Decision-making using agent-based modeling

- A case study of complexity at Unilever Bestfoods

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Master Thesis at Technology Management no 95./2004
ISSN: 1651-0100
ISRN LUTVDG/TVTM--04/5095--SE
KFS i Lund AB
Lund 2004
Printed in Sweden

Abstract

Title: **Making decisions using agent-based modeling**

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Problem: The industry structure could be viewed as changing. A problem for some mangers is the knowing how the consequences of their decisions affect their supply chain in advance.

Purpose: The purpose is divided into two parts. (1) To examine the possibility of applying the complexity theory through an agent-based model at a supply chain. (2) To investigate and evaluate different future scenarios at Unilever Bestfoods Nordic's supply chain through an agent-based model.

Method: A case study method was chosen and the data has been collected through interviews, observations and document studies. The data was finally analyzed through a custom-made agent-based computer model.

Conclusions: The parts of the supply chain studied at Unilever Bestfoods Nordic's (UBFN) displays internal properties in the same way as heterogeneous agents exist in a complex adaptive system (CAS). These agents all have different rules guiding them as well as some degree of freedom, or dimensionality, which enable them to self-organize. When the agents struggle to improve their own fitness they at the same time change the conditions for other agents. The authors believe that UBFN can certainly be viewed as a CAS. The computer model was verified through historical data to make sure that it was valid for answering what-if questions. Manipulating input parameters and observing the outcome has strongly convinced the authors that the constructed ABM is suitable as a basis for decision. The results of the simulations, in several cases both novel and interesting, were well received at UBFN at lead to further inquiries about the future and discussions about change at UBFN.

Key words: Agent-based modeling, complex adaptive systems, complexity theory, production planning, supply chain, Unilever Bestfoods Nordic's.

Preface

"Education is what remains after one has forgotten everything he learned in school" (Albert Einstein)

Sometimes the path that lay in front of the traveler leads to an unknown goal and sometimes the goal is firmly set in the mind of the traveler while the path is nowhere to be found. We feel that our case offered a little bit of both. When beginning this journey of knowledge our goal was as clear as the purest spring creek but we did not know in which direction to set out. Later on, after discovering seldom-trekked paths we sometimes lost sight of the goal and were not sure where we would end up. In times like those it is a relief and a comfort to have a guide, somebody who has traveled paths before, knowing its hazards and at the same time is aware of the goal of the journey. We believe to have found several guides who have helped us with both the paths and the goal.

We would like to thank our guides at Unilever Bestfoods Nordic in Helsingborg. Martin Valdemarsson was our supervisor at the company and always had the time. A big thank is due to the group of managers, consisting of Per Sandström, Seppo Helander, and Per Holm, committing their time and expertise of Unilever, and thus improving the results of this thesis. Thank you!

At Lund University we owe enormous gratitude to Fredrik Nilsson of Packaging Logistics department and Carl-Henric of the Business Administration department. Fredrik with great knowledge of the research field together with his passion of the subject and Carl-Henric with his experience of thesis writing, have both contributed greatly and are major reasons for the existence of this thesis. Thank you!

Additionally there are people we owe gratitude to; all the employees at Unilever that supplied us with information and endured our relentless and nagging questions, Angela Barnett-Lindberg for proofreading our thesis (not the preface), our caring and loving families and girlfriends who always have supported and believed in us. Thank you!

Lund, May 2004

David Fredrik Magnus

Table of contents

1 Background

"There will come a time when you believe everything is finished. That will be the beginning." (Louis L'Amour)

Being a manager isn't easy in today's fast-paced and volatile economy[1]. However, a reasonable question to ask is: Is it any harder today than it was yesterday? Many of the questions people in managerial positions ask are the same questions that have been raised and answered many times in the past. So why do the questions keep reoccurring and why are they still causing managers problems? *Answers are the answer!* Even if the same questions are raised in every generation of managers, our ever-changing environment makes it necessary for every generation of managers to answer the questions in a different fashion[2]. From a strategic point of view the entire industry assumption base has changed, from a stable industry structure to viewing the industry as in rapid and unpredictable change[3].

There are several ways to handle uncertainty, but when talking about companies that produce goods the most important aspect could be considered the production, or as Terry Hill puts it: *"…the area of manufacturing strategy is short of concepts, ideas and language"*[4]. Managers have for years been working on improving production in different ways but still feel that there is room for enhancements. One of the main problems, the inherent complexity of a production line, makes the identification of cause and effect associations difficult. This results in changing or rearranging the production line, on hunches, that could be devastating if it turns out that the imagined improvement actually resulted in costing the company a lot of money or worse - bankruptcy. Another matter that can complicate things is the fact that in some industries, such as that of fast moving consumer goods, the product cannot be produced at the time of consumption. Instead, the customer's needs are somewhere in the future - not at the time of production.[5]

It is important to note the difference between complicated and complex. A complicated problem can be hard to solve due to some difficult equation or an undetectable relationship. A complex problem is something else. It could either be the sheer number of interacting elements that makes calculations hard, or nonlinear interactions between elements that leads to multiple futures and surprising responses.[6]

How can managers tackle these issues? Some of them insist on finding the *optimal* production levels to cope with shifting customer demands and in this day and age the customer is king. At the same time the industry is faster than ever to denounce the

[1] Hammer (2001) p.3
[2] Hammer (2001) p.5
[3] Brown and Eisenhardt (1998) p.8
[4] Hill (1995) p.xxiii
[5] Davidsson & Wernstedt (2002) p.763
[6] Allen (2000) p.78-79

academic world and say that what goes on between the walls of universities is seldom applicable to the real world.[7]
This way of thinking poses some conflicting issues, or rather a paradox. Optimization originating in the academic world (subjects such as mathematics, physics etc.) is a general term for the search of an extreme property, either maximum or minimum. An example of a maximum optimization is a search for the highest possible speed of a machine and an example of a minimum optimization is a search for the minimum cost of transportation. Since optimization stems from theory it can only exist for theoretically constructed situations. Examples of such situations are math or static situations constructed to test students on theories learned on how to calculate static situations. Continuing on this line of reasoning, and incorporating the statement of rapid and unpredictable changes, might lead to a surreptitious feeling that using optimization in a non-academic environment will lead to nothing more than frustration. In other words, if the world of business is separate from the world of academics there can be no optimization, but only improvements of the current situation, given the present parameters.

1.1 Definition of the problem

The industry structure of fast moving consumer goods is changing. Fast paced deliveries are often expected on short notice orders from customers. Supply chain managers could be required to make instant decisions to satisfy customer demand while at the same time planning for the future[8]. The origin of the problem could be viewed as coming from two factors: First the supply chain as being complex, instead of just complicated, so complex that it is impossible to detect how changes in part of the chain will affect other parts in the chain which are not directly connected. Secondly, today's empirical testing of different solutions based on more or less motivated hunches relying on experience, might be hazardous because it could jeopardize the output of the company and in the extension render the company costly losses. As hinted above the problem of the industry could be viewed as how to successfully predict, or at least understand, how different changes in a supply chain will influence the output, bearing in mind all the inherent complexity of the supply chain.

Another issue exists within the academia and its continuous need of empirical evidence, meaning pragmatic proof of whether or not it is possible to apply the theory of complexity to the supply chain. Authors such as Choi et al. and Nilsson are convinced that the area of complexity theory, previously applied to evolutionary biology, organizational theory, and social science, will be an asset to supply chain management, but so far only a few cases, where the theory has been applied, exist. A way of applying the complexity theory in reality is by using agent-based modeling. Previous studies have shown successful results[9]. Among the reasons why the theory has been applied so sparingly is that it is a new area of research, which could make

[7] Hammer (2001) p.5-7
[8] Hill, T. (1995) p.xxiii
[9] www.eurobios.com (2004-05-27)

the research method different, and maybe even more important the difficulty of investigating an overall supply chain which could have uncountable connection.

1.2 Purpose of the study

The purpose of this study is divided into two parts. (1) An academic purpose intending to contribute to scientific research and (2) A practical purpose that intends to solve concrete problems through a case study:

1. To examine the possibility of applying the complexity theory through an agent-based model at a supply chain.
2. To investigate and evaluate different future scenarios at Unilever Bestfoods Nordic's (UBFN) supply chain, in order to help the company as a basis for future decisions, through an agent-based model and simulation with focus on production parameters.[10]

1.2.1 Objective of the purpose

To be able to meet the purpose, it has been broken down into four concrete and applicable objectives:

- Creating an understanding about viewing the supply chain in the light of complexity theory.
- Creating a usable agent-based computer model of the case company.
- Verifying the created model through historical data
- Applying changes to the verified model to give answers to different scenarios, in the form of what-if questions, asked by the case company in order to assemble a basis for decision-making.

1.3 Target audience

The main target readers of this study are as follows; supervisors and employees of the case company chosen for this study, supervisors from Lund Institute of Technology and Lund School of Economics and Management and fellow students of the Technology Management program. Of course it is also the expectation of the authors that the study will be of interest to researches and people generally fascinated by the field of complexity science, agent-based modeling and supply chain management.

1.4 Confidentiality

The empirical data that constitute the foundation of this study are partly confidential. This implies that all data, for instance sales and production quantities, collected directly from UBFN are manipulated or put in an appendix that are excluded in the printed version of the report. However, all results based on the collected data are authentic. This has been done out of concern for the best interests of UBFN.

[10] Examples of production parameters are batch size, safety stock, and service level.

1.5 Expected results

The study will provide answers to a variety of hypothetical situations posed by the examined case study. The hypothetical situations will be in the form of different "what-if" questions that will be tested in an agent-based simulation and analyzed in an attempt to provide answers. By testing the questions asked in the case study, complexity theory's contribution to supply chain management will also be tested.

1.6 Chapter guide

This passage exists to help and guide the reader through this study.

Chapter one, which the reader has almost finished, contains an introduction to the study as well as a definition of what will be studied. It is divided into background, problem formulation, purpose, target audience, confidentiality and this disposition.

Chapter two undertakes the task of describing the research policy chosen for this study. These methodological choices and their consequences are presented as well as the tools for collecting and analyzing the data.

Chapter three presents an introduction to complexity theory, a short background and brief description of complex adaptive systems.

Chapter four presents an introduction to the theories of logistics and supply chain management from the study's basic assumptions point of view.

Chapter five presents an overall empirical view of the case study company, UBFN. The empirical data is structured according to the studied part of the supply chain; forecast, product planning, production and inventory.

Chapter six synthesize together chapter three, four and five in order to give the reader a chance to understand the authors' interpretation and application of the theory to the empirical data and to answer a couple of questions.

Chapter seven describes the agent-based model of the supply chain at UBFN. It presents the different parts of the model as well as the connections between them.

Chapter eight describes the verification process of the model, both qualitative and quantitative. It then presents the sixteen different scenarios and their simulated result.

Chapter nine analyses the way in which the model is created as well as the verification of the model, then it analyses the result of the sixteen simulations before choosing a couple of simulations to analyze further.

Chapter ten presents the final conclusions as well as answers the purpose by summarizing the most important parts of chapters six and nine.

2 Methodology

”It is easier to do a job right than to explain why you didn’t!” (Martin van Buren)

2.1 Basic assumptions

For a conducted investigation to be considered a useful contribution to science, the authors believe that it is necessary for it to include a presentation of the researchers’ basic assumptions. Without an understanding of the authors’ perception of reality, their interpretation of the theoretical framework, their knowledge in the specific area of the study and their understanding of the methodological choices, the reader might not be able to fully take advantage of the findings and conclusions. That is why it is of great importance that both the researchers and the readers have an understanding of the chosen method.[11] Another aspect of a researcher’s view of the world is that it actually controls what is being researched and how. If there exists a belief within a field of science that the world is objective and the product of experiments is deterministic with results that can be deducted, the research will be conducted in that manner. All the tools and theories will be based on the assumption of a positivistic world and all the fieldwork will focus on the explaining of a connection between events in a deduced manner. In the same way that a researcher’s world affects the way his or her research is conducted, the research affects the practical level within that field of science and how people perform their daily work, see figure 1. The connection between a world view and practical work means that the view of the world in one way or another influences workplaces and how people think everywhere and all the time.[12]

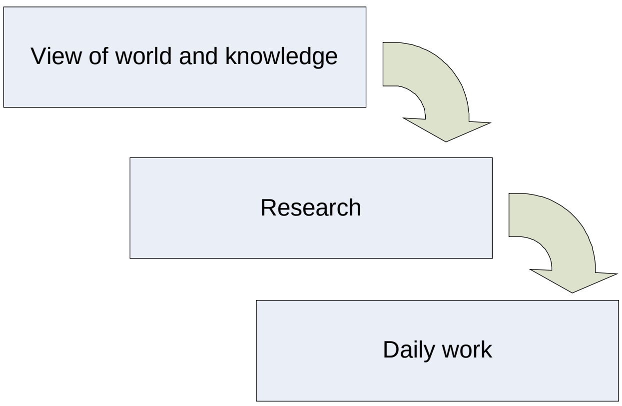

Figure 1 How the view of the world impacts the daily work. Modified from Arlbjörn & Halldorsson (2002 p. 31)

[11] Holme & Solvang (1997) p.11-15
[12] Nilsson (2003) p.2

This thesis is based on the belief that the world is neither a social construction nor an objective reality. Instead the world is viewed as a compromise between the two of them. The detailed activities studied are viewed in an objective way meaning that when looking at isolated parts of the studied system it is possible to determine, at some aggregate level at least, how the parts act and react in different situations. It is possible to determine and deduce what are the parameters that are affected and changed. On the other hand when the different parts and activities are put together, the overall system is viewed as socially constructed. According to the researchers when parts are put together it is hard to know what will happen by deduction.[13]

From a positivistic point of view only real and observational objects are to be examined. Furthermore, it is recommended that all scientific work should be conducted according to the same method; the researcher should focus on cause and effect relationships and try to obtain generalization in the results.[14] These aspects are applicable when the detailed activities are viewed in an isolated environment. The hermeneutic point of view is on the other hand focused on social significance, how different people perceive different situations, which impact the consistency has, and how a system reacts to change.[15] The hermeneutic perspective is used when examining the overall system because of its complex and dynamic composition.

Consequently, the choice of perspective is dependent on the abstraction level of the study. A high overall level, a low detailed level or something in between implies different ways of viewing the research object. We are aware that this way of perceiving the world has several implications. It affects the problems dealt with as well as the theories and methods used. One must also be aware of the impact this perception can have on the method of collecting and interpreting data. This study will try to minimize these risks by critical awareness and consciousness along the way.[16]

2.2 General research design

In order to avoid the risks described above, the researcher must also decide on a suitable method to collect and interpret data. Though the scientific contribution of this study is to apply the theoretical framework of complex adaptive systems through a simulation, it is important that this is done in an explicitly described and traceable way so the simulation could be repeated by other researchers. The ability to redo an experiment of any kind is important to the reliability of a paper.[17]

There are common ways of conducting research. By combining the inductive and deductive approach, a third approach called abduction has emerged.[18] None of these approaches is however completely applicable to this study. Instead simulation in itself

[13] Nilsson (2003) p.2
[14] Bryman (1997) p.24
[15] Lundahl & Skärvad (1999) p.42
[16] Andersen (1998) p.207
[17] Wallén (1996) p.66
[18] Alvesson & Sköldberg (1994) p.42

could be viewed as a research methodology. Like deduction it starts with a set of explicit assumptions. But in contrast to deduction, it does not prove theorems. Instead it generates data that can be analyzed inductively. Unlike induction, though, the simulated data come from specified and constructed rules rather than from direct measurement of the real world. In that way simulation can be used to aid intuition instead of just finding inductive patterns or deductive consequences.[19]

2.3 Work progress

Initially the study adopted an explorative manner. To gain a better understanding of the area regarding complex adaptive systems, adaptive logistics and agent-based systems, articles and literature published within the areas mentioned above were studied. The process then became more descriptive with focus on the overall mapping of the supply chain at UBFN. At this point enough knowledge, of the theoretical framework as well as of the object of the investigation, was collected to formulate a more precise problem.

The overall mapping process was followed by a more detailed examination of the different parts of the supply chain. Concurrent to this, data was collected in three different ways; interviews, observations and document studies. When collected, the data was structured in a detailed way that enabled it to be easily modeled, since the next step was to build a simulation model of the supply chain using the collected and already structured data. The model was initially calibrated to the current situation of the supply chain before simulating any changes in parameters or values. As a final step several simulations were made and analyzed from which conclusions were drawn.

During the study, books and articles were sought using different databases available in Lund and the reference lists of certain articles. Search strings such as complexity theory, complex adaptive systems, adaptive logistics, simulation and subordinated areas within these were used.

2.4 Theoretical research design

It is of great importance that all the chosen theory for a study is of relevance in reaching the purpose. All other literature, however interesting, is extraneous. To try to fulfill the purposes the authors have studied literature about complexity theory. Since the subject is relatively new, much of the studied material has been in the form of articles. It is important to bear in mind that only two articles were found where complexity theory had been applied to logistics. To complement this body of knowledge, literature about supply chains, logistics, operations management, and production were studied. Since an uncountable number existed in these areas, the main problem here was to limit the number of books and articles to read.

[19] Axelrod (1997) p.16

The major contribution the authors hope to make, to the academic world on the one hand and the business world (through UBFN) on the other hand, is the simulation of a supply chain. To be able to do this, the authors have, in addition to literature in complexity theory and logistics, also deepened their knowledge about object oriented programming, agent-based modeling, and simulations.

2.5 Empirical research design

A case study was chosen for collecting the empirical data. This case study method is divided into three parts; open interviews, observations and studying of documents. The background to the choice of a case study is often the discovery of a certain problem. The problem is often also examined in its natural environment so possible connections and other contextually important factors can interact in a natural way.[20]

When constructing a model for simulation the data to be used is of great importance, not only the type of data collected but also the way in which it is collected. By using a bottom-up approach when collecting the data, this study is able to deal with the complexity of a supply chain without actually understanding it. As figure 2 shows, this is done by isolating the parts identified in reality, and separately collecting the data needed to model these different parts. This implies that the separate parts of the system are built from the bottom by the data collected precisely for that part.

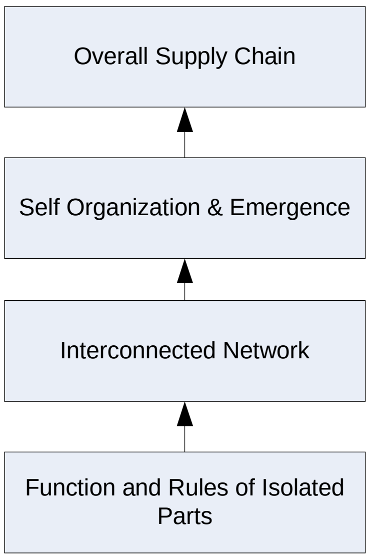

Figure 2 An overview of the process of data collection.

[20] Merriam (1994) p.21

When these parts are put together as a network they could be said to represent a complex system.[21] Together the parts and interactions between them create an environment, which self-organize and emerge in such a complex way that neither the researcher nor the reader is able to understand the overall system.[22] This implies that the study is synthesizing in its nature. In contrast to only breaking down the parts and analyzing them this study also put them together and considered the parts working in a system. The actual model took form alongside the collection of data. It has therefore been continuously improved as the process has continued.

This process of collecting data from different isolated parts and then putting it together in a system is, by the authors, refereed to as agent mapping.

2.5.1 Introduction to the case study

The chosen case in this study is Unilever Bestfoods Nordic's (UBFN) production plant and market and sales unit situated in Helsingborg, Sweden. The plant consists of three different factories producing margarine, dairy cream alternatives and cream cheeses. The plant is constructed according to its material flow, which starts in the harbor where the raw material is delivered. The first step when the raw material is delivered is the process of mixing the margarine, whereupon the margarine is transferred into a tub, a bottle or wrapped in foil. Then the margarine is packed on pallets and sent to stock. After a certain time in stock, the finished products are delivered to customers. The plant uses a minimum of workers in the actual production, meaning the greater part is automated.

Because of the structured material flow and the highly automated production, the case subject is believed to be interesting for investigating the theoretical framework of this study. By gathering empirical data from UBFN and then analyzing results through a simulation, the test of the application of complexity theory on the supply chain can be further investigated. In addition, the actual results of the simulations could be an important source of answers for UBFN, which already possess some ideas concerning its supply chain.

The primary criteria for the choice of company for the case study were accessibility towards the study and the possession of a physical supply chain. UBFN had both of these and had in addition identified a number of issues to be studied in its supply chain. The fact that UBFN worked in the segment called "fast moving consumer goods" strengthened the choice even more though this put extra pressure on a supply chain according to production efficiency and delivery time.

When conducting a case study it is effectiveness to stay sensitive to all kinds of impressions. It is also important to keep in mind that it is impossible to interview *everybody* or collect *all* relevant information.[23]

[21] d'Amours & Guinet (2003) p.151
[22] Axelrod (1997) p.5
[23] Merriam (1994) p.50-65

2.5.2 Interviews

To gain a better overall view of the supply chain in the beginning of the study the interview method was used. These initial interviews were conducted in an open way and took the form of a conversation between the interviewers and the interviewed. At this stage the interviewees contained key persons such as the supply chain manager, the material manager, the works director and the warehouse manager. Apart from getting a better overview, the main reason for this choice of method was to find out why different policies and routines were established and why certain operations were conducted in a particular way. It also gave the collected data a historical perspective, which gave more extensive answers to the questions mentioned above.

