a proposal from supervisor Fredrik Nilsson who has extensive experience from this type of studies. In 2003 he initiated a similar study at Smurfit Kappa Sweden but the project was never concluded. Therefore, the foundation of topic and objective of the study was already drawn up to some extent.

---

15 Patton et al. (2003): p. 63
16 Patton et al. (2003): p. 60; Darke et al. (1998): p. 275
17 Darke et al. (1998): p. 275
18 Eisenhardt (1989): p. 534
19 Hellström & Nilsson (2006): p. 1
20 Darke et al. (1998): p. 279
21 Patton et al. (2003): p. 66

In a case study it is important to broadly define the scope so that the researcher will be able to change direction for new aims.[22] In this case the scope was already partly determined but when initiating the project the focus was to create a wide apprehension of the objectives. This has made it possible for us to build our own structure after the given condition.

The work of this study primarily aims to apply complexity theory on a production process and to develop a model for simulating the order and information flow at SKS production site in Eslöv. The authors have the intent of implementing the model since it constitutes as a foundation for the analysis of the study.

2.2.2. Select the Case

The case in this study is Smurfit Kappa Sweden, a renowned company in the corrugated board industry. The production site in Eslöv, in which the study was carried out, manufactures corrugated board and packages through an advanced production layout. The layout of the factory is constructed to handle a high variation of products that are passing through every day. The production consists of several different machines and a refined distribution system which together form a complex system.

Due to the characteristics of the production the case of SKS suits the objective of this study very well. Also, the employees at SKS are familiar with the problems in the production which made the process much easier. When selecting a case it is important that the researchers can fully investigate the subject[23]. To get as much insight in the company as possible contact with strategic and relevant personnel was established.

2.2.3. Build Initial Theory through a Literature Review

To establish and increase the validity and reliability of the findings in a case study it is of great importance that existing literature on relevant theories is studied. The theories helps frame the case study and constitutes as a reference when analysing the findings of the study.[24] In this study a great number of different literatures have been studied to gain an understanding of the case. Complexity theory is adopted since the authors believe that the SKS production is to be viewed as a complex system. The complexity theory offers the possibility to manage the complexity of SKS's production and it gives a more accurate perspective of the study. To gain a comprehensive view over the supply chain studies within Supply Chain Management has been made.

The literature study performed included books, articles and reports. Most of the material was found through the Internet and the university library database at Lund University. Common words during searches were complexity theory, production planning, and production scheduling and agent-based modelling. Since the

[22] Patton et al. (2003): p. 66
[23] Patton et al. (2003): p. 67
[24] Patton et al. (2003): p. 67

combination of the chosen theories is most uncommon a number of interviews where carried out to further explore the theories and improve the search. Ph.D. Fredrik Nilsson, Division of Packaging Logistics, LTH has been the main respondent in these interviews since he possess knowledge within the area.

2.2.4. Collecting and Organising the Data Gathering

When performing a case study all collected data must be documented and organised during the study. Drake et al. suggests that a case study database should be build to include all data, such as documents, audio tapes of interviews, notes of observations made by the researchers during the data collection activities. The database should be organised so that the researchers easily can reach the case data during or after the study.[25] During the study at SKS all documents has been saved on the authors' computers and on a web-based database. The saved documents have been used as a foundation when proceeding on with the study. By using a database other persons can review the documents used and the reliability of the study thereby increases.[26]

2.2.4.1. Interviews

To gain a fuller understanding of the problem it was essential to obtain knowledge of SKS's organisation, culture and the goals of the internal supply chain. Over the course of the first weeks several interviews with persons in different positions within the SKS production in Eslöv where carried out. The interviews were held in an informal manner, but followed similar structure in order to give broad perspective of each issue and area. The results gave an overall understanding of the order and information flow in the internal supply chain and revealed insights of multifaceted issues. It is important when interviewing, that the researcher maintain focus on the study to avoid being overwhelmed with information[27]. To keep the focus the subsequent in-depth interviews followed a more structured plan. The questions varied depending on the issue and respondent to uphold the focus on the studied area at time. During the interviews both authors attended, asking questions and taking notes, in order to reduce the risk of misinterpreting the information. To further reduce the risk of missing information the interviews where recorded after permission from the respondent.

2.2.4.2. Observations

The interviews where followed by observation studies in the production to gain greater detailed information of the workflow and manufacturing limitations. As complement to the observation several informal interviews with the work personnel where carried out. There are two kinds of observations which an observer can engage in. The first one is the *open observation* where the participants has accepted and know about the observer. Second is the *hidden observation* where the observation is unknown to the participants.[28]

[25] Darke et al. (1998): p. 283
[26] Darke et al. (1998): p. 283
[27] Patton et al. (2003): p. 67
[28] Holme & Solvang (1997): p. 111

During the study the authors had the possibility to walk around freely and observe the production. The observations provided necessary information concerning different deviations within the production. Further thorough observations where carried out at the production planning and production preparation. During these observations the authors sat next to the workers and followed their daily work. To gain full outcome from the observations field notes where taken and documented.

2.2.4.3. Reviewing Documents

It has been essential for this study to examine existing documents concerning specific types of data, e.g. machine time, setup time, and productivity etc. On the one hand the information from the documents has constituted as a foundation for the interviews. On the other hand it has generated historical data for the authors to use when simulating the production. During the review of the documents a dialog with workers at SKS was upheld to reduce the risk of misinterpret the information.

Examples of documents reviewed included the machine handbook and official presentation material. The machine handbook consists of detailed information concerning production capacity, work flow, and other information concerning the use of each machine. The presentation material contained information about the company and the daily work at SKS.

2.2.5. Analysing the Data and reaching Conclusion

When all data is collected it is time to put the facts together. Patton et al. claims that the ultimate goal of a case study is to uncover patterns, determine meanings, construct conclusion and build theory[29]. An important step to reach this goal is creating a rich description through an analysis. Analysis implies that the reality, according to the system view, is described through a study of its entities in proportion to the system as whole[30]. In this study the understanding of the relationships between the entities of the system has been central and because of that the authors uses a two step analysis. The first analysis aims to point out how complexity theory can be incorporated with the field of logistics. The method of agent-based modelling is used to create an understanding of how the characteristics at SKS can be viewed as a complex adaptive system which is a prerequisite for the further analysis. Also to uncover interesting patterns and improvement areas within the production process the authors have used the technique of cognitive mapping, which is described below. The second analysis is carried out by using scenario simulations through a computerised agent-based model. By analysing the results from the simulation interesting *what-if* questions can be answered and the relative leverage of improvement areas can be determined.

2.2.5.1. Cognitive Mapping

Cognitive mapping is considered to be a well established technique in the field of research. The purpose of it is to create a representation of an individual or group

[29] Patton et al. (2003): p. 67
[30] Arbnor & Bjerke (1994): p. 110

beliefs concerning an area studied at the time.[31] Eden describes a cognitive map as: "*a representation of thinking about a problem that follows from the process of mapping*" and further that "*a map is like a network with nodes and connections constituted by arrows*".[32] In a cognitive map the arrows could be said to represent a cause-and-effect from one parameter to another. The tail of the arrow is taken to cause which would influence the statement at the arrowhead.[33]

Since a cognitive map represents a qualitative description of a phenomenon there are distinct advantages in comparing it with developed quantitative measures. By doing that the qualitative measures could be enhanced but not necessarily replaced.[34] This leads to that cognitive mapping preferably could be followed by methods like simulation modelling.[35]

2.2.5.2. Agent-based Modelling

There are many approaches of simulating a complex system and one of the applicable methods is through agent-based modelling (ABM). ABM is extensively used within complexity theory and springs from object-oriented programming and distributed artificial intelligence. ABM is not comprehensive solution to explain all aspects of the complexity theory and complex systems, instead it should be seen as a useful tool to gain insight.[36]

Within the logistics perspective the use of an agent-based model, also known as agent-based system, has shown to be applicable. The ABM provides a method which can handle real-life logistics operations[37], such as manufacturing, process control, and transportation systems by mentioning a few[38]. One important aspect, among others, within these operations is the decision making process which often can be difficult for a human decision maker, due to the complexity of a manufacturing process with its large number of processes and machines. For a system or model to handle this complexity Cheeseman et al. states a pair of requirements for a decision tool, namely:[39]

- The model or system should have the ability to handle unexpected events and continue to offer the user a feasible and robust solution. Dynamic properties, that provide a mechanism for adaptation and change, are therefore essential.
- A planning or scheduling tool must be flexible. The tool with a generic construction, which can be tailored by a user to different manufacturing operations, makes an attractive alternative.

[31] Langfield-Smith et al. (1992): p. 1135
[32] Eden (2004): p. 673
[33] Eden (2004): p. 674
[34] Langfield-Smith et al. (1992): p. 1135
[35] Eden (2004): p. 673
[36] Nilsson (2005): p. 75
[37] Nilsson (2005): p. 77
[38] Jennings et al. (1998): p. 25-26
[39] Cheeseman et al. (2005): p. 479-480

ABM is a way to address these challenges as it offers a proactive problem solving tool. The focus of ABM is on agents and their relationships with other agents or entities[40]. In comparison to other, more traditional programming methods, the agents in an agent-based model determine independently the best way to solve a problem in order to achieve an overall objective.[41]

2.2.5.3. Agents and their Qualities

An intelligent agent is a software program that has the ability to operate autonomously to solve user-defined problems. According to Nilsson an agent, in a logistics context, might represent a machine, the order handling process, inventory handling and further production planning and scheduling[42]. The definition of an intelligent agent suggests the following properties to be inherent: [43]

- Autonomous – function without the need for user intervention
- Proactive – operate independently to work towards a goal
- Reactive – responds to changes in the environment and changes in the course of action
- Social – interact with other agents in order to exchange information as required

Cheeseman et al. states that, in order to make the agents applicable to highly dynamic environments, further properties can be added. Based on the information at hand these properties concern reasoning and planning capabilities and are: *beliefs*, which is how an agent views the world, what it believes to be true; *desires*, which are the goals that an agent is trying to achieve; and *intentions*, what an agent plans to do, based on its beliefs, to achieve its desires. These properties enable the agents to view their environment in real time and adapt their approach to reach their goals which they are trying to achieve. This implies that, without any user intervention, unexpected fluctuations and in surroundings can be taken into account immediately and acted upon in real time.[44]

2.2.5.4. Why Agent-based Modelling?

Because of the huge amount of data collected in this case a computerised simulation model was an appropriate tool to use. ABM, as a simulation method, has showed in several cases that it is capable of handling complex systems such as logistics and manufacturing processes. Further, Hellström & Nilsson states that simulation as a method gives the researcher possibility to develop a model of a real or proposed system so that the behaviour of the system may be studied under specific conditions. Also, simulation enables the researcher to explore different "*what if*" scenarios which is a part of this study. Since the agent-based model aims to identify areas with potential to increase the output and capacity utilisation within the production it could

[40] Nilsson (2005): p. 76
[41] Cheeseman et al. (2005): p. 480
[42] Nilsson (2005): p. 76, 81
[43] Cheeseman et al. (2005): p. 480
[44] Cheeseman et al. (2005): p. 480

work as a decision tool for the production management at SKS in Eslöv. This requires an understanding of the behaviours and results which the simulation model provides.[45]

Another advantage is that by combining simulation with case study research the weaknesses of each method can be harmonised and in the same time increase their strengths. When starting with a case study the aim is to gain an in depth understanding of the phenomenon and context. The simulation method then can help to obtain further insights of behaviour and performance of the studied system. Hellström & Nilsson identifies further advantages as it facilitates:[46]

- An iterative research process, which in turn enables: a way to identify and measure relevant characteristics; further insights; and a way to strengthen the theorising process
- Triangulation of methods
- Systematic data collection
- An expanded time horizon of the study by using historical data or scenarios

In contrast to the advantage of simulation there are some disadvantages when using a simulation model, such as ABM. To be able to build and gain the maximum use of a model the researchers have to possess knowledge within computer programming plus that a model often take some time to build. It also demands a great deal of knowledge about the system as well as the characteristics of the system under study.[47] In that case the case study approach makes a contribution by providing the researcher with qualitative data to create an in-depth understanding of the case.

Since a simulation aims to capture real-life behaviours one must see to the verification and validation of the simulation model. Model verification refers to the assurance that the computer programming of the conceptual model is correct. Model validation refers to the computerised models' accuracy consistent with the proposed application of the model.[48] The verification and validation of the simulation model used in this thesis will be presented in Chapter 8.

2.3. Criticism of chosen Approach

One of the most common criticisms of the case study approach is that it is subjective and strongly influenced by the researchers. The researchers play a central roll in influencing the study in two ways: access and personal background. Access refers to how close the researcher can get to the object of study and personal background refers to factors like knowledge, insights and previous experiences.[49] During the proceeding of this particular study the accessibility has not been a limitation. Whenever the

[45] Hellström & Nilsson (2006): p. 3
[46] Hellström & Nilsson (2006): p. 9
[47] Hellström & Nilsson (2006): p. 4
[48] Hellström & Nilsson (2006): p. 4
[49] Patton et al. (2003): p. 68

authors where asking or observing, the participants where always helping and the fact that there was a possibility to walk around freely was an advantage.

In the study the authors' personal background is of highest relevance. The authors' backgrounds are within Computer Science and Business Administration and Economics. The common denominator is Technology Management, which is a program in which this master thesis is a part of. None of the authors has experience from this sort of study before, which can bee seen as a disadvantage but also as an advantage because of the fact that the authors can contribute with a new and different perspective.

Further mentionable criticism is due to the disadvantages of using a simulation model, i.e. it is complicated and requires both time and effort. However the authors believe that the advantages of simulation prevail over the disadvantages.

2.4. Reliability and Validity

When estimating the quality of a study one uses the terms *validity* and *reliability*. Validity is measured by how the theoretical framework corresponds to the empirical data and how relevant the empirical data is for the study. With reliability the trustworthiness of the information is measured, i.e. if the researcher really has measured what is supposed to be measured.[50]

Besides the fact that case study approach is assumed to be subjective and influenced by the researcher they are also criticised for the lack of rigour. This criticism is founded on the fact that most case studies have no standard methodological procedure.[51] Due to this criticism the five step case study roadmap, presented in Chapter 2.2, was adopted to conduct a useful case study. Along the process of the roadmap all field notes, interviews and protocols where documented in a case study database. In principle any other author or researcher could get access to these documents and see what has been measured and done. In this case, use of the database thereby increases the reliability of the study[52].

[50] Andersen (1998): p.85
[51] Patton et al. (2003): p. 66
[52] Darke et al. (1998): p. 283

3. Smurfit Kappa Group Overview

This chapter makes a short presentation of corrugated boards and Smurfit Kappa Group, the Swedish market of corrugated boards and Smurfit Kappa Group's organisation. This is in order to give an insight into the situation which the SKS production at Eslöv resides in.

3.1. What is Corrugated Board?

The well-deserved question of what product Smurfit Kappa Group is producing has the answer of a well-known and long-standing efficient product, but often unnoticed in our daily lives. Corrugated board is the thick paper used for many different packaging solutions, such as boxes, wrapping, racks and much more. The corrugated board itself is made from a combination of two sheets of paper called *liners* glued to a corrugated inner medium called fluting.[53]

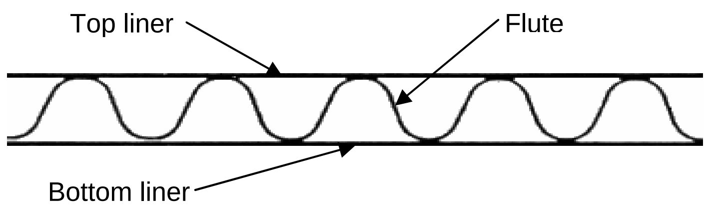

Figure 1. Single wall (double face) corrugated board is constructed by one fluted paper glued between two liners.[54]

These three layers of paper are assembled in a way that gives the overall structure a better strength than that of each distinct layer, much in similarity to the theory of systems approach where the sum of its components are not equal to the whole. This construction offers a wide variety of corrugated board, each with different flute sizes and profiles which can be combined into many different designs to create packages with different characteristics and performances.[55]

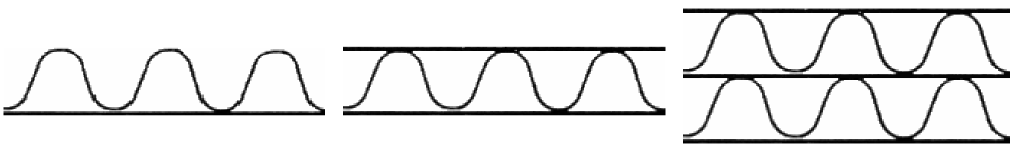

Figure 2. Here are some examples of different corrugated board types. From the left: single face, single wall and double wall. A single faced board can be added to a double wall to create tri-wall (triple wall) corrugated board.

[53] *FEFCO – What is corrugated?*, http://www.fefco.org/index.php?id=103 (2006-03-27)
[54] *TIS – Types of corrugated board*, http://www.tis-gdv.de/tis_e/verpack/papier/wp_arten/wp_arten.htm (2006-03-27)
[55] *FEFCO – What is corrugated?*, http://www.fefco.org/index.php?id=103 (2006-03-27)

3.2. The Packaging Company

Smurfit Kappa Group was formed in December of 2005 as a product of the merger between Jefferson Smurfit Group and Kappa Packaging, thus becoming one of the major packaging suppliers in Europe with a continuing strong position in Latin America. Smurfit Kappa Group combined Jefferson Smurfit Group's previous strong positions, particularly in Western and Southern Europe, with those of Kappa Packaging, who were particularly strong in Northern and Eastern Europe. The newly shaped company attained a net sale in 2005 of € 4437 million. Smurfit Kappa Group produces a wide variety of products as containerboard, solid board, graphic board, corrugated and solid board packaging. [56]

The company's corrugated division is concentrated to Europe where it has operations in twenty countries and the ability to supply to customers everywhere in Europe. Smurfit Kappa Group has a high concentration in western regions of Europe but has strong focus with growing operations in countries previously referred to as Eastern Europe.[57]

Smurfit Kappa Group is able to offer a complete range of corrugated packaging, together with folding cartons, partitions, tubes and composites. In addition to this Smurfit Kappa Group can offer a complete spectrum of printing, thus creating an efficient and attractive product.

Figure 3. Examples of various packaging solutions with print

But this, almost a century old market, is characterised by excess capacity in practically all regional sectors. There are for the time being too many producers and factories for supplying the diminishing market demand. This has led Smurfit Kappa Group on a hunt for the weakest factories and increasing capacity utilisation for the remaining.[58]

[56] *Smurfit Kappa Group*, http://www.smurfitkappa.com (2006-03-15)
[57] *Smurfit Kappa Group*, http://www.smurfitkappa.com (2006-03-15)
[58] Kvist, Per. 2006-03-02

3.3. The Swedish Market

Since the merger of Jefferson Smurfit Group and Kappa Packaging the Swedish market is dominated by the three largest competitors; Smurfit Kappa Group, SCA Packaging and Stora Enso. The market also include many minor and more differentiated corrugated board manufactures, but these only constitute a small part of the market and are therefore are not seen as prime competitors.[59]

The market is characterised by short-term planning from the majority of customers, where many customers want their packages the next day or preferably the same day. This is partly due to that many customers overlook the packaging process and take it for granted in their own production. In general this yields a short production planning and that most production facilities must have a short lead time. This short lead time also puts pressures on short transportation time and distances. The short-term mindset can be one of the reasons for an enclosed Swedish and Nordic market with previous low external competition.[60]

However, during the last couple of years an increasing global competition within Swedish market has been noticeable. Many simpler packages with lower quality requirements are imported from low cost countries, e.g. large quantities of pizza cartons are imported from China and Eastern Europe. The domestic corrugated board market is also declining through the introduction of substitute packages, e.g. within fruit and vegetables commerce has the use of reusable plastic cases replaced disposable corrugated board cases.[61]

The corrugate board market, as a whole, is also under pressure where the combination of weak demand and excess capacity led to a progressive reduction of paper prices. This, in turn, led to pressure on corrugated prices. The declining product prices, combined with rising input costs, particularly in energy, characterised a tough operating environment and led to an underlying reduction in profitability.[62]

3.4. Organisation

Smurfit Kappa Group has a wide variety of corrugated board factories, where SKS's factories are categorised into four different production groups. These groups span from large bulk producing factories with limited flexibility to high-flexible factories with print capability, such as SKS in Eslöv. Within each group the factories share experiences and learn from each others production in order to create best practices. These factories are also benchmarked against each other, where they compete to rank as high as possible in order to receive higher funding.[63]

---

[59] Kvist, Per. 2006-03-02
[60] Dahlgren, Fredrik. 2006-03-02
[61] Dahlgren, Fredrik. 2006-03-02; Kvist, Per. 2006-03-02
[62] *Smurfit Kappa Group – 2005 Fourth Quarter and Full Year Results*, http://www.smurfitkappa.com (2006-03-01)
[63] Dahlgren, Fredrik. 2006-03-08

The factories are evaluated using many measurements, such as trim, starch usage, capacity utilisation, output volume and fulltime personnel per million entered sheets. Entered sheets refer to a sheet's every entry into a machine, i.e. if a sheet passes through two machines it attains two entries. There is a special focus on the two latter measurements, volume output and fulltime personnel per million entered sheets, which gives the factories a motivation to chase volume. This in turn makes factories prioritise running larger orders and also a high capacity utilisation of all personnel. The long-term effects of this focus for a flexible factory with printing capability as Eslöv, is not up for discussion here but fore the reader to contemplate over.[64]

With the merger in December of 2005 there where requirements from the EU Commission to solve potential competition problems in several countries by disposal of numerous plants in Europe. In Sweden Smurfit Kappa Group disposed of two corrugated plants of the total six plants, thus reducing Smurfit Kappa Group's newly combined share from 40-50% to 30-40%.[65]

These factors of increased external and internal competition, and strengthened demand for improved profitability and output, have put SKS's Eslöv production in a complex and challenging situation.

[64] Kvist, Per. 2006-03-02
[65] *Case No COMP/M.3935 - JEFFERSON SMURFIT/KAPPA* (2006-03-28): p. 7-14

4. Theoretical Framework

In this chapter the theoretical framework of the master thesis is presented and the chapter will follow the three primary areas: complexity theory, supply chain management, production planning and production responsiveness.

4.1. Complexity Theory

Complexity theory is not easily defined since it is fairly young research field and encompasses a large amount of scientific studies. There are many definitions of what complexity is and it has been debated at numerous occasions. It is not the intention of this thesis to give a comprehensive list of all different definitions and uses of complexity and related definitions. Instead the most relevant explanations for this thesis are briefly discussed in this section.

Complexity is often referred to as being at *“the edge of Chaos”*[66], which implies that complexity is positioned between complete order and complete chaos. As the expression also asserts complexity occurs near chaos, i.e. it is closer to chaos than order. This gives a hint about the essential difference between ordinary systems and complex systems. Nothing happens with a system in an orderly state until an external force changes the state, as a comparison to the contrary, a system in state of chaos is subject to continuous and rapid changes until an external force makes the system stable. As Waidringer states it is important to note that this chaotic behaviour, given rise by chaos and complexity, is not unmanageable and it is possible to control chaos and complexity within the system.[67]

Most of the complex structures that can be found in reality are vastly redundant and by using that redundancy it is possible to simplify the description. Thus it is possible to manage and control these structures and phenomena. It is critical for the simulation to find and use the right and the most efficient description possible in order to accomplish simplification. [68]

As mentioned earlier the complex systems view, and systems approach, proclaims that a whole system cannot be fully understood by reducing it into smaller manageable units. This is partially due to the rules that are imposed on the system as a whole are divergent from the rules and behaviours of the individual elements within the system. The rules and behaviours of the individual elements also produce the central characteristics of complex systems: non-linearity, self-organisation, emergence and adaptation.[69]

[66] Langton (1990): p. 36
[67] Waidringer (2001): p. 34-36
[68] Waidringer (2001): p. 32
[69] McCarthy (2004): p. 126

4.1.1. Non-linearity

The characteristic of non-linearity is that the input or change in the system is not proportional to the output or effect. Thus one cause may have one type of effect in one part of the system but may affect the system differently if applied to another part of the system. This characteristic is also closely connected to the concepts of multifinality and equifinality in a system.[70]

4.1.2. Self-organisation

Self-organisation refers to a system's ability to organise itself to handle external disturbances and changes. McCarthy asserts that self-organisation is a product of the collective interactions, dependency and circularity of actors and organisational systems, thus creating a complex and remarkable effective behaviour. Self-organisation is also seen as a product of the non-linearity which appears within the system.[71]

In order to understand the self-organisation characteristic it is required to view the system as an open box and not as a black box, where the inputs and outputs are the sole cause of the dynamics for the system. Instead one must study the interior, the elements and the connections of the system to comprehend the dynamic behaviour. It is essential to understand the self-organisational behaviour of systems in order to identify the possibilities of controlling the system.[72]

4.1.3. Emergence

Emergence is the result of the systems evolution and non-linearity. Emergence is identified as the complex behaviour which is created by the collective behaviour, i.e. self-organisation of several elements, which could not be formed by individual behaviour. The behaviour of the many simple elements interacts in such a way that the behaviour of the whole is complex which implies that the behaviour of one element cannot indicate the behaviour of the whole. McCarthy also describe that the outcome of the emergence is often unforeseen and sometimes unique. Bar-Yam states that the characteristic of emergence is often not appreciated or understood since it requires mathematical and conceptual effort to understand. [73]

4.1.4. Adaptation

Nilsson & Waidringer argue that adaptation is a central property of logistic complexity.[74] Adaptation is the way elements within the system make proactive and reactive actions to cope with changes in the systems environment. This means that elements adapt their behaviour and structure to alterations in their local context.[75]

[70] McCarthy (2004): p. 126
[71] Bonabeau & Meyer (2001): p. 107-108; McCarthy (2004): p. 127
[72] Nilsson (2003): p. 17-19
[73] Bar-Yam (1997): p. 5, 9-10; McCarthy (2004): pg. 126-127
[74] Nilsson & Waidringer (2002): p. 14
[75] Nilsson (2003): p. 21

It is important to distinguish between adaptation and flexibility. Bonabeu & Merger state that flexibility emerges as a result of self-organisation in the system, but they make no distinction between the definitions of flexibility and adaptation, and treat flexibility as adaptation[76]. The authors see flexibility as an essential part of adaptation but whereas flexibility is the ability to change temporarily only to return to its original equilibrium state, adaptation holds the ability to learn thus adapting its original state to the changes in the environment.

4.1.5. Complex Adaptive Systems

Complex adaptive systems (CAS) are systems constituting of elements and agents with the capability of adaptation. This is due to, as discussed earlier, the agents' ability to act and react to changes in their local context. Choi, Dooley and Rungtusanatham refer to CAS as *"a system that emerges over time into a coherent form, and adapts and organizes itself without any singular entity deliberately managing or controlling it"* – so a truly complex type of system. Examples of CAS are cells, brains, ant colonies and traffic formations generated by vehicles on a roadway. Choi, Dooley and Rungtusanatham also define the underlying dynamics of CAS as its internal mechanism, environment and co-evolution, shown in Figure 4. [77]

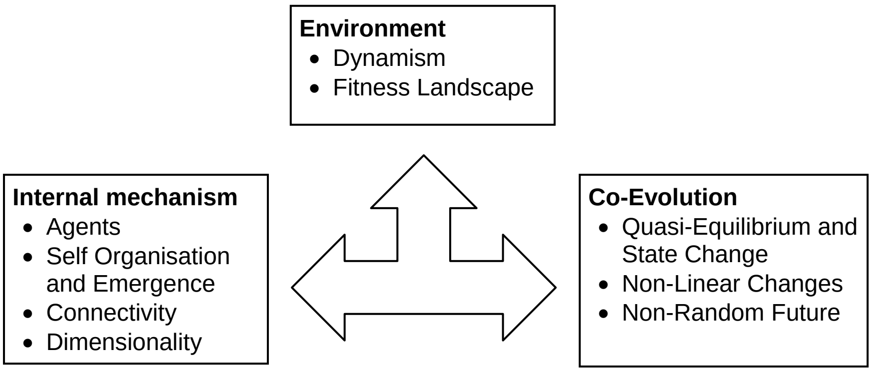

Figure 4. Three dimensions which define the dynamics of a CAS.[78]

4.1.6. Internal Mechanism

These are the dynamic functions which retains inside a CAS and define its internal structure. The internal mechanism consists of agents, self-organisation and emergence, connectivity and dimensionality.

4.1.6.1. Agents

The entities which populate the CAS are referred to as agents and participate in the continual evolution and transformation of the system. Though a system is only defined to bear an agency if it sustains the ability to intervene meaningfully in the

[76] Bonabeau & Meyer (2001): p. 107
[77] Choi, Dooley & Rungtusanatham (2001): p. 352
[78] Choi, Dooley & Rungtusanatham (2001): p. 353

course of events. So a complex system as water is not a CAS, since its elements (molecules) do not have this ability.[79]

An agent may refer to an individual but also to a team, a division or an organisation of elements. All of the CAS's agents are in some way connected to other agents to distribute information and resources. The type and scale of these connections vary depending upon the type of CAS. Each agent also follows a collective set of rules, values, beliefs and assumptions that are established within the system, though the vast majority of these rules and norms are dominated by a few central conventions. This is why agents are often referred to follow a few simple rules.[80]

4.1.6.2. Self Organisation and Emergence

As discussed earlier, self-organisation refers is the behaviour produced by the collective actions of several agents. Nilsson states that self-organisational behaviour makes the system robust and adaptive, and creates structure within CAS. [81] These properties of self-organisation generate new emergent patterns and behaviours – emergence. Emergence within the system makes its behaviour unanticipated and the outcome creates new opportunities.[82]

4.1.6.3. Connectivity

The complexity within CAS is determined by the level of connectivity, i.e. the number of connections between agents. When the level of connectivity increases the chains of connected agents, called inter-relationships, also increases. The quantity of inter-relationships within a CAS is important because it indicates the potential for the network to engage in global communication from within. The quantity also implies the potential for chain reactions and effects at a distance.[83] No or too few inter-relationships create a stable behaviour, and too many inter-relationships create an unstructured and chaotic behaviour[84].

4.1.6.4. Dimensionality

Dimensionality refers to the degree of freedom which resides for the agents. Higher degree of control restricts the individual behaviour, thus decreasing the complexity and enabling a more stable CAS. In comparison a higher degree of local autonomy enables a creative and emergent behaviour.

4.1.7. Environment

The environment of a CAS both affects the system and is affected by it. The environment is characterised by dynamism and fitness landscape, which will be discussed below.

[79] Choi, Dooley & Rungtusanatham (2001): p. 352-353
[80] Choi, Dooley & Rungtusanatham (2001): p. 353
[81] Nilsson (2003): p. 28
[82] McCarthy (2004): pg. 127; Choi, Dooley & Rungtusanatham (2001): p. 353
[83] Choi, Dooley & Rungtusanatham (2001): p. 354
[84] Nilsson (2003): p. 27

4.1.7.1. Dynamism

As Choi, Dooley and Rungtusanatham express it: *"the only thing constant is change"*. The CAS and environment is in constant change, where the CAS's alter its boundaries by including or excluding agents in its network. The environment can modify the rules which alter the CAS's fitness, and as the CAS change this will affect other local CASs which in turn will eventually change their joint environment.[85]

4.1.7.2. Fitness Landscape

Fitness landscape is the term used to illustrate the CAS's surroundings and imply on the agents ability to adapt and create greater fitness to its environment. The landscape is characterised by its rugged surface, illustrated a terrain of valleys and hills. Within this terrain agents strive for reaching the high tops which represent more favourable positions. However, as Nilsson states the agents affect their surroundings the landscape becomes dynamic and interchangeable. This creates a rugged and changing environment where an agent's fitness to its environment will change over time.[86]

4.1.8. Co-Evolution

Choi, Dooley and Rungtusanatham enlighten a problem with many management theories as in them *"an environment is often viewed as a disjointed entity that exists independent of the individual members that reside within the environment"*. In contrast it is essential for a CAS to be viewed as a system that both reacts to and creates its environment. [87]

Co-evolution refers to the interconnected development between agents, where one agent's adaptation is affected by preceding actions in its environment and will affect others' future behaviour in its surrounding. Nilsson exemplifies it as: *"each firm or group of firms can be identified in some kind of niche. This niche is a dynamical result of previous actions performed by agents within the firm, as well as actions performed by agents from other firms directly and indirectly connected in some way to the firm"*.[88]

4.1.8.1. Quasi-Equilibrium and State Change

As mentioned earlier, a CAS resides on *"the edge of chaos"* also described as a quasi-equilibrium state. This state enables the system to react to changes and still uphold order. As the external environment pushes the CAS farther from the point of quasi-equilibrium the CAS becomes more sensitive to environmental changes. At some point an incremental or radical state change will occur giving the CAS a new point of quasi-equilibrium.[89]

---

[85] Choi, Dooley & Rungtusanatham (2001): p. 354-355
[86] Choi, Dooley & Rungtusanatham (2001): p. 355; McCarthy (2004): pg. 127-129; Nilsson (2003): p. 29-30
[87] Choi, Dooley & Rungtusanatham (2001): p. 356
[88] Nilsson (2003): p. 30
[89] Choi, Dooley & Rungtusanatham (2001): p. 356

4.1.8.2. Non-Linear Changes

As for a complex system the property non-linearity also applies for CAS. Therefore large input changes may cause small outcome changes, and small input changes may cause large outcome changes.

4.1.8.3. Non-Random Future

Just because it is improbable to predict the future behaviour of a complex system, it does not mean that the behaviour is random. This is because a set characteristic pattern emerges in the CAS, despite the dynamics of CAS and its environment. Through the knowledge of these patterns it is probable to attain a limited predictive capability for a prediction of a CAS's state at a future point in time.[90]

4.2. Supply Chain Management

The purpose of this part of the report is to give the reader a brief introduction to logistics and Supply Chain Management (SCM). During the work process of this master thesis the authors have used this knowledge to create an overall understanding of logistics and SCM, and its effects on SKS's organisation. The theories serve to give the reader a similar overall understanding as the authors of the subject. The parts presented in this section are those who make significant contributions to the case. For additional knowledge within these areas we recommend further research.

4.2.1. Definitions of Logistics and SCM

It is common knowledge that logistics involve some sort of physical movement from one place to another but today it has become much more than that.[91] Through history an abundance of different definitions has emerged with different contents and intentions. One definition is from the Council of Logistics Management who defined logistics as:[92]

"*the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements.*"

The concept of logistics can be further developed into a wider significance, SCM. There are some definitions that equate the SCM with the traditional logistics concept,[93] but the factors that characterise SCM focus on relationship management and the performance improvements that it results in. To be successful SCM also requires cross-functional integration of important processes within firm and across the

[90] Choi, Dooley & Rungtusanatham (2001): p. 357
[91] Lummus et al. (2001): p. 426
[92] Lummus et al. (2001): p. 426
[93] Skjøtt-Larsen (1999): p. 41

network of firms that comprise the supply chain.[94] A definition that corresponds to these characteristics is:[95]

"the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole"

According to Schary & Skjøtt-Larsen a supply chain can be visualised through many perspectives and it contains five operating processes: *product*, *production*, *procurement*, *distribution*, and *demand management*.[96] When it comes to managing the entire supply chain Lambert defines eight different key SCM processes, where one is manufacture flow management. These processes are based on the fact that companies cannot optimise their product flow without implementing a process approach to the business. However, there is no common standard in the industry. The value of having a standard business process is that companies comprising a supply chain can use the same language and link up their processes.[97]

To sum up the discussion about logistics and SCM, the later is somewhat larger than the previous. As Lummus et al. puts it: *"supply chain management is not just another name for logistics. It includes elements that are not included in a definition of logistics, such as information systems integration and coordination of planning and control activities"*. Further, SCM is to be seen more like a strategic management tool for increasing the customer satisfaction to improve the competitiveness and profitability of a company.[98]

Below a presentation of processes which has affected the study at SKS will be carried out. Since the purpose of this chapter was to give an overview the processes are described in a general way. The product as an operating process is to be taking into consideration because of its ability to determine the production process, logistics requirements for transport, inventory, and time for delivery.[99]

4.2.2. Production

The production within a company plays a central part in the supply chain because it is adding value to the product flow. Depending on how a company decides to design their production it is influencing the inventory, transport, and time of delivery.[100] In fact, production techniques have become a critical factor to remain competitive on the global marketplace. Today, the global market demands both product and volume flexibility and it is of great importance that companies meet these demands. This

[94] Lambert (2004): p. 19
[95] Skjøtt-Larsen (1999): p. 41
[96] Schary & Skjøtt-Larsen (2003): p. 34-35
[97] Lambert (2004): p. 20
[98] Lummus et al. (2001): p. 428
[99] Schary & Skjøtt-Larsen (2003): p. 35
[100] Schary & Skjøtt-Larsen (2003): p. 35

implies that companies have to develop the ability to increase capacity as well as capabilities for quicker order response and to match unique customer demands.[101]

For companies to compete within the industry it is to an advantage for a company to adopt a manufacturing strategy. When viewing manufacturing strategy it is often separated in two parts: the *process* of manufacturing strategy and its *content*. Further the content of manufacturing strategy will be briefly presented through three different paradigms; *competing through manufacturing, strategic choices in manufacturing strategy* and *best practice*. The content is to be viewed as the strategic choices in process and infrastructure.[102]

The first paradigm can be described as "Competing through manufacturing" and implies that companies should compete through its manufacturing capabilities. Important issues within this paradigm are the key success factors and the order winners. Competitive dimensions in manufacturing are for example cost, dependability, and flexibility. "Order winners" can be described as those criteria's that wins orders against the competition, e.g. price, delivery, quality, product design and variety. Capabilities that may not win orders but gives the possibility for a company to enter a market are called "qualifiers". This paradigm brings out the fact that by combining the capabilities of manufacturing with the key success factors the company will maximise the competitiveness. Thus it demands a prevailing shared vision within the company.[103]

The second paradigm concerns the internal and external consistency between choices in manufacturing strategy and is called "Strategic choices in manufacturing strategy". In a manufacturing company the common choices in manufacturing strategy are among other things plant and equipment, production planning and control, and organisation and management. The choice of manufacturing process is also a common and important choice to consider as a manufacture.[104] The basic choices in manufacturing processes are project, job shops, batch, line and continuous process. The processes are determined by the size of the production run progressing from the scale of a single project to continuous flow processes with large volumes.[105] In terms of consistency the choice of process is dependent on both the market strategy and on the order-winning criteria.[106]

The last paradigm is termed "Best practice" and is the most recent of the three paradigms. During the years best practice has been brought into greater prominence due to three different stimuli presented below:[107]

- The outstanding performance of Japanese manufacturing industry

[101] Schary & Skjøtt-Larsen (2003): p. 152
[102] Voss (2005): p. 1211-1212
[103] Voss (2005): p. 1212-1213
[104] Voss (2005): p. 1214
[105] Schary & Skjøtt-Larsen (2003): p. 159-160
[106] Voss (2005): p. 1214
[107] Voss (2005): p. 1215

- The growth of business process-based approaches and benchmarking
- The emergence of awards such as the European Quality award.