This open interview method is often used when the researcher has relatively little knowledge in the area or about the object.[24] The open interview is thus an excellent tool to obtain a deeper understanding of behavior and motives. The open interview also enables a collection of descriptions of the interviewee's world of definitions and concepts. The collected material from this kind of interview is often analyzed in a qualitative way, which puts high demands on the researcher.[25]

In addition to the open interviews several semi-structured interviews were conducted as we achieved a greater understanding of the company and its processes. Often when a general level of a person's behavior or motives or even a subject exists but there is an array of possible angles, the semi-structured interview is a good approach. Commonly an interview guide is used to show certain aspects that have been identified earlier. The benefit of doing interviews compared to, let's say, surveys is the high number of useful replies of intimate questions. On the other hand interviews require more work, time, and most of all an appointment that suits both the interviewer and the interviewee.[26] The main risk when using interviews is the possibility of response bias during the actual interview. This implies that the questions are answered in a way that makes either the person or the company look better, or in a way that gives the authors the answers they might wish.[27]

At all interviews notes were taken by at least two of the interviewers, these notes were then discussed after the interview to ensure the interpretation of the collected data.

2.5.3 Observations

If the interviews mainly gave answers to the question "why", the observations focused on answering the questions of "what" and "how". Through a number of visits and tours in the production plant we were able to observe the daily operations and how the operations were executed. One of the main advantages of the observation method is that the observer notices operations and routines as an "outsider". This

[24] Merriam (1994) p.88
[25] Andersen (1998) p.161
[26] Andersen (1998) p.161-164
[27] Holme & Solvang (1997) p. 94

offers the researcher a greater understanding of the subject by a direct view instead of relying on memory pictures.[28]

The purpose of our first visit to the production facility of UBFN was to get an overall understanding of the material flow. It was a walk-along observation together with Klas Ernegård the person in charge of the margarine production which was also our main focus although we also made some observations of the dairy cream alternative (DCA) production and packaging. The observations started at the beginning of the production with the preparation and seasoning of oil and water and continued to areas where the oil and water were mixed to specific products. Following the material flow the observation went on to the packaging part of the production, both tub packaging and pallet packaging. The impressions of this observation were that a general understanding for the production part of UBFN was acquired, but further observations were needed to form a comprehensive picture of different aspects at UBFN.

At our second observation opportunity at UBFN a visit to the warehouse together with Anders Mjörner, warehouse manager was conducted. The purpose was to learn more about the actual operations in the highly automated warehouse. The observations were made at the important junctions in the material flow and led to a greater understanding of the operations in the warehouse at UBFN.

When conducting an observation the researcher must be aware of his or her role as observer. One role is what Merriam call “observer-participator”. It implies that the observer is known by the group but his or her participation in the group is secondary to the collection of data.[29]

Our third and last major observation was made at the department of production planning. We sat alongside Jörgen Palm when he planned the production for the following week. The observations were passive in their nature, as we observed and asked questions regarding the planning process, where necessary.

2.5.4 Studies of documents

Documents, as opposed to interviews and observations, are often produced for other reasons than scientific which often imply that they do not possess the same limitations. This makes a critical view of the document’s background, purpose, source, etc. of great importance.[30]

Most of the documents used in this study consisted of statistical databases containing facts about the production process. For example, specifications about production time, stock keeping time, etc. for each relevant product and which production process they use. Other statistical documents used were different historical facts about forecasts, sales, forecast accuracy, etc. In addition to these two types of quantitative documents

[28] Merriam (1994) p.102
[29] Merriam (1994) p.106
[30] Merriam (1994) p.119

a third type was also used. This included presentation material about the company and contained a comprehensive view of the company’s history and strategy as well as its current situation in the value chain.

Because these documents were produced for other reasons than scientific they often contained more data than needed for the study. This demanded a careful selection process when transforming data into applicable information. An important part of the research process when using documents[31] is to make an adequate selection and decide the value of the material. However, documents are a completely stable source of information compared to interviews and observations.[32] To minimize the risks concerning the selection process, a careful calibration to the current situation was carried out before simulation. This calibration was simplified by the stability of the data from the studied documents.

2.5.5 Data collection issues

Of course a case company such as UBFN offers many possibilities when modeling a supply chain. Since UBFN also turnovers a large amount of products daily it gave us an active supply chain to work with, which implies a lot of data. In other words, UBFN seemed to represent a suitable base for this type of study. However, a number of minor difficulties occurred along the way.

In a number of situations the study are missing data. An example is that every product has its own average wash time. This is missing for a couple of products since the authors were not able to obtain the data. Instead these products use the default wash time of its production line. It only differs on a few decimals but it is nonetheless a type of missing data. These factors are referred to as practical factors. Another practical factor is that some of the collected data turned out to be incorrect. This has in its turn either taken extra time when retrieving the correct data or in some cases changed the demand for data. One external factor behind this is also the fact that UBFN at the moment is using separate supporting software programs for the stock, the production planning and the rest of the company. This has on the other hand given us a valuable insight into the software programs situation at an international company.

Related to these practical factors, the authors identified something referred to as social factors. These consist of the different roles at UBFN. Sometimes it appears that people do not know which type of data other people possess. Persons who are supposed to possess certain data, according to somebody else, have several times turned out not to. Somebody with the overall possession of data would have facilitated the study and could have answered a number of internal questions at UBFN. This combined with a better historical storage of data, such as the service level and number of pallets in stock, would probably also have made a difference to both the study and the company. Another social aspect is the wealth of experience that a number of employees display, in most of the cases this, of course, is a good

[31] Holme & Solvang (1997) p.125
[32] Merriam (1994) p.121

thing but sometimes it is hard to influence or get detailed information about a process from someone who does the job almost without analyzing how they do it.

In addition to practical and social factors, the study also encountered a third kind of factor. This is referred to as political factors. For instance is the battle between production and stock a well known political aspect. They both want to lower their individual costs which many times results in a worse situation for the other part. There have also been situations where the production planning department has held the sales department responsible of high stock levels and vice versa. Other political aspects have been noted at some of the meetings where the participants sometimes have expressed different opinions concerning the same thing. Maybe this is a result of internal prestige between different strategies within the departments at UBFN.

2.6 Analyzing research design

A system can be considered complex when there are so many variables and interacting forces that it cannot be understood or optimized through a top down approach although, these systems use a few simple rules at a local level which are easy to understand. A rule can be, for instance, "Produce more of a product when stock level falls to x days' demand". However, it is possible to simulate the system behavior by programming software agents and letting them interact. This is called agent-based modeling.[33]

2.6.1 Agent-based modeling

Agent-based modeling, which is not yet commonplace, is catching on especially at companies with complex supply networks. In computer simulations, software agents can represent the individual components of the supply system, such as production lines, stock, production planning, stores etc. The behavior of each agent is programmed via rules that imitate actual behavior. The simulations make the agents interact and are able to let a company perform what-if analyses to test the impact of new logistics rules on key metrics.[34]

2.6.2 What is an agent in a computer model?

An agent in a computer model is a “proactive” software entity, which has:

- Data and encapsulation of a software object.
- Its own thread of control (which makes it an active object).
- The ability to execute autonomously without being invoked externally (compare to “reactive”).[35]

[33] Anthes (2003) p.2
[34] Anthes (2003) p.1
[35] Van Dyke Parunak (1998) p.1

More specifically, agents should have the following properties:

- Autonomy: agents encapsulate some states of their environment (i.e. other agents), and make decisions about what to do based on these states;
- Reactivity: agents are able to respond to changes in their environment;
- Pro-activeness: agents are able to exhibit goal-oriented behavior by taking initiative;
- Social ability: agents interact with other agents by sending messages to other agents, and thus cooperate, negotiate and compete in order to achieve collective or individual goals.[36]

Agents differ from one another in their internal structure. In a real world system each individual could be mapped as an agent, but most common is the functional approach, which divides the agents into the systems functions (i.e. functions of a company). However, there are a few exceptions, as for instance a “Watch Dog” agent, which often does not exist in a real system, but can be added to the computer model in order to watch the system without affecting it. [37]

2.6.3 Motivation of chosen method

In the authors’ case, the huge amount of data makes a pen-and-paper solution very difficult. Thus, we have chosen a computer simulation of the model. Also according to Nilsson logistics and manufacturing are suitable for the use of agent-based modeling (ABM) due to the distributed activities and decision-making being distributed in both time and space plus the fact that they are made up of several interacting parts with conflicting constraints. Finally both logistics and manufacturing are likely to exhibit an emergent behavior.[38]

Nilsson identifies the following advantages of ABM:

- An ABM model mimics real-life events since the agents acting in the model are representations of actual entities in reality.
- ABM allows heterogeneity and heterogeneity exists. In ABM there is no need to bundle agents together.
- Decentralization and decentralized decision-making is possible in ABM.
- The ABM does not have to be defined in advance because it is scaleable. This also means that sub-systems can be developed separately.
- An ABM could be constructed covering several companies without them being worried about information leaking out because of limited transparency.[39]

In order to solve the actual problem, several approaches can be made. The most common approach when simulating is the equation based modeling (EBM), which means that the model includes a set of equations, and the analysis consists of their

[36] Lim & Zhang (2003) p. 379
[37] Van Dyke Parunak (1998) p.3
[38] Nilsson (2004) p.9-16
[39] Nilsson (2004) p.9-16

evaluation. However, ABM competes with EBM when it comes to executing the model on a computer. In ABM, the model consists of a set of agents that encapsulate the behaviors of the various individuals that make up the system. [40] Evaluation of such a system comes from the simulation when allowing the agents to interact. ABM and EBM have several things in common, but differ in two ways:

1. The relationships among the entities they model.
2. The level at which they focus their attention.

The drawback, according to Nilsson, of the ABM could be viewed as the high cost of building it both in time and effort compared to the equation-based models.[41] Another issue which might be named as a drawback is that programming experience is required. On the other hand, a rather profound mathematical knowledge is needed for EBMs.

The authors have chosen ABM because of its following advantages:

- ABM is easier to construct and behaviors are difficult to translate into equation formalism (as in EBM). This means that the model designer does not need to consider the complexity itself. Each agent is modeled as if it were isolated from the other agents that it does not directly communicate with, which means that the modeler only needs to consider the direct relations in the network and the agent's behavior with respect to these relations.
- ABM offers additional levels of validation. Both EBM and ABM can be validated at the aggregate level (system level) when comparing the input and output with the real system (e.g. black box behavior). In addition to the system level, ABM can be validated at the individual level, which means that each agent can be modeled from a local observation.
- ABM supports more direct experimentation. The model can be used to evaluate "what-if" scenarios, which means that for example one or more agent's behavior can be changed instantly and the consequences for the system can be observed. This also means that ABMs are easier to translate back into practice, e.g. a company can change one individual's behavior after the result of the simulation of the model.
- ABMs offers a greater flexibility, any model built could later on be further developed and for instance agents could be added or removed.[42]

2.7 The authors' approach to agent-based modeling

When the authors first started the project, there were already several agent-based modeling kits available. Some of them are free, while others are available at a price. However, the authors chose to build a model of their own. The purpose was to gain full control of what happens behind the scene (the actual code), customize the model with the graphical interface and to really learn how an agent-based model is built

[40] Van Dyke et al. (1998) p.13
[41] Nilsson (2004) p.9-16
[42] Van Dyke et al. (1998) p.13

from scratch. Another fact that motivated the authors to build the model was that, according to the authors, it is easier to fit a model to UBFN than fit UBFN to a model.

The authors started by building the basic elements of the model by taking into account what common traits the elements needed. The traits of the elements were mapped by using the following assumptions suggested by the authors.

An agent in a computer model must be able to:

- Communicate with other agents by sending and receiving messages spoken in the same language.
- Read and interpret its environment and the status of its surrounding agents that actually form the environment.
- Make decisions at the exact same timeframe as the other agents without changing the environment so the order of execution in the software should have no special meaning or affect other agents during the same timeframe.

The rest of the traits of the elements are individual and describe the actual behavior of the agent.

The messages used by the agents are written on a blackboard, and the message itself contains the address of the sender and the address of receiver and the message itself.

In order to speed up the software, the following approach was used: the agents' natural state when not performing tasks is a form of sleep and the system does not check on the agent before it gets an indication that the agent is supposed to wake up. This enables the system to not check on the agents every second to see if it is time for the agent to perform a task. Instead the system can leap to a timeframe where it knows that an agent is due for an action.

The model does not know which things the agent must do, but it listens to what the agents divulge about the next time they want to be executed or if there are any messages waiting for it. This led us to divide an agent's operation into two specific capabilities: (1) offensive and (2) defensive.

An offensive capability means that the agent takes the initiative to do something. This initiative can be related to a specific time (e.g. Monday 12 p.m.). The defensive capability means that the agent is triggered when a message arrives and does something related to this message. For example another agent asks for information and the agent answers.

This approach results in only a few lines of code, visualized in figure 3, in order to calculate the next time something is happening in the model. Basically, this can be explained as:

1. While there are messages on the blackboard, send the messages to the correct address and make the receiving agent execute any procedure specified in the message. Collect all new messages into a new blackboard.

2. Find out the next time that one or more agents want to be executed and step forward to this time.
3. Execute all agents that want to be executed and collect all new messages into the new blackboard.
4. Replace the old blackboard with the new blackboard

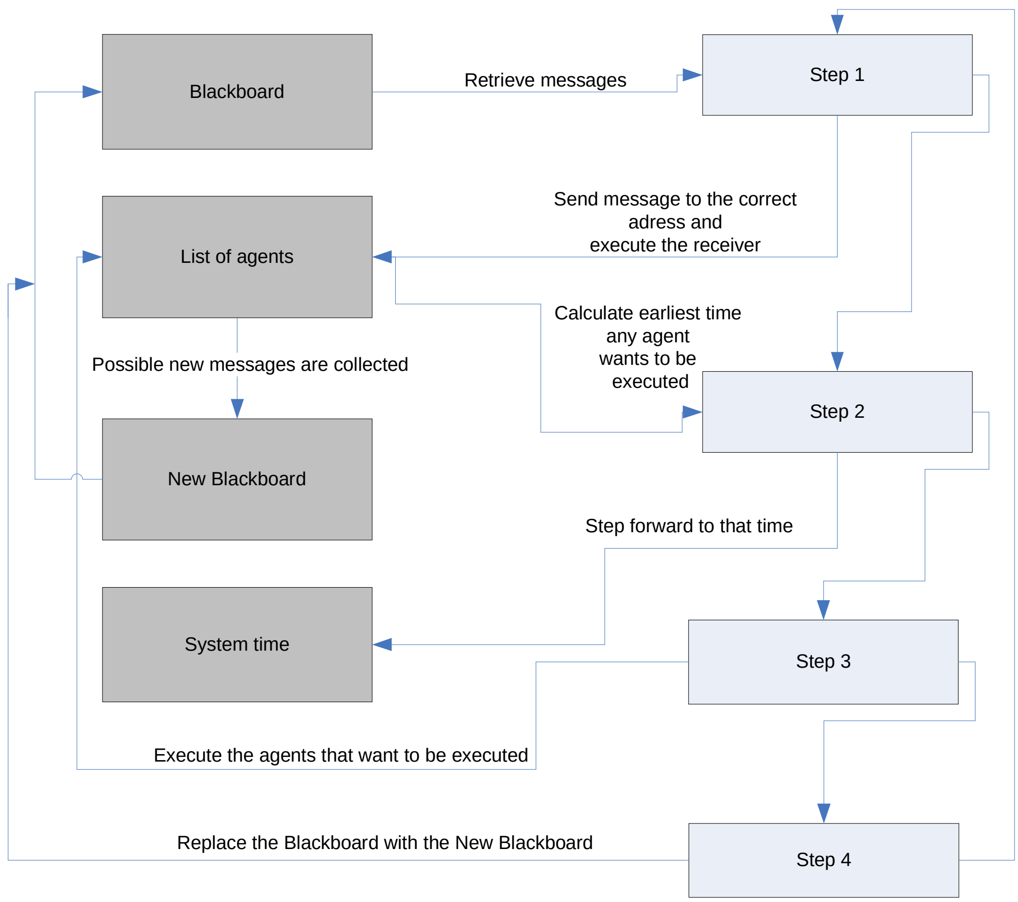

Figure 3 A visualization of how the model works.

This process, from step 1-4 can be repeated over and over again to the point of time where simulation should end.

To make this work, each agent must have an execute function. Each agent implements two types of execute functions so it can be executed both when a message arrives and when it wants to. All the agents are located in a list of agents, which the model repeats though at each step of the simulation.

2.8 Report quality

The validation of qualitative research, method and analysis comprises a control of the trustworthiness. Overall, this trustworthiness is obtained by the use of a relevant theoretical framework, a transparent view of the empirical findings and through a reasonable interpretation.

Two common aspects of trustworthiness is the validity and reliability of the study. In short, validity means to what extent the study really measures what it intends to measure while reliability implies to what extent the study would show the same results if repeated. These two aspects could then be divided into several types of validity and reliability.[43]

This study intends to obtain valid and reliable results through the use of triangulation. Triangulation implies that the researcher studies the object from several aspects or with the use of several methods for data collection.[44]

In this study data was collected with the use of the above-mentioned three methods, interviews, observations and the document studies. In addition to this the data about the supply chain was collected from the different parts of the chain; production planning, production, stock and logistics, which gave the data many different political aspects. In this way an empirical triangulation was conducted. When differing opinions were presented the disagreements were settled through a search of further evidence, either through the collection of more data in another way or through further theoretical studies.

[43] Bryman (1997) p.40-41
[44] Bryman (1997) p.157

2.9 Demarcations

The study was conducted at UBFN in Helsingborg with a focus on the margarine production. This implies an exclusion of the production of dairy cream alternatives and cream cheese, which are also produced at the plant in Helsingborg. Within the margarine production the study excludes the first and last parts of the internal supply chain, the procurement of raw- and package material and the final delivery of finished goods. See figure 4. This gives the study a focus on forecasting, productions planning, production and warehouse.

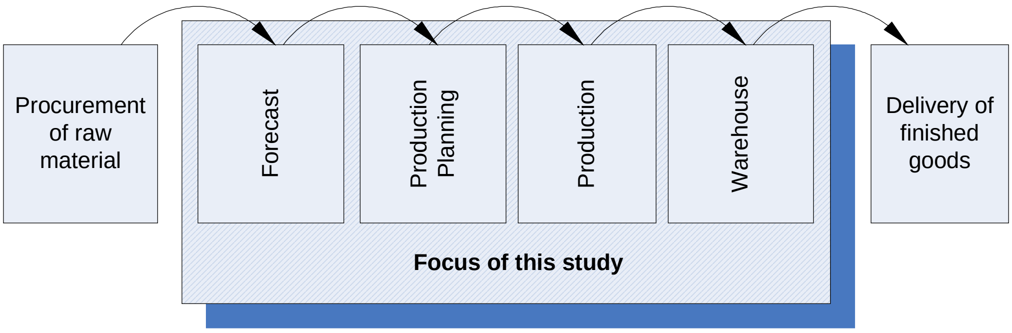

Figure 4 The focus of this study.

In addition to the above-mentioned empirical demarcations containing geographical reach and choice of supply chain activities, there are also demarcations within the studied area. A model is always a simplification of reality and even if this model might come closer to reality there are a couple of aspects that are left out. The level of abstraction could be said to be a driver of how close to reality the model is. This study is done at a relatively high level of abstraction, which implies that it does not take minor details into account. For example, if people trip and fall and therefore have to stop a production line or if people take coffee breaks at different times from day to day. The model does capture these things in a longer perspective since it uses historical values with a calculated standard deviation. But in a shorter perspective these aspects might not occur at the exact time.

2.10 Generalization of the results

Generalizations of qualitative results from case studies are usually questionable since they often only study one single situation. If more than one case is studied the possibility of generalization improves.[45] In this study only one case is studied but a generalization might be based on the triangulation and the fact that the supply chain is viewed from a high level of abstraction.

[45] Bryman (1997) p.107

In more detail the results of this study intend to be two-fold, as mentioned above. The results concerning the case study will in its whole only be applicable to the case study, but could give an indication about possible general changes. Some of the basic conceptual understanding of the industry and a general supply chain and some of the basic programming might be applicable in similar situations and cases. This is also a question of what level of abstraction the study is carried out at, see figure 5. This study is done at a relatively high level of abstraction, which makes it easier to generalize.

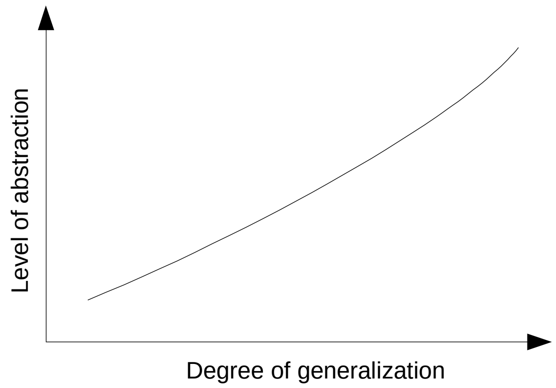

Figure 5 The relation between degree of generalization and level abstraction.

The result of the second part concerning the applicability of complexity theory should be highly interesting for the academic world and the industry alike. Given a positive result, not only of this study but of a series of similar studies on different cases in different industries and different supply chains, it could be suspected that supply chain management is heading for a new way of thinking or in other words a shift in paradigm[46].

[46] Defined in this context by Thomas Kuhn in his 1962 work *The Structure of Scientific Revolutions*

3 Introduction to Complexity Theory

"Doubt is not a pleasant condition, but certainty is absurd." (Voltaire)

This chapter will introduce the reader to the subject of Complexity Theory. It is important to bear in mind that the subject has had an exponential growth during the last decade so this introduction does not claim, in any way, to cover the full extent of the subject. The reason the theory of complexity has been chosen as a beacon in this paper is due to the focus of previous research within the field of logistics. This focus has mainly been positivistic with planning, prediction, rationality, and control in mind, but this does not coincide with the authors' view of the world. As mentioned earlier the authors of this paper believe that when trying to grasp a situation of aggregate character, the world is more of a socially constructed nature, and the complex nature of a supply chain is far from predictable. Therefore the, up until now, usually used theories could not hope to explain the complexity of a supply chain, and complexity theory is introduced.

Complexity can be identified everywhere and is often defined as the edge of chaos, meaning not quite order and not quite chaos. If there was a scale with objects in order on the left side and chaotic objects on the right, complexity and systems displaying complexity are found along an imagined line splitting the two states, see figure 6.

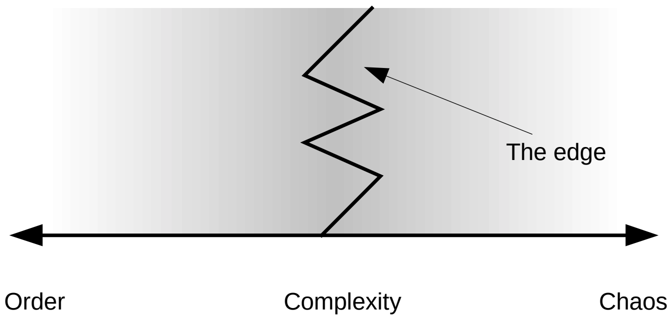

Figure 6 An overview of what complexity is.

Even though complexity is a neighbor to chaos (and order) as it were, it is important to keep in mind the palpable difference between them. Chaos Theory is, unlike Complexity Theory, derived from and based on purely mathematical and deterministic assumptions.[47] Although no agreed definition of chaos exists there are three main components most definitions include: non-periodic behavior, a deterministic system, and sensitivity to initial conditions. Complexity on the other hand is often described with other attributes such as self-organization, emergence and adaptation.[48] Another way the difference between chaos and complexity is explained is that Chaos Theory shows how complicated and unpredictable consequences can

[47] Nilsson (2003) appendix 1
[48] Nilsson (2003) p.17

originate from simple laws while Complexity Theory demonstrates how simple effects can come from complex causes.[49]

3.1 Self-organization

According to McCarthy self-organization is the product of interactions and dependencies between actors or agents in a system[50], and Fontana and Ballati argue that self-organization comes from actions not following predictable paths such as non-linear paths. Most authors though agree that self-organization does not originate from a single individual trying to create order, meaning nobody is the boss or has the power to provide the control necessary to create the outcome.

Self-organization is the process of bringing to order or increasing regularity without outside guidance, making a self-organizing system, a system that increases its order or regularity. This means that when viewing a system that self-organizes it is important to abandon the black-box view, and focus on studying the smallest parts or elements that have any impact on the system.[51] The black-box view assumes that the dynamics in a system derives from the inputs and the outputs, neglecting what goes on inside the studied object, such as interactions between heterogeneous elements inside the system, see figure 7. By abandoning the view and accepting heterogeneity the possibility to understand connections within the system emerges.

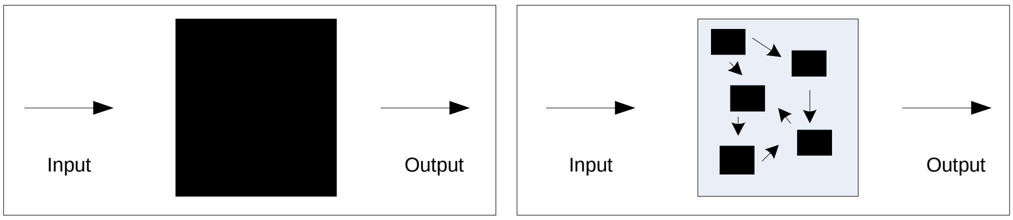

Figure 7 A visualization of the two ways of viewing a system.

"The superiority of self-organizing systems is illustrated by biological systems where the complex product can be formed with unsurpassed accuracy, efficiency, and speed"[52]. There are literally millions of self-organizing systems in nature and one of these biological systems -the ant colony - will exemplify such a system. Ants follow two simple rules; deploy a pheromone (chemical scent) wherever you go, and follow the strongest pheromone deployed by other ants (of the same colony). Now imagine two ants leaving the colony to search for food, finding the same food source. The only thing is that one of the ants found a shorter path to the food source and thus can return to the colony faster. By returning to the colony, and applying the deployment rule, its scent will now be twice as strong as the other ants' (that have not returned yet)

[49] Anderson (1999) p.7
[50] McCarthy (2004) p.129
[51] Nilsson (2003) p.18
[52] Biebracher et al. (1995) p.14

pheromone trail. Since all other ants in the colony abide by the follow pheromone rule they will start walking down the path of the fastest returning ant. This means that even though the second ant returns and its trail is as strong as the first ant's was when it returned, the shorter path will now be endowed with a even stronger scent from the ants now walking the trail deploying pheromones.[53]

3.2 Emergence

When a pattern, constructed of several elements on a lower level, is observed on a higher level it is often referred to as emergence[54]. Emergence is the result of several elements or agents collective effort or action creating a pattern or combined behavior, which could not have been created by any individual action. Another way to view the occurrence of emergence is provided by McCarthy who points out that the origin of emergence is the system's evolution i.e. self-organization, and the non-linearity that exists in a complex system. The phenomenon of emergence is often unanticipated and a nontrivial result of relatively simple interactions of simple components.[55] Adam Smith's concept of the invisible hand could be viewed as an early example of discovering emergence since it referred to system-level properties created by lower level elements.[56]

According to Bar-Yam[57] the big effort it takes to understand the properties and consequences of emergence could be a reason why this phenomenon, so far, is unappreciated and only vaguely understood. Another example of emergence, to help in this illustration, which can be found in Brown and Eisenhardt's book "Competing on the edge" uses the American prairie as a subject. For many years scientist tried to recreate the prairie as it once was in 18th and 19th century America. Initially the approach was to "assemble" the new vegetation. A plot of land, where there was once a prairie, was cleared of its vegetation and seeds of prairie type flowers were planted. The plot was cleared because urban type weeds are more aggressive and might dominate the prairie vegetation. The plan failed because the urban weeds came back in such numbers that the prairie vegetation was knocked out.[58]

Drawing from previous experiences, the next time a plot was chosen where both urban and prairie type vegetation already existed. With careful management and slow introduction of more and more prairie type vegetation after a period of two years the situation had changed. The prairie was now a fact and animal life native to prairies started to inhabit the area. Even prairie plants not planted in the area started to appear! Brown and Eisenhardt draw a couple of lessons from this prairie example. First of all organisms or complex systems cannot be assembled - they have to emerge. Secondly,

[53] Bonabeau (2001) p.110
[54] Nilsson (2003) p.20
[55] www.wordiq.com (2004-02-13) & I. McCarthy (2004) p.127
[56] Axelrod and Cohen (2000) p.19
[57] Bar-Yam (1997) p.14
[58] Brown and Eisenhardt (1998) p.137

it matters what initial parameters exist. Thirdly and finally the order in which things are done matters. [59]

3.3 Adaptation

Adaptation is, according to Nilsson (2003) action both proactive and reaction to perceived changes in the environment. The actions (and reactions) are performed in cooperation and competition, by elements or groups of elements[60]. Bonabeu (2001) uses the word flexibility to describe the ability to adapt and considers that it is a result of self-organization[61]. In order for a system to be adaptive the intrinsic agents have to be adaptive in themselves and there has to exist heterogeneity in the system[62]. In Axelrod's book "The complexity of cooperation" (1997) adaptation is the main alternative to rational choice. Rational choice is often assumed when studying social systems, not because it is realistic or because it offers better advice, but because it allows the deduction of results. This makes it easier to draw conclusions about how a system will act or react.[63]

For an example of adaptation let's once again turn to the world of nature. In honeybee hives work is very specialized. There are for instance foraging bees (bees looking for food), there are combat bees, and nursing bees. However, if food supply is low many of the bees will abandon their specialized tasks and help the foraging bees to search for food.[64]

3.4 CAS

The three above-mentioned key characteristics that usually are used to describe Complexity Theory are native to a complex adaptive system (CAS) that refers to a system that often emerges over time into a coherent form, and adapts and organizes itself with any singular entity deliberately managing or controlling it[65]. Recent studies of CAS emphasize the interplay between the environment and the system resulting in a co-evolution i.e. the system influences the environment and the environment influences the system. CAS exists all around (and in) us in the natural world. Examples from the natural world include ant colonies, flocks of birds and the human body but there are also instances of constructed CAS such as political parties and scientific communities.

[59] Brown and Eisenhardt (1998) p.142
[60] Nilsson (2003) p.21
[61] Bonabeau (2001) p.110
[62] Nilsson (2003) p.24
[63] Axelrod (1997) p.4
[64] Bonabeu (2001) p.111
[65] Holland (1995) p. 13

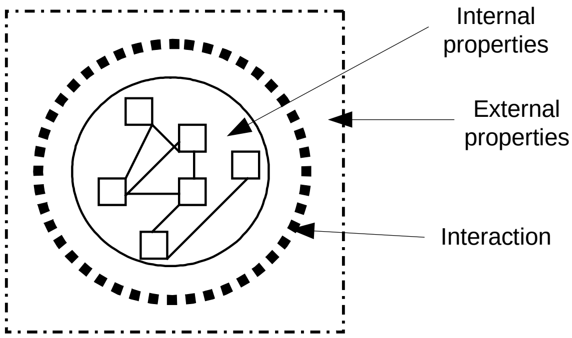

Figure 8 – Three parts of a CAS; internal properties, external properties and interactions.

In short a CAS is made up of three parts; internal properties, external properties and the interactions between the internal and external properties. Internal properties are agents and their schemata, connectivity, and dimensionality and these properties are characterized by what takes place with the individual elements in the system. The external properties are fitness landscapes and co-evolution. These properties deal with those features defined as (if that is possible) outside the system. Finally the interactions consist of self-organization, emergence, quasi-equilibrium, and the future[66]. See figure 8 for a visualization of the three parts.

3.5 Internal Properties

The internal properties concern the agents and their behavior (also known as schemata) as well as connectivity and dimensionality.

3.5.1 Agents and their schemata

Agents are the population of a CAS. The nature of the agent differs when the level of analysis changes. On disaggregate level an agent could be an individual or a forklift whilst when taking a more aggregate level the agent might be a factory or an entire organization.[67] As mentioned above, the agents have to be adaptive in order for the whole CAS to be adaptive and also the heterogeneity of the agents is an important issue. Nilsson (2003) also argues that in order for the system to be dynamic there can be agents with more or less influence over other agents, but there can be no “master agent”.

Schemata are rules or norms that guide the agents in their behavior. The individual agent’s behaviors however affect the other agents’ behavior. In effect this means that an agent creates the environment it exists in at the same time as the environment shapes the agent.[68] As agents are heterogeneous they often possess different schemata and as the agents are continuously influenced by each other, the schemata tend to

[66] Nilsson (2003) p.23 and Choi et al (2001) p.353
[67] Choi et al (2001) p.353
[68] Nilsson (2003) p.24-26

evolve or change over time[69]. Despite the difference in schemata between agents and the changing nature of schemata the pattern of Pareto principle could be considered dormant in the systems activities: a few rules dominate the bulk of the behavior.[70] Hence a CAS is often regarded as being governed by a few, simple rules.

3.5.2 Connectivity

The level of connections between different elements or agents in a CAS is termed connectivity. The connections are used for interaction and to deliver both positive and negative feedback[71]. The number of connections indicates the potential for communication and the variety in behavior[72], but the link is not entirely trivial. If the numbers of connections are either too low or too high it will affect the CAS negatively. Too few means the agents act independently and behavior of the system will be random.[73] According to Coleman this might reduce creativity and learning. Too many connections could mean an unstable system and a time consuming communication.

3.5.3 Dimensionality

The definition of dimensionality, according to Choi et al is the individual agent's possibility to decide its own behavior within the system. This possibility is commonly referred to as degrees of freedom. A high level of automation can lead to the emergence of a new pattern of behavior compared to high levels of control.

3.6 External Properties

The external properties involve viewing the CAS as a fitness landscapes and examine its ability to co-evolve.

3.6.1 The fitness landscape

The concept of the fitness landscape has been attributed to Sewall Wright, who in 1932 created mathematical models to describe some of Darwin's theory of evolution. The fitness landscape was used to show how an organism could evolve and create a greater fitness.[74] In the mid nineties Stuart Kauffman and William MacReady applied the theory of fitness landscapes to the world of business. They had observed the similarity between a biological organism and an organization's adaptive manner. They came to the conclusion that all evolution, technical or biological was actually co-evolution (explained later). This meant that optimization, as usually discussed, as a function with one maximum or minimum point, was futile to discuss.[75]

[69] Anderson (1999) p.220
[70] Choi et al (2001) p.353
[71] Nilsson (2003) p.26
[72] Stacey (1995) p.489
[73] Choi et al (2001) p.354
[74] McCarthy (2004) p.132
[75] Kauffman and MacReady (1995)

The fitness landscape is what surrounds the internal properties of a CAS and the environment that agents act in. It is often described as a rugged surface with plenty of hills and valleys where being on top of a hill means having a high fitness and being in a valley means having less fitness, see figure 9. The surface is created by the actions of the agents[76]. Fitness in itself refers to goodness, i.e. how well something is performing according to its present preferences.

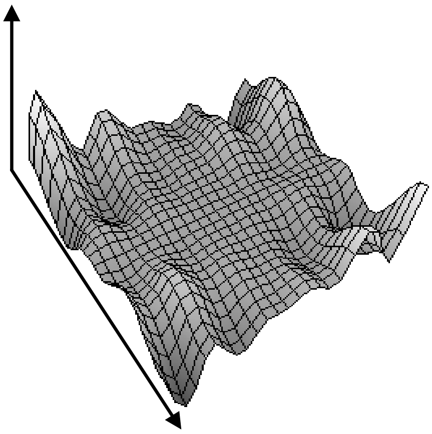

Figure 9 An example of the rugged surface of a fitness landscape.

Achieving higher fitness could be problematic, and more specifically there are two parts in striving for higher fitness that cause systems difficulties to what as appears to be a simple task. First of all the combination of many different hilltops and valleys makes it hard to determine if the present position of the system is a position on a high mountain or the top a position on just a little hill. This is problematic because it requires the system not only to climb hilltops but also, while climbing, to search for better hills to climb. Secondly, dynamics, even more than the search for hilltops complicates matters for the system. Since, explained below, the environment at the same time as it shapes the system is affected by the system; the environment changes as agents try to adapt to their environment. This adds difficulty to the already hard task of increasing the fitness for the system. What once was an ample hilltop can diminish to a small knoll requiring the system to both exploit existing knowledge and to explore new knowledge[77]. In Nilsson (2003) the dynamics of the fitness landscape is created by the agents aspiring higher fitness and when changing their own fitness altering the entire landscape[78].

On a more practical application level the search for better fitness could be viewed as the search for improvement strategies and need for awareness of feedback loops and interactions between different members of the system[79].

[76] Nilsson (2003) p.29
[77] Choi et al. (2001) p.355
[78] Nilsson (2003) p.29
[79] Lissack (1999) p.118

3.6.2 Co-Evolution

Due to feedback and interaction through competition or co-operation in a system and between different systems, the environment creates niches for agents to reside within[80]. A niche is in other words the result of several agents' combined efforts and is a non-static state. Since the agents continually interact, they force the different parts of the system to change. When the system changes it in turn bring alterations to the agents or even the birth and/or death to agents.

An example of co-evolution is the supply-tier system. When a firm decides to choose one supplier as a system supplier (supplier of main systems and not just individual parts) this creates a completely new stage for second- and third-tier suppliers that will now supply the new system supplier.[81]

3.7 Interactions

This part presents the interactions within a CAS; self-organization, emergence, the quasi-equilibrium and the possibility to predict the future.

3.7.1 Emergence

The emergent behavior of a CAS often makes the system unpredictable and the outcome counterintuitive. The emergent pattern of the system is a result of all the interactions that take place between its agents, but no agent can by itself predict what pattern will emerge. The emergence of the system opens up for the constant creation of new opportunities and sees to it that the system is always in transition. The transitional aspect is given further consideration when taking into account the notion about CAS ceasing to exist when it enters a state of equilibrium[82].

3.7.2 Self-Organization

When a system allows self-organization, it enables the agents to, by themselves, explore the environment and solve problems in different formations. It is through this kind of interaction that emergence occurs and the interactions can only exist in an open system. According to Nilsson *"self-organization is a powerful drive to make the system robust and adaptive"*[83].

3.7.3 Quasi-Equilibrium

Complex systems and CAS find themselves on the edge of chaos, which implies that they are in a quasi-equilibrium state. This is a state between order and disorder. Considering the aspect of co-evolution makes it hard to portray a CAS system in equilibrium[84]. The fact that the system is positioned on the edge of chaos means that

[80] Nilsson (2003) p.30
[81] Choi et al. (2001) p.356
[82] Nilsson (2003) p.27-28
[83] Nilsson (2003) p.27-28
[84] Choi et al. (2001) p.356

the system requires energy to maintain its place. If energy is not added, the system will come to order, like a marble coming to rest at the bottom of a cup. The marble will stay at the bottom of the cup until energy is added, but there is no additional energy needed to keep it at the bottom. When energy is added, according to Brown & Eisenhardt, a state of dissipative equilibrium occurs. The system enters a state of orderly disequilibrium[85].

3.7.4 The Future

Agents in a CAS will always try to anticipate the future based on the past. The past is made up of schemata modified by the agents to fit their local surrounding. The need to find patterns is so strong that agents sometimes see patterns that are not even there.[86]

3.8 The Paradox of Optimization

Optimization is a word that belongs to a different view of systems and is unfortunately unachievable for a CAS. Unfortunately because a CAS is, as the name implies, complex, meaning ever changing due to for instance connectivity and interdependencies and adaptive to its dynamic environment. Yet often agents within systems try to reach optimal positions themselves and frequently search for optimization for the entire system.

There are several reasons why optimization is unattainable. Generally the concept of fitness landscapes implies that there is not one static optimal point but, at any given time, several points of high fitness, and these high-fitness points keep moving around since the fitness landscape is continually reshaping. The landscape is dynamic due to the interaction between agents. The interaction is guided by agent's agenda and is therefore heterogeneous.

On a higher level the problem with optimization could be envisioned as the problems with prediction. To successfully be able to optimize the result of an alteration has to be known in advance. The complexity of a CAS originates, not from the system itself but from the interactions between agents. These interactions are heterogeneous, non-linear, and evolving. This means that small alterations to a single agent could lead to huge and unpredictable results for the entire system, while big policy change could mean no results at all. This also means that predictions cannot be made by just looking at isolated parts of a system, but rather the whole system has to be included. All in all there is simply no way to predict what is going to happen and therefore searching for optimization is futile.[87]

[85] Brown & Eisenhardt (1998) p.28-29
[86] Nilsson (2003) p.31
[87] Nilsson (2004) p.4-7

4 Introduction to logistics

"Amateurs talk about tactics, but professionals study logistics." (Robert H. Barrow)

The theory concerning logistics and supply chain management is chosen to give both the author and the reader a similar overall understanding of the subject. The theory is of a general kind which supports a wider application of the analysis as well as suggestions to further research.

4.1 Background and definitions

Logistics as an activity is thousands of years old and originates from the earliest organized forms of trade and agriculture. But it was not until World War II, when playing a major impact for the Allied, that it received any recognition or emphasis. Shortly after that, during the 1960s, it became one of the last real frontiers of opportunity for organizations. The deregulation of the transportation industry during the 1970s and 1980s combined with a growing focus on cost control gave logistics an even bigger focus. Logistics was now an international concern, which was strengthened even more through the rapid growth of information technology during the 1990s.[88] Today logistics is seen as a part of a supply chain. The council of logistics management use the following definition:[89]

"Logistics Management is that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements."

To fully understand this definition, some knowledge of the term supply chain is beneficial. Schary & Skjött-Larsen use the following definition of the supply chain:[90]

"The supply chain is an integrative approach to manage the total flow of a distribution channel from the supplier to the ultimate user."

4.2 The contents of logistics

Now the concepts, and the way they are used in this study, are understood. The next step is to examine them further by breaking them down into relevant parts. According to Schary & Skjött-Larsen there are five key processes within a supply chain[91]:

- Product design and inventory
- Production
- Procurement

[88] Lambert et al (1998) p.5-7
[89] www.clm1.org (2004-02-17)
[90] Schary & Skjött-Larsen (2001) p.25
[91] Schary & Skjött-Larsen (2001) p.35

- Distribution
- Demand management (forecasting)

In relation to this presentation of activities Lambert et al however mention that the key to effectively running the logistics process is “the total cost concept”. This implies reducing the total cost of logistics activities rather than focusing on different activities in isolation. Isolating a part and reducing its cost may have the opposite effect on another part in the process.[92]

Even though UBFN possess all of the above-mentioned processes this study focuses on forecasting, production and inventory. The theories behind these three will for that reason be more carefully presented below in the same order as they appear in UBFN’s supply chain.