Along with the three paradigms above, measurement is also considered to be a part of the manufacturing strategy. In the literature different suggestions and frameworks have been laid out to show the importance of measurement in manufacturing strategy. For example a *balanced scorecard* is a tool that matches the measurements with the company's strategic needs.[108]

4.2.3. Performance Measurement

Supply chains consists of several connected processes which requires separate improvements in order to optimize the over all performance. A way to identify an independent and related improvement process is through measurement which is highly conformable for supply chains. According to Robson, measurement has been acknowledge within organisations and that the approach is about identifying *"What"* can be measured and *"How"* to measure it. This in turn demands the prerequisite of challenge the question *"Why"* it should be measured in the first place.[109]

As is often said; *"What get measured gets done"* or *"If you cannot measure it, you cannot manage it"*, the inference is often drawn that the more that is measured, the more will be managed and improved. However, it is important to identify those measurements that will contribute to an overall improvement in performance and reassess those who are not. In fact, in order to gain the greatest return on investments of implementing and maintaining the measurement system, the very minimum set of measurements should be chosen which could lead to an overall effectiveness of a process.[110] In the same way, unacceptable performance of a process is much easier to detect due to the minimum set of measurements. This implies that measurements can be used to identify when the process is not delivering the desired performance. In other words, the focus of the measurements is on failure which may seem odd, but often in order to achieve success, failure must be avoided.[111] Further, by using a measurement approach on a supply chain Robson states: *"it is possible to work back from the head of the supply chain, identifying those few performance measures that are critical to failure at each interface and agree a strategy that will progressively improve the overall performance of the whole chain"*.[112]

4.2.4. Production Planning, Scheduling and Control

Production planning is often mentioned as an essential part of the supply chain due to its relationships with different functions inside and outside the company walls. Production planning usually begins with, and is thereby very dependent of an order forecast from sales or marketing.[113] After that the main goal is to satisfying the

[108] Voss (2005): p. 1216
[109] Robson (2004): p. 510, 517
[110] Robson (2004): p. 511
[111] Robson (2004): p. 515
[112] Robson (2004): p. 517
[113] Schary & Skjøtt-Larsen (2003): p. 167

customer by delivering the correct order quantity with the requested quality at the agreed delivery date. Today, an environment of increasing product design, reduced product life cycles and enhanced customer expectations, focus has been enhanced to find effective planning control systems.[114] These systems help the planner to establish the production scheduling which is a plan for what product will be made at what time utilising what recourses. The purpose of this plan is to control the operations taking place in the plant. Important considerations when scheduling is to take into account the capacity of productive recourses to make the scheduled products.[115]

Production planning, scheduling and control are processes connected to the management of manufacturing flow. Manufacturing flow management includes all activities needed to obtain, implement, and manage manufactory flexibility on the one hand in the supply chain and on the other hand to process products though the plant. When managing the planning process one has to consider the fact to produce a wide variety of products at the lowest possible cost. For the production planners to uphold this flexibility takes us back to the importance of relationships with other functions within the supply chain.[116] To further point out the importance of relationships, Towers & Ashford mean that production planning and control should be focusing on relationship marketing and the links with the customers. Moreover, they argue that the link between internal capability of the manufacturing and the customer is vital for manufacturing effectiveness when meeting the requirements of the end customer.[117]

4.2.5. Demand Management and Forecasting

Demand Management is a catchall term which includes activities like forecasting, customer order processing, market coordination, and sales support.[118] Further Lambert mentions activities like increasing flexibility and reducing variability as parts of demand management. It is the process that balances the requirements of the customer with the capabilities within the supply chain, meaning matching demand with supply. An effective demand management process can minimize disruptions throughout the supply chain by reducing uncertainty and providing efficient flows.[119]

4.3. Production Responsiveness and Vulnerability of Supply Chains

In industries operation management, e.g. production planning, in SCM is usually executed under normal working conditions. The working personnel generally do not taking into account the unplanned events that may occur during the process, events that may affect the expected normal flow of materials and components.[120] These circumstances have generated a focus on managing operations under conditions of

[114] Towers & Ashford (2001): p. 2
[115] Parsons & Phelps (2001): p. 561
[116] Lambert (2004): p. 21
[117] Towers & Ashford (2001): p. 3
[118] Schary & Skjøtt-Larsen (2003): p. 35
[119] Lambert (2004): p. 21
[120] Svensson (2000): p. 731

increasing change.[121] Changes or disturbances are common phenomenon in supply chains according to the literature and it is affecting the vulnerability of the company and supply chain. Vulnerability is defined by Svensson as:[122]

"the existence of random disturbances that lead to deviations in the supply chain of components and materials from normal, expected or planned schedules or activities, all of which cause negative effects or consequences for the involved manufacturer and its sub-contractors"

The effects of this definition are seen as negative effects but there is also the possibility that the effects are positive. If positive, then one has to maximise the benefit. In fact, changes or disturbances may not always affect the operational performance, but according to Matson & McFarlane they must have the potential to.[123]

There are many models or concepts for preventing or handling disturbances in the supply chain.[124] Production responsiveness is a conception that explains the ability of a production system to achieve its goals in the presence of disturbances. The types of goals are for example quality, safety, delivery and cost which describes a desirable behaviour of the system seen as whole. In other words, production responsiveness is concerned with how one unit within a company behaves in respond to events that are affecting its operational performance.[125]

For a company to be able to prevent or handle different disturbances it requires a set of responsiveness capabilities. The required capabilities are presented together with factors that are influencing the production responsiveness in Figure 5.

[121] Matson & McFarlane (1999): p. 765
[122] Svensson (2000): p. 732
[123] Matson & McFarlane (1999): p. 767
[124] Svensson (2000): p. 733
[125] Matson & McFarlane (1999): p. 767-8

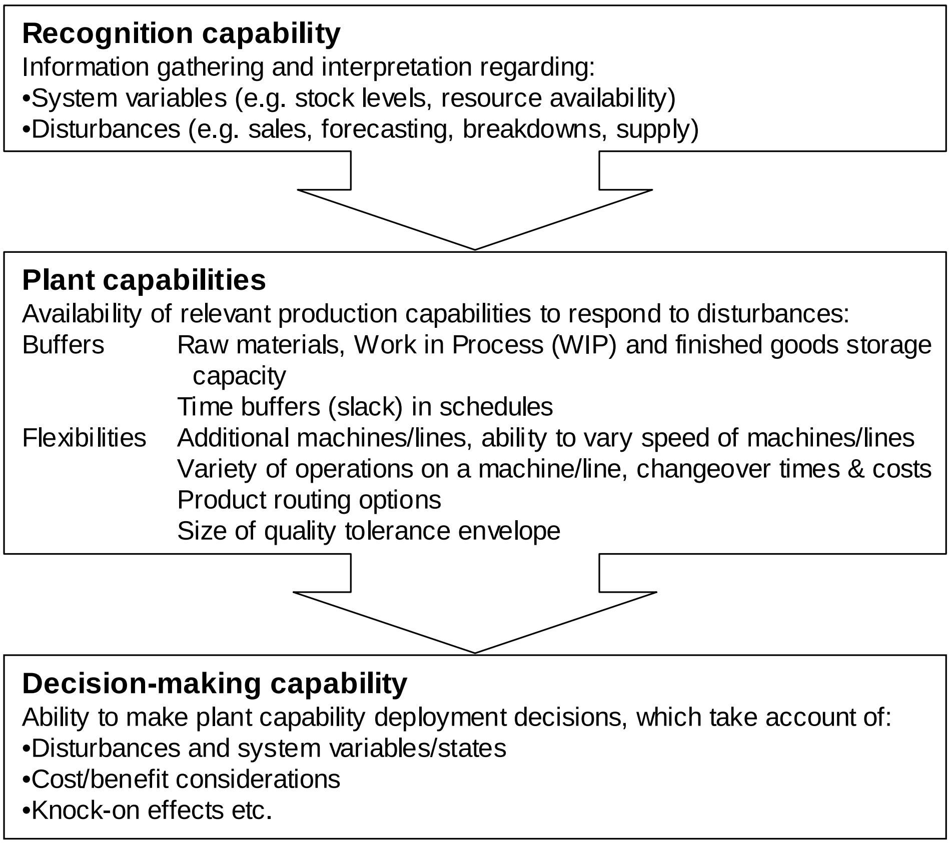

Figure 5. Capabilities and factors influencing production responsiveness[126]

[126] Matson & McFarlane (1999): p. 770

5. SKS in Eslöv – The Case Study

In this chapter the internal supply chain within SKS in Eslöv, from order placement to finished goods, is described. It also describes the work process of production and production planning which creates the basis for the model.

5.1. SKS Internal Supply Chain

As within most supply chains the SKS internal supply chain consists of two main flows, the order or physical flow and information flow. The two flows are tightly connected and streams hand in hand throughout the process, from order placement to finish goods. In this chapter these two flows will be described more thoroughly, starting with the workflow for orders. Since the study focuses on the processes from when the order is taken over by the production planners to the phase when the order is distributed to the finished goods stock the inherent processes of the focus will be presented. However, to give the reader an understanding of the creation of an order the order process is presented through a briefly description.

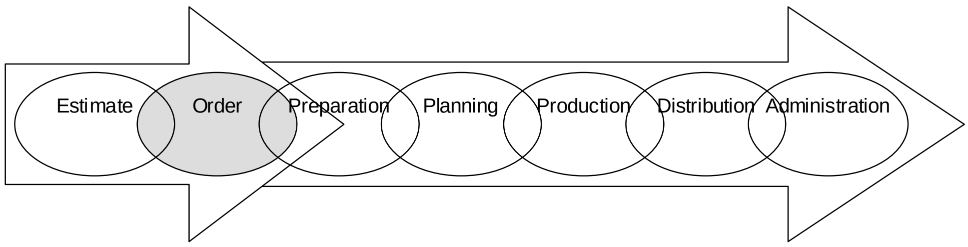

Figure 6. The left arrow represent the sales process and the right arrow the delivery process. The circles represent all functions within the main process.

Within SKS in Eslöv the main process is divided into two subsequent processes, where the first process, the sales process, is separated from the following process, the delivery process. As can be seen in Figure 6, the order process takes place as a part of the sales process but also the small part of the delivery process.[127] The minute an order is released, i.e. the customer has placed an order and it is granted by the sales department, the order is handled through the Enterprise Resource Planning (ERP) system known as POPPE. Dependent on the type of order it then takes different paths which are called: *new, repeat special* and *repeat order (high-way).* A new order is characterised by if the product never has been manufactured at the factory for the present customer. The repeat special implies that the order has been manufactured before but it requires an order of extra material, e.g. plastic handle, or if the requested material has to be ordered in advance. The last type of order, i.e. the “high-way” order, implies that the order runs directly from order placement, without any further processing, through the order process to the production planning. This is possible since the order has been manufactured before at the factory and all the tools needed are at place. Because of that the “high-way” order simply runs through the order

[127] Smurfit Kappa Sweden, *POPPE Manuals* (2001)

process it has to fulfil some requirements.[128] First of all the customer has to be creditworthy which always is controlled when register a new customer. Secondly, the article has to be produced at the factory before and third, no extra requirements as applies for repeat special. The fourth and fifths requirements are that no special qualities are needed and that the order does not have to be manufactured within the nearest five days. If one or more of these requirements is not fulfilled the order becomes a repeat special.[129] Finally, when the order has reached the order confirmation a traffic department approves the time of delivery. Then the work of preparation and planning begins and an order confirmation is sent to the customer.

5.1.1. The Information Flow

Along the order flow runs a real-time information flow trough the controlling computer systems, POPPE and PC-Topp. POPPE is a self developed ERP system for SKS and PC-Topp constitutes the Manufacturing Execution System (MES). The system contains all the necessary information about the order and the specific product which is to be manufactured. During the whole process the necessary information for the specific operation is distributed to the unit that is operating a certain part of the process, i.e. production planners, machine operators, production preparation, and service department. This implies that the operator gets the specific information needed for the operation which, in turn, helps reducing an overflow of information that is unnecessary.[130] The production planners use the PC-Topp system to send information to all the machines and their operators. In the same way the operators use the system to report any failure by entering certain codes in to the systems. The operator's only report if the failure has lasted more than two minutes. Unless it is a known type of failure the planners can see what is wrong in the production through the PC-Topp system in real time. If it is an unusual failure the machine operators mostly report by telephone.[131]

When the order is ready for production a working card is printed out by one of the production planners. The working card contains information about, e.g. machine adjustments, for the specific order and physically follows the order throughout the production process. As each step in the production is concluded the machine operator makes a note on the working card and passes it on to the following step. The operator should note any complement made to guarantee the quality of the product. All other information that the operator is in need of, like instructions and temporary changes, is stored and can be reached from the PC-Topp system.[132]

5.2. Production

The production in Eslöv consists of several process steps which are fairly automated. The majority of the transportation between the machines is made by automated

[128] Dahlgren, Fredrik. 2006-03-02
[129] Smurfit Kappa Sweden, *POPPE Manuals* (2001)
[130] Dahlgren, Fredrik. 2006-03-02
[131] Dahlgren, Fredrik. 2006-03-08
[132] Jönsson, Elna. 2006-03-03

guided vehicle (AGV) trucks, but each machine is controlled by a team of operators. The production is illustrated conceptually in Figure 7, where the machines are categorised into subgroups. The production consists of two primary groups, corrugated board machine (group 1) and converters (group 3 and 5). Between the production groups there are two buffers (2 and 4), one used for the storage of orders going to the converters (3), and the second for the orders going to the converters with folding and gluing (5). All orders are sent via the last group (6) for strapping and stretch filming before sent to the delivery unit.

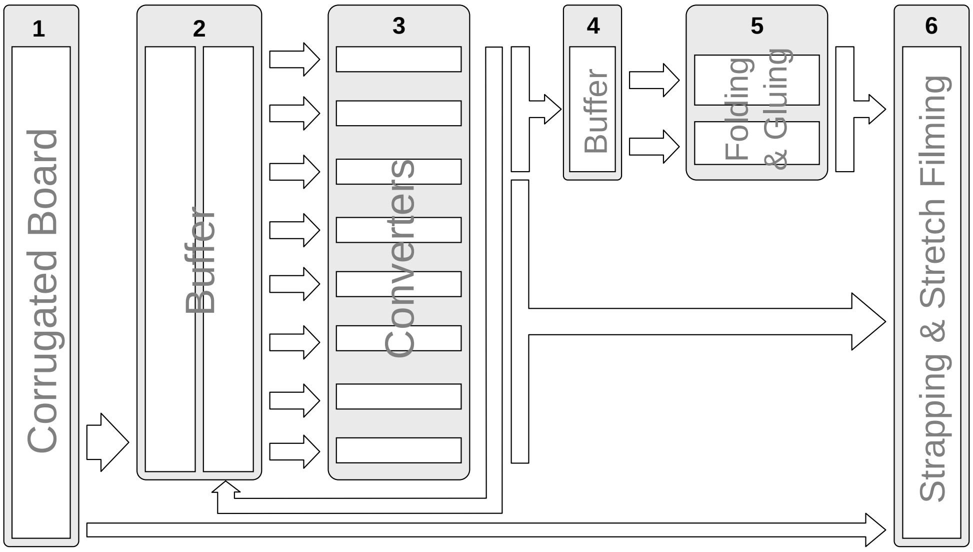

Figure 7. The figure presents a conceptual model of the production at the plant in Eslöv. The production groups are clustered into six different sections and the different product flows are illustrated by the arrows in between sections.

The corrugated board machine consists of three in line machines to combine two to five layers of paper to form single face, single wall or double wall board. A simplification is that the first machine produces single wall, one of the following machine also produces single faced board which is combined with the first single wall to create double wall. The corrugated board is then cut and stacked into sheets. The machine is able to simultaneously produce two different orders which use the same quality of corrugated board but with different dimensions for the sheets. When an order is produced and it requires further processing, it is distributed to the buffer in group 2. If not, the order is distributed directly to the strapping and stretch filming before it is placed in stock of finished goods. These types of orders simply consist of plain paper sheets.

The first buffer after the corrugated board machine consists of two parts. This makes it possible to adjust the placing of the piles of paper sheets, so that the piles comes as close as possible regarding to the following converter. Those piles that belong to the same order are coordinated to the same converter through the buffer and the AGV trucks.

The converters consists of two groups of machines, where the first group consist of eight machines for printing and punching, followed by the second group consisting of two machines for folding and gluing. The converters process the product during to the customer's specific needs, which in turn may imply several converting steps by different machines. The machines of group 3 have different features with different limitations. There are two main categories of features: printing and punching. Some machines only have the capability of printing and therefore, in most cases, must be followed by a punching machine. In turn, there are machines with the single capability of punching paper sheets in various sizes. These machines are able to process paper sheets, with or without any print. Then there are machines that both handle printing and punching. Which machines to use is most dependent on the requirements of the end product. Since some of the machines have similar features, some machines can take orders from one another or another machine, thus orders with the same articles can take a different machine route.

If the order requires more than one converter in group 3, the piles of paper sheets are sent back to buffer and distributed to the next converter in the same group. When the order has run through all the required machines in group 3 it is distributed further, either directly to the strapping and stretch filming or through the buffer, in group 4, to the last converters in group 5. These last converters are those which fold and glue the paper sheets into boxes.

5.3. Production Planning

In order to manage the high variety of products and complicated order flow SKS in Eslöv is most dependent of the production planning group. The group consists of three persons who are responsible for two different processes within the production planning process. The production planners are in constant contact with each other, which is a prerequisite to effectively manage the planning. Overall communication is most important due to the fact that the production planning constitutes the link between the production and market[133]. The tools for planning and optimisation are mainly PC-Topp. Before going into these processes a more comprehensive description of the production planning will be presented.

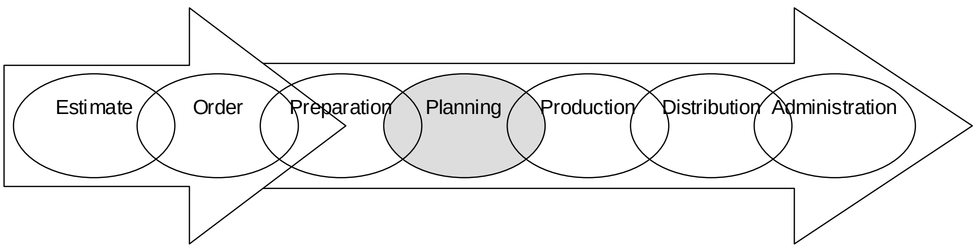

Figure 8. The planning process with its surrounding processes in the main process.

[133] Dahlgren, Fredrik. 2006-03-08

Even though the main planning is concentrated before and under the production, the production planning comes in as early as when an order is registered. The purpose then is to control the time of delivery by performing a backward planning. Backward planning simply means that one starts with the time of delivery and then plan the time of production backwards step by step to ensure the time of delivery. When this is carried out the production planning re-enters the process after production preparation has released the order. This process between preparation and planning is dependent on if it is a new article or if it is an old one. If the article and order is previously known and there is not any changes the order is delivered directly to the production planning. Besides the control of time of delivery a coarse planning is made. The coarse planning is carried out through POPPE and aims to evenly distribute the workload between the machines. Through control and the coarse planning planners can find an alternative machine route if the planed machine route does not work. POPPE is also capable of providing a new time of delivery if the alternative machine flow is not possible.

"The production flow of a product is dependent on the number of manufacturing steps. It is important that the product does not have to wait in buffer, but also that the machines should not be lacking material. This demands for a certain balance"[134]

When an order is ready for production it is time for detail planning and optimisation. This work is carried out by means of PC-Topp and is separated due to each planning focus; planning of corrugated board machine and planning of the converters. In this stage the planners strives to have eight hours of non-changeable planning which is not an easy task due to different types of deviations or disturbances.[135] All orders are placed in an order list that is distributed out to the machines. Besides the machines the service group receives the order list which enables them to deliver tools, such as stereos, a form of printing block, and punch tools, and paint on time.