4.2.1 Forecasting

When asked about reasons for engaging in forecasting, companies answer with a number of reasons; to increase customer satisfaction, to schedule production more efficiently, to lower safety stock and to reduce obsolescence cost, just to mention a few. Depending on the purpose of the forecast the time horizon might change, this is usually long term, midrange or short term. Firms often use all three of them. Long term usually cover three years and is used for long-range planning and strategic decisions. Midrange often ranges from one to three years and affects budgeting issues and sales plans while short term has the greatest impact on the operational logistics planning.[93]

Lambert et al describe two forecasting methods. The first is called surveying buyer intentions, which, as it sounds, implies that data is collected about the customer population. The main disadvantage is that it is costly and that the chosen population is misrepresentative. The second is called judgment sampling. This method is based on assessments of salespeople or certain experts in the area. The main disadvantage here is that the forecast might become biased.[94]

Today firms are moving towards a demand-based production. One way is by using vendor management inventory whereby the supplier is located at the customer and is responsible for the customer’s stock[95]. Another is by using continuous replenishment through a more transparent relation to the firm’s suppliers and customer[96].

4.2.2 Production planning

Production planning is characterized by a strong dependence between the different parts of the supply chain such as forecasting and stock. It is also time dependent and

[92] Lambert et al (1998) p.15
[93] Lambert et al (1998) p.189-190
[94] Lambert et al (1998) p.172
[95] Disney & Towill (2003) p.636
[96] Lambert et al (1998) p.173-174

varies from time to time, which makes production planning particularly complicated.[97]

Two of the main differences between the fast consumer goods industry and other industries are that fast consumer goods possess stock initiated production planning and have to take maturity and expiring dates into account. Stock initiated means that it aims to keep a certain stock in order to keep a certain service level towards the consumers, it is in other words not possible to apply an order initiated planning process. The fact that products need to mature and that they finally expire makes the production process even more complicated, as mentioned above. This puts pressure on the company to keep a low stock and try to minimize the time the products are kept there.[98]

4.2.3 Production

When a company is faced with the choice of appropriate manufacturing strategy there are three central questions that need to be asked. (1) The “make or buy decision” concerns whether the company should manufacture in-house or buy out. (2) The identification of appropriate technologies to apply on the manufacturing process. (3) The last question concerns the choice of process. This implies that the company decides to manufacture in-house and that the suitable technology is applicable. Hill mentions five classical types of processes; project, jobbing, batch, line and processing. See figure 10.[99]

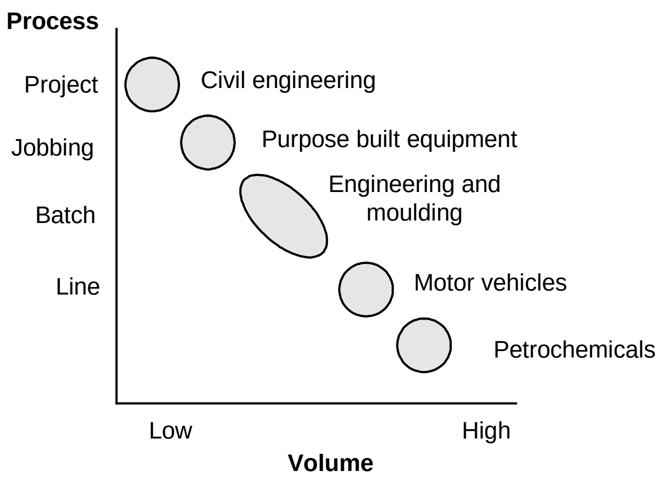

Figure 10 The different types of processes according till Hill (1995).

A project often contains a unique and complex product, which requires large-scale inputs to achieve the customer’s demand. An example of a project is an aerospace

[97] Axsäter (1979) p.15
[98] Lundgren (1985) p.19
[99] Hill (1995) p.105-107

program which also implies that the project normally take place where it is intended to be built since it not feasible to move it. The second process, jobbing, is also used when the product is of an individual nature. It requires that the company interprets the customer's demand for a specific design or operation. Even if the work is conducted at the company it requires a close and transparent relation to the customer. When a company is using the third process, batch, its intention is often to cover a wide range of volumes. This is done dividing the manufacturing task into a series of appropriate operations, which together make the products involved. The batch process requires a balanced trade-off between lower costs of repetition and the flexibility needed to meet customer demand. Line is the forth process and it requires dedicated production units. Often the company possesses a small range of products with high volumes and produces them in a standardized way. The final choice is continuous processing which is widely used in the petrochemical industry. It involves a highly automated process where the material is passed through different stages and refined into one or more products.[100]

Even if the different processes are described separately above, they are however often combined into hybrid solutions. The most usual solution contains the batch process combined with one of the other, for example batch processing is often used to make components for products while the choice of line is used to assemble them into final products. How the final process will look is often a result of the company's market characteristics as well as the production volumes.

In the case of batch processing there are often a wide range of volumes involved. Ordinary trade-offs are low/high volumes, special/standard products and make to order/make to stock decisions. To cope with this instant change the batch process need to be flexible. This flexibility also governs the finished goods inventory level. As the company moves away from the low-volume section, represented by projects and jobbing, a centralized control becomes more appropriate and the production manager's role becomes more of a batch coordinating one.[101]

4.2.4 Inventory

For many firms, inventory represents the largest investment, so a comparison between inventory and other capital investments is very relevant. Inventory also involves a number of costs. If they vary with the quantity of inventory, Lambert et al labels them as carrying costs. There are four carrying costs; capital costs, inventory service costs, storage space costs and inventory risk costs.

A capital cost implies both the overall investment and the cost for the units produced. The cost for units produced can be calculated through the method of direct costing where fixed and variable costs are separated and fixed costs are excluded from inventory values. But it can also be calculated through absorption costing where the fixed costs are included in the inventory values and divided between the products. An

[100] Hill (1995) p.107-113
[101] Hill (1995) p.113-127

inventory service cost contains everything from personnel costs to taxes and insurances. A storage space cost relates to four different types of warehouses; plant, public, rented and company-owned. The last of the four carrying costs are inventory risk costs that include obsolescence costs, damage costs, shrinkage costs and relocation costs.[102]

In general it seems that the best way to lower the carrying costs is to increase inventory turnover. Even if this is the case most of the times it is not always true. Possibly when increasing the turnover the cost for another transport exceeds the savings in carrying costs. It is only desirable to increase the turnover until this optimal point. See figure 11.

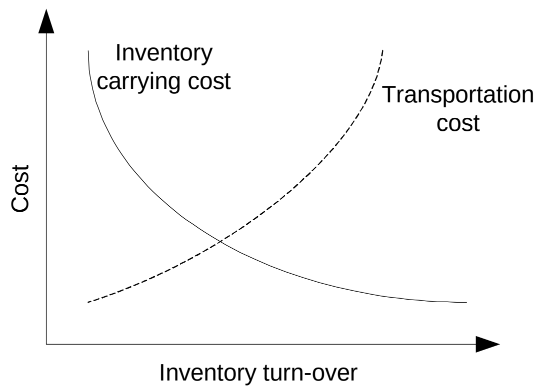

Figure 11 A visualization of inventory carrying cost and transportation cost.

Inventory reductions often have a great impact on a firm's profitability, mainly in two ways. First, profitability is improved as a consequence of a reduction in inventory carrying costs and secondly, inventory turnover increases because average inventory would be lower on the same sales.[103]

[102] Lambert et al. (1998) p.152-160
[103] Lambert et al. (1998) p.165-175

5 Unilever Bestfoods Nordic's – The Case Study

"Reality is that which, when you stop believing in it, doesn't go away." (Philip Dick)

The empirical data is collected through interviews, observations and document studies and is structured according to the studied part of UBFN's supply chain; forecasting, product planning, production and stock. The interviews are conducted with Per Holm and Jörgen Palm from production planning, Seppo Helander, Håkan Leveau and Klas Ernegård from production, Anders Mjörner and Kent Lillsjö from the warehouse and Pär Sandström and Martin Valdemarsson from the supply chain.

5.1 Introduction to the UBFN supply chain

The studied part of UBFN's supply chain contains forecasting, production planning, production and warehouse (i.e. stock). The production and storages facilities in Helsingborg could be considered somewhat strange. Even though the two facilities lie in immediate proximity they belong to two different Unilever units; forecasting and the warehouse belongs to the market and sales unit (MSU) while product planning and production belongs to the sourcing unit (SU), see figure 12. MSU presents a forecast to the production planning, together with an examination of the stock level and the production situation; the production planning then produces a plan. The production unit then executes this plan and finishes with the transportation of the goods to stock. The supply chain unit surveys and supports the different units through the whole production process.

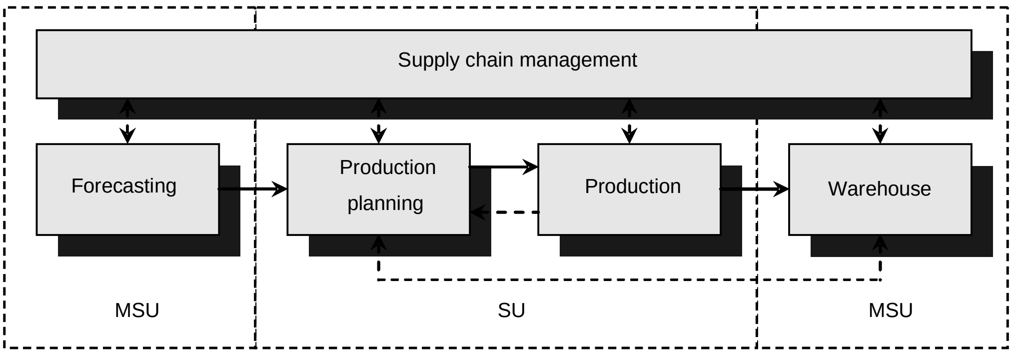

Figure 12 A visualization of the internal supply chain at UBFN.

5.2 The present situation at UBFN

Like many other companies UBFN strives to reach advantages through economies of scale. Over the last ten years UBFN has reduced from eleven to two plants in the Nordic region, the one in Helsingborg and a plant in Uppsala. The centralization resulted in a rapid growth in production and stock and made Helsingborg the supplier of the Nordic countries; Denmark, Finland, and Sweden. During the consolidation over the last years several other changes have affected the production plant as well as the warehouse.[104] The changes are of several different kinds such as the discussion about how harmful fat is, consumers' varying preferences, and the development of newer and faster production equipment together with smarter and highly automated stock keeping equipment.

5.3 Forecasting

The forecasts are produced by the sales unit, which belongs to the MSU. These forecasts are based on historical sales figures, such as the sales of the current week last year and the recent trends in the market. In addition to this, consideration is taken to present product campaigns and special offers.[105] Per Holm, material manager explains that:

"The forecasts control everything"[106]

The data collected from forecasting to model the supply chain is actual forecasts from January 2003 to December 2004. In addition to this, actual sales have also been collected from January 2003 until the end of March 2004. This data was then used as input to the production planning as well as a verification of the model.

5.4 Production planning

Production planning is the process of deciding production levels of all of UBFN products given the current forecasts and stock level. The process is highly automated but human planners are used to input data at the final stages of the planning. Planners attend development courses to learn academic approaches to productions planning, but as mentioned earlier, since the work is automated, they rarely use their knowledge about for instance the Wilson formula, but are well versed in the use of the computer system. Or as the production planner explained:

"[the Wilson formula]… is not used at this factory"[107]

The work itself is carried out every Tuesday and starts with general planning that stretches twelve weeks into the future. The twelve weeks of planning is done manually and after it is done a computer application plans another 40 weeks into the future, which results in a full year of advance planning. The following week the same procedure is repeated and the old planning results are discarded. The reason for having a twelve-week horizon is the time it takes to order different kinds of packaging material.[108]

104 Helander (2004-02-18)
105 Valdemarsson (2004-02-12)
106 Holm (2004-02-18)
107 Palm (2004-03-09)
108 Palm (2004-03-09)

After the general planning phase is ready, a detailed planning is done for the coming week. This product-by-product and day-by-day plan has the aim of always having a high service level. To achieve a high service level the planners have as a rule to keep approximately one to two weeks of stock coverage.[109] The exact stock level of a specific product is, apart from being the desired safety stock, is determined during the week it is normally produced. A product produced early in the week usually has a somewhat lower safety stock and a product produced later in the week has rather a higher safety stock. The detailed production planning always tries to look at both the stock level and forecasts, but when an updated forecast is missing, the planning procedure often uses the previous weeks' forecast and adds personal experience to try to predict the needed amount. Another issue is that the production planner uses stock levels updated on Sundays even though the planning process starts two days later, on Tuesday. This is due to the fact that the stock keeping system currently employed only generates data on a weekly basis.[110]

5.5 Production

The production plant at UBFN also belongs to the SU and consists of three production units; margarine, dairy cream alternatives and cream cheese. These three units possess separate production, filling and packaging processes. However, after the initial packaging all three units share the same plastic wrapping unit and transportation line between production and warehouse.[111]

5.5.1 Margarine production

The margarine unit produces about 70 different articles at eleven production lines, which implies continuous changeovers to cover varying demand. The capacities of the different production lines are measured in how many strokes per minute the filling machine can manage. This usually follows the year in which the machine is purchased; a newer machine performs more strokes per minute. For instance the new 600 gram filling machine is able to produce 60 strokes a minute, which with four parallel tub lines generates a production capacity of 240 tubs per minute at that line.[112]

Every production line consists of a preparatory part where water, oil and other ingredients are mixed, a filling part where the margarine is put into a tub, a bottle or wrapped in foil and a packaging part where it is boxed into transport units and put on pallets. The preparation part takes place in the basement below the packaging parts and the margarine has to go through several meters of pipes to reach the filling process. These pipes contain approximately 2,000 kilograms per production line. This is done with a push technique and means that when a tank in the preparation part is empty, for instance before a changeover, there is no pressure to push through the last mixed margarine. So every changeover implies a certain waste of margarine, which is

[109] Palm (2004-03-09)
[110] Palm (2004-03-09).
[111] Valdemarsson (2004-02-12)
[112] Helander (2004-02-18)

melted and used in a later batch. However melting down the margarine adds yet another cost to the production process of margarine.[113]

Besides changeovers due to the type of margarine, there are two more types of changeovers. These are changeovers due to different pallets and display stands as well as changeovers due to different tub and bottle formats. However, a changeover due to the type of margarine has the largest impact on the preparatory part, its pipes and demands the longest time (approximately two hours).[114] This changeover contains several elements, resulting in different costs to the process:

- Cost of raw materials.
- Cost of packaging materials.
- Conversion cost of melting down the margarine.
- Operator hours to run changeover.
- Hours to run the changeover.
- Waste of raw materials.[115]

To control and evaluate the production process, several machine performance indices are used. These indices are based on following machine time analysis (figure 13):

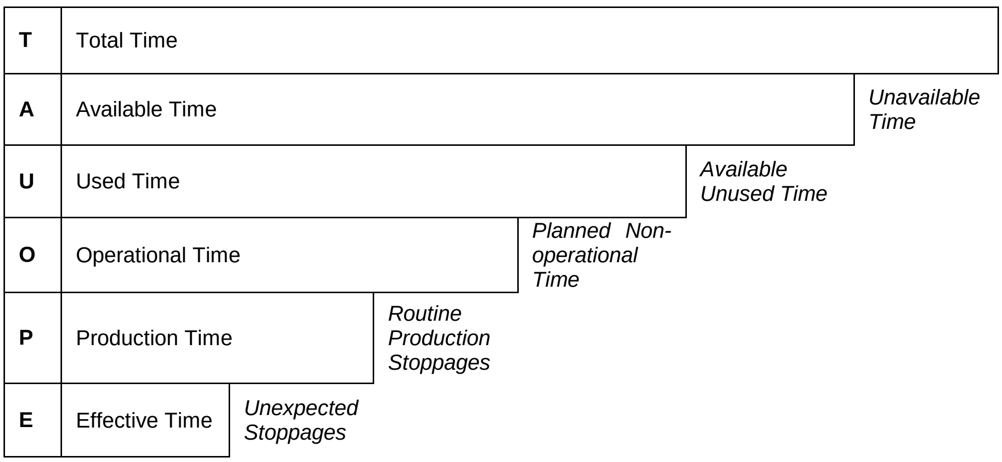

Figure 13 An overview of the performance indices at UBFN.

From this time analysis, eight different performance indices are calculated but production efficiency and operational efficiency are the two most commonly used at UBFN. They are both presented in percentage values, *production efficiency* is calculated through E/P*100 while *operational efficiency* is calculated through E/O*100. Production efficiency is, in other words, a measurement of how well a line is working when it is in direct use, thus excluding the time due to changeovers.

[113] Ernegård (2004-02-17)
[114] Helander (2004-02-18)
[115] Unilever internal economic batch-size model.

Operational efficiency, on the other hand, is a measure that takes changeover times into account and this time continues from the production decision until the batch is finished.[116]

The aim at UBFN's production plant is to work in three shifts per day from Sunday 22:00 to Friday 21:00 and to avoid working at weekends. This corresponds to A, in the time analysis above, that constitutes the base of the plan. Lately, however, this strategy has not always been managed, mainly due to several overall changes in the production unit such as machines that have switched places or new ones that have been bought and set up.[117]

When interviewing people from the production unit they often gave their personal view of the supply chain. In short the authors perceived some of these aspects to contain a wish for larger batches and a dream of dedicated production lines.

5.6 Stock

Like the forecasting unit the warehouse belongs to the MSU. Its responsibility stretches from when the products are produced and the pallets are wrapped in plastic until they are shipped and received by the customer. One sensitive condition in this industry is that the products have to be stored chilled, which limits UBFN's options of finding and hiring external stock possibilities. At the moment UBFN is moving towards a solution where all products are stored at the same temperature instead of having different temperatures, which means different inventories for various products. Even if the warehouse has the same temperature it is divided into two parts, a large fully automated stock that handles complete pallets and half-pallets and a smaller picking stock where deliveries of small quantities are handled. About 1,000 pallets leave UBFN's stock every day, which sums up to roughly 200,000 pallets a year.[118]

The automated stock has room for 11,600 pallets, but a few are always blocked. The average usages level of the stock is about 85-90 percent but sometimes, for instance when the production has been running during the weekend, the usage level reaches maximum and in some extreme cases even above 100 percent.[119] This forces UBFN to engage an external overflow stock that is costly. At present, UBFN is employing an overflow warehouse that is situated in Malmö. Reasons for this include cost, there are nearer warehouses but they cost too much, short notice availability, nearer warehouses cannot guarantee room in their stock, and quality, some of the closer warehouses did not pass UBFN's internal quality assurance specifications. Another reason for using Malmö is that UBFN deploys trucks from Helsingborg to Malmö five days every week that are empty on the return journey to Helsingborg, so there is

[116] Pamco card, Internal company material
[117] Ernegård (2004-03-17)
[118] Mjörner (2004-03-17)
[119] Mjörner (2004-03-17)

no additional cost of transportation when using a warehouse in Malmö.[120] There are at the moment no discussions about whether to expand the stock.[121]

In the stock about 50-70 percent is used to store margarine products. The rest of the space is used for dairy cream alternatives (DCA), cream cheeses and to some extent products delivered from other Unilever factories intended for the Nordic market. According to Mjörner and Lillsjö the allocation between margarine on the one side and DCAs and cream cheese on the other is wrong. Looking at the number of kilograms sold, margarine should be allowed at least 80 percent of the storage facility.[122]

The authors have noticed when reviewing forecast and stock data, that the stock coverage for some products is often higher than the desired one to two weeks, and for some products significantly higher. Some persons at management level are not sure why stock levels that previously were at desired level are up, but they suspect that there might be several causes; such as increasing variety and lessened production flexibility. The distribution manager put as:

"It feels like they [the production] lacks the flexibility it once possessed […] it has been lost somehow"[123]

The problem of over-coverage is a sensitive problem for warehouse personnel since they cannot, in any way, affect what actually gets produced, which means they have to accept any and all products produced by the sourcing unit (SU). Management level warehouse staff has opted for the inclusion of them in the production planning process to produce better feedback between the SU but at the present time, no changes in production planning procedures have been made.[124]

5.6.1 The margarine categories

Products within the category of margarine occupy about 50-70 percent of the stock. These products are stored according to the principle of "first in first out" and the computer system keeps track of their expiring dates. The system also handles times disposed to crystallization and maturing of the different products.[125]

When asked about their thoughts of the "production-stock situation" concerning margarine, the warehouse personnel responded with a wish for smaller production batches. They claim that this would imply; a lower risk, a smaller amount of cassations and an easier load of the stock.[126]

[120] Lillsjö & Mjörner (2004-04-05)
[121] Waldemarsson (2004-02-09)
[122] Lillsjö & Mjörner (2004-03-09)
[123] Mjörner (2004-03-09)
[124] Lillsjö & Mjörner (2004-03-09)
[125] Mjörner (2004-03-17)
[126] Mjörner (2004-03-17)

5.7 Costs

When collecting data from the different parts of the supply chain, costs that affect those parts were collected as well. Most of these costs were obtained from the finance department at UBFN. These are direct costs that are triggered by producing more of a unit:

- Cost of raw material.
- Cost of packaging material.
- Cost of labor.
- Cost of storage (both in Helsingborg and at an overflow stock).
- Cost of capital.
- Cost of delivering a pallet.

In addition to this a number of different factors that take time from production and thereby involve costs, but are not actual costs, were collected or calculated as well:

- The time for product changes were calculated from 2003.
- The times for washes were calculated from 2003.
- The amount of products melted down because of being too long in stock and becoming old.

6 Talking the talk

"If we knew what we were doing, it wouldn't be called research, would it?" (Albert Einstein)

In this chapter the theory of complexity will be incorporated with the field of logistics. This is done from the case company's point of view, using concepts introduced in chapter three. The intention of this chapter is partly to describe the authors' view of UBFN as a CAS and partly to demonstrate the authors' belief that a supply chain, any supply chain, could, and perhaps even should, be viewed from the perspective of complexity. This chapter is also an attempt to give the reader the authors' point of view in order to help them understand the chain of thought used further on in this paper.

6.1 UBFN viewed from a complexity theory perspective

A supply chain is full of different elements. What these elements are depends on the level of analysis, but typically they consist of nodes along the supply chain. Since the nodes could be anything from firms, production lines, warehouses, production planning, or transports, the nodes could arguably be considered heterogeneous. Another feature of the different elements, or agents, is that they continuously try to improve their present situation. They strive toward improvement of themselves, and the system they reside within is an example of adaptation. In this case study, five different parts were identified as agents; the production planning, the production lines, the planning system, the stock, and the customers amassed into three country-based markets, these agents and their connections are displayed in figure 14. The underlying causes for the choice of these particular agents are that they are in a reasonable level of abstraction with respect to our bounded project time frame.

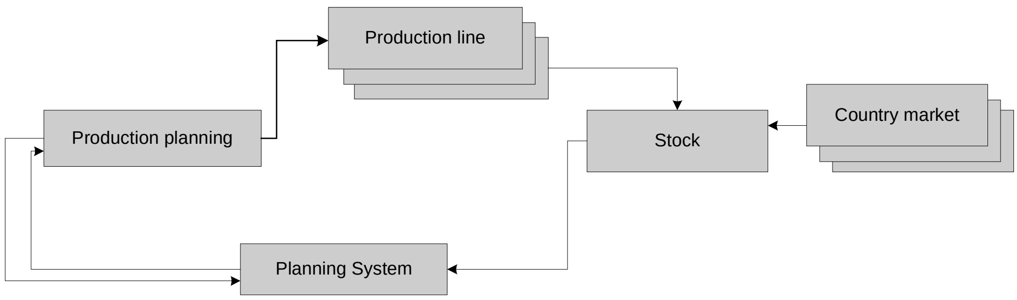

Figure 14 An overall view of the agent-based model.

As mentioned in earlier chapters agents act according to a set of rules, called schemata. From the wide variety of agents follows the probability of different sets of rules or schemata. A production planner will obviously have different work conditions than a truck driver. Both of them are limited, through the physical and mental boundaries of their respective work place, for example the existing production apparatus or the safety rules of the company. These boundaries create a common set of schemata and the agents could be seen as governed by a small set of rules, the Pareto principal.[127]

Another important aspect of a CAS is dimensionality or the level of freedom of an agent. An interesting aspect is that efficiency is commonly linked with control in the supply chain, and frequently means installing a single enterprise requirement planning system, like SAP[128] or achieving a common quality system such as ISO 9000 or Six Sigma[129]. Implementing a control system on a supply chain though can lead to unexpected negative consequences and there is no empirical data supporting the actual performance improvement[130]. A reason for this might be the reduction in freedom, which is needed in a CAS. Another aspect of freedom or rather the limitation thereof, is the strictly physical limitation of the CAS, such as speeds, time, and space.

6.2 The stock as an agent

The stock agent keeps track of the stock at UBFN. This entails knowing what kind of products are in stock and the number of available units. In order to figure out how many of the total number of units are available the stock also keeps track of the production date and a specific products maturity time[131]. The final information the stock registers is the products' specific expiry time in order to make sure no old items are shipped. The reason the stock keeps track of the stock is so, when an order comes from the market, it is possible to continuously calculate the service level by dividing the number of delivered items with the sum of the number of delivered items and the number of not-delivered items (which equals ordered items).

Basically, the stock as an agent should mainly have the following requirements:

- Receive and store pallets from the production lines
- Receive and deliver orders from the markets
- Send stock balance to the planning system.

These rules indicate that the stock is connected to the planning system, the market, and the production lines (see figure 14). The connections are used to send messages to indicate what agents are doing in order to allow other agents to adapt their behavior. Generally a supply chain is full of connections, often described as flows, just as with the Stock in this case. The flows are categorized into material flows, information flows, and monetary flows[132]. The interruptions between the flows are the activities that occur at the different nodes in the supply chain, such as planning, transactions,

[127] Nilsson (2003) p.43-45
[128] One of the business systems used at UBFN
[129] www.isixsigma.com (2004-05-16)
[130] Choi et al. (2001) p.360
[131] All products need time to mature. The time differs between two days to two weeks.
[132] Schary & Skjött-Larsen (2001) p.53

production, packaging, and transportation[133]. This implies that flows, of different kinds, take place amid nodes and the nodes can be viewed as connected. The flows are affected by negative (restricting) and positive (amplifying) feedback. The negative feedback could for example be capacity restraints and an example of positive feedback is the bullwhip effect.

The dimensionality of the stock is low. The stock has no option but to accept the items delivered by the production lines and it has to accept and deliver the orders sent by the markets. The one thing the stock controls is when to send an update to the planning system, but in reality this parameter is decided by the planning cycles.

6.3 The planning system as an agent

The planning system contains a simplified version of the stock list received from the stock. The main purpose of this agent is to mimic a specific behavior found at UBFN in which the production planner doesn't use actual stock level data but data updated at specific intervals. This means that the planning system could be described as a snapshot of the stock level.

Basically, the planning system as an agent should mainly have the following requirements:

- Receive and store stock balance from the stock.
- Send stock balance to production planner.

The planning system is connected to the stock and the production planner. The dimensionality of the planning system is low. It is completely controlled by the stock and by the production planner.

6.4 The production planner as an agent

The production planner can be considered to plan the outcome of stock level. Unfortunately, it cannot decide the stock level directly. It can only be done via instructing the production lines by using information that is available at the specific planning occasion.

Basically, the production planner as an agent should mainly have the following schemata:

- Ask the planning system for the latest stock balance
- When the stock balance is received, make a production plan by using the stock balance together with production and forecast data.
- Send the production plan to the production lines

The production planner is connected to the production lines and the planning system. The dimensionality of a production planner is high, as it can be described as the first

[133] Nilsson (2003) p.47

point of the information flow. It takes the initiative to make a production plan, the production lines have to listen and attempt to produce the desired quantity and the stock must accept the quantity being produced. On the other hand, the production planner requires information from the stock, through the planning system to be able to make a plan. Thus, an incorrect stock balance may be likely to affect the entire system.

6.5 The production lines

The Production lines is not one agent. Every actual production line at UBFN is represented as an agent. The reason is that every agent has unique properties, such as speed, products produced, and change over time. In addition there exist unique properties for each product when produced at a specific production line.

Basically, a production line as an agent should mainly have the following requirements:

- Receive a production plan from the production planner and execute the plan by attempting to produce the desired quantity of each item.
- Send produced pallets to the stock

The production line is connected to the production planner and the stock. The dimensionality of a production line is low. The agent decides when to send a pallet of items to the stock, but the number of items on a pallet is fixed. A production line could theoretically decide to change the order in which it wants to produce products, but in reality it always produces, by the production planner, in the, predetermined way specified in a product list. The quantity of a product, although set by the production planner, is in the end to some degree up to the production line.

6.6 The Complex Adaptive System at UBFN

So far the agents at UBFN have been described separately, explaining how they act as agents and to what other agents they are connected. That is however not enough when observing and trying to describe a CAS, because it is with interaction that the external properties appear in a system.

The CAS exists within a fitness landscape, the environment of rugged surfaces, and the CAS agents try to increase their fitness by climbing as high as possible on the rugged surface. In the case of the supply chain, increasing fitness can mean faster deliveries, lower stock, or larger batches. As different nodes or agents try to increase their own fitness they alter the landscape at the same time for other agents in a non-linear way due to the connectivity of the supply chain[134].

The authors perceive that there at UBFN are obvious conflicts between different agents trying to increase their fitness. The production lines (and production planning)

[134] Nilsson (2003) p.47-48

would like to produce as large batches as possible of the same product since this increases their performance. Also a part of the measuring system is focused on how much of the possible production time is used for actual production. Production time is lost every time there is a switch between products.

The stock on the other hand strives toward as low a stock level as possible; due to being measured on the cost of stock and products scrapped. In addition every time the stock capacity is exceeded there are also the costs associated with the use of an overflow stock. Keeping this in mind it is natural that the stock wants the production to use as small batches as possible. As each of these agents try to increase their fitness, the fitness landscape of the other agent changes. This striving toward local fitness is illustrated in figure 15 below.

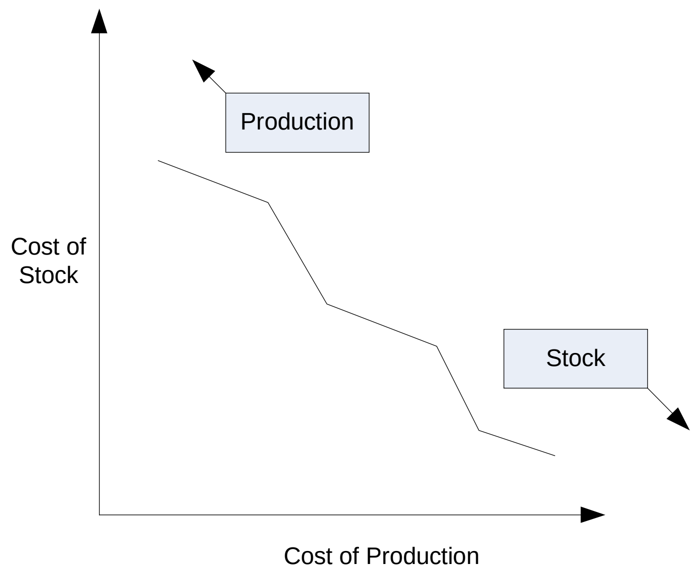

Figure 15 A visualization of striving towards local fitness.

Another issue to be considered is the co-evolution of the agents. When agents are connected to each other they adapt to each other’s behavior. This implies it is not enough to just observe the agents at the lowest level but it will be necessary to observe the interaction between agents such as production planning and production for instance. At UBFN some co-evolution was observed. For instance before the production planners receive the data they use to produce forecasts, employees at the sales department sometimes can edit the numbers on the basis of what they describe as gut feeling, and in other words could be described as many years of experience. Another example is the arrangement between the production and the production planner. Since the time it takes for a changeover depends on whether the systems needs to be washed between products or not, there is a particular order of production on a production line, namely where the least number of washes is required. This order of production has been communicated to the production planner, who takes this order into account when planning a week’s production.

Emergence is a feature of CAS that is particularly hard to grasp and applying it to the supply chain does not make it more comprehensible, but nonetheless emergence is an important feature. A supply chain department is an emergent phenomenon in itself. Consisting of several different agents, from managerial positions with tasks such as monitoring and evaluating to agents involved with customer relations and performing actual deliveries, they together generate what is considered a supply chain department. And their respective tasks are, compared to the combined result, relatively simple. At UBFN, the products produced at the margarine factory are an example of such emergence. No agent by itself can control the chain, making sure that packages of margarine are produced. Still, consumers can actually buy UBFN products in almost any store.

In addition to the overall emergent pattern at UBFN there also exist emergent patterns between agents. For instance the production planner always tries to retain a safety stock of one and a half weeks. But due to the interactions with the production lines where the production order is set, products produced later on in the production order (hence produced later during the week) will not have the desired coverage. So, in order to remedy the problem, whenever the production planners encounter a product produced late in the week they tend to increase the coverage somewhat to about 1.8 - 2 weeks cover. The same thread of reasoning exists with products produced early in the week only in that case the coverage is lowered.

Another aspect of emergence of the supply chain is process. As mentioned earlier the supply chain is often considered as a flow interrupted by activities. This is also a pointer showing that the results of the actual flows of the supply chain emerge from the interactions of several agents[135]. Yet another important aspect is the unpredictability of an emergent pattern that stems from the uncountable number of possible outcomes. This might prove problematic when changes are made to the supply chain, due to an unexpected outcome. The changes possible at the case company are, not surprisingly, uncountable. Merely looking at the agent-based model constructed by the authors there are several parameters settable that all affect the outcome. From the speed of the production lines to the day the production plan is set, from the batch size to preciseness of forecasting and from the amount of weeks cover in the warehouse to how long it takes to change from one product to another. These parameters could, as already mentioned, be the difference between great improvement and disaster.

At UBFN the entire production is a process and therefore the result of emergence. Every agent plays a part in this process and is a part of the outcome. It could sometimes be seen as a "minor miracle" that UBFN's products exist on shelves in different stores due to the sheer complexity of production process, yet the task of a single agent when viewed in isolation is relatively simple. The prerequisite of emergence is self-organization, and in the supply chain self-organization is a natural

[135] Nilsson (2003) p.48-49

part. A supply chain is an open system and contains agents with at least some degree of freedom. These two parameters make it possible for agents, such as supply chain managers, to act on their own to improve their fitness.[136] In this paper the case study displays the property of self-organization. For instance nobody decides that a single product should not be produced over long time periods, but the system "knows" that if it were to be done the consequences would be severe (i.e. products thrown away or the absence of other products).

The quasi-equilibrium property is evident at UBFN. There is a constant stream of changes going on in the plant. Production lines are added, relocated, and sometimes even removed. The computer systems are updated and changed. New products are adopted and others are dropped. It has been a long time since two different years displayed the same production prerequisites. The change that goes on at UBFN is, as it was mentioned in chapter three, necessary for survival, because the aim of the changes are to provide better products wanted by the customer (and in the prolongation the consumer). Obviously, according to the authors, the reasoning is: no change, no customer and no customer, no UBFN.

Agents residing in a supply chain try to anticipate the future using perceived patterns in the past. This can lead to fitting or unfitting behavior depending on how other agents perceive patterns. Since agents also can perceive the future in different ways their actions, when encountering different situations, may differ very much. For example is customer demand an occurrence in the future that agents in different ways try to anticipate through patterns in the past.[137] Historic data together with future campaigns control the forecasts used as input when planning the production at UBFN, in other words a way to look into the future.

6.7 Synthesizing summary

The major prerequisite for using agent-based modeling and simulation, as a tool for analyzing the supply chain is that it actually can be viewed as a Complex Adaptive System (CAS). Therefore it is of importance to demonstrate these similarities between the properties of a CAS and those of a supply chain.

As shown the CAS consists of three main components; internal properties, external properties and the results arising from interactions among the internal and external properties. These parts were described in chapter three and are a summary of several authors' idea of a CAS, see figure 16. The created framework is used again throughout this chapter when viewing the supply chains in general and UBFN in particular, through the perspective of the CAS.

The results were interesting and striking. UBFN displayed the properties of a CAS at several levels. It contains heterogonous agents constantly trying to improve their

[136] Nilsson (2003) p.50
[137] Nilsson (2003) p.53

fitness. The agents exhibit an ability to adapt to each other's behavior without any master agent controlling every detail of daily routines. Also the emerging behavior in the supply chain is something that does not exist on agent level, but appears when the agents act together. These are all key characteristics for a CAS and give a strong indication that the UBFN supply chain could be viewed as a CAS. Further, on going through the rest of the specific properties; connectivity, dimensionality, the fitness landscape, co-evolution, quasi-equilibrium and the anticipation of the future, UBFN displays all these properties as well.

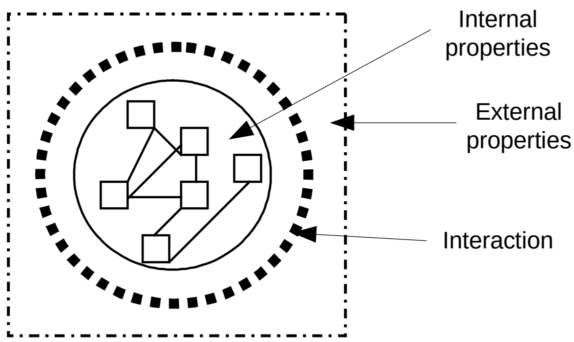

Figure 16 The three parts of a CAS; internal properties, external properties and interactions.

Due to the similarity between the properties of a CAS and that of UBFN it is quite safe to assume that at least UBFN's supply chain can be described through the looking glass of complexity theory. But what about supply chains in general? The question is huge, but there are a couple of conclusions that can be made.

According to Schary and Skjött-Larsen the five key processes of supply chain management are; product design and inventory, production, procurement, distribution, demand management (forecasting), and the case study of UBFN focuses on forecasting, production and inventory, cutting away procurement and distribution. It is somewhat reasonable to assume that those activities covered by the case study exist within other producing companies as well. Furthermore adding parts of the supply chain, such as distribution or procurement, shouldn't make the supply chain less likely to fit the description of a CAS.

When concluding this chapter it seems like the objectives it set out to fulfill were reached. It has created an understanding about viewing the supply chain in the light of complexity theory. Even if several different opinions concerning company strategies were discovered, the employees certainly agreed on one thing: the importance of this study's continuance into a concrete model, which could examine the total supply chain situation. In other words the authors have proved that the theory can talk the talk, but the question remains whether it can walk the walk.

7 The model

"Computers are useless. They can only give you answers." (Pablo Picasso)

Since the supply chain at UBFN displays the properties to be viewed as a CAS the next natural step is to model and simulate it. The case model is built in Microsoft Visual J++ 6.0, which is a Java development tool for Microsoft Windows, enabling the developer to easily develop a graphical user interface fitting various versions of the Windows operating system.

The model itself consists of almost hundreds of Java classes. Most of the classes are help classes, which are mainly used for communications, data containers, database connections and model specific data members such as pallets, articles, and products. However, each agent is modeled with a class, inherited from a generic agent class enabling the agent to have both the offensive and the defensive capabilities described in chapter two. These inherited classes model the agents in the system and are named ProductionPlannerAgent, MarketAgent, ProductionLineAgent, StockAgent and PlanningSystemAgent. In order to keep track of all measurable data that is generated during a simulation run, a class named WatchdogAgent has also been added.

Name of agent	Description
MarketAgent	Represents a country specific market of UBFN.
ProductionPlannerAgent	Represents the production planning function at UBFN.
ProductionLineAgent	Represents a production line at UBFN.
PlanningSystemAgent	Represents the internal computer system at UBFN and in the model, it especially handles the stock balance information between the ProductionPlannerAgent and the StockAgent. The stock balance is used for production planning in order to take a snapshot of the stock level at a specific time.
StockAgent	Represents the stock (including over flow stock) at UBFN.
WatchDogAgent	Is used for measuring stock levels, operational efficiency, service level, costs etc. It generates historical data for the world outside the model, i.e. the model output parameters.

Table 1 – Description of the agents

The agents have both direct and indirect relations to other agents in the model. The direct relations are shown in figure 17. A drawn arrow, from one agent to another, means that the agent affects the other agent directly via messages. This goes for all agents except the WatchDogAgent, which can read the properties of all desired agents at one time, albeit without asking the other agent for information. However, the WatchDog agent is not able to affect the system in any way.

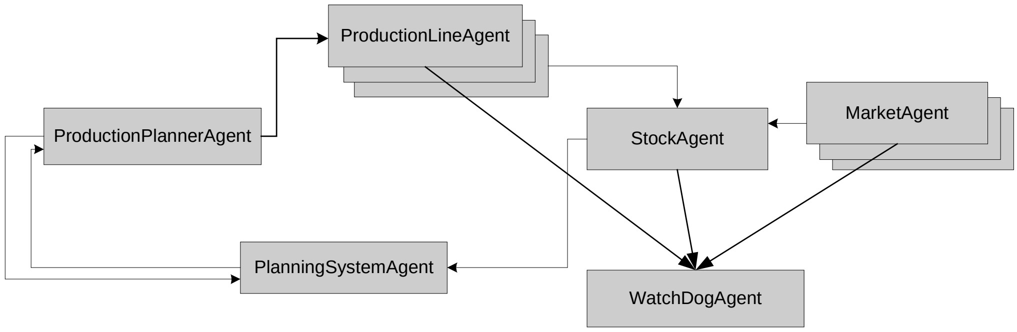

Figure 17 - The agents and the affect relations

As we illustrated in figure 17, there is more than one copy of each agent active in the system. The ProductionLineAgent has the same amount of duplicates as the number of production lines in use. The MarketAgent has three duplicates, which is equal to the three country specific markets (Sweden, Denmark and Finland) of UBFN.

7.1 MarketAgent

The MarketAgent has two capabilities, both of which are offensive. These can be described as follows:

1. Once each Monday the MarketAgent gathers information about the weekly orders. There are two ways of doing this, depending on the parameter settings: (1) actual sales of the same week from sales history or (2) estimated sales from forecast data with item and country specific forecast error calculated with a Gaussian distribution. The weekly orders are simultaneously divided into daily orders with a uniformed distribution algorithm.
2. Once each weekday (Monday to Friday) at 12 a.m. the MarketAgent sends a message to the StockAgent, with the day’s orders, containing the quantity of each item ordered

7.2 PlanningSystemAgent

The PlanningSystemAgent only has defensive capabilities, which are:

1. The stock balance is stored when the StockAgent sends stock balance information.
2. The ProductionPlannerAgent is answered when it asks for the stock balance.

7.3 ProductionLineAgent

The ProductionLineAgent has both defensive and offensive capabilities. The defensive capabilities are:

1. If a production plan is received from ProductionPlannerAgent, the plan is stored.

2. If the ProductionLineAgent has not finished its earlier production plan it can either ignore it, or put the not finished items into the new plan at their corresponding position in the plan. This behavior depends on the parameter settings described below.