5.3.1. Planning of Corrugated Board Machine

The corrugated board machine at SKS in Eslöv is the most important part of the production. When planning the corrugated board machine the planner first has to consider the time of delivery. Because of the backward planning the planner also has to check with the planner of converters so that a start time of production can be scheduled. [136] The planner then has the possibility to plan the production of corrugated board in time or in advance[137], not too early since the customers has the possibility to cancel their orders ten days before time of delivery[138]. This is dependent on other different variables that the planner must take into account and which are specific for the corrugated board machine. In order to optimise the corrugated board machine the planner must consider the type of paper, grammage and paper quality to prevent frequent roll changes and thereby more waste. Considering the dimensions of the

[134] Berglin, Mikael. 2006-03-07
[135] Dahlgren, Fredrik. 2006-03-08, Karlsson, Stefan. 2006-03-08, Jönsson, Elna. 2006-03-03
[136] Karlsson, Stefan. 2006-03-08
[137] Karlsson, Stefan. 2006-03-08
[138] Berglin, Mikael. 2006-03-07

specific product the planner can combine two orders when running the corrugated board machine by selecting a certain roll size, i.e. width of paper roll. The goal is to maximise the width of the paper roll and by that lowering the cost of production. These considerations, in turn, aims to reduce the inevitable waste caused by the "trim" that is created when cutting the sheets of corrugated board.[139]

5.3.2. Planning of Converters

Simultaneously as the corrugated board machine is planned and scheduled the converters have to be prepared. This implies that the machines should receive information about which orders to produce at what time and with which tools. The converters consist of ten machines with different features. Mostly an order has to go through several converters before it is further transported, which in turn makes the planning more complex. The main object of planning the converters is to optimise the capacity among the converters so that most of the machines are running at the same time. Often different disturbances occur, e.g. a machine stops for some reason, which implies that maybe the order flow must be redirected. The production planner then must consider different alternatives to make the best of the situation.[140]

When planning the converters the time of delivery has first priority. Since the converters are the last process before filming and strapping, and later inventory of finished goods, it is important that the products are ready on time. It is also eligible if an order has the same adjustments on the machine so that setup times can be reduced. Another factor to consider is to combine orders which have the same recipient. The planner then must coordinate the orders so that they are ready at the same time.[141]

5.3.3. Communication

As mentioned above, the communication is of most importance for the production planners. The PC-Topp system provides the planners with information about the condition of the production, e.g. real time information in terms of stop codes, the orders and products present location, and order flow[142]. Thus, this information is sometime limited in its context. Since the production planners are highly affected of how the production flows the communication with the shop floor workers is frequent. The needed information from the production concerns lack of tools, as stereos or punch tool. If the planners do not receive this information they may start an order although the lack of tools. The same goes for any failure in the production, all things has to be reported.[143]

In order to go through the scheduled production and detect any impediments the production planners have daily meetings with the production team-leaders and some of the operators. At certain conditions discussions arises between the planners and production, concerning which machine to run for a specific order. Production

[139] Karlsson, Stefan. 2006-03-08
[140] Jönsson, Elna. 2006-03-03
[141] Jönsson, Elna. 2006-03-03
[142] Dahlgren, Fredrik. 2006-03-02
[143] Jönsson, Elna. 2006-03-03, Karlsson, Stefan. 2006-03-08

planners consult the machine operators which often possess great in-depth knowledge about the machine conditions. Collaboration between production planner and operators are seen as essential.[144]

Further important information concerns the market demand and information about customers specific needs. To be able to serve the customer with what they need the communication with the sales department is also of great importance. The planners gets daily phone calls from customer that either want to change the order or change delivery date. Problem occurs when this type of information reach the planners too late.[145] As the production planning constitutes a filter between the market and production the planners have to rely on the actual orders they receive and build their planning upon these orders. However, if a better forecast could be received it would facilitate the planning of the production.[146]

5.3.4. Production Planning Issues

Besides the production planning itself there are many problems and issues during the production planning process which in turn increases the complexity. As mentioned above the lack of production and customer information, creating balance in the production, and production disruptions are some of them. Disturbances or deviations are divided into two main categories: order and production related. The order related deviations are, for example, when a high priority order is placed or when the mix of products is not suitable for optimal capacity. The production related deviations that occurs can further be divided into two categories: unplanned and planned deviations. The planned deviations can be taking in calculations since they can be foreseen by the production planners. Examples of planned deviations are meetings, education of personnel, and maintenance of machines and facilities. The unplanned deviations are much more difficult to predict and therefore, more or less, causes most of the problems. According to a list of stop-codes used at SKS these unplanned deviations can be categorised as: mechanical failure, electrical failure, tools, process failure, and lack of orders. There is also one category that can be both planned and unplanned, which is shortage of personnel. Meetings and educations are examples of planned shortage of personnel and sudden lack of personnel is considered unplanned.[147] Below, in Table 1, examples of deviations and disturbances are presented together with the causes behind and effect of them.

[144] Jönsson, Elna. 2006-03-03
[145] Jönsson, Elna. 2006-03-03
[146] Karlsson, Stefan. 2006-03-08, Berglin, Mikael. 2006-03-07
[147] Dahlgren, Fredrik. 2006-03-08

Cause	Disturbances/deviations	Effects
Un-preferable mix of products Converter failure Non-optimal planning	Buffer full	Have to stop the corrugated board machine
Inadequate service Careless machine adjustments	Machine is broken	Stop in production Redirect orders if possible Loss of delivery or displacement of time of delivery
Un-preferable mix of products Some machines are faster Shortage of personnel	Uneven degree of coverage in the production	Some machines are standing still
Lack of information Changes in schedule	Wrong tools and paint	Delay in production
Estimated time do not corresponding to real time	Deviations in time	Displacement of time
More important orders comes first	Extra orders	Displacement in planning
Lack of raw material Non-optimal planning	Lack of material	Delay in production Other machines will be affected

Table 1. Examples of disturbances and deviations, the causes of them and their effects

5.4. Stock

As the orders are finished in production they are transported to the stock of finished goods, which is operated by the delivery unit. Most often the goods are sent directly to further transportation but sometimes they occupy the inventory for a short time. In the other end, the stock of raw material is operated by one of the production planners. The stock of raw materials is controlled by a minimum/maximum strategy for the most common products and Vendor Managed Inventory (VMI) for special products which costs dependent on consumption.[148] The strategy of using a min/max inventory is rather unusual in the business, whereas most of the competitors are ordering their raw material after demand and with much shorter time-horizons.[149]

Former, the stock has never been a limitation for SKS in Eslöv and is therefore not included in this study. Although, during the work of this master thesis some problems occurred, concerning the supply of raw material, e.g. paper. One of SKS's suppliers has closed one of their factories which has lead to that SKS now have some problems to be flexible when order raw material. The result is that some products are hard to get with short notice.[150]

[148] Karlsson, Stefan. 2006-03-08
[149] Dahlgren, Fredrik. 2006-03-08
[150] Dahlgren, Fredrik. 2006-04-13

6. Applying Complexity to SKS Production

This chapter aims at combining the two main theoretical areas, complexity theory and supply chain management, and show how complexity can be viewed through a logistic perspective. The logistic perspective is in turn a reflection of the case study at SKS in Eslöv where the main elements which are essential for the further process of this thesis are discussed. The purpose is thereby an introduction for the reader to create an understanding of the authors' view, before entering the further analysis of the SKS production process. The analysis will be concluded with a discussion and further an identification of improvement areas in line with an increased production output.

6.1. The SKS Production in a Complexity Perspective

During the process of this study several books and articles on how a whole supply chain can be viewed from a complexity perspective was reviewed[151]. However, in this particular study the focus is on the internal supply chain within a factory and how the complexity perspective can be applied under such circumstances. As a supply chain the internal process of a company consists of several separated but interdependent elements. The different elements are for example: production planning, machines, inventory, and transportations which all are heterogonous due to their characteristics and objectives. These elements are striving to individually improve their present situation as well as the system, considering both defined rules and objectives as well as emerged behaviours. The fact that every element is striving for improvement is sign of adaptation. The elements constitute a system that is most similar with a complex system, i.e. the system is in a constant state of change. These changes are in turn difficult to manage even if it is sometime possible. Another characteristic, which corresponds to the situation at SKS in Eslöv, is that the system is most affected by external factors, e.g. customer uncertainty and delivery failure. These external factors have the capability to change the state of the system. Perhaps the most significant characteristic of the internal supply chain is the need for a holistic view to be able to understand the system. By only studying the individual elements and their behaviour a comprehensive understanding is unreachable even if the behaviours of the individual elements produce the characteristic of a complex system.

In the case study of SKS in Eslöv three main categories of elements are identified: production planning, machines and buffer. These elements are further developed as agents who are presented in Figure 9. The part of production planning consists of an agent itself, the machines consists of agents representing each machine and the buffer category contains of two agents representing each buffer (see also Figure 7 for a schematic picture). When choosing the agents consideration was taken to the time limit of the study and the belief that these agents are representative to reach the purpose of this thesis.

[151] Choi, Dooley & Rungtusanatham (2001); Darley et al. (2004); McCarthy (2004); Nilsson (2005); Waidringer (2001)

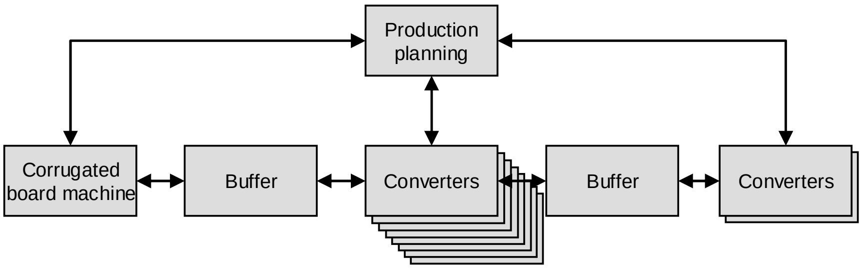

Figure 9. An overall view of the agent-based model

6.2. Agents of SKS

Below the chosen agents of SKS production site in Eslöv is described in general. Further detailed information will be presented in Chapter 7. The purpose is to give the reader an insight of how the authors view the system and how the agents act and interact, individually and with each other. The agents' actions are determined by its individual rules and an emergent behaviour. The overall objective of the system in this study is to identify improvement areas for increased production output as well as an increased capacity utilisation.

6.2.1. The Buffer Agent

There are two buffer agents at the SKS's production in Eslöv which operate in the same manner, but have different stock levels and serve different machines. The buffer agents' primary purpose is to keep track of work in process (WIP) stock.

The agents' activities consist of:
- Receive and store orders from machines
- Send orders to the converters

These buffers are not by definition agents since they have little autonomy and take no decision by themselves. All of the buffers' activities are prompted by messages from machines. The buffers are connected to preceding and subsequent machines, which send messages to deliver an order or to retrieve an order. The buffers are capable to decline delivery of orders when the stock is full and decline requests of orders when the order is not in stock.

6.2.2. The Machine Agents

The machinery at SKS in Eslöv is represented by several machine agents which each has its distinctive characteristic, for instance sheet dimensions, production speed and setup time.

The machine agents' activities consist of:
- Receive production plan from planner
- Retrieve order from stock or buffer, and fabricate requested quantity of product
- Deliver order to buffer or delivery unit

The machine agents are connected to one or both of the buffers, where the machine agents deliver and request orders. The machine agents are also connected to the planner in order to receive an order plan and send information of deviations.

6.2.2.1. Corrugated Board Machine Agent

The corrugated board machine consists of three in-line machines which are represented by one agent. This agent is an extension of the machine agent and has the same properties as machine agent but receives its orders directly from the planner, thus circumventing the raw material stock.

6.2.2.2. Converter Machine Agent

There are ten different converters within the production, all represented by an agent each. Besides the ground properties the agents inherent from the machine agent, each agent has its own properties. The main differences among the agents are such properties like applicable tools and task. The task refers to which type of operation the machine conduct: printing, punching or both printing and punching.

6.2.3. Production Planning Agent

The production planning is to be considering as an agent who is managing the control of the order flow. The main task of the planner is to supply each machine with orders that are added to the machines' order queues. Also, the production planner agent has the responsibility for manage possible unscheduled deviations within the production process. The agent is connected to each machine agent in order to send the production plan and receive essential information concerning the status of the production.

The production planner agent's activities consist of:

- Sending orders to each machines order queue
- Optimising the corrugated board machine and converter queues
- Handling deviations in production

6.3. SKS in Eslöv as a Complex Adaptive System

The definitions of the chosen agents above show how agents act and interact with each other. These characteristics in turn make it possible for an agent to act and react to different changes in their environment which is a sign of adaptability. Adaptation is, as mentioned in Chapter 4.1.5, a prerequisite for a CAS. The way that the agents interact also indicates that because of the large amount of connections, the system is considered to be truly complex. To further investigate how the SKS production in Eslöv can be viewed as a CAS the different dimensions of CAS incorporated with the situation of the case will be reviewed.

6.3.1. Adaptability

As an extension of the previous paragraph some examples of adaptability have been observed at SKS in Eslöv. The examples clearly show how the agents have to adapt their selves to the situation. For instance when one of the converters has reported a major failure which would take some time to repair, the production planner of the corrugated board machine has to reschedule the production plan for the corrugated board machine. This is vital if the affected converter possesses a high production speed. The rescheduling aims to supply those converters who are still working so that they will not stop due to lack of orders but also to prevent a full buffer. The rescheduling in the corrugated board machine implies new optimisation with consideration to other orders running at the same time. Another example is when some of the operators have reported in sick. This often implies that a machine is understaffed and cannot be utilised for a whole shift, which the production planners have to be informed about. If the production planners are not informed in time the planner take the understaffed machine into account when scheduling the production plans for the next eight hours and the seven day planning. The production planners then have to re-plan the production to optimise the production flow.

6.3.2. Connectivity

What has been showed in previous chapters the internal supply chain, as a system, consists of several dynamic functions. The agents themselves are highly dynamic in character and so is the connection between them. Not only are the connections dynamic, they are also great in number which is known as the connectivity within a CAS. As the system is put under change, e.g. a machine failure occurs, the agents have to find a way in order to reach the overall system objectives. Within SKS in Eslöv, a situation like this could be describes as when a machine stops because of a failure and the time to repair the failure is uncertain the planner must, if possible, consider other alternatives to produce the order on time. The production planner then has to check with other agents in the production in order to choose an appropriate action. Often these interactions are more complex in character due to the amount and content of the information exchanged which in turn takes the system to a state of chaos.

6.3.3. Dimensionality

Another element of the CAS is the level of freedom of the agents which is arguable considering the studied case. The agents or parts of the production, mainly the machines, are partly limited due to the specific technical characteristics, i.e. speed, dimensions and time. However, their autonomous behaviour thus creates a certain level of freedom which supports the state as a CAS. Another aspect that should be considered is if the control of the production system, with its elements, becomes too static. In such case the individual behaviour of the agent will be restricted and the system would become more stable.

6.3.4. Environment

The production viewed as a CAS is highly affected by its surrounding environment. For example the system is dependent on deliveries from suppliers, the stock of raw material, and stock of finished goods. Still, these parts of the process are not included in this study and can therefore not be considered, although they are affecting the CAS. Instead the CAS can be viewed as its own environment which is affected by its internal elements. The CAS find itself within a fitness landscape, which is described as a rugged surface, where the agents of the CAS strives to climb as high as possible on the tops of the landscape to increase their fitness. Yet, when the agents are striving for a more favourable position they are changing their environment to a more dynamic state.

At SKS in Eslöv one can argue that the different parts or agents are in conflict with each other when striving for their respective fitness. Since the different converters are mostly dependent on one or two other converters they most certainly affect each other. A single converter agent strives to increase its speed and decrease its setup time and waste, but most importantly reduce its deviations. This behaviour will in turn affect the prerequisite of the landscape and the other agents. Again, if one converter agent maximizes its fitness the preceding and following machine agent will most likely be affected. The authors believe that this behaviour is not identical for all machine agents at SKS in Eslöv. It can be discussed whether some machines have alternative motivation in their strive to increase their fitness. However there is a strong correlation between the modelled and actual behaviour but they may differ in efficiency.

The production planner agent strives to optimize the flow towards a maximum capacity utilisation and production output. At SKS in Eslöv the production planner agent represent three production planners which together try to optimise the production flow. Unfortunately the planning is not always unchanged because of deviations like high-prioritised orders that have to be processed or machine stops and lack of personnel. This behaviour affects the ongoing production as the existing orders have to be rescheduled and the machine routes would have to be reorganised. The production planner’s behaviour and action have a significant impact upon the surrounding landscape which the other agents have to adapt to in order to increase their fitness.

6.3.5. Co-evolution

The complex of problems in the described example above indicates of another parameter of a CAS, namely the co-evolution. In the same way as the meaning of co-evolution the interconnected development of the SKS agents is dependent of every single agent’s adaptation and actions. During the study at SKS some examples of co-evolution was brought to the authors’ attention. As co-evolution is a phenomenon that evolves over time, SKS’s former manufacturing choices could be considered to be examples of co-evolution. For instance, since the time SKS in Eslöv decided to invest in a high-speed printing machine the production has become much more focused on printing. This has implied that the rest of the machines in the production also have been affected. Due to the more advanced printing requirements the process speed of the machines was reduced in the beginning in order to uphold quality. But as the machines successively adapted their selves to the effects of the new machine, the process speed could gradually be increased.

When talking about co-evolution, the characteristic which concerns the state of the system is of interest, i.e. if the systems state is near chaos or order. A CAS is able to react to changes because of its state which is near chaos, the quasi-equilibrium state. The production process at SKS is in constant state of change in order to improve the production output and reduce the controllable waste. These tasks are essential for SKS to uphold a competitive position within the industry. The production process is also affected by its surrounding environment which by its various influences has the possibility to affect the state of the system. Since a system is adapting to changes the system will probably enter a new state or quasi-equilibrium. For example if a new set of products is introduced it will influence the production process to change in order to handle the new products. As the state of the production process has to change it may become more sensitive to other environmental changes.

6.3.6. Non-linearity

A typical characteristic of a CAS is the non-linearity within the system. In supply chains this characteristic is often a common fact. It means that changes in the system will in turn cause either minor or larger changes in another part of the system. At SKS the non-linearity is observed in several cases. A showing example is caused by the high variety of order flows through the different machines. As starting point an order has a determined machine route but if changes are made, e.g. in the corrugated board machine, the machine route may have to be changed. It may imply that an order that was set to run trough a certain number and types of machines now have to run through a different number and types of machines. In line with the change of the route the work process around the order will also change. The number of possible machine routes at SKS has been calculated by the authors to approximately one hundred.

6.3.7. Emergence and Self Organisation

The emergence within a CAS is a difficult phenomenon to comprehend. However, to be able to try to understand emergence the self-organisation of the elements has to be considered. Self-organisation is the systems ability to handle external changes by organising itself. Within a logistic perspective it implies that the parts of the supply chain, like the example of non-linearity, are organised in order to handle the situation. Also, to understand the behaviour of the elements of the supply chain it is essential to view the system as an open box. If the self-organisation behaviour of the supply chain is not understood it will be difficult to influence. Within the SKS production system the behaviour of the machines and their operators have to be understood so that the production planners are able to optimise the production flow and order variety.

As the areas of non-linearity and evolution now are discussed as well as the phenomenon of self-organisation the characteristics of emergence will be further incorporated within the logistic perspective. A supply chain in a wider context shows typical signs of emergence due to its content of several different agents with a variety of level. The individual actions of the agents within the system are to be considered as simple but due to the interactions between them the effects become complex. This in turn makes the outcome unpredictable. The authors would like to argue that within SKS the emergence behaviour of the production system is even more obvious. The production is highly dependent of all the agents working together. This implies that one agent on its own is not capable of controlling the production process by itself.

To further clarify the above discussion the authors would like to refer to the multi-stage production process at SKS. This shows that one machine cannot possibly direct the production process by its own because of its dependence of the other machines in line, and further to the complex behaviour created of the collective actions of the machines.

The process of the production can also be seen as an aspect of emergence. The production process is often affected in various ways caused of deviations and disturbances. In order to handle the deviation and disturbance or any other activity the process, by the actions of agents, seem to emerge. This behaviour is also connected to the unpredictability of the outcome of any change within the process. By changing activities of the process the outcome is often unforeseen and unique, for example; what happens if the speed is increased on one of the converters? Such questions of "*what if*" are the authors aim to answer by performing simulations through the agent-based model developed for the study.