Its offensive capabilities can be described as follows:

1. If the ProductionLine is producing and has produced a pallet of the item it is currently producing and there is more to produce of the current item, it sends one pallet marked with today's date to StockAgent. Then, it continues to produce the next pallet (which could either be a full pallet or the last pallet which seldom is a complete pallet). If the pallet is the last pallet of item, the ProductionLine's state is set to not producing.
2. If the ProductionLine is not producing and there is more to produce and the emulsion system is free (some production lines share emulsion system) to use, then it goes through the following steps:
    a. Next item in the production plan is removed.
    b. It changes the line to produce next item and calculates the changeover time.
    c. The time to produce a pallet is calculated.
    d. The state is set to "*Producing item*"
    e. The agent goes inactive until the change-over has been made and the first pallet is produced

    Alternatively, it goes inactive until a new production plan has been received or if the emulsion system was busy, the ProductionLine goes inactive for one minute before it starts to repeat through the offensive capabilities 1 and 2.

7.4 ProductionPlannerAgent

The offensive capabilities of ProductionPlannerAgent can be described as follows:

1. Once each Tuesday the ProductionPlannerAgent asks PlanningSystemAgent for the stock balance.
2. Once each Sunday when a production plan has been made, the production plan is sent to the ProductionLineAgents.

Its defensive capability is:

– If the stock list is received from the PlanningSystemAgent, a production plan is made.

The production plan is made, by executing the following process: For each ProductionLineAgent in the system, ProductionPlannerAgent finds out which items to produce on the production line. The items are received in the pre-defined production order. For each of the items, the following process is undertaken:

1. *Start hour* of production of item is estimated.
2. The quantity to produce next week is calculated by
    a. Calculating the safety stock cover to set via the start time by formula $cover = (cover\ setting \cdot 7 + start\ hour / 24) / 7$

   b. The quantity of the item in stock is set to the start value.
   c. The quantity produced is or planned to produce this week is added.
   d. The forecast quantity of this week, next week (the week of production) and for *cover* weeks is added.
   e. If the result is equal or greater than zero, there is no need to produce anything next week.
   f. Alternatively, the quantity to produce is the same as the negative value of the result.
   g. If the quantity is less than the smallest allowed batch quantity, the quantity to produce is set to the minimum batch quantity.
3. It finds out if the same item is planned on another production line.
4. If that is the case, subtract this quantity from the calculated quantity.
5. If quantity to produce is greater than zero, and the line has available planned utility, the item with its calculated quantity is added to the production plan.
6. If estimated utility exceeds maximum allowed utility, the quantity is reduced to match the maximum level of planned utility.

The batch setting is checked for each of the items in the production plan. If the batch setting is set to “split”, the quantity is divided into two production occasions in the production plan. This happens only if quantity is greater than twice the minimum batch quantity.

7.5 StockAgent

The StockAgent’s offensive capabilities are:

1. Once each Friday all old pallets are removed from stock (this is when shelf life multiplied by shelf life percent is overridden)
2. Once each Sunday the stock list is sent to PlanningSystemAgent

Note that the stock list sent to PlanningSystemAgent is a simplified stock list, which does not give information of old or not matured items. The StockAgent’s defensive capabilities are:

1. If a pallet is received from a ProductionLineAgent, the pallet is added to the stock.
   a. If the stock level is greater than maximum stock limit, the pallet is marked as “in overflow stock”
2. If the market agents send an order, the following occurs:
   a. If there are quantities that were supposed to be delivered earlier but were not (due to lack of products), it initiates the *take from stock process* for the rest quantity
   b. The *take from stock process* is initiated for the ordinary ordered quantity

The *take from stock process* includes the following steps:

1. The quantity of items in stock is checked, only looking at items that are matured and not out of date.

2. If there are enough items in stock to cover the order, the corresponding pallets are removed
3. Otherwise, only the existing quantity from stock is removed.

This process remembers the number of transport units delivered directly as wells as the quantity to be delivered later (due to the fact that there were not enough items) and the rest quantity delivered this time.

7.6 WatchDogAgent

WatchDogAgent is activated each Sunday 10 p.m. (This is the same time as a new production plan is sent by ProductionPlannerAgent). It measures all the output parameters described below.

7.7 Parameters

To let the model act as UBFN would, the different agents' behavior must be taken into consideration. In order to make the model a playground for different tests and analyses, most of the rules and behaviors are not locked, but are instead controlled via input parameters.

The parameters in the model consist of two types: Input and output parameters. The input parameters are furthermore divided into standard parameters, which can easily be set before a simulation starts, and system parameters that require more specific data manipulation in the model data.

7.7.1 Standard input parameters

The standard input parameters are based on requests of the case company, these are:

Changeover multiple

- A number which each changeover (in time units) should be multiplied by in order to increase or reduce changeover times

Use real orders

- A Boolean value which sets the behavior of the markets. Value "Yes" means that real orders are used if they exist. Otherwise, and if value is "No", orders will normally be distributed around the forecast with standard deviation as the specific forecast deviation for the ordered item in the specified country market.

Continue current production

- A Boolean value which sets the behaviors of the production lines. Value "Yes" means that the production line shall continue to produce the current item in the production before new items are produced if a new production plan has been received. Value "No" means the opposite: All production will be stopped.

Clear old production plan

- A Boolean value which sets the behavior of the production lines. Value “Yes” means that if the production line is not finished with the current plan when a new plan is received, it should take the items in the current plan and stuff it into the new plan at the corresponding place. Value “No” means that the current production plan will be ignored.

Safety stock

- A number in weeks, which the safety stock cover which will be planned for to maintain. This number is used to calculate the batch quantity of a coming production

Line utilization

- A percentage which will be used as a limit of maximum hours of production when a production plan is made. 100 percent equals seven days with 24 hours a day.

Forecast deviation for Sweden, Denmark and Finland

- A multiple the amount of forecast deviation the model considers, 1 equals full historical deviation and 0 no deviation which implies perfect forecasting.

Simulation start cover

- A value in weeks, which corresponds to the cover in weeks the stock shall have when the simulation starts.

Shelf life (percent)

- Stock keeping time at UBFN in percent of the batch life cycle. A batch life cycle is from the date of production (including the maturing process) to the date when the goods are considered too old for consumption.

Mature direct after being produced

- A Boolean value. Value “Yes” means that if the item is mature directly after production, it is ready for deliverance. Default value is “No”, which implies that there is a processing time. The maturing time is different from item to item.

Product change loss

- A value in percent. The percentage corresponds to the loss of raw material in the system when a change from one item to another is made.

System volume

- A value in kilograms which corresponds to the system volume that is washed out when changing products using wash.

Plan after last OE

- A Boolean value. Value “Yes” means that the production plan considers the production lines operational efficiency of last week when production planning. Value “No” means that a production plan is made considering the target operational efficiency of the specific production line.

Cost of one machine hour

- A number representing the cost of one machine hour. Machine hours are based on when the machines are in operation.

Limit of stock (pallets)

- Number of pallets dedicated to the margarine production in Helsingborg before using overflow stock.

Stock storage cost per day

- The cost of a pallet in stock per day.

Cost of capital per day

- The rate of day (in percent) to calculate the cost of capital in stock; the rate is multiplied with the aggregated cost of producing the units.

Cost of overflow per day

- A value representing the cost of one pallet in overflow stock.

One-time fee of overflow

- A one-time fee including transport, inbound and outbound logistics when a pallet is moved back and forth from stock to overflow stock.

Cost of outbound pallet

- Cost of an outbound pallet from stock.

7.7.2 System parameters

The system parameters are described in several tables in a database. These parameters determine the behaviors of the model and their values are based on collected data. An overview of the parameters and their connections can be seen below.

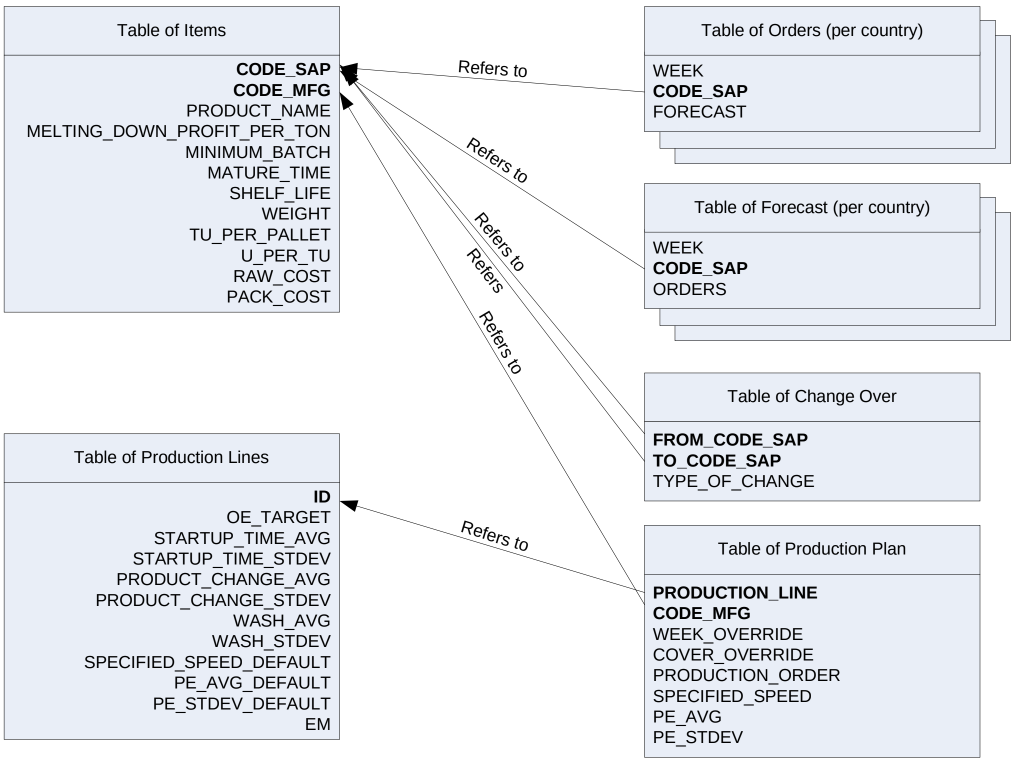

Figure 18 – System parameters and their connections

Table of items contains all the items, which are simulated. Each product can consist of several items. Each item has its own specifications, which give consequences for production management, stock management and the entire supply chain. The item parameters are:

Parameter name	Description
CODE_SAP	Represents the item code in the SAP system
CODE_MFG	Represents the item code in the MFG system
PRODUCT_NAME	The name of the item
MELTING_DOWN_PROFIT_PER_TON	The profit gained by melting down 1000 kg of the item
MINIMUM_BATCH	The minimum batch in transport units which can be produced at one time
MATURE_TIME	Processing time in hours until the item is ready for sale
SHELF_LIFE	Time in days from the date of production to when the item is considered as old.
WEIGHT	The net weight of one transport unit
TU_PER_PALLET	Number of transport units per pallet
U_PER_TU	Number of units per transport unit
RAW_COST	Raw material cost per transport unit
PACK_COST	Pack material cost per transport unit

Table 2 – Table of items

The production lines are loaded and configured automatically from the production lines table. Default values shown below are considered only if values for the specific item at the specific line cannot be found in the table of production plan.

Parameter name	Description
ID	The identification number of the production line
OE_TARGET	The target operational efficiency of the line
STARTUP_TIME_AVG	Average start-up time of the line
STARTUP_TIME_STDEV	Standard deviation start-up time of the line
PRODUCT_CHANGE_AVG	Average product change time of the line
PRODUCT_CHANGE_STDEV	Standard deviation product change time of the line
WASH_AVG	Average time of wash for the line
WASH_STDEV	Standard deviation time of wash for the line
SPECIFIED_SPEED_DEFAULT	Default specified speed for the line
PE_AVG_DEFAULT	Default production efficiency average for the line
PE_STDEV_DEFAULT	Default production efficiency standard deviation for the line
EM	The emulsion system the line uses

Table 3 – Table of Production Lines

In order to generate a production plan, the coming week's forecast is needed. It is also required when the model is set to generate orders from the forecast. There is one table of forecast for each country market.

Parameter name	Description
WEEK	The week of forecast
CODE_SAP	The unique item code of the item, as found in table of items, which the forecast is for
FORECAST	Forecast quantity in number of transport units, for the specified week and item code.

Table 4 – Table of forecast (country specific)

When the model is acting after real order history, the table of orders is needed. It has the same design except that forecast is switched to orders.

Parameter name	Description
WEEK	The week of market orders
CODE_SAP	The unique item code of the item, as found in table of items, which the orders are for
ORDERS	Order quantity in number of transport units, for the specified week and item code.

Table 5 – Table of orders (country specific)

When a change from one item to another is being made on the production lines, the production line must know the type of change. A change could mean that a wash of the system is required or if only change of pack material (normal product change) is required. The table of changeover describes this.

Parameter name	Description
FROM_CODE_SAP	The unique SAP code of the item, as found in table of items, which the change will be from.
TO_CODE_SAP	The unique SAP code of the item, as found in table of items, which the change will be to.
TYPE	Type of change. Value ‘W’ equals wash, and value ‘P’ equals product change.

Table 6 – Table of change over

In order to make a realistic production plan, several parameters are required. The item to produce before another is already defined in most cases, due to reduce system washes.

Parameter name	Description
PRODUCTION_LINE	The unique identification number of the production line
CODE_MFG	The unique item identification code, found in table of items, on the production line
WEEK_OVERRIDE	Overrides weekly plan. The item runs in general each week, if this field is empty. Value ‘O’ means “run the item only odd weeks”, and value ‘E’ means “run the item only even weeks”.
COVER_OVERRIDE	Overrides safety stock cover. If this field is empty and field WEEK_OVERRIDE is not set, the cover is set to the standard input parameter for cover setting. If the field is empty and field WEEK_OVERRIDE is set, the cover setting will be standard input parameter setting for cover setting multiplied by two. Otherwise, this field setting will be used.
PRODUCTION_ORDER	A number 1...n, describing the order of production for the item on the production line.
SPECIFIED_SPEED	The specified speed, for which the item will use on the production line.
PE_AVG	Average production efficiency, historically on the production line.
PE_STDEV	Production efficiency standard deviation, historically on the production line.

Table 7 – Table of production plan

7.7.3 Output parameters

The model output parameters are listed as a parameter value at a specific date as the figure below shows.

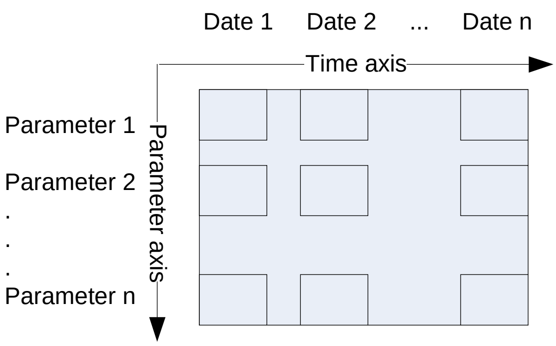

Figure 19 – Output parameters

The output parameters are measured at the end of each week. These are (where [*x*] means for each of the *x*):

Date
- The date of output (in general each Sunday 10 p.m.)

Pallets in stock
- Number of pallets in original stock

Pallets in over flow
- Number of pallets in overflow stock

Pallets removed
- Number of pallets removed last week

[line] OE
- Operational efficiency of line last week

[line] Utilization
- Actual line utilization of last week

[line] Planned utilization
- Planned line utilization of last week

[line] Number of washes
- Number of washes of last week

[line] Number of product changes
- Number of normal product changes of last week

[Item] Service level
- Item service level of last week

[item] Delivered
- Number of ordered transport units of item delivered directly last week

[item] Rest
- Number of ordered transport units of item not delivered last week

[item] Delivered rest
- Number of transport units of item earlier not delivered, but delivered last week.

[item] in stock
- Number of transport units of item in stock

[item] Cover
- Item cover in weeks

[item] Forecast
- Last week's forecast in number of transport units of item

[item] Order
- Last week's order in number of transport units of item

[item] Plan for next week
- Number of transport units of item planned to produce coming week

[item] Last production
- Number of transport units of item produced last week

[item] Pallets removed
- Number of pallets of removed of item last week

Weighted average cover
- Weighted (with respect to items in stock) average of cover

Raw material cost
- Raw material cost of items produced last week

Pack material cost

- Pack material cost of items produced last week

Labor cost
- Labor cost of last week's production

Cost of washes
- Cost of washes last week

Cost of product changes
- Cost of normal product changes last week

Cost of storage
- Cost of storage last week

Cost of outbound pallets
- Cost of pallets delivered last week

Cost of capital
- Cost of capital last week

Cost of melting down
- Cost/profit of melted down pallets last week

Total cost
- Total cost of last week (sum of all costs above)

7.8 Graphical User Interface

The Graphical User Interface (GUI) was developed to simplify the procedure of creating what-if scenarios and thus also increasing the model's value as a tool for creating basis for decisions. When the program is executed a model setup screen is shown, see figure 20 below.

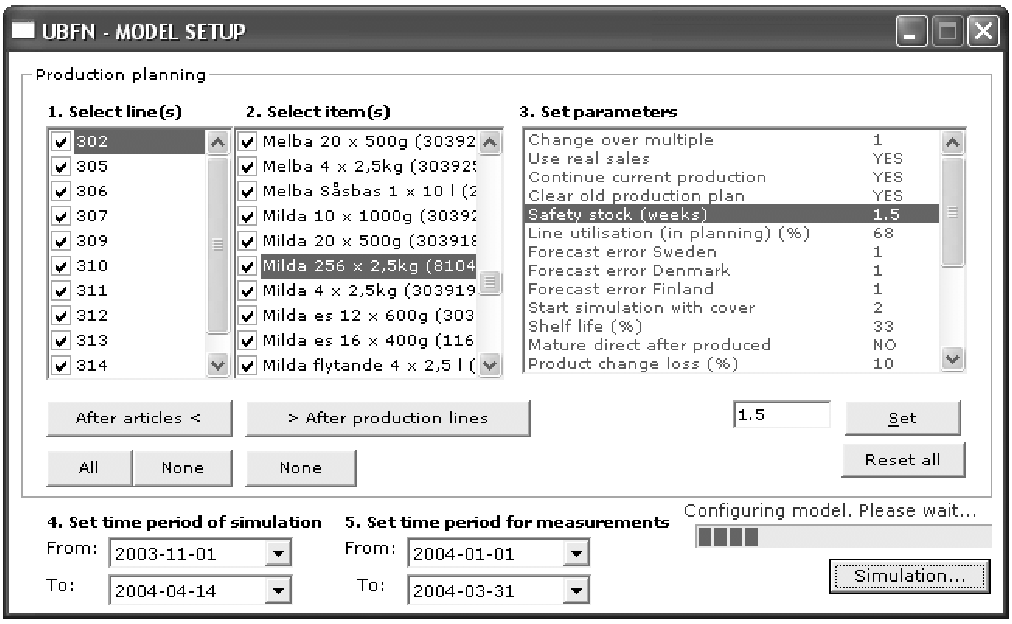

Figure 20 The Graphical User Interface.

The setup screen consists of three different lists of parameters and two time span parameters. The first list (numbered 1 in the figure) is used to select which production lines are to be active during the simulation. The production line can also be chosen from the items that are selected. The active items are selected from the second list (numbered 2 in the figure). The selection of items is conducted in the same way as the selection of production lines and, as with the production lines, the items can be selected after the production lines that are selected for the simulation (called after production lines in the setup screen) The third list (numbered 3 in the figure) is used to set the input parameters and contains several options that can be set easily before a simulation is run.

The two time span parameters (numbered 4 and 5 in the figure) are used to control from and to which dates the simulation is to run and from and to which dates the Watchdog is to collect data. When all the parameters are set the "Simulation…" button is pressed and the program prepares a simulation.

When the program has collected all the necessary information from the databases the simulation screen appears (see figure 21).

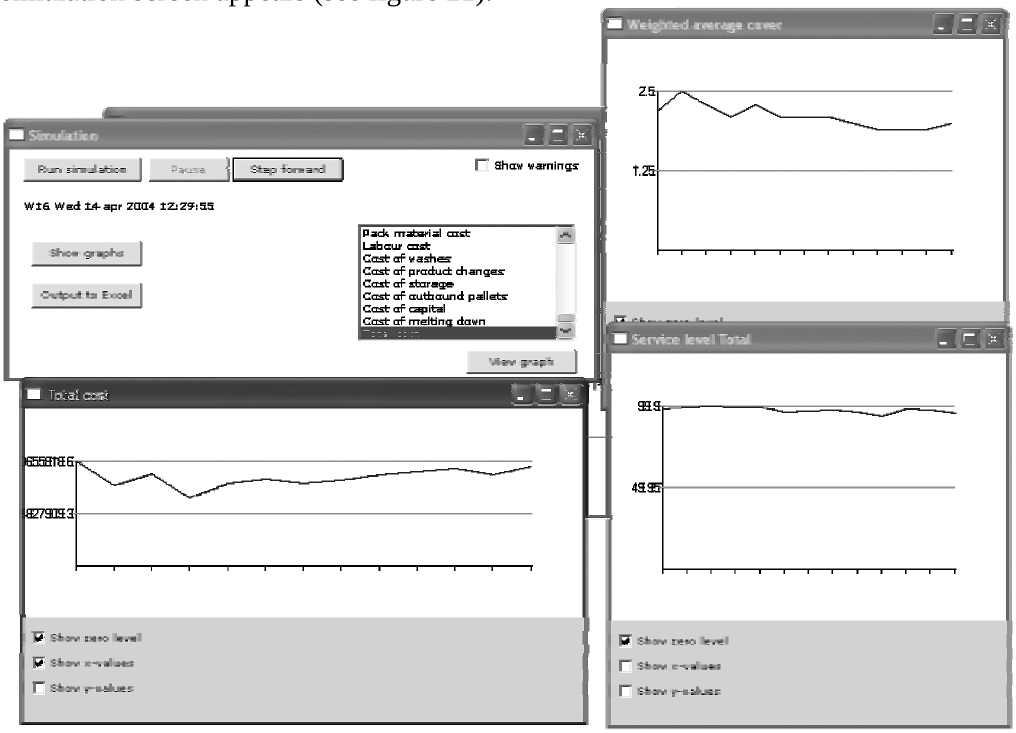

Figure 21 The simulation screen and a few examples of output screens.