6.4. Synthesising Summary

In the discussion above the authors have described how the production process at SKS in Eslöv can be viewed as a CAS. At least it is the authors' opinion that the production process behaves like a CAS. By pointing out the similarities between the elements of a CAS and the inherent parts of the case study the four properties of complexity theory (non-linearity, self-organisation, emergence and adaptation) can be said to exist. Thereby it seems probable that complexity theory is suitable for analysing and describing supply chains and productions processes.

To summarise the similarities between SKS in Eslöv and the properties of CAS it contains the same heterogeneous agents which are all individually strives to reach a better fitness within their environment. This behaviour of the agents is affecting other agents and eventually the system as whole. These characteristics also show that the agents have the ability to take actions on their own and are not in need for an overall control. The emergence of the system also exists at SKS in Eslöv due to the interactions of the agents as they work together in a changeable multi-stage manufacturing process. Further, reviewing the rest of the inherent properties within dimension of CAS; internal mechanism, co-evolution and environment, they all seem to be confirmed at SKS in Eslöv.

6.5. Improvement Identification

In order to identify relevant improvement areas for increased capacity utilisation the responsiveness capabilities of the production is analysed using the theory presented in Chapter 4.3.1. This is because these capabilities are essential to handle disturbances in the complex and vulnerable production process which SKS in Eslöv possess.

6.5.1. Recognition capabilities

These capabilities refer to the information gathering and interpretation in order to recognise disturbances. SKS in Eslöv uses a wide variety of system variables for information gathering. The majority of these can be studied in real-time through PC-Topp which facilitates an easy overview and faster responses. But frequent deviations and misinformation has slowed the users' responses to alterations in system variables. Thereby disturbance information is complemented with telephone calls and other interactions. Many of the system variables preferably used afterwards with weekly or monthly performance evaluations which facilitate greater awareness and learning experience for future detections.

Within the production the operators and production planner often have capabilities of quickly interpret disturbances when they occur but have marginal capabilities of predict disturbances in the near future. When dealing disturbances the immediate interpretation is often halted by a varied reporting from machine operators. This lack of timely information creates hesitation and insecurity for handling the deviations.

6.5.2. Plant capabilities

At SKS in Eslöv they have varied production capabilities of responding to disturbances. SKS in Eslöv have a strong buffer capability in the raw material and finished goods stock has historically possessed a large capacity which strong capability to respond upon disturbances. The buffers can handle deviations since they comprise of a relative large capacity, but the slack in schedule is limited due to the requirements of short lead times in the production. This restrains the buffers capability to handle deviations.

There is a high flexibility in the production but it has some boundaries. Many converters withhold a variety of operations which entail flexibility for deviations and a limited number of alternative machines enable several orders to take different routes thus circumventing disturbances. This flexibility is however constrained by the relative long changeover time due to surrounding processes for the rerouting and rescheduling, e.g. distribution and preparation of tools. The constrained production speed speeds of the converters prevent quick recovery of slack in schedule after disturbance. The quality tolerance is small but is compensated through frequent overproductions and fast compensating additional production.

6.5.3. Decision-making capabilities

The decision-making capabilities refer to abilities to make capability deployment decisions. Through out the production process necessary system variables are accessible from every machine unit through PC-Topp but the machine operators only have a limited decision authority for disturbances. They may primarily only handle deviations which can be corrected in their immediate surroundings. The majority of disturbances must however be coordinated and handled by the production planners. This implies a slower responsiveness since it must be handled centrally instead of a decentralised local effort.

Due to complex relationship within the production process system the operators and production planner have limited understanding and influence of the knock-on effects for certain disturbances.

6.5.4. Improvement Areas

From the previous analysis of SKS in Eslöv the authors have, in dialogue with production management at SKS in Eslöv, identified four improvement areas that may have a significant impact upon the capacity utilisation. The identified areas are:

- Production speed
- Setup time
- Indirect time
- Order composition

The production speed and setup time involve SKS's plant capabilities and indirect time both encompasses plant and decision-making capabilities. The order composition is not based upon the capability analysis but refer to changing the flexibility utilisation of the production. A more thoroughly description and analysis of the cause-and-effect relation of these improvement areas are illustrated with cognitive mapping. It is the authors' belief that by using a cognitive map in combination with the conceptual model with its agents a reliable analysis can be made. The purpose of this discussion is to give reader an insight of how the authors' view the underlying factors which leads to the future scenarios.

The production speed refers to how fast the machines are able to produce a certain order. The speed in the machines is determined by many factors, especially technical prerequisites, but if the speed is increased an interesting pattern emerges. The most obvious effect is that the time for producing an order will be reduced and by that the speed of the production flow is gaining speed. Improvements of setup times would most likely have similar but lesser effect. After this improvement the pattern takes two possible paths which can be viewed in Figure 10. One path leads to a better utilisation of capacity with a presumed increased output as a result. The other possibility is that the increased speed of the flow will increase the amount of interactions among the agents which in turn increases the connectivity in the system. An increased connectivity will entail an increased complexity in line with the theory presented in Chapter 4.1.5. A higher degree of complexity will require a higher level of coordination which in turn may lead to additional deviations and increased indirect time. This pattern creates a feedback loop since the increased indirect time in turn will affect the speed of production flow in a negative way. Yet, an interesting relationship emerges due to the positive and negative effects on the speed of flow which concerns whether one of the antitheses will dominate or not. The authors would like to argue that there are many ways of which the speed of production flow may be affected and that is why the outcome is difficult to predict.

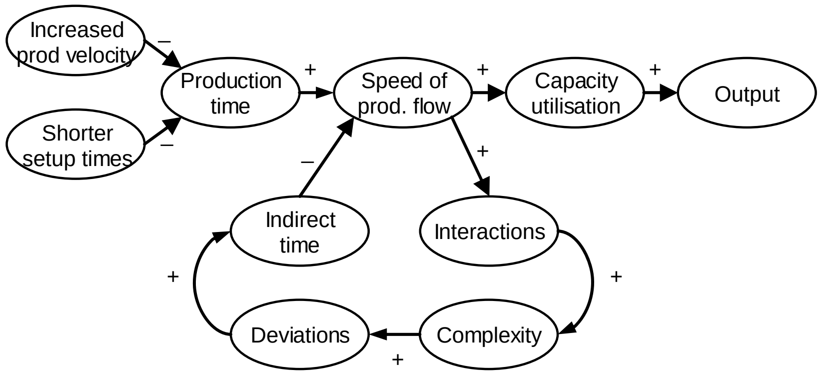

Figure 10. Cognitive maps of how the authors view the identified parameters of the system. A negative sign (-) means that the cause decreases the statement at the arrowhead and a positive sign (+) implies that the cause increases the statement at the arrowhead. The feedback loops effects are not illustrated since their relative strength is not identified. For example decreased production time will increase the production flow speed but increased indirect time will decrease the production flow speed. The resulting change in production flow speed is difficult to predict.

Indirect time refers to unscheduled deviations which occur in the system for several reasons. For example unscheduled stops in the production, caused by technical failures or hesitations of agents, is to be considered as indirect time. These types of indirect time have also appeared to be a common fact as mentioned in Chapter 5.3.4. A decrease of indirect time is illustrated in Figure 11. By reducing deviations and reducing the time of deviations the indirect time will decrease. This in turn will probably increase the speed of the flow through the production because of fewer interruptions. If the speed of the production flow increases the capacity utilisation will increase which in turn will also increase the output. But as defined above an increase in production flow will also lead an increase in the indirect time thus creating a feedback loop.

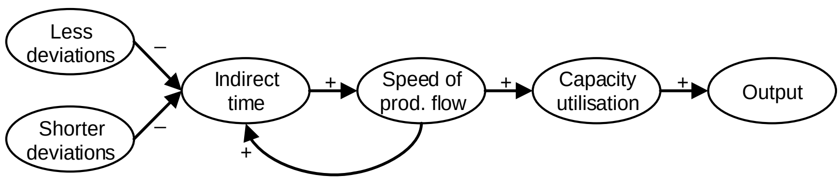

Figure 11. A cognitive map of a decrease in indirect time.

The production planner's strive for an optimal flow is highly dependent of the order composition and the machine state of the production. The orders have to be planned in a way that is optimal for the production system with its inherent machines. If the orders and the composition of them could be better controlled to facilitate a better planning the production process could be improved. A better order composition can induce an output change illustrated in Figure 12. A more optimal production plan would enable longer process times because similar orders with the same machine settings could be processed after each other and fewer machine adjustments would be necessary. Longer process times would then imply that the production speed in the machines could increase which connects to the previous production speed pattern. Longer process times thus have another effect as it probably will reduce the amount of interactions, in terms of changeovers, taken by the agents within the system. Less actions and interactions have the opposite effect on the complexity of the system as in the discussion earlier about the two different paths in the pattern of increased production speed. However, a lower level of complexity implies that the system will be easier to handle which in turn has an effect of deviations and thereby the indirect time. Since less deviations and indirect time would eliminate some of the disruptions in the production the flow of the production can run faster and more smoothly. Yet, this behaviour has some complications since an increased speed of the flow will stress the system which may cause more deviations. This constitutes another interesting feedback loop with a relationship of decreasing and increasing deviations whose outcome is difficult to predict.

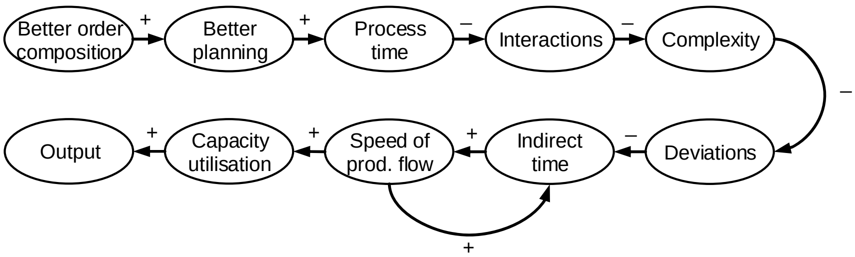

Figure 12. A cognitive map where better order composition may increase the output.

The identified areas are all interconnected which imply that they will affect each other in various complex patterns. Thus a simple change may lead to unpredicted changes in other parts, which in turn may affect several other elements, and so fort. Due to this a series of simulations will be performed in order to evaluate the identified areas effect on capacity utilisation and their relative leverage. In order to execute the scenarios the agent-based model has been implemented in a computerised model which will be described in the following chapter.

7. Creating the Model

In this chapter the computerised model for the simulation is visualised and explained. The agents, parameters and interface are described in order to illustrate the prerequisites for the simulations. The assumptions and limitations of the model will conclude the chapter.

7.1. The Model

In the previous chapter the authors outlined the discussion about how the production process at SKS in Eslöv can be viewed as a CAS. In order to answer the complex question marks of the most complex system a simulation through a model of the production process is carried out. The model was developed and implemented by the use of Eclipse SDK, a Java development program. The program facilitated great resources for error detection of the simulation and graphical illustrations of the model.

The model is based on an ABM-simulation framework called SCABS which is developed by one of the authors' supervisors, Fredrik Nilsson and his co-worker Magnus Loodberg. The framework is used as a foundation which enables basic simulation management and monitoring. In order to implement the model the framework is extended with several SKS specific classes representing the different elements of the model. The majority of classes consist of support classes used for information representation and distribution, e.g. orders, messages and articles. Each of the agents are represented by different agent classes; BufferAgent, CorrugatorAgent, ConverterAgent and PlannerAgent. All of the agents inherit common features from one super agent, DefaultAgent, and the machines inherit from MachineAgent. A FinishedGoodsAgent is introduced to monitor the order completions. The inheritance hierarchy is illustrated in Figure 13.

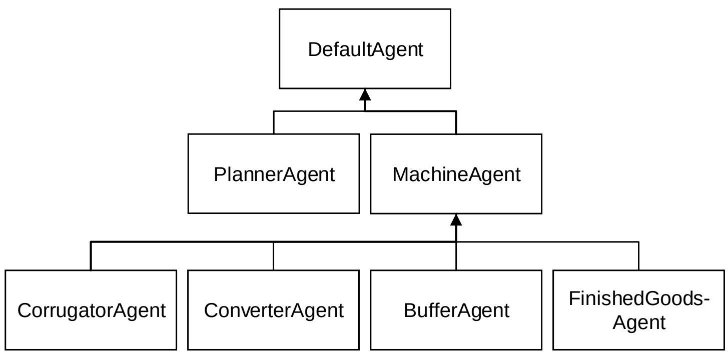

Figure 13. Inheritance hierarchy of agents in model.

The model holds two instances of BufferAgents and the same numbers of ConverterAgents as there are converters. The connections between agents are dynamically created depending upon situation. The PlannerAgent can create direct connections with all MachineAgents, whereas the MachineAgents are indirectly connected to each other through the BufferAgents. The main connections are illustrated in Figure 14. The agents communicate with each other through asymmetric message passing, thus eliminating undesired interaction effects.

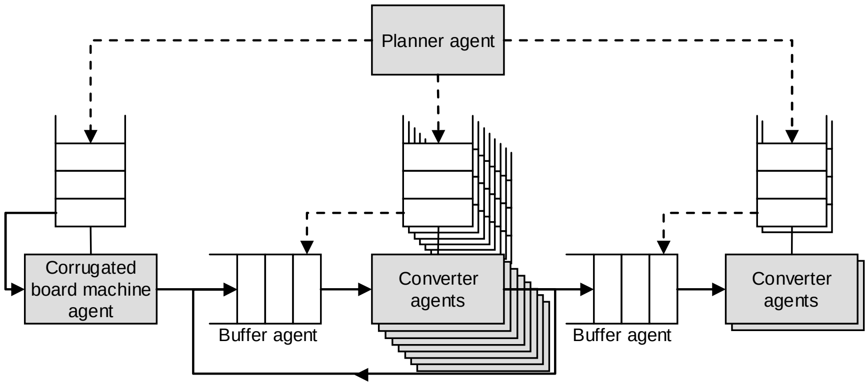

Figure 14. The primary connections between agents in the model, where the dashed arrows illustrate information flow and the unbroken arrows illustrate the order flow. The white boxes represent the production plans and queues of each MachineAgent.

7.1.1. BufferAgent

The BufferAgent represents a buffer between the machines and has two primary capabilities, which are:

1. Receive orders from a MachineAgent which the BufferAgent either can accept or decline depending upon the stock level.
2. Deliver orders to a MachineAgent if the order is in the buffer otherwise decline the request.

7.1.2. CorrugatorAgent

The CorrugatorAgent represents the corrugated board machine and have capabilities in form of:

1. Receive production plan from PlannerAgent.
2. Produce orders according to production plan, using the following steps:
    a. Select next order to produce.
    b. Calculate the setup time and the time to produce the order.
    c. When the order is finished the ConverterAgent send the order to either the BufferAgents or FinishedGoodsAgent depending upon the orders route.
    d. Update production time plan.
3. If an unscheduled deviation occurs, e.g. unscheduled stop, the CorrugatorAgent notifies the PlannerAgent with a message.

7.1.3. ConverterAgent

The ConverterAgent represents a converter and is similar to the CorrugatorAgent in majority of capabilities, which are described as follows:

1. Receive production plan from PlannerAgent.

2. Produce orders according to production plan, through the following steps:
    a. Select next order to produce.
    b. Request order from the appropriate BufferAgent
    c. Upon delivery calculate the setup time and time to produce the order.
    d. When the order is finished the ConverterAgent send the order to either the BufferAgents or FinishedGoodsAgent depending upon the orders route.
    e. Update production time plan.
3. If an unscheduled deviation occurs, e.g. an order cannot be delivered from the BufferAgent, the ConverterAgent messages the PlannerAgent for further instruction.

7.1.4. PlannerAgent

The PlannerAgent represents the production planning and have primarily capabilities for planning orders for the CorrugatorAgent and ConverterAgent. The agent also handles deviation reports and tries to solve them. The PlannerAgents capabilities can be describes as:

1. Once every day plan orders for CorrugatorAgent and send production plan. The orders are chosen from orders with a delivery date within the given time horizon. The planning is made to optimise the use of the CorrugatorAgent and minimize the excess waste while producing the orders. The optimisation is done by:
    a. Select an order which is ready to be planned.
    b. Analyse if the order on its own or in combination with another order produces minimum waste.
    c. Calculate estimated time of completion and add order or order pair to production plan for CorrugatorAgent.
2. Once every day plan orders in ConverterAgents and send production plan. The planning of ConvertAgents is made accordingly:
    a. Select an order which is ready to be planned in the ConverterAgents
    b. Since the order is produced is several steps the PlannerAgent plans the order for all steps. Several orders can also be produced in alternative machines which may accelerate the process time. The following process is made for each production step:
        i. Check queue time and estimated run time for the primary ConverterAgent.
        ii. Check queue time and estimated run time for alternative ConverterAgents.
        iii. Select the fastest ConverterAgent and add order to the production plan for the ConverterAgent.
        iv. Update queue time for ConverterAgent.
3. Receive deviation reports and analyse order flow to most appropriately handle the deviation. Depending upon the deviations impact the PlannerAgent may either:
    a. Change production plan for affected MachineAgent, e.g. by running another order.

b. Hold manufacturing for the affected MachineAgent and wait until deviation has been resolved.

7.1.5. FinishedGoodsAgent

The FinishedGoodsAgent is utilized to receive and confirm orders sent from MachineAgents. It is primarily used for recording measurements of deliveries of finished goods and does not affect the simulations performance.

7.2. Parameters

In order to facilitate different scenarios in the simulation the conditions and behaviours of the agents are controlled by different input parameters. These parameters are divided into to different types: scenario input parameters, which are set in the beginning of the simulation, and system parameters, which contain historic data. The model also supplies output parameters of the simulation for analysis.

7.2.1. Scenario Input Parameters

The scenario input parameters encompass a variety of variables used in different locations within the simulation. The input parameters are select to suit the scenarios, presented later on in Chapter 8.2, and are developed in cooperation with the employees at SKS in Eslöv. A short description of each parameter is described below:

Setup Time Modification
The parameter is a percentage number which is multiplied with the setup time for each order. The parameter primarily only affect the actual setup time of the agent and not the estimated setup time used for planning orders.

Process Time Modification
Same as for the setup time, this parameter is multiplied with the process time for each order. The order does not affect the estimated production time used for planning order.

Indirect Time Modification
The parameter also is multiplied with the time of each unscheduled deviation. This parameter does not affect the planning since the indirect time is not used for planning of productions.

Minimum Order Size
The parameter specifies the minimum amount of sheets used in an order. All orders which contains fewer sheets than the minimum order size is disregarded. By default the value is zero (0) where no order is disregarded.

Minimum Area Size
Similar to the previous parameter, this specifies the minimum total square meters of an order. Smaller orders are disregarded and the parameter is by default zero (0).

Minimum Punch Size
Defines a minimum number of punches an order must have in all machines and orders with fewer punches are disregarded. The parameter is by default zero (0).

Compensate Order Removal
When orders are disregarded this parameter specifies a Boolean value that determines whether to consolidate the similar disregarded orders into larger orders. If the value is true the consolidated orders have to be larger than a specified amount of sheets, which is defined next.

Compensate Order Size
The variable sets the minimum amount of sheets the consolidated orders must have in order to be executed.

Planning Horizon
The variable is the number of days that specifies the PlannerAgents planning horizon for the CorrugatorAgent and ConverterAgents. The time horizon is by default seven days.

7.2.2. System Parameters

The system parameters are located in several tables inside a database. These parameters define the order and production flow in the simulation. The values are acquired from the historical performance from the SKS production. In Figure 15 a relational diagram of the system parameters is specified.