This screen is used to control the progress of the simulation. There is a button to start and pause the simulation and also a button that can be used when the simulation is paused to continue the simulation one time frame per button-click. Any time during the simulation the program can create output graphs of all the data stored in the WatchDogAgent. Pressing the “Show graphs” button and then choosing an output parameter does this. These graphs are somewhat inadequate when the purpose is to compare different scenarios but are nonetheless interesting to see how the different output parameters change over time. the “Output to Excel” button can also be used and when the button is pressed the contents in the WatchDogAgent are converted to an Excel sheet and the input parameters are copied to a second Excel sheet so it is easier to keep track of the parameter settings for that specific simulation.

What can not be seen in the figures is, when running many simulations with equal input parameters in order to make an average, the program can be set to do this automatically.

7.9 Model assumptions

To be able to complete the model, a couple of assumptions were needed. These assumptions are of two major kinds: assumptions due to lack of data and assumptions made because of the level of complexity, meaning that simplifications were needed. The assumptions have all been discussed between the authors and in dialog with UBFN to make sure the assumptions were reasonable. It is important to note that lack of data does not mean that the data was missing from UBFN, rather it means that the authors were not able to collect the data in time, often due to reasons mentioned in chapter 2.5.5

7.9.1 Due to lack of data

The assumptions due to lack of data were initially surprising to the authors because of the belief that a company of that size records all data. What had not occurred to the authors was that the bottom-up approach employed was quite novel and therefore the availability of the data needed could be scarce.

There was a lack of data concerning the smallest possible batch since UBFN used an economic measure when determining batch size so one assumption was that the smallest batch size is four tons when an item lacks that information in the database. Just like the smallest batch size, some items lack the actual changeover time. In those cases a worst-case scenario was assumed meaning the largest time period needed on the specific production line. Another assumption due to lack of data is that the forecast data made four weeks in advance (called Forecast-4) is as good as the forecast data made one week in advance (called Forecast-1). This assumption was considered very minor since UBFN also, most of time, use Forecast-4 data. Also when dealing with sales, there was an assumption that the authors needed to make concerning the difference between orders and sales. UBFN keeps track of all sales but uses orders to calculate service level. The assumption was made that the sales equaled orders even though it was apparent that it did not.

For a number of items even sales data were missing for some time periods. In these cases an assumption was made and the forecast was used instead, calculated with a Gaussian distribution with forecast error deviation. Another situation where no data was available was for all future events. For instance the new production lines were barely up and running. There was no telling the performance of the machine when they had been trimmed in. In those cases estimated average and standard deviation of production efficiency as well as specified speed were used.

7.9.2 Simplifications

The simplifications made in the model were made because of the difficulty of reconstructing reality in computer code. The difficulties are either because there is no structured way in how some tasks are performed or because of the fast pace of change that exists at UBFN.

One major simplification was the fixation of the factory. This means that the production line chosen at the beginning of a simulation stays the same during the entire simulation. Another change is the production efficiency. The production efficiency of the production lines is in reality increasing from the point of when the production starts, meaning that it is more likely to have an unplanned stop in the beginning of the production than in the end. The historical production efficiency is used, but it does not differ. The stops are instead distributed uniformly, which gives no difference in production efficiency when viewing an isolated production of an item.

Another situation where a simplification is used is when a large campaign for a specific product is prepared. During these time periods the production planner in reality starts several weeks in advance and rapidly builds up the stock level in order to cope with the rising number of orders during the campaign week(s). The model production planner does not work that way and instead always has a fixed number of week’s foresight corresponding to the parameter setting relating to the safety stock cover in weeks.

8 The simulation

"The best way to predict the future is to invent it." (Alan Kay)

This chapter describes the outcome of the simulations that were performed with the model specified in chapter 7. Before the results are presented there is a short discussion about agent mapping and also a consideration about how the model was verified.

8.1 Agent mapping

Agent mapping is an expression used by the authors to describe the process of describing how the agent act. The information for the mapping of the agents was gathered through interviews, observations, and document studies. This material is actually equal to the empirical part of this study and can be found in chapter five. The material in chapter five was used to put together the behavior of the agents and to find out how the different agents are connected. See figure 22.

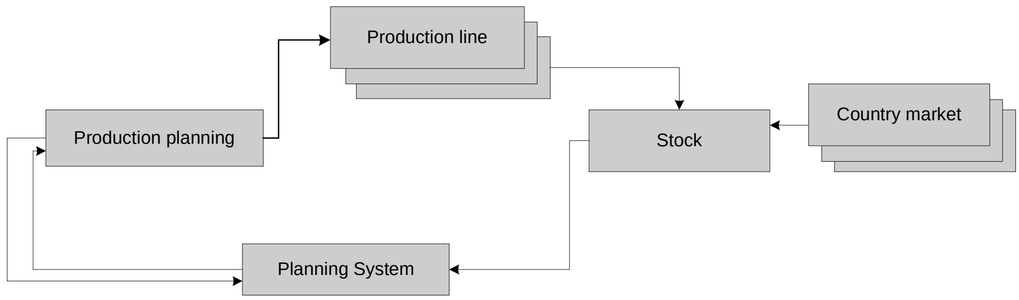

Figure 22 An overview of the model.

8.2 Verification

Before any simulations of scenarios began the model had to be verified. This verification ensured or at least increased the reliability and validity of the tool. The verification process could be divided into two parts: a qualitative verification and a quantitative verification. The purpose of the qualitative verification was to check the individual agent behavior while the purpose of the quantitative verification was to make sure that the agent's interactions create a reasonable result. Another reason the quantitative verification was needed was to guarantee that UBFN employees involved in this paper felt confident that model actually worked.

8.3 Qualitative Verification

The qualitative verification of the model can be viewed as having started as soon as the model began to be created. As described in chapters two and five the authors started the study with a series of interviews. These interviews were used to create the foundation of the model. Further interviews were conducted along the way until the model was considered ready for testing (the quantitative verification). When the authors felt sure about the model a new series of interviews commenced, this time with the explicit purpose of verifying the model. An overview of the model (see figure 22) was shown to the questioned persons who in turn were asked to describe routines and procedures. The description was compared to the model's procedures and routines, which existed in the computer code. If any question marks remained further question were asked to clarify the situation. After the interviews a reverse process started. The working routines of the model were explained to the employees corresponding to different functions. After all the parts of the model had been through this practice the model was seen as having been verified qualitatively.

The people used for the final qualitative verification were as mentioned earlier the employees who have complete knowledge of a particular agent in the model. The reason they possess the knowledge of the agent is that the agent actually does what the employee does on a daily basis. This means that verification of the Stock agent and the Market agent were carried out by Anders Mjörner and Kent Lillsjö, who are in charge of distribution and the warehouse, respectively. They have knowledge of customer behavior and how the stock operates. Per Holm, who is head of the planning department and thus has intricate knowledge about the system, verified the Planning System. The Production Planner was verified by Jörgen Palm, whose job it is to plan all the margarine production at the factory at Helsingborg. Palm has planning sessions every week and has full knowledge of all the details in the planning process. Finally the Production Lines were verified by, on the one hand, Klas Ernegård who manages operations in the margarine factory and, on the other hand, by Håkan Leveau. Leveau is in charge of the improvement process at the entire factory in Helsingborg and had - because of that - access to data concerning machine speeds, delays etc.

8.4 Quantitative Verification

The quantitative verification started when the qualitative verification was finished. It consisted of letting the model simulate the constructed part of UBFN over a known historic period of time and with a verified setting of parameters. The chosen time period was January 1st to March 21st. The reasons this time period was used for the quantitative verification are:

- Output levels were known
- Production line parameters were known
- Specific production lines for products were known
- The dynamic environment of the factory was relatively stable at the time

In short, comparably reliable data exist for the time period because of the stable environment at UBFN. The parameter setting was checked and rechecked by employees and were as follows.

Parameter	Setting
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 8 Settings during the verification.

Beside the parameter settings, the model contains a vide variety of system parameters that can be found in chapter 7. Since the model contains several parameters that use an average setting with a standard deviation, the verification scenario was simulated ten times. The output chosen for verification, total service level and stock level of each simulation was copied into a Microsoft Excel sheet and an average of all of the ten simulations was calculated. The numbers were then converted using Microsoft Excel. The stock level is shown in figure 23 and the service level in figure 24. The reason these two output parameters were chosen for the verification was due to comparable data existing at UBFN.

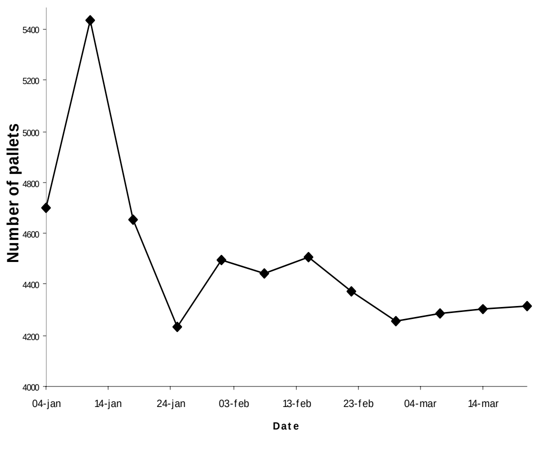

Figure 23 Output from verification: Pallets in stock per week

In the end it turned out that the data existing at UBFN was calculated in a different way, which made it hard to compare to the results of the model. Therefore the graphs were also discussed during a meeting with the manager of the Nordic Supply Chain, the Works Director, the manager of Production, and the supervisor of the study.

During the meeting it was concluded that both these output parameters of the verification corresponded well with what actually had happened at UBFN during the first three months of 2004.

The pallets in stock hade actually been 4,500 with a slight variation and sometimes it had been above 5,500 pallets which has forced UBFN to use an overflow stock. Also the service level appeared valid, for instance everybody recognized the dip in the beginning of February. In addition to these two output parameters a comparison with the operational efficiency of the margarine factory was performed and those numbers also corresponded.

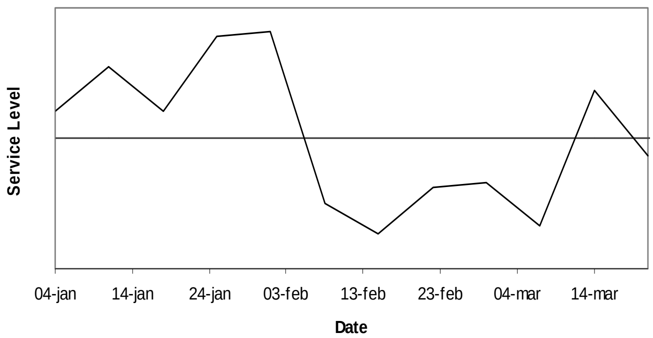

Figure 24 Output from verification: Service Level (straight line is average)

8.5 The scenarios

After the verification session of the model it was time to simulate a number of future scenarios or “what if” situations. These scenarios were decided at a meeting by a group of managers at UBFN. About a week before the meeting they were all handed a list of parameters, an explanation of them and a number of default scenarios in which they could change different parameters and arrange their own scenarios. Together with the list they were also given clear instructions about the process to ensure that everybody would interpret the information in the same way. These instructions were:

1. Read about the parameters to get an overall view of them and how they are programmed (see chapter seven).
2. View the matrix to get an understanding of the default settings of the parameters (see table 8).
3. Try to imagine which of these parameters you would like to change (not every parameter must be changed in every scenario) and within which interval.
4. Fill out at least five different scenarios that you would like to run.
5. Bring your suggestion to the upcoming meeting so the group can discuss it and agree on a couple of scenarios.

During the following meeting the group decided on sixteen different scenarios to run. These scenarios are presented below and the thoughts and discussions behind them are explained. The parameters that are changed in the different scenarios are marked with gray background in the tables. The scenarios are divided into two groups; production related scenarios and stock and forecast related scenarios.

These sixteen scenarios are then compared to a base scenario. This scenario acts as a reference, which is run with the same parameter setting as the verification (see table 8.1) and the same underlying basic settings as the sixteen scenarios. These underlying basic settings are:

- Simulation time: 2004-01-01 – 2004-12-31.
- All production lines are enabled.
- All margarine products are produced.
- The demand parameter is the long forecast (twelve months).
- The production agents continue the production of a current batch even if interrupted by a weekend.
- Other batches waiting for production when interrupted by a weekend are cleared and added to next week's production.

The main reason for using the base scenario for comparison instead of using absolute values was two-fold. The primary reason was to give UBFN confidentiality and to avoid revealing any corporate secrets. The second reason was to increase the reliability of the study. Even if the model overall reflects the reality there are always certain aspects that are difficult, maybe even impossible, to program and model. These could be aspects like those mentioned in chapter two; if people trip and fall and therefore have to stop a production line or if people take different coffee breaks from day to day. By using relative numbers the model reflects the behavior of the different parameter changes instead of giving the absolute numbers of UBFN.

To enhance the accuracy of the simulations every scenario, including the base scenario was run 30 times. Then an average, of the four main output parameters, was calculated from the 30 different sessions. 30 times was chosen so as to be able to use Gaussian distribution when interpreting the results. This implies a total of over 500 different simulations.

8.5.1 Production related scenarios

Scenarios one to eight are production related. The two first scenarios are shown in table 9 and involve changes in batch sizes, the size of what is produced at a certain time between changeovers. The first is halved and in the second duplicated. This was decided to examine whether to produce certain products more or less often.

Scenario 1

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	0.5
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 2

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	2
Stock Rate (%)	7
Change Time (M)	0.75
System Volume (Ton)	2
Disabled Production Lines	None

Table 9 Scenario one and two manipulate the parameter batch size.

In scenario three and four focus lies on the improvement of changeovers, see table 10. In the third scenario the change time is halved and in the forth scenario the system volume is halved which implies that UBFN only loses half the mixed margarine in the pipes when changing products. Both of the parameter manipulations aim to examine how much can be saved if improving these aspects of a changeover.

Scenario 3

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	0.5
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 4

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	1
Disabled Production Lines	None

Table 10 Scenario three and four manipulate the parameters change time and system volume.

Scenario five combines scenario three and four to find out the total savings for these two efficiency improvements in the changeover process, se the left part of table 11. In scenario six in the right part of table 11, the production utility is set to 100 percent. This is to examine the difference in cost, the utilization of stock and production between a planned seven-day week and a regular five-day week (68 percent).

Scenario 5:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	0.5
System Volume (Ton)	1
Disabled Production Lines	None

Scenario 6:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	100
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 11 Scenario five manipulates the parameters change time, system volume while scenario six manipulates production utility.

Scenarios seven and eight both disable production line 315. This is an old and relatively slow line, which is planned or likely to be replaced in the future. While scenario seven settles with this parameter change, scenario eight draws up a dream scenario, see table 12. In addition to the disabled production line it halves the change time as well as the system volume and sets the production utility to 100 percent.

Scenario 7:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	315

Scenario 8:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	100
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	0.5
System Volume (Ton)	1
Disabled Production Lines	315

Table 12 Scenario seven and eight disable production line 315 and in addition to this scenario eight manipulates change time, system volume and production utility.

8.5.2 Stock and forecast related scenarios

The last eight scenarios, nine to sixteen, are stock and forecast related. Scenario nine, on the left of table 13, basically examines the cost of not being able to perfectly predict the demand by setting the forecast deviation to zero. Scenario ten, on the right of table 13, examines the result of having endless stock capacity. In short, the question is what will happen with the total cost when no costs of overflow stock exist.

Scenario 9:

Parameter:	Setting:
Forecast Deviation (M)	0
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 10:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	∞
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 13 Scenario nine manipulates forecast deviation and scenario ten stock capacity.

Scenarios eleven and twelve focus on manipulating the level of safety stock, see table 14. The standard setting is 1.2 weeks and these scenarios both increase and decrease this parameter by 33 percent. Scenario eleven decreases the safety stock to 0.8 while scenario twelve increase it to 1.6. The main reason for these manipulations is to examine the impact of the safety stock on the service level.

Scenario 11:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	0.8
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 12:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.6
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 14 Scenario eleven and twelve manipulate the parameter safety stock.

Scenarios thirteen and fourteen, in table 15, focus on manipulating the parameter shelf life, which implies the time UBFN owns of the product's total lifecycle. The standard setting is 33 percent and scenario thirteen examines the difference from the amount UBFN used to own, 50 percent, while scenario fourteen examines the consequences if this time is halved.

Scenario 13:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	50
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 14:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	16.5
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 15 Scenario thirteen and fourteen manipulates the parameter shelf life.

Scenario fifteen, on the left of table 16, is combining two of the above-mentioned aspects. An improvement of the forecasts by 50 percent, forecast deviation is set to 0.5, and a decrease in safety stock by 33 percent, safety stock is set to 0.8 weeks. The final scenario, number 16 on the right of table 16, manipulates the parameter stock rate. This is to examine how an increase in the cost of capital affects the total cost.

Scenario 15:

Parameter:	Setting:
Forecast Deviation (M)	0.5
Safety Stock (weeks)	0.8
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Scenario 16:

Parameter:	Setting:
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	20
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 16 Scenario fifteen manipulates forecast deviation and safety stock while scenario sixteen manipulates stock rate.

8.6 The results of the simulation

In this chapter the results of the sixteen scenarios, simulated 30 times each, are presented. The four output parameters are presented in relative numbers compared to the base scenario where plus (+) implies a higher value and minus (-) a lower value than the base scenario. The input parameters of the base scenario are shown in the table below.

Parameter	Setting
Forecast Deviation (M)	1
Safety Stock (weeks)	1.2
Production Utility (%)	68
Stock Capacity (Pallets)	5500
Shelf Life (%)	33
Batch Size (M)	1
Stock Rate (%)	7
Change Time (M)	1
System Volume (Ton)	2
Disabled Production Lines	None

Table 17 The settings for the base scenario

A more detailed list of the output results can be found in appendix A through D. It is for the most part from this material the authors have drawn their conclusions, and for the interested reader the authors suggest a closer look. For the more casual reader the authors believe that the results presented in this chapter are more than sufficient.

8.6.1 The results of the production related scenarios

The results of the simulations are, just as the scenarios, divided into production related and stock and forecast related scenarios. As mentioned above four output parameters a shown, Stock level, Production utility, Service level, and Total Cost. The parameters were stipulate by UBFN, and summarize the factors that the company finds most interesting to observe.

Scenario	Stock level	Utilization	Service Level	Total Cost
1 - Half batch size	-2.8 %	5.2 %	0.9 %	0.9 %
2 - Double batch size	15.7 %	0.0 %	1.9 %	1.8 %
3 - Half change time	0.0 %	-5.5 %	-0.1 %	-0.3 %
4 - Half system volume	0.5 %	-0.1 %	-0.3 %	-1.0 %

Table 18 Results for scenarios one through four

Table 18 shows the results of simulation one through four. It is important to keep in mind since a percentage of deviation from the base scenario is used when presenting the results. The results of the base scenario were not depicted in absolute numbers, due to confidentiality issues. Also the exact number is of less interest instead the focus should be directed towards the general direction of the results (increase or decrease in output parameters).

Scenario 2 increase pallets in stock by over 15 percent is the biggest change in stock of scenario one to four, but also the three percent change in scenario 1 is noteworthy. Scenarios 1 and 2 display changes in service level with almost one and two percent respectively otherwise the service level is approximately unchanged. The average utilization rose in scenario 1 with slightly more than five percent and decreased in scenario 3 with more than five percent. For the rest of the scenarios the utilization was unchanged. Here as with pallets in overflow a large increase or decrease does not mean much in actual numbers. Individual lines, like 312, 314, and 315 are barely used (312 not at all) in the base scenario and that is the reason sharp increases are displayed. In total yearly cost scenarios 1 and 2 result in an increase of one and two percent respectively and scenario 4 results in a decrease of one percent. One percent change in the yearly cost represents approximately 4 MSEK.

Scenario	Stock level	Utilization	Service Level	Total Cost
5 - Half system volume and change time	0.3 %	-6.2 %	0.9 %	1.9 %
6 - Production utility 100 %	0.9 %	-0.3 %	0.4 %	1.0 %
7 - Production line 315 disabled	0.0 %	-0.1 %	-0.5 %	0.1 %
8 - Scenarios 3,4,5, and 7 together	0.6 %	-6.0 %	0.0 %	1.9 %

Table 19 Results for scenarios five through eight

In table 19 the results from simulations 5 through 8 are displayed. The largest change in stock level is in the results of scenario 6 where there was an increase of almost one percent. Also all scenarios display increased risk of needing to send pallets to an overflow warehouse. In scenario 5 there was an increase of almost one percent in the service level and in scenario 6 it rose by almost half a percent. Scenario 7 displayed a decrease of half a percent in the service level. The results of scenarios 5 and 6 show a decrease in average utilization of six percent, and in total yearly cost both scenarios 5 and 8 show a decrease of one percent. A decrease by 100 percent in utility in a specific production line or if there is no number at all indicates that the production line is not used (see appendix with detailed results).