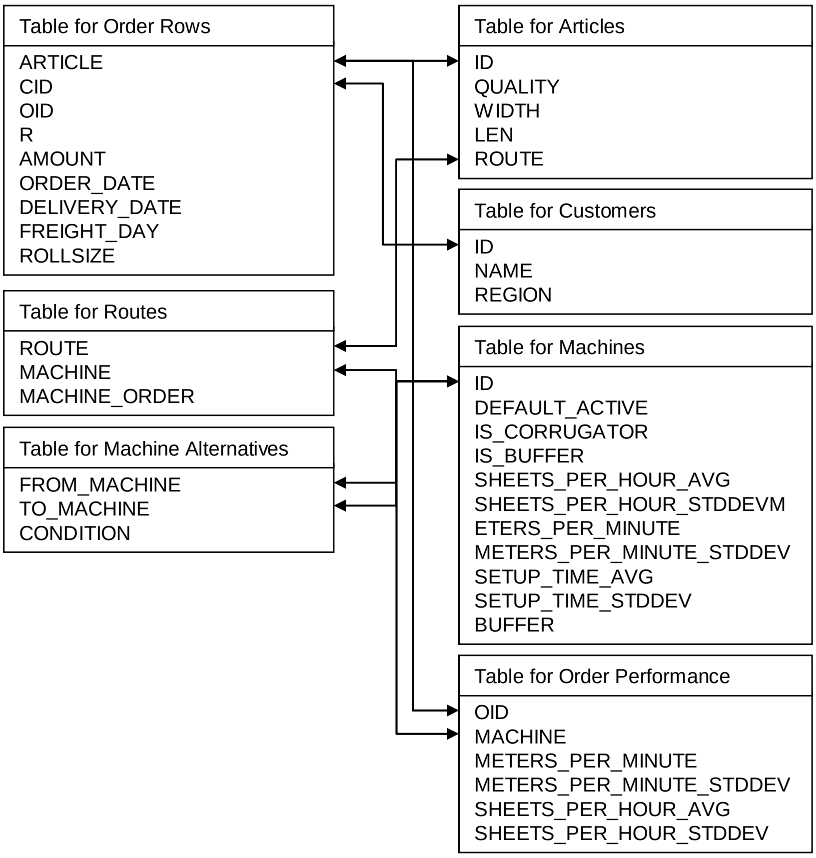

Figure 15. A relational diagram of database tables where the arrows represent the relational connections between the tables.

The characteristics and the production performance of each agent are specified in Table 2. The performance measurement are based upon statistical data from the given time period and are used if there is no order specific performance measurement.

Variable	Description
ID	Identification number of the agent
DEFAULT_ACTIVE	One (1) if agent active by default
IS_CORRUGATOR	One (1) if agent is CorrugatorAgent
IS_BUFFER	One (1) if agent is CorrugatorAgent
METERS_PER_MINUTE	Average meters of corrugated board per minute
METERS_PER_MINUTE_STDDEV	Standard deviation meters of corrugated board per minute
PUNCHES_PER_HOUR_AVG	Average punches per hour for ConverterAgent
PUNCHES_PER_HOUR_STDDEV	Standard deviation punches per hour
SETUP_TIME_AVG	Average setup time
SETUP_TIME_STDDEV	Standard deviation setup time
BUFFER	The ID of the preceding BufferAgent

Table 2. Table of Machines

The database contains information for every order row that determines the basic data for the production. In Table 3 a short specification of the database table is presented.

Variable	Description
ARTICLE	Identification number of article
CID	Identification number of customer
OID	Identification number of order
R	Order row number
AMOUNT	Amount of sheets
ORDER_DATE	Order date, i.e. the date when PlannerAgent recieves the order
DELIVERY_DATE	Delivery date
FREIGHT_DAYS	Number of days to transport order to customer
ROLLSIZE	Size of roll

Table 3. Table for Order Rows

Each order row is connected with an article number which specify the geometrical measurement and the primary route of the article. These characteristics are defined in Table 4.

Variable	Description
ID	Identification number of article
QUALITY	Quality of paper
WIDTH	Width of sheet
LEN	Length of sheet
ROUTE	Identification number of route

Table 4. Table for Articles

The order routes are defined in Table 5 which provides machine and the order of them.

Variable	Description
ROUTE	Identification number of route
MACHINE	Identification number of machine
MACHINE_ORDER	Order of machine in route

Table 5. Table for Routes

A few of the machines are able to produce the same orders. As seen in Table 6 some alternative routes can be only one-way, i.e. an order from machine 1 can be produced in machine 2 but orders from machine 2 cannot be produced in machine 1.

Variable	Description
FROM_MACHINE	Identification number of machine which have an alternative machine
TO_MACHINE	Identification number of the alternative machine
CONDITION	Define whether the route is active or inactive

Table 6. Table for Machine Alternatives

In order to resemble the actual production performance the system utilise the specific performance measurements for each order in the different machines. The structure of these parameters can be viewed in Table 7.

Variable	Description
OID	Identification number of order
MACHINE	Identification number of machine
METERS_PER_MINUTE	Average meters of corrugated board per minute for the specific order
METERS_PER_MINUTE_STDDEV	Standard deviation meters of corrugated board per minute for the specific order
PUNCHES_PER_HOUR_AVG	Average punches per hour for ConverterAgent for the specific order
PUNCHES_PER_HOUR_STDDEV	Standard deviation punches per hour for the specific order

Table 7. Table for Order Performance

Finally the database contains information of the specific customers which placed orders during the specified period. The customer variables are presented in Table 8.

Variable	Description
ID	Identification number of customer
NAME	Name of customer
REGION	Region of customer

Table 8. Table of Customers

7.2.3. Output Parameters

The output variables are recorded during the simulation at different occasions. Each record is connected with the time of the recording and generates a graph over how the parameter changes over time. Each parameter is associated with a specific agent and all parameters are recorded on a weekly basis. Some output parameters are recorded on a daily or more frequent basis. The parameters are presented in Table 9.

Parameter	Description
Free Capacity	Unutilised time
Utilisation	Utilisations grade of a MachineAgent
On-Time-In-Full	Amount of orders delivered on time
Number of orders in buffer	Orders waiting for further processing in the buffers
Number of sheets in buffer	The total amount of sheets in one of the buffers

Table 9. Output parameters of the model.

7.3. The Graphical User Interface

For easy setup and presentation of the parameters a Graphical User Interface (GUI) is utilised. The model uses different interfaces for the setup and simulation of the model. For the setup of model two dialog windows. The first setup dialog is used for modifications of the scenario input parameters and the second setup dialog is used for enabling or disabling machines for the simulation. After specifying parameters the second setup dialog appears, Figure 16. This dialog is used for disable different machine during the simulation. Enabled machines are illustrated by a green colour and disabled machines by a red colour. When the "*OK*" button is pressed the program retrieves data from the database and constructs the model.

Figure 16. The second setup dialog to activate or deactivate any MachineAgents.

When all necessary data are collected and the model is built the simulation interface appears, see Figure 17. This interface is used both for progress control of the simulation and output presentation. The interface is divided into two dialog windows, where the "*SKS simulation*"-dialog is used for control and the "*Output analyser*"-dialog is used for generating output graphs. The "*SKS Simulation*"-dialog contains buttons to start, pause, step and reset the simulation. It also enables the ability to run a batch of simulations. When the specified amount of simulation is completed the "*Reset*"-button must be pressed for running further subsequent simulation with the same parameters.

It is possible to generate output graphs during the whole simulation to view the current status of the simulation. This is done by choosing desired variable in "*Run*", "*Agent*" and "*Variables*", and pressing "*Build Graph*".

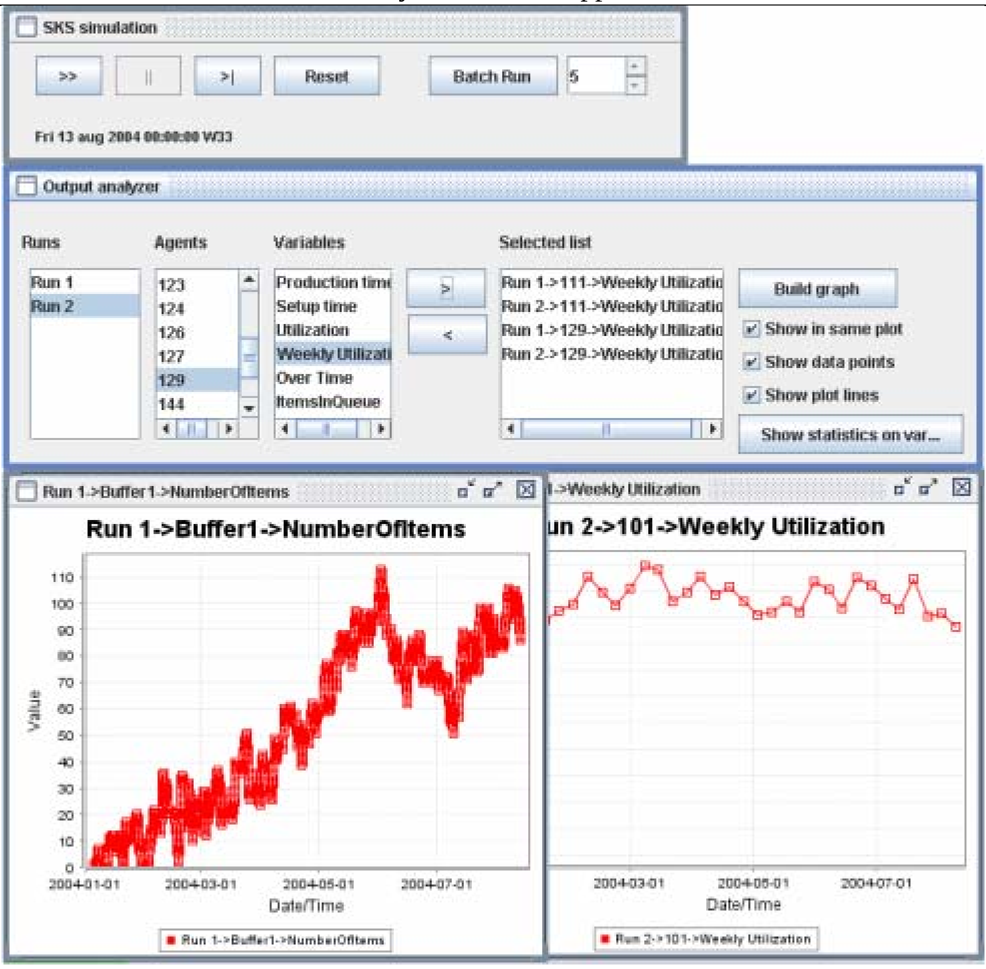

Figure 17. The simulation GUI for executing and monitoring the simulation. The top dialog, SKS Simulation, controls the simulation and execution. The middle dialog used for displaying graphs and statistics of the variables. The two bottom dialog displays examples of the output graphs.

7.4. Model Assumptions and Limitations

During the creation of the model a set of assumptions and limitations were needed in order to complete the model. The main limitation during the creation of the model was the lack of data which in cause of the complex system has demanded some simplifications in the model compare to the real-life settings which the model suppose to reflect. The assumptions taken was discussed and accepted by the supervisors, both at Lund University and SKS in Eslöv. In the defence of SKS the lack of data is not referring to an inability to provide the authors with data. Rather it refers to that the data does not exist or the failures within the received data. The time limit of the study was of course also a contributing cause.

7.4.1. Lack of Data

Since the authors did only have moderate experiences of modelling and simulation the expectations where modest. To gain a larger understanding of ABM-simulations the authors studied earlier simulations but spent little time on considering data gathering. Early on the authors attained performance data for 2004, but to gain a more accurate simulation model and partly due to data inconsistencies in 2004 measurements the authors choose to collect data for 2005.

When reviewing the data of 2005, several inconsistencies were revealed. For example a number of data measurements showed machines running small orders for several days without any interruption. This implied that the performance of the machine is affected, i.e. an order seems to have been produced with a low and incorrect production speed. Other failures in the data gathered concerns the incorrect numbers of produced sheets in some cases and wrong reports of deviations. In order to handle these incorrect data, several assumptions were taken for these extreme values. Instead a value, calculated with a Gaussian distribution with deviation dependent on data type, is used in cases of extreme values. In those cases when a manual adjustment of data has been possible the change has been controlled by the workers at SKS.

Due to faulty measurements and lack of data some unintentional simplifications had to be made in the simulations model. Yet it is the beliefs of the authors that these will only negligible affect the value and result of the simulation.

7.4.2. Simplifications

Because of the difficulty of reflecting the reality in a computer model some simplifications were made. The difficulties refer to the complexity of the production with its rapid changes and multi-stage production. The complexity makes it difficult to the different tasks and how they are performed within the production process.

Some of the simplifications have been made due to the increasing complexity of the implementation of the model. As the model has grown iterative so has the complexity in the structure of the model, this in turn demands more knowledge and time for each added dimension. Thus the simulation has been restricted to run between fixed hours of the week, where the MachineAgent manufacture Monday-Thursday 05.30-23.38 and Friday 05.30-14.06. The production is halted over the weekend only to begin anew on Monday. The simulation takes no account to holidays or other time implications which occur in real life during the simulation period. The simulation model also allows orders to finish after the specified end of the shift. However this time is recorded as overtime.

Unscheduled deviations are also dispensed between the order runs using a Gaussian distribution which is also used for the calculation of their experienced duration. All of these calculations are based upon statistical date for 2005. The simulation starts with empty BufferAgents which is not the actual case. This is taken into respect because the measurement is not begun until after two months when the simulation model is believed to have found a quasi-equilibrium state.

The PlannerAgent is the agent with most complicated and complex behaviour in the model. Since the restriction of a computerised model cannot fully simulate human behaviour which partially dominate the production planners actions. Thus the authors have sought to recreate an activity pattern for the PlannerAgent controlled by a set of defined algorithms. But this pattern has it limitations which make the simulation diverge from the actual results, but the pattern is found to work sufficiently accurate.

8. Scenario Simulations

In this chapter the simulated scenarios is described followed by a presentation of the outcome of the simulations. The chapter is introduced by a presentation of how the authors have verified and validated the simulation model specified in the previous chapter.

8.1. Validation and Verification of Model

Before the scenarios and the results of the simulations are presented a discussion of the model verification and validation will be carried out. In Chapter 2.4 a short presentation of the two conceptions were held and in this chapter the author intend to finish that discussion. As a reminder, model verification refers to the assurance that the computer programming of the conceptual model is correct. Model validation refers to the computerised models' accuracy consistent with the proposed application of the model. In order to discuss the verification and validation of the simulation model four areas that will gain approval of the model has been selected. These four areas are; data validation, conceptual model validation, computerised model verification, and operational validation suggested by Hellström & Nilsson.[152]

8.1.1. Data Validation

When performing simulations the need for correct data is of great importance. The production data used reflected the year of 2005 and constitutes the period of simulation. The validation of the data aims to ensure that the data is adequate for the building, evaluation and testing of the model[153]. The data where validated through repeated consultations with Fredrik Dahlgren at SKS in Eslöv. Several meetings were also held with Fredrik Nilsson and Magnus Loodberg, who both has experience from simulation models, to validate the data. By reviewing the collected production data the proper data for the simulation was finally reached. The data was repeatedly validated during the construction of the model since the lack of time. Otherwise it would have been preferable if the data validation was separated in time from the validation of the model itself.

8.1.2. Conceptual Model Validation

Before any programming was conducted with the model the conceptual model had to be controlled. Conceptual model validation is defined by Sargent as: "*determine that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem entity is 'reasonable' for the intended purpose of the model".*[154] The model was repeatedly validated during the work process since the foundation of the model is built on the performed interviews and observations at the case company. Later the final validation was done by letting workers at SKS in Eslöv review the model to ensure the reflection of the real-life

[152] Hellström & Nilsson (2006): p. 4
[153] Sargent (2005): p. 132
[154] Sargent (2005): p. 132

settings. For every part of the model, representing an element in the production process, detailed information of routines and procedures were collected in order to prepare for the computer programming of the model. It has been of great importance that the right people with the right knowledge were questioned so that every detail was brought to the authors' attention. As for the theories behind the model the authors have studied several business cases where similar agent-based models was used incorporated with the fields of complexity theory and supply chain management. Discussions with supervisors at Lund University were held to ensure the conceptual models applicability due to the purpose.

8.1.3. Computerised Model Verification

With the conceptual model as a foundation the computer programming was then initiated. The verification of the computerised model aims to assure that the actual programming as well as the implementation of the conceptual model is acceptable.[155] The computerised model is verified through that it is programmed in Java language, a higher-level programming language. Further, the computer program is designed, developed and implemented with a software engineering technique called object-oriented design. To ensure that the model is programmed and implemented correctly several tests and error checks have been made. Last, but not less important, is that the programming language is specified in line with the purpose of the study.

8.1.4. Operational Validation

Operational validation is used for the determination that the model's output behaviour has the required accuracy for the purpose of the model.[156] During the validation of the simulation model the authors had access to the studied system and historical production data. The historical data was feed into the simulation model several times in order to quantitatively compare the outcome with history and thereby determine its accuracy. To further secure the operational requirements of the model, workers at SKS in Eslöv reviewed the outcome and behaviour of the validation simulations. This provided a qualitative analysis whether the outcome and behaviour was reasonable or not. Fortunately the results where satisfactory which opened the door for the actual scenario simulations presented below.

8.2. The Scenarios

To be able to reach the purpose of this thesis on time the development of the scenarios was initiated before the model was verified and validated. On the basis of the discussion held in Chapter 6.5.4 the authors identified various improvement areas which could be used for simulation, in order to clarify their relative influence on the system performance as a whole. These thoughts were then distributed to the workers at SKS in Eslöv as a foundation for a further discussion of the scenarios. The final scenarios were then decided at a meeting where parts of the production management team were present. Together with the authors' suggestions of scenarios instructions were attached in order to reduce any misinterpretation. Mainly the instructions

[155] Sargent (2005): p. 132
[156] Sargent (2005): p. 132

considered that the workers should view the presented material and come up with comments and, if necessary, identify with new possible scenarios. Also, the scenarios should aim to focus on factors influencing the production output as well as the capacity utilisation, which were the two main areas determined in the beginning of this study. To further guide the workers at SKS in Eslöv in the scenario development some prerequisites were given:

- Period of simulation: 2005-01-01 – 2005-12-31
- All machines are available, excluding those machines that are put out of order
- All types of orders should be processed
- Unlimited delivery of raw material
- The production stands still from 23.48 in the evening until 05.30 in the morning
- The production stands still during weekends
- An order should be processed in full in respective machine even if interrupted by a weekend or night.
- Other orders that are in line for process is transferred to the next weeks' or days' production.

After the meeting eight different scenarios which all should have an interesting influence of the production process, were specified. The eight scenarios are presented below and are divided into four main groups: process time, setup time, indirect time and type of order.

In order to compare the developed scenarios to a normal state a base scenario was constructed to constitute as a reference. The base scenario was built upon the same parameters as were used during the verification and validation of the model. The base scenario was simulated twenty times and after each simulation the output values were transported from the simulation model to a Microsoft Excel document where an average value for each parameter was calculated. The reason for simulating the base scenario twenty times is to get a reliable average result. The base scenario could be simulated more times but considering the time and effort every simulation takes the authors decided that twenty simulations were sufficient. The values were then used as a reference when performing the scenarios by putting the average values from each scenario in relation to the base scenario.

In order to better understand the output parameters, presented in Chapter 7.2.3, a more descriptive presentation of them is needed. The *utilisation* parameter refers to the utilisation grade of the production system as whole. During the simulations the utilisation grade for every machine was calculated but the authors choose to only present the value for the system in this thesis. The utilisation is the process time plus setup time in relation to accessible time. *Free capacity* stands for the time when a machine is not in process during working hours, e.g. the machine does not have any planned orders during a shift or day. Free capacity is defined as accessible time excluding setup time, process time and indirect time. The *on-time-in-full* parameter measures how many orders that are processed and ready on delivery time. The last parameter is the *buffer size* which measures the number of orders and sheets in the buffer during the simulation time.

During the simulations the authors also had access and used other parameters in order to validate the results from the simulations. Also when an extraordinary result came up the additional parameters was useful to understand the specific behaviour of the simulation. The additional parameters are not presented in this thesis because the authors believe that they are not providing any additional value analysis.

8.2.1. Process Time Improvement Scenario

The process time of every machine is important since it constitutes as a competitive advantage within the industry. A fast machine opens the opportunity for more orders and a flexible production. Scenario one involves a decrease of the process time with 20%.

8.2.2. Setup Time Improvement Scenario

Within SKS factory there is a constant work of improving the setup times in order to be more productive. Scenario two therefore involves a reduction of setup time with 20% in order to evaluate the effects of this never ending progress.

8.2.3. Indirect Time Improvement Scenarios

A main issue for manufacturing companies is the time when production is halted because of disturbances and deviations. Many types of disturbances and deviations can be managed through different minor improvements but some cannot be affected. Despite the non-improvable disturbances, scenario three involves a reduction of indirect time with 20%.

Due to the belief of a connection between process time and indirect time scenario eight and nine will combine the two parameters. In scenario four the process time is increased with 15% and the indirect time is reduced with 20%. In scenario five the percentages are inversely, i.e. process time is increased with 20% and indirect time is reduced with 15%.

8.2.4. Type of Order Scenarios

Since the large variety of products, which are produced in the SKS production in Eslöv, the question concerning consequence of order size arose. The purpose of the scenarios is to examine the effects of the orders with small batch sizes, i.e. if the smaller orders are affecting the capacity utilisation. Scenario six and seven disregard orders with fewer than 700 sheets respectively orders which require less than 700 punches in total. This is due to that one punch on one sheet in a converter may produce several minor sheets with specific article dimensions. For example, the processing of an order with an order size of 2800 may only require 700 punches if the converters can produce four minor sheets per punch.

To further examine the effects of the small orders scenario eight and nine are performed. In scenario eight all orders with a total area less than 700 m^2 are disregarded, mainly to see the effects in the corrugated board machine.

8.3. Results of the Simulation

In this chapter the results of eight simulated scenarios are presented. The scenarios are simulated ten times each in order to assure a correct average outcome in the end. The results are presented in the same order as the scenarios above but are clustered in groups as follows: scenario one through three, scenario four through five and finally scenario six through eight. The reason for regrouping the scenarios is mainly to clarify the differences between the first three scenarios containing the main improvement parameters. Further, scenario four and five are similar in character and scenario six through eight are in the same category.

The results are divided into two tables for each scenario group. The first result table illustrates the performance changes in total utilisation, free capacity and on-time-in-full deliveries. The second result table shows the buffer sizes for the different scenarios. Since the buffers primarily only obstruct the system when they are heavily used the buffer measurements show both average and maximum value. The other result measurements consist of aggregated values for the system as a whole. The specific machine results for utilisation and free capacity can be viewed in Appendix A.

All of the result measurements are presented as percentage deviation from the base scenario, due to confidentiality concerns. This does not constitute a problem since the presented measurements give a clear direction of results.

8.3.1. Scenario One through Three – Performance Evaluation

Scenario one through three each modifies one identified improvement area of either process time, setup time or indirect time. Table 10 shows the performance result of the scenarios.

Scenario	Utilisation	Free Capacity	On-Time-In-Full
1 - 20% Process Time	-10,7%	7,1%	0,7%
2 - 20% Setup Time	-7,0%	4,4%	0,5%
3 - 20% Indirect Time	-0,1%	6,5%	0,9%

Table 10. Performance results from scenario one through three

Significant for the utilisation results is that the setup time and process time improvements yield a decreased utilisation. This is due to the measurement of utilisation which is calculated as the setup time and process time divided by the accessible time. As the same amount of orders are produced faster but still measured over the same period of time, the utilisation will decrease but the free capacity will increase as seen in Table 10. Scenario two's utilisation measurement is primarily influenced by two print converters which have a significant larger setup time in comparison to the other converters.

Scenario three slightly decreases the utilisation but most noteworthy is that three converters increase their utilisation and three converters decrease their utilisation which together yields only a small decrease. However the indirect time improvement delivery a high freed capacity.

Significant for all the scenarios is that the performance improvements only generate less than a one percent on-time-in-full enhancement.

Scenario	Buffer 1 Avg	Buffer 1 Max	Buffer 2 Avg	Buffer 2 Max
1 - 20% Process Time	-5,3%	-10,5%	3,2%	4,6%
2 - 20% Setup Time	-19,6%	-10,6%	-1,6%	2,9%
3 - 20% Indirect Time	-18,8%	-18,7%	-18,3%	-7,8%

Table 11. Buffer results from scenario one through three

The buffer results in Table 11 show a more diverse outcome. Scenario one decreases the average Buffer 1 size slightly but increase overall utilisation of the Buffer 2. In comparison scenario two more higher decrease of the average Buffer 1 size but yield the same maximum value as scenario one, as well as an increased maximum for Buffer 2. Scenario three has a similar average for Buffer 1 as scenario two but generates a drastically decrease of the overall utilisation for both Buffer 1 and Buffer 2.

8.3.2. Scenario Four through Five – Process Time vs. Indirect Time

Scenario four and five both contain a combination of process time and indirect time improvements. Table 12 presents the results of the two inversed scenarios which are to be compared with each other.

Scenario	Utilisation	Free Capacity	On-Time-In-Full
4 - 15% Process Time 20% Indirect Time	-8,1%	11,2%	1,1%
5 - 20% Process Time 15% Indirect Time	-10,7%	11,5%	1,1%

Table 12. Performance results from scenario four through five

Overall the two scenarios show similar results apart from the utilisation parameter where scenario five generates a larger decrease in utilisation. Bearing in mind the results in Chapter 8.3.1 where the process time had a larger effect on the utilisation than the indirect time may be an explanation of the outcome. A significant characteristic for scenario four and five is that the free capacity parameter has a high percentage in both scenarios. Concerning the on-time-in-full parameter both scenarios provide over one percent increases which is relatively high in contrast to the other scenarios.

Scenario	Buffer 1 Avg	Buffer 1 Max	Buffer 2 Avg	Buffer 2 Max
4 - 15% Process Time 20% Indirect Time	-23,1%	-15,7%	-18,0%	-8,6%
5 - 20% Process Time 15% Indirect Time	-16,4%	-16,5%	-10,1%	1,1%

Table 13. Buffer results from scenario four through five

The results of the buffers are presented in Table 13. Scenario four has a positive effect on the buffers since the scenario decreases the buffer levels with high values. Scenario five shows the same pattern except in the Buffer 2 max parameter where the number of orders and sheets slightly increases. The decreases are a bit smaller than in scenario four apart from the -16.5% in the Buffer 1 max parameter which is lager. Noteworthy is that Buffer 1 gets a greater benefit form both scenario four and five than Buffer 2.

8.3.3. Scenario Six through Eight – Pre-condition Evaluation

Scenario six through eight seek to evaluate the system performance when removing smaller batch runs from the production. The simulation uses almost 9000 orders during simulation period and scenario six involves removing approximate 500 small orders, scenario seven removes around 1500 orders and scenario eight removes roughly 1000 orders.

Scenario	Utilisation	Free Capacity	On-Time-In-Full
6 - Min 700 Order Size	-1,8%	2,6%	0,6%
7 - Min 700 Punches	-7,0%	8,4%	0,6%
8 - Min 700 Area	-7,0%	8,2%	0,8%

Table 14. Performance results from scenario six through eight

Table 14 displays the relative performance variations for each scenario. Scenario six entails only a minor utilisation decrease and gives a freed capacity of 2.6 %. Scenario seven and eight delivers both high differences from the base scenario, with an approximate utilisation decrease of 7 % and freed capacity increase of 8 %. Scenario seven generates a marginal increased freed capacity than scenario eight, but a lower on-time-in-full.

Scenario	Buffer 1 Avg	Buffer 1 Max	Buffer 2 Avg	Buffer 2 Max
6 - Min 700 Order Size	-20,1%	-14,1%	-13,7%	-5,8%
7 - Min 700 Punches	-28,3%	-15,8%	-20,4%	-16,4%
8 - Min 700 Area	-32,2%	-26,8%	-22,2%	-17,6%

Table 15. Buffer results from scenario six through eight

The buffer results in Table 15 illustrate the scenarios impact on the buffer sizes. Scenario six generates a lower overall utilisation of both Buffer 1 and Buffer 2. But whereas both scenarios seven and eight yield a lower average buffer size, scenario seven has a higher utilisation peak in Buffer 1 than scenario eight.

9. Analysis of Production CAS

In this chapter the authors will present a discussion through an analysis of chapter seven and eight combined with former findings and chapters. First the scenarios will be analysed which will present the most important notifications of the scenarios. Suggestions of improvements concerning the identified improvement areas will be discussed and thereafter an analysis about the applicability of ABM and its advantages and disadvantages will be carried out.

9.1. Scenario Analysis

Below the scenarios of Chapter 8.2 are briefly analysed. The scenarios will be analysed in the same groups as were presented in Chapter 8.3. Every chapter will follow the structure which begins with an analysis of the performance changes. Thereafter an analysis of the buffer sizes will follow and to conclude every chapter a synthesising summary will be presented.

9.1.1. Performance Evaluation

The first distinguished characteristic of the performance evaluation is that scenario one, which decreases the process time, result in a better overall utilisation grade than scenario two, which decreases the setup time. This is probably the result of that most of the converters are more affected by the process time improvements in comparison to the setup time improvements. Yet, an interesting result is that two printing converters break the pattern and are more affected by setup time improvements. The authors mean that this is because of that the two printing converters suffer from longer setup times than other machines, i.e. the total setup time constitutes a larger share, compared to process time, of the accessible time. This behaviour seems to be the opposite in the other converters and is therefore the reason that the majority of the converters have a larger difference in scenario one. The corrugated board machine also follows the pattern and is affected to a much greater extent in scenario one compared to scenario two.

Scenario three implies a decrease of indirect time and has no affection on the utilisation. The reason is that indirect time is not included when calculating the utilisation. On the other hand, the decrease in indirect time has an effect on the prerequisites of the system where the simulation production planning are utilising the machines differently. A legible example of this behaviour is that the utilisation increases for machines with alternative machines and the utilisation decreases for the alternative machines. In other words, the simulation production planning is utilising the alternative machines to a lower degree. This behaviour is also noted in scenario one and two. The consequence of this behaviour would be for SKS to focus on orders which should be planned in the alternative machines.

Bear in mind that a negative utilisation should be seen as a positive effect on the system performance. This is due to that the simulation do not generate additional orders, thus the machines will have an increased free capacity. Therefore the decreased utilisation must be compared with the increased free capacity for the scenarios. Overall, scenario one and three result in a higher degree of free capacity than scenario two. When viewing the results for each machine it appears that each scenario has the greatest effect on those machines with the larger share of the parameter which is changed in the scenario. Nevertheless, due to the complexity which resides within the system it is the overall result that is essential for the evaluation.

The corrugated board machine obtains a significant high degree of free capacity in scenario one and three which implies that the machine is producing same amount of orders in less time. Because of the increased speed, the following converters do not seem to be able to handle the situation. It appears that some converters can not adjust them self to handle the situation and thereby obstruct the system. This discussion implies that since the corrugated board machine has a history of over capacity the improvement activities should primarily focus on the converters.

When reviewing the results from the on-time-in-full parameter only marginal improvements can be observed. Not surprisingly scenario one and three displays the best results but the on-time-in-full parameter is constrained by the limitations of the simulation. The on-time-in-full parameter cannot display large changes due to the limited order quantity which is based on historical data.

Moving on to the buffer parameters where scenario one generates a lower buffer size in Buffer 1 than in Buffer 2. Consequently this implies that the two latter converters suffer from higher load. Scenario two generates a better average effect on Buffer 1 than in scenario one and the results show that the system will handle a stressed situation due to the low buffer size. The Buffer 2 is marginally affected but is not as favourable as for Buffer 1. Scenario three is different in character with a larger effect on the buffers. The results shows that the system will get a more favourable throughput of orders and that the system thereby becomes more robust. In turn, the robustness makes the system more resilient to production changes.

To sum up the performance evaluation scenarios the utilisation is mostly affected by scenario one and two. The free capacity parameter gets the best results through scenario one and three where scenario two has relative high effect on individual converters but not on the system as whole. Scenario three generates the strongest effect on the buffers and in combination with the increased free capacity it show signs of a stronger robustness of the system.

During the discussion in Chapter 6.5.4 some questions arose whether the feedback loops, illustrated in the cognitive maps, would have a negative affect on the system. The simulation of scenario one through three does not seem to show any significant negative effect on the system as a whole. To further investigate the relationship between the two dominant factors in scenario one through three, i.e. process time and indirect time, they will be discussed in the next chapter.

9.1.2. Process Time vs. Indirect Time

Scenario four and five generates equivalent performance changes in the simulations. The difference in utilisation comes from the indirect time modification which does not directly affect the utilisation measurements. Both scenarios entail a very similar effect on each machine. However scenario five with its higher process time modification does receive a marginal higher free capacity for the system as a whole.

Scenario four has a stronger overall buffer utilisation with both low average and maximum utilisations of the buffers, but scenario five has a lower maximum for Buffer 1. In turn scenario five has higher values for Buffer 2. This indicates that scenario five gives a good robustness for the preceding converters whereas scenario four has a greater robustness for the whole system.

Scenario five may be the better scenario as it implies a higher free capacity and a resilient Buffer 1 but scenario four generates better circumstances for the whole system. The distinction is not clear as scenario four and five does not show a similar distinctive difference between improvements in process time and indirect time as were seen in scenario one and three. One possibility is that system has reached a certain constraint where the further modifications only imply limited improvement potentials. The substantial changes imposed in scenario four and five may entail that the system must find a new quasi-equilibrium which the simulation cannot provide.

To conclude scenarios one through five the simulation has roughly identified the relative leverage of the three improvement areas; process time, setup time and indirect time. Most significant leverage was illustrated in scenarios one and three were process time and indirect time both had a larger impact than the setup time scenario. Indirect time stands out as the overall effective improvement area which SKS should focus on. A decrease of indirect time will both increase the free capacity and strengthen the robustness of the system during times of high production load.

As a result of both the CAS analysis and simulation indirect time also seem to be the more striking factor in comparison to setup time and process time. For SKS in Eslöv a substantial improvement in setup time will be difficult since SKS has historically had a strong focus on setup time reduction through techniques as SMED. A process time reduction shows great potential in the simulation results, but since process time improvements is in greater extent dependent of physical constraint of the machines and order characteristics than indirect time. Indirect time is primarily caused by human interactions and their consequences which in turn makes it easier for SKS to manage.

9.1.3. Pre-condition Evaluation

Scenario six through eight was performed to examine the effect of order with small batch sizes on the systems capacity utilisation. As seen from the results scenario six has the smallest system performance change. The scenario only has marginal -1.8 % utilisation change and increases the free capacity with 2.6 %. These minor changes may show that the system can effectively handle these 500 small batches and not affect the system performance as a whole.

Both scenario seven and eight have similar high performance change upon the system. The utilisation is one of the lowest in all scenarios and the free capacity is the highest of all at 8.4% and 8.2 %. This illustrate that these types of orders demand a considerable amount of the system capacity. When studying the changes for each machine these orders have a significant impact upon a couple of converters but do not affect the latter converters in the production which implies that these orders is converted a fair number of early process steps. Both scenario seven and eight have an equally high effect on the corrugated board machine.

All of the scenarios give a high variation of the buffer utilisation. Both scenario six and scenario seven has a low average buffer size with a moderately higher maximum for both buffers. Though scenario seven has a lower Buffer 2 utilisation, which is also noticeable for scenario eight. Scenario eight on the other hand has an overall lower utilisation of Buffer 1 than the two other scenarios.

Both scenario seven and eight entail a high increase in system performance. However scenario eight does has an even greater impact per order as scenario seven exclude 1500 orders and scenario eight merely removes 1000 orders. Scenario six excludes 500 orders which in turn only slightly increase the free capacity but give a better buffer utilisation. Overall the system seems to be most significantly affected by the total area of the orders. Orders with small total area do demand much of SKS production capacity and seem to obstruct the production when it is under higher stress.

Though these scenarios imply a more effective overall system it may not be simple to perform such radical change to the order composition. In order to fully understand the orders impact a further study of implications from the changes in order composition must be performed. The profitability which the orders entail is not included in this study but may constitute a substantial sum for SKS in Eslöv. These smaller orders may also be a prerequisite for retain some customer, as they may prove to be essential qualifiers or order-winners for SKS in Eslöv. Most significantly for these scenarios is for SKS to consider if SKS in Eslöv should exclude the small batches since the production has a great focus on flexibility and customisation. Thus further studies in the effects of smaller orders are needed.

9.2. Suggestions of Improvements

In this part the authors will present suggestions of improvements related to the four improvement areas identified through the CAS analysis in Chapter 6.5.4 and the result from the scenario analysis in Chapter 9.1.

Concerning the most effective improvement area identified though analysis and simulation, i.e. indirect time, the authors claim for several areas to improve. Since most of indirect time factors, e.g. waiting for order and waiting for tools, are inherited in the computerised model the question stands for hesitation of the agents. In order to manage this problem a change in the individual behaviour of the agents is demanded. Thus to prevent types of hesitations more rapid communications and coordination is desirable. Faster communications with relevant information would provide more effective coordination of the agents. To minimise an increased complexity it would require a simple set of rules, which in turn can assist the agents with the decision making in situations of hesitation. The authors recommend that a specific package of measurements is introduced at every station within the production. The rules and measurements would be machine task specific and serve to solve the problem with minimum interactions from other parties. The rules should enhance the operators' abilities to deal with the problem themselves and report relevant information as soon as possible. This should minimise the production planner's effort and primarily only involve affected parts. For example when a machine is missing tools, paint or other necessary accessories the machine operators should in greater extent handle the problem themselves with the production service.

Another way to handle the indirect time, which is in turn connected with the previous paragraph, is to give the agents the freedom or possibility to influence their prerequisites in the surrounding environment. This implies a responsibility for the machine operators to use the indirect time in order to adapt their selves to the situation and take action, i.e. the agents will improve their fitness in the complex system. For example, if a machine agent is affected by many changeovers the agent could reduce the amount of changeovers by choose its order composition.

By giving the agent more freedom and responsibility the authors believes that the agent will enhance its perception of the system. A way to increase the agents' possibility to affect their situation could be to set up production goals which the agents have to achieve. For example instead of a detailed eight hour production plan defined by the production planner, a machine could have the autonomy to choose from a set of predefined orders the most optimal order flow for the shift, day or couple of days. This autonomy will successively increase the complexity of the system but decrease the complexity for the production planner. Such a control shift should alter the state of the system, which should increase the self-organisation and adaptability of the production. This in turn may increase the robustness for unscheduled deviations.

To set up goals, in combination with the agents' increased responsibility, may also have a positive affect on the production speed and process time within the production. If the agents are able to optimise their processes with fewer stops as a result, the orders could be processed with a higher average speed. Further, to improve the speed in the machines the authors would like point out that it requires frequent quality controls. Quality controls consist of ocular inspection to verify sheet and print quality. The quality control will be a requisite to detect a presumed increased failure rate and handle quality deviations.

As identified in Chapter 6.5.4 the order composition has a major impact upon the prerequisites for order planning. By influencing the order composition to reflect the capacity utilisation a greater manageability can be attained. SKS in Eslöv illustrate their sales function and production as two separated subsequent one-way arrows where sales define the input of the production. This image also reflects the actual process where the sales department has little feedback from productions current and future capacity. The sales department has access to information but coordination from the productions needs is seldom conducted. A greater mutual exchange of both departments' conditions could entail a better order composition which in turn suggests a faster production pace at a lower cost. For example sales could focus on specific order types in order to fill unutilised capacity in greater extent. Such interactions are vital in order to effectively influence the order composition.

The production also has a varied insight of the future order flow and is primarily limited to a short planning horizon. In order to profitably manage the order composition a longer planning horizon is preferable. As of now the customer relationships a limited to a unilateral exchange where the customer relay little of their future orders. In order to attain a likely mutual improvement a more satisfying interaction with customers are required. Such collaborations could result in better forecasts which would make the planning process and the optimisation easier.

A holistic view of the whole value chain, both within SKS itself and the supply chain, is a natural and essential next step in order to increase capacity utilisation. The production cannot limit itself to its own boundaries but need to form a greater fitness to the supply chain landscape as a whole.

9.3. What about ABM?

With the goal of being able to simulate the production process at SKS in Eslöv the authors decided to create their own agent-based model, presented in Chapter 6, in order to handle the evident complexity of the system. ABM has proved to contain several advantages and disadvantages which were presented in Chapter 2 and which will be further discussed on the basis of the case study.

There is no doubt that, during the creation of the model, the authors have gained a useful comprehension of the system which the model reflects. It is the authors' belief that by only view the production process from a strict agent mapping would not have be sufficient due to the complex cause-and-effect relations within the system. Instead, by contemplate the system from a complex view and the inherent elements as agents the authors have discovered the "actual system". This means that actions and connections within the system has been possible to taken into account in our process of analysing the production in order to locate parameters that are affecting the production output. The gained understanding of the system has also made it possible to identify patterns of how capacity utilisation affects the output but not to what extent. ABM has proven the unmistakeable complexity of a corrugated board production. By providing this notion the authors believe that the analysis of this thesis would bring an increased understanding for the workers at SKS in Eslöv. If every worker is aware of the prevailing circumstances in the production it would be easier for the production management to plan and optimise the production.

Perhaps the most significant advantage of ABM is the possibility to translate the real-life settings to a model. The model can then be used for simulation and problem solving purposes in order to be able predict possible forthcoming changes. As every agent in the model has the same properties as the element it reflects the authors have had the possibility to change the prerequisites of the system. By changing the prerequisites of the system scenario simulation is possible.

The authors concur with presented the disadvantages of ABM in Chapter 2. Firstly it requires a great deal of programming skills to be able to develop an agent-based model. The programming is written in Java code and it is of great importance that every real-life setting is represented in the code. In order to develop and build the model the authors chose to create a conceptual model of the system. This conceptual model was created through observations and interviews at the case company to receive an in-depth knowledge about the characteristics of the system. The most evident disadvantage of using simulation through ABM is the time staking activities to transform the agent-based model into a computerised model. Apart from the programming, simulation models are highly dependent on the input data of the model and often this data is not available at hand, which was the case in this particular study. Due to the lack of data the verification and validation of the model was postponed.

9.3.1. The Authors Reflections of ABM

With the exception of the discussion above, the authors have made some further reflections of using ABM as a tool in this case study. The question of measurement data does not only include the difficulties of finding it, it also requires that the data is accurate. The failures in the received data may have been caused by many things that cannot be properly explained. Thus, the authors recommend that this is taken into consideration by the production management at the case company in order to facilitate any further use of the data. Inaccurate data may have the consequences of unnecessary assumptions and limitations which affects the credibility of ABM.

By developing and using ABM, the difficulties of simplifying the complexity of a system into a model are prominent. It means that every action and interaction of the agents within the system should be translated into a set of simple rules, which requires great knowledge and insight of the system. Once again, the difficulties of reflecting the real-life settings are proved.

Another significant reflection made during the construction of the model was that for every new added part to the model the more complex the model construction turned out to be. This implied that every new addition required increasingly more knowledge, data and time due to new altered prerequisites of the model. A speculative comparison is that that there is an exponential relation between complexity and knowledge; the more complex the model gets the required knowledge increases exponentially. The result is that the work effort of constructing an ABM is difficult to predict.

The model developed in this study uses historical data in order to simulate the production process. The use of historical data does have some restraints that the authors would like to highlight. The main limitation is that the model is vulnerable to major changes of the system. A major change in the system would probably change the complexity which must be incorporated in the model. In turn the model then has to be modified in order to handle the new-emerged system and its new state or quasi-equilibrium. However, by using historical data during simulations may still provide the user with insight and understanding of possible effects caused by future changes in the system.

Historical data has another important function during the development process of the model, namely the process of verification and validation. Due to the actions and interactions within the model it is not possible to know what the outcome would be like if a simulation is not made. To be certain that the simulation reflects the actual actions it is therefore an advantage to have access to historical data where the outcome is known. The historical data can be executed in the model in order to compare the outcome with history and see if it is a match. If it is a match and the data and conceptual model are validated, the model is considered to be verified.

In order to gather the critical information needed for building the model the authors have followed and structural case study approach presented in Chapter 2.2. The approach contains a combination of data gathering methods which have been essential; interviews, observations and reviewing documents. This has given the possibility to capture the actual events of the production process and verify the agents of the model along the way. Despite a successful data gathering the authors believe that a more specific data gathering should have been performed earlier in the process so that the conceptual model could have been developed and verified in an earlier stage. This would have given the opportunity for a higher concentration on the agents of the model and gain a deeper understanding of them. It would probably also facilitate the implementation of the model. In contrast it can be argued that a wider understanding of the complex system as whole has been acquired. This has generated a useful insight due to the authors’ approach of viewing production as a system and not by its elements separately. In conclusion a structured approach is preferable in cases of complexity and when performing ABM.

10. Conclusion

As a final chapter the conclusions of this master thesis is presented. The criticism of the thesis content and suggestions of further research is also discussed to conclude the journey of this master thesis.

This thesis set out with two purposes, one theoretical, involving the applicability of complexity theory on an empirical case and one practical which involved an identification of improvement areas. Regarding the first purpose this thesis has proved that complexity is a significant part of the production process at SKS's production site in Eslöv. Through a holistic complex system approach and by iteratively exploring the system's components the authors distinguished system behaviour, connections and finally agents wherefrom the complexity emerged. With the discussion in Chapter 6.3 the authors demonstrated that the production process fulfilled the properties of a Complex Adaptive Systems (CAS). Further, by mapping and utilising Agent-Based Modelling (ABM) the complexity of the system could be transferred to a model.

ABM has shown efficiency in capturing real-life settings, but the experience show that it takes much effort and knowledge to construct the model. Due to limitation of the model, programming and time essential assumptions and simplifications must be made in order to construct a feasible representation of reality. ABM is a preferable tool for illustrating the complexity of the system, gaining an in-depth understanding, identifying and evaluating the inherent entities' behaviour within the system.

The second purpose has also been fulfilled through creation of an agent-based model which reflects the complexity which resides in SKS's production site in Eslöv. With the use of the model the authors have identified four improvement areas:

- Production speed
- Setup time
- Indirect time
- Order composition

Improvements in these areas provides the possibility of an increased capacity utilisation and production output. This is facilitated as improvements in production speed and setup time increases system performance and lowered indirect time as well as better order composition increases responsiveness for disturbances and reduces deviations. In order to determine the relative leverage of each improvement area the authors also implemented a computerised simulation model with the agent-based model as a foundation. Eight scenarios based on the improvement areas were then simulated and the outcome displayed some interesting results. The simulations show that improvements in indirect time have the greatest potential of increasing capacity and robustness for the system. Production speed also demonstrated great potential for capacity and robustness improvement, but is believed to be more difficult to manage compared to indirect time improvements.

From the results of the analysis and simulation the authors have two primary recommendations for SKS's production in Eslöv in order to improve these identified areas. System performance and production responsiveness can be increased by altering the machine operator's individual behaviour. By providing a goal oriented responsibility with extended freedom for machine operators to choose their own order composition and handle disturbances a more effective utilisation can be attained. The other recommendation concerns a more bilateral exchange of conditions between production and sales department. This will facilitate an enhanced possibility to influence the order composition to attain an increased capacity utilisation and production output. By extending beyond the company boundaries and offering an exchange of SKS's condition and customer requirements a better forecast and advanced planning will be achieved.

The structured approach of this thesis can preferably be adopted in other future modelling of complex systems. However, the created model in this case cannot be applied to other similar complex systems since it reflects the specific conditions of this particular case. The model can be used as an analogical aid for simulations of similar systems.

10.1. Criticism of Study

A criticism that applies for this study is that the authors have underestimated the time and effort for applying and modelling the complexity which constitute the production process in a simulation model. With this knowledge the authors could have either initiated the modelling sooner in the study or chose another approach. Another approach that applies a more bottom-up procedure to gain understanding may have implied a faster process. By first studying the individual elements the agents could have been established in an earlier stage. Yet, this approach could have entailed that an essential system connection or behaviour was overlooked in the process.

Another criticism is the fact that the authors have not considered or evaluated any other modelling method. Since the beginning of the study ABM has been the obvious method due to its advantages in circumstances such as the case in this study. The fact that ABM is a fairly young research area was also a contributing cause.

The choice of production output as a part of the purpose for the model was a request from the case company. It could be argued whether this was a righteous choice in order to improve the production process as a whole. Measurements which focus on the customer and profitability may have better reflected the needs of Smurfit Kappa Group or any other company for that matter. Production output is limited to the actual production and only partially reflects the profitability.

10.2. Further Research

The created model in this study could be enhanced to encompass other measurements. The present production output is measured in volume and an increased output does not necessarily correspond to an increased profitability. Further research could imply identifying profitable orders and customers thus SKS could concentrate on manufacture the profitable volume. However, this would require detailed analysis of costs and intangible values which the orders imply.

In this master thesis indirect time was identified as the improvement area with the most potential to affect the production capacity. However due to limited scope of this master thesis SKS should perform a more detailed study on how to manage the indirect time which occurs within the production process. This implies that SKS in Eslöv must clearly specify a responsiveness framework with rules and measurements. This may require a cross-functional collaboration in order to study the detailed technical aspects of the production and order process.

Other further research could imply extending the model to incorporate other functions within SKS in Eslöv, e.g. production service, sales and stock. The effects of shortage in stock of raw material, as mentioned in Chapter 5.4, would have been interesting to investigate. This could also be combined with an investigation concerning cost of storage.

As an ideal extension of the model further development to facilitate a more adaptive structure and intelligent agents, in combination with integration of SKS’s real-time information system could have implied a real-time decision-making tool to support the production planning in its daily challenges. However, this would probably cost more than the tool is worth.

Within the research field the authors believe there is still much to do concerning the applicability of ABM on a real production or supply chain. Consequently more agent-based models in the production and logistic research field must be constructed and implemented in order to validate and verify the performances.

11. References

11.1. Published Material

Ackoff, R. L. *Towards a System of Systems Concept*, Management Science, Vol. 17, No. 11 (1971)

Andersen, I. *Den uppenbara verkligheten – Val av samhällsvetenskaplig metod*, Lund: Studentlittaeratur (1998)

Arbnor, I. & Bjerke, B. *Företagsekonomisk metodlära*, Lund: Studentlitteraur (1994)

Bar-Yam, Y. *Dynamics of Complex Systems*, USA: Perseus Books (1997)

Baumgärtel, H. *Processing for Production Logistics*, IEEE Intelligent Systems No. 1 Vol. 15 (2000)

Bjerke, B. *Some Comments on Methodology in Management Research*, Studies in the Economics and Organisations of Action, No. 8 (1981)

Bonabeau, E. & Meyer, C., Swarm *Intelligence: A Whole New Way to Think About Business*, Harvard Business Review, Vol. 79, Issue: 5 (2001)

Cheesseman, M. J., Swann, P., Hesketh, G. B. & Barnes, S. *Adaptive manufacturing scheduling: a flexible and configurable agent-based prototype*, Production Planning & Control, Vol. 16, No. 5 (2005)

Choi, T. Y., Dooley, K. J., and Rungtusanatham, M. *Supply networks and complex adaptive systems: control versus emerge*, Journal of Operations Management, Vol. 19, No. 3 (2001)

Darke, P., Shanks, G. & Broadbent, M. *Successfully completing case study research: combining rigour, relevance and pragmatism*, Information Systems Journal, Vol. 8, No. 4 (1998)

Darley, V., von Tessin, P. & Sanders, D. *An agent-based model of a corrugated box factory: The tradeoff between finished-goods-stock and on-time-in-full-delivery*, Proceedings 5th Workshop on Agent-Based Simulation, Lisbon, Portugal (2004)

Eden, C., *Analysing cognitive maps to help structure issues or problems*, European Journal of Operational Research, Vol. 159, No. 3 (2004)

Eisenhardt, K. M. *Building Theories from Case Study Research*, Academy of Management Review, Vol. 14, No. 4 (1989)

Hellström, D. & Nilsson, F. *Combining Case Study and Simulation Methods in Supply Chain Management Research*, Proceedings of 15th annual IPSERA & 4th

Worldwide research symposium on Purchasing and supply chain management (2006)

Holme, I. M. & Solvang, K. B. *Forskningsmetodik, om kvalitativa och kvantitativa metoder*, Lund: Studentlitteratur (1997)

Jennings, N. R., Sycara, K. & Wooldridge, M. *A Roadmap of Agent Research and Development,* Autonomous Agents and Multi-Agent Systems, Vol. 1, No. 1 (1998)

Lambert, D. M. *The eight essential supply chain management processes,* Supply Chain Management Review, Vol. 8, No. 6 (2004)

Lambert, D. M., Stock, J. R., & Ellram, L. M. *Fundamentals of Logistics Management*, International ed., London: McGraw-Hill Higher Education (1998)

Langfield-Smith et al. *Measuring Differences Between Cognitive Maps*, The Journal of Operational Research Society, Vol. 43, No. 12 (1992)

Langton, C. G. *Computation at the edge of chaos: phase transitions and emergent computation,* Physics D, Vol. 42, No. 1-3 (1990)

Lummus, R. R., Krumwiede, D. W., and Vokurka, R. J., *The relationship of logistics to supply chain management: developing a common industry definition*, Industrial Management & Data Systems, Vol. 101, No. 8 (2001)

Matson, J. B. & McFarlane, D. C., *Assessing the responsiveness of existing production operations*, International Journal of Operations & Production Management, Vol. 19, No. 8 (1999)

McCarthy, I. P. *Manufacturing strategy: understanding the fitness landscape*, International Journal of Operations & Production Management, Vol. 24, Issue 2 (2004)

Nilsson, F. & Waidringer, J. *Logistics Management from a Complexity Perspective*, Managing the Complex IV, Fort Myers, Florida (2002)

Nilsson, F. *A Complex Adaptive Systems Approach on Logistics,* Licentiate thesis, Department of Design Science, Division of Packaging Logistics, Lund University, Lund (2003)

Nilsson, F. *Adaptive Logistics – using complexity theory to facilitate increased effectiveness in logistics*, Doctoral Thesis, Division of Packaging Logistics, Lund University, Lund (2005)

Parsons, D. J. & Phelps, R. A., *Production scheduling validity in high level supply chain models,* Simulation Conference, 2001. Proceedings of the Winter, Vol. 1 (2001)

Patton, E. & Appelbaum, S. H. *The Case for Case Studies in Management Research*, Management Research News, Vol. 26, No. 5 (2003)

Robson, I. *From process measurement to performance improvement*, Business Process Management Journal, Vol. 10, No. 5 (2004)

Sargent, R. G. Verification and validation of simulation models, in: M.E., Kuhl et al., eds., Proceedings from the 2005 Winter Simulation Conference (2005)

Schary, P. B. & Skjøtt-Larsen, T. *Managing the Global Supply Chain*, Denmark: Copenhagen Business School Press (2003)

Skjøtt-Larsen, T., *Supply Chain Management: A new Challenge for Researchers and Managers in Logistics*, International Journal of Logistics Management, Vol. 10, No. 2 (1999)

Svensson, G., *A conceptual framework for the analysis of vulnerability in supply chains*, International Journal of Physical Distribution & Logistics Management, Vol. 30, No. 9 (2000)

Towers, N. & Ashford, R., *The Supply Chain Management of production planning and sustainable customer relationships*, Management Research News, Vol. 24, No. 14 (2001)

Voss, C. A., *Alternative paradigms for manufacturing strategy*, International Journal of Operations & Production Management, Vol. 25, No. 12 (2005)

11.2. Interviews

Berglin, Mikael. Production Manager, Eslöv, 2006-03-07

Dahlgren, Fredrik. Production Planning Manager, Eslöv, 2006-03-02, 2006-03-08, 2006-04-13

Jönsson, Elna. Production Planner, Eslöv, 2006-03-03

Karlsson, Stefan. Production Planner, Eslöv, 2006-03-08

Kvist, Per. Production Coordinator, Eslöv, 2006-03-02

11.3. Unpublished SKS Material

Smurfit Kappa Sweden, *POPPE Manuals* (2001)

11.4. Electronic material

Case No COMP/M.3935 - JEFFERSON SMURFIT/KAPPA, http://europa.eu.int/comm/competition/mergers/cases/decisions/m3935_20051110_20212_en.pdf (2006-03-28)

FEFCO – What is corrugated?, http://www.fefco.org/index.php?id=103 (2006-03-27)

Smurfit Kappa Group, http://www.smurfitkappa.com (2006-03-15)

Smurfit Kappa Group – 2005 Fourth Quarter and Full Year Results, http://www.smurfitkappa.com (2006-03-01)

TIS – Types of corrugated board, http://www.tis-gdv.de/tis_e/verpack/papier/wp_arten/ (2006-03-27)

Appendix A

This appendix presents tables of the machine utilisation and free capacity variation for scenario one through eight. The appendix also holds a short machine specification.

Machine	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
101	-19,97%	-0,50%	0,00%	-14,98%	-19,97%	-0,70%	-1,90%	-1,90%
111	-4,81%	-11,47%	0,09%	-3,54%	-4,70%	-4,16%	-7,04%	-7,06%
112	-3,84%	-11,98%	0,15%	-2,96%	-3,87%	-0,53%	-10,97%	-11,10%
115	-14,24%	-4,11%	0,04%	-10,74%	-14,23%	-3,23%	-4,54%	-4,45%
121	-16,41%	-11,20%	-4,62%	-16,20%	-18,46%	-6,05%	-8,12%	-9,82%
123	-9,98%	-7,29%	1,00%	-7,31%	-9,04%	0,47%	-8,74%	-8,66%
124	-8,25%	-9,00%	-0,25%	-6,30%	-8,33%	-1,40%	-2,89%	-2,88%
126	-6,68%	-10,31%	-0,22%	-5,04%	-6,63%	-2,60%	-22,14%	-22,25%
127	-9,99%	-7,82%	-1,23%	-7,47%	-10,34%	-1,39%	-11,21%	-10,99%
129	-8,25%	-3,65%	2,65%	-4,54%	-7,48%	-0,66%	-1,88%	-1,31%
144	-8,97%	-3,66%	2,38%	-4,49%	-7,18%	-1,32%	-2,78%	-2,60%
146	-15,16%	-10,26%	-3,92%	-15,83%	-17,02%	-1,38%	-5,00%	-4,79%

Table 16. Utilisation variation for the machines in scenario one through eight

Machine	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
101	55,04%	-2,85%	34,10%	57,70%	69,17%	5,68%	17,74%	16,98%
111	7,72%	17,66%	19,30%	25,38%	21,64%	12,90%	22,48%	19,93%
112	3,54%	9,11%	6,12%	8,77%	8,22%	1,35%	13,52%	13,73%
115	27,12%	8,65%	8,39%	28,45%	31,45%	10,70%	13,72%	14,18%
121	3,28%	1,93%	4,53%	6,98%	6,72%	2,37%	3,60%	3,96%
123	8,73%	6,25%	7,66%	14,66%	13,23%	0,57%	12,32%	12,50%
124	6,66%	7,36%	6,81%	11,32%	11,46%	3,14%	4,05%	4,03%
126	3,10%	4,84%	5,00%	7,29%	7,16%	2,15%	18,16%	18,13%
127	6,36%	4,87%	5,95%	10,42%	11,31%	1,28%	13,22%	13,05%
129	1,48%	0,87%	4,15%	5,97%	6,00%	1,06%	1,65%	1,59%
144	2,30%	1,13%	1,41%	3,17%	3,41%	0,64%	1,56%	1,02%
146	2,96%	1,84%	2,41%	4,59%	4,46%	0,51%	1,52%	1,57%

Table 17. Free capacity variation for the machines in scenario one through eight

Machine	Type	Print Cap.	Punsch Cap.	Folding & Gluing Cap.
101	Corrugator			
111	Converter	X		
112	Converter	X		
115	Converter	X	X	
121	Converter		X	
123	Converter	X	X	
124	Converter	X	X	
126	Converter		X	
127	Converter	X	X	
129	Converter		X	
144	Converter			X
146	Converter			X

Table 18. Machine specifications