8.6.2 The results of the stock and forecast related scenarios

This part shows the results of the stock and forecast related scenarios. Once again the reader should bear in mind that the results are a percentage of deviation from the base scenario.

Scenario	Stock level	Utilization	Service Level	Total Cost
9 - Forecast deviation set to zero	-4.7 %	2.8 %	6.3 %	3.6 %
10 - Stock capacity set to infinity	0.1 %	0.2 %	-0.2 %	-0.2 %
11 - Safety stock set to 0.8 weeks	-26.2 %	-0.5 %	-9.1 %	-1.0 %
12 - Safety stock set to 1.6 weeks	15.6 %	0.8 %	3.2 %	1.3 %

Table 20 Results for scenarios nine through twelve

Scenarios 9 and 11 show a decrease in stock level by almost five respectively twenty six percent, while the stock level increases by almost sixteen percent in scenario 12. In scenarios 9, 10, and 11 the risk for needing an overflow warehouse is eliminated while in scenario 12 it increases so much that it is almost certain that an overflow warehouse will be needed. The service levels in scenarios 9 and 12 are increased by slightly more than 6 and 3 percent respectively, while it is decreased in scenario 11 by more than 9 percent. The utilization is increased in scenario 9 by almost 3 percent and in scenario 12 by almost one percent. In scenario 9 there is an increase in total yearly costs by over 3 percent and in scenario 12 by slightly more than one percent. Scenario 11 displays a decrease in total yearly cost by one percent.

Scenario	Stock level	Utilization	Service Level	Total Cost
13 - Shelf life set to 50 %	1.0 %	-1.2 %	0.3 %	-0.6 %
14 - Shelf life set to 17 %	-7.2 %	6.5 %	-1.5 %	3.7 %
15 - Forecast deviation 0.5 and safety stock 0.8	-28.9 %	1.3 %	0.1 %	1.0 %
16 - Stock interest rate set to 20 %	0.3 %	-0.1 %	0.0 %	0.0 %

Table 21 Results for scenarios thirteen through sixteen

In table 14 the results from simulations 13 through 16 are displayed. Scenario 14 and 15 display a decrease in stock level and also a decrease in using an overflow warehouse. In scenario 14 there is a decrease in service level by one and a half percent while there is almost no change in the other scenarios. The utilization decreased in scenario 13 by slightly more than one percent while in scenarios 14 and 15, the utilization increased by more than six and more than one percent respectively. The total yearly costs increased in scenario 14 by almost four percent and in scenario 15 by one percent.

9 Walking the walk

"I hear and I forget. I see and I remember. I do and I understand." (Confucius)

Looking back (to the beginning of this paper) this paper set out to answer two questions. One concerns the applicability of complexity theory at a supply chain. This was done in chapter six. The other question concerns the ability to construct a bottom-up model through answering what-if questions with an agent-based simulation created of the case company.

The question was broken down into a number of objectives:

- Creating a usable agent-based computer model of the case company.
- Verifying the created model through historical data
- Applying changes to the verified model to give answers to different scenarios, in the form of what-if questions, asked by the case company in order to assemble a basis for decision-making.

It is the authors' belief that by fulfilling these objectives the overall purpose of the paper will be fulfilled as well. Due to the authors' belief this chapter will start by discussing the concrete objectives and then debouch into a general discussion of the purpose.

9.1 Creation and verification of a model

Why bundle together two of the objectives? The reason is simpler than it might seem but still requires some explaining. An agent-based model is constructed through a bottom-up process, describing agents at a lower level. This means isolating agents and trying to identify their behavior and with which other agents they interact. The processes can be viewed as a classical analysis where a larger problem is broken down into smaller parts and then studied. However, the difference is how the parts are put together and observed and how the individual behavior of the agents contributes to the emergent behavior of the entire system. Since the human mind cannot fathom the outcome it becomes necessary to use computer simulation to observe the outcome. Once the model has been put together there is no easy way of telling if the outcome is due to an unexpected interaction or simply a programming error. Finishing the chain of reasoning leads to the conclusion that the only way of knowing if the model really reproduces what is going on to a greater or lesser degree is by verifying it with historical data or events where the outcome is known. To do that the simulation is run during a period of time that has already occurred and for which data exists. The outcome of the simulation is checked with the historical data and if they match the model is, at least at an abstract level, verified.

Summarizing the last paragraph implies that the only way to create a usable computer model is through verifying the model, its behavior and simulation through historical data and that is why the two objectives are bundled together. Furthermore to ensure, or at least improve, the outcome of the simulation a verification of the computer agents needs to be performed. The former type of verification is thus a form of quantitative verification and the latter a qualitative verification. In this paper the qualitative precedes the quantitative verification.

As shown in chapters six and seven it is possible to create a usable agent-based computer model of the UBFN supply chain. The model is programmed with Java and the agents are set to a relatively high level of abstraction; the production planning, the planning system, the different production lines, the stock and the markets. This could be done in a different way where every agent could have been divided into a number of further agents. This level of abstraction was chosen since we believed that a lower level would not give much further information in relation to the effort needed.

As shown in chapter eight the verification went well overall. The model produced the same pattern in output parameters as UBFN presented for January 1st to March 21st even though this period was something of a running-in period where data was missing for a couple of new production lines installed during the late fall of 2003. This could be said to have been one of the difficulties during the verification. Of the four output parameters (service level, total cost, the production utility and pallets in stock) the total cost is not usable when checking outcome with historical data. This is due to different ways of calculating costs; instead the cost parameter is used when comparing different scenarios.

We believe that the main reason for the successful verification is the careful and precise data collection process; mostly due to the combination of the three different collection techniques of interviews, observations and document studies, which verified most of the collected data along the way. This triangulation also made it possible to create such an accurate model where both the different agents and the connections between them act as they actually do at UBFN. On the downside, an earlier mapping of the agents and their processes could have facilitated the work further. An earlier discussion with UBFN about the scenarios would also have given the authors a straighter path when collecting the data. Both these aspects would have saved valuable time and given a possibility to reallocate the time for the study.

Other aspects that have to be considered when looking at the verification are the deviations from the model and the reality that exists, which affects the output parameters. The model uses forecast data produced four weeks before the selling week (called Forecast-4), while UBFN uses forecast data altered one week before the selling week (Forecast-1) when calculating service level. The Forecast-1 is naturally better than Forecast-4 when looking at forecast deviation, this leads to the model having a larger forecast error built into it. *The larger forecast error will most certainly lead to a consistently lower service level*. Another aspect is a simple matter such as national holidays. The model's schedule is not aware of certain days being holidays. And during national holidays there are no outbound deliveries, meaning customers do not order items, and this alters the stock level. The alteration of the stock level in turn affects other output parameters such as stock level and utilization. Furthermore since the model uses mean values together with standard deviation one really bad historical week in reality could manifest itself as several somewhat poor weeks in the model.

These types of difficulties will always have to be contended with when using this kind of model. One way of handling it is to look at simulations over a longer time period, which evens out problems like national holidays. Another way is to compare relative instead of absolute numbers when simulating different scenarios, instead of comparing, for instance, certain costs of different departments at UBFN. We have chosen to compare the change in this cost between a base scenario and the different simulations.

The verification process is the key to creating decision tools using agent-based modeling. If this process is skipped or rushed through, the results of any ABM is uncertain. The more ways in which a model can be verified the better. As mentioned earlier the verification process has further significance. Not only is the process needed for the use of the model as a decision tool but it is also needed for support of the company where the model is constructed. Without this support the model has no future.

Other interesting point the authors discovered is the order in which the verification should be performed. Since the model shows the emerging patterns created by individual agents, the verification process, just as the model itself, has to be a bottom up process. This means that the verification should start with the individual agents (qualitative verification) and then move on and verify system behavior (quantitative verification). By performing the verification in this order the system performance is calibrated before it is put together and programming errors are more easily identified. This verification order is by no means a guarantee that the overall system will perform, but it increases the understanding of the reasons why the output parameters of the overall system could be wrong.

In conclusion the authors have spent a large part of the time at UBFN constructing and verifying a model following the actual situation at UBFN, but are aware of the differences between reality and the constructed model. This fact together with a successful verification session with UBFN employees makes the authors believe that the constructed model represents the reality at UBFN. By establishing this and taking into account chapters six, seven, and eight the authors strongly believe that it is possible to construct a usable model of the case study and that the constructed model was successfully verified using historical data.

9.2 Scenario analysis

Below all the scenarios are briefly analyzed, followed by a deeper discussion about the most interesting scenarios and results.

9.2.1 Scenario 1

When manipulating the batch size to half regular size, meaning that each production occasion will occur twice a week with half the production quantity instead, several things can be observed. First, the stock level in average decreased about three percent, giving three percent less costs of storage and capital. Second, the service-level increased by about one percent. Third, the risk of pallets becoming old decreased by about 15 percent. Unfortunately, this scenario also required 116 percent more washes, 32 percent more product changes, as well as an increase of five percent in labor costs due to higher production utilization, which will increase the total cost by about one percent.

The explanation for the increase in product changes and system washes can easily be explained as when there are about twice the amount of production occasions every week, and switching from one item to another requires a wash or a system wash, which will theoretically give twice the amount of changes. A changeover also demands time to implement, which means that the production line employees have to work more time, explaining the increase in labor costs.

To answer the question of the stock decrease of three percent, the following illustration can be considered. If an item is to be produced every week in a theoretical world when the sales are stable, the stock level will increase to a maximum level when a production batch has been completed and decrease to the safety stock-level when next week's production is about to start[138]. This is illustrated in the figure on the left hand side below.

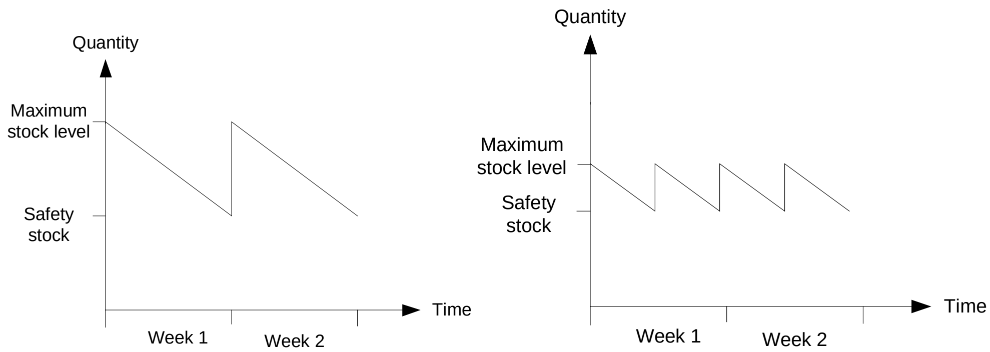

Figure 25 The stock level when producing once a week and twice a week

When the batch-size is divided by two, still the same quantity is produced each week, but in two production occasions. Note that the sales are still constant. In this case the

[138] Of course, in a theoretical world, there is no need for a safety stock.

maximum stock-level will decrease, which is illustrated in the figure on the right hand side above.

The decrease in stock-level can be calculated when dividing the areas below the curve in each figure. The area in the last figure is not half the area in the first figure, because of the safety stock. However, in the real case a decrease of three percent was observed, which means that the safety stock is a large part of the area.

The increment in service-level can be explained as there are more different items available the entire time, the safety stock is the same for all items and the number of pallets removed from the stock is lower because the stock is much fresher than compared to the base scenario.

The question is whether cutting the batch size in half is a good decision. The higher production cost, which together with other savings in other parts of the supply chain resulting in a total increase in costs of one percent, must be weighed against the change in service level. Is the one percent increase in total costs worth the one percent increase in service level?

9.2.2 Scenario 2

When the batch-size is doubled in the same theoretical world as described in scenario 1 the stock level is moving up as illustrated in figure 26.

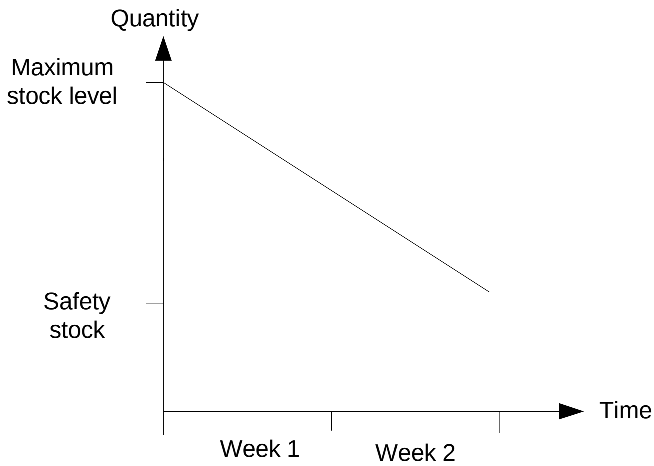

Figure 26 The stock level when producing every other week.

In the figure, it can be noted that every other week has a larger safety stock. Thus the safety stock is on average higher, which leads to a higher service-level. Unfortunately, a higher safety stock means that the risk of pallets getting old increased. This can be confirmed by the output of the simulation, which shows that the total production is one percent more and items were melted down (the oil in old products can be reused through melting down) twice as much. On the other hand, the number of system washes and product changes halved in size, leading to less utilization of the production lines. The stock could not fit all the pallets and the overflow stock has to be used. This production setting leads in general to about two percent higher costs.

A high stock level will always improve the service level but where should UBFN draw the line? There is another issue when dealing with consumer dailies that have a short life span and every time a product is thrown out money is wasted.

9.2.3 Scenario 3

In scenario 3, the changeover multiple was set to 0.5, which leads to 50 percent reduction in change time when switching from one item to another or when performing a system wash. It can be noticed that this decrease lead to six percent reduction in utilization at the production lines, which in turn decreased the labor costs. Unfortunately, it has an effect on the stock, which can be explained as the items will be ready earlier during the week than planned, which increases the risk of overflow stock usage. Yet, the total cost remains unchanged. When changing this setting, the operational efficiency target of the production lines should also be changed, so that the planning should be more correct. Changing the changeover time will demand changing other parameters as well. It is interesting to note that this change isolated will not give a positive effect on the overall system, which is the opposite of what the authors (and UBFN employees) expected. However, this demands further investigation.

9.2.4 Scenario 4

It is afterwards shown that scenario 4 not would have needed a simulation because the system volume does not affect anything in the system except the cost of system washes and production changes. However, the simulation was performed and the outcome was a decrease of one percent in total costs. This means that a reconstruction of the pipes to half of the length of today will render a yearly cost reduction of approximately 2 MSEK and if this yearly saving is lower than the required payback (normally two to three years) it is worth the work.

9.2.5 Scenario 5

When combining scenarios 3 and 4, the output data shows an exact combination of the two scenarios meaning that the results are the same as in scenario 3, except the cost of product changes and system washes which are the same as in scenario 4. Since it lacks synergy effect this scenario point towards a nonsensical decision. Instead these two parameter manipulations should be combined with other parameter settings.

9.2.6 Scenario 6

Increasing the planned utilization to 100 percent (seven days a week) allows the production planner to plan more than today’s 68 percent (five days a week) utilization. However, with the current parameter settings (as in the base scenario) of the simulations, there is no need to produce on the weekends. The results are almost the same as in the base scenario, except some items are automatically dedicated to one production line, instead of two or three production lines in the base scenario. Here it can be seen that there is absolutely no need for the use of support lines (312, 314, and 315), because the new production lines can handle the entire production quantity. Maybe the production unit initially needs to increase the planned workdays from five to seven days but in the long run it looks like they will manage without the support lines even over five days. The outcome of the simulation could also appear in the base scenario if the production planner has more available information. Since the planner lacks online information the outcome of the production line utilization will not be the same as the planned.

9.2.7 Scenario 7

In scenario 7, line 315 was not available at all. The outcome of the simulation showed no major effects. This can be seen as a verification that an overcapacity exists in the factory. An important observation from this simulation, even though this model does not deal with it, is that if production line 315 were disabled there would firstly be an income when selling the production line and secondly there would be a decrease in write-off costs. So even if the model does not directly deal with this aspect it is safe to say that this would lower the costs, at least at the production unit.

9.2.8 Scenario 8

Scenario 8 is a combination of scenarios 3, 4, 6 and 7. Again, the results are the same as in scenario 5, except for what has been described in scenarios 6 and 7, which has no extraordinary effect.

9.2.9 Scenario 9

In scenario 9, where the forecast deviation error was set to zero, the authors expected the service level to become 100 percent. However, the result was 99.8 percent, and there were a lot of cost increases, except for the stock level, which decreased about five percent. This result can have several explanations. All the production related costs became higher because the number of produced units grew with about four percent, as a result of four percent higher sales. In reality, the sales might actually be higher when there is no forecast error. But there is a systematic error in the model, due to how the forecast deviation error is calculated. From the forecast-sales data it has been noticed that the average forecast is higher than the average actual sales. Due to this fact the forecast deviation error is calculated from the forecast-sales differences and the orders are always systemically lower than the forecast, as illustrated in figure 27.

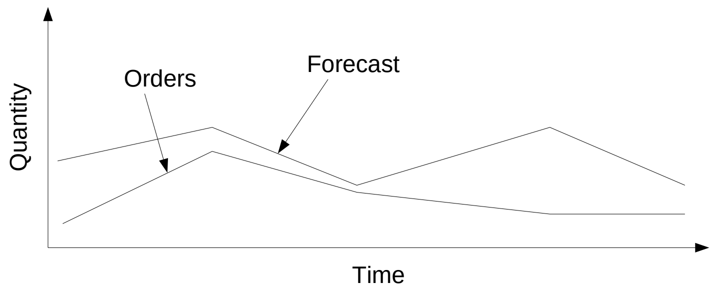

Figure 27 The systematic error between forecast and sales.

When setting the forecast error to zero, the systematic error will also be eliminated (as shown below in figure 28) and the outcome is in total more orders.

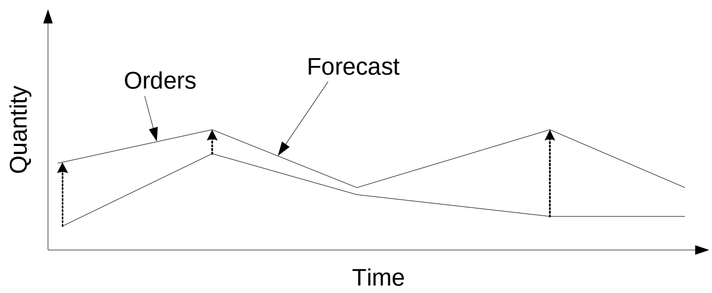

Figure 28 The reduction of the systematic error between forecast and sales.

The 99.8 percent, and not 100 percent, service-level can be explained by the fact that the production planner makes mistakes during the planning process, because of its curtailed information about the future. The forecast is 100 percent correct, but it does not know how the machines will work. There can for example be a major unexpected production stoppage, which was not exactly counted for and the production volume of an item will not become the same as the expected volume. The fact is, when a production plan is made for the coming week, the current week's production is not yet finished and the production outcome is expected to be the same as planned. Yet another fact that is also a contributory factor is that information about the stock is incomplete. The production planner does not know if an item in stock will become unusable soon and thrown away and does not consider producing more to fill the coming forecast quantity. Although the later issue is not very likely in this case as the result shows that there is only an insignificant amount of old pallets in the system.

9.2.10 Scenario 10

In scenario 10, the overflow stock was removed by setting maximum stock level to infinity. There is nothing special to say about this scenario, due to the fact that the overflow stock is not actually used in the base scenario. Another input parameter configuration might have given different results, such as the parameter settings during the verification, which is the present situation at UBFN. This is in other words only interesting to simulate in combination with a higher pressure on the production unit, which implies larger batches and higher stock levels.

9.2.11 Scenario 11

When decreasing the safety stock to 0.8 weeks cover the result gets interesting. First of all, the stock level is decreased by 26 percent together with the costs of capital and storage. Fewer items in stock minimize the risk of items becoming old and, as a consequence, fewer items had to be produced. But a decrease in service level of nine percent could hardly be accepted even if the total cost is decreased by one percent. This is a scenario that would be interesting to research further with simulation entailing other parameter settings or in the combination with a more transparent and intelligent planning system that would offer a continuously updated stock situation.

9.2.12 Scenario 12

The safety stock setting is a very important parameter, which can be seen in both scenario 11 and scenario 12. When the safety stock was set to 1.6 weeks cover, the service level increased by three percent, but the costs follows as well. It is likely that the overflow stock will be used, and the risk of old items in stock will also increase. However, it is not up to the authors to decide if three percent increase in service-level is worth more than a 60 percent increase in storage costs.

9.2.13 Scenario 13

Scenario 13 tested the outcome as if the case company owned 50 percent of the shelf life instead of 33 percent that UBFN owns today. The result showed that there were no major changes in the outcome. The production costs were lowered due to a lower utilization, but instead the cost of capital and storage went up, due to more pallets in stock for a longer time period. A larger part of the product’s life (50 percent) does in other words not imply a better situation for UBFN. Instead the planning situation of today is not able to handle this type of situation.

9.2.14 Scenario 14

Scenario 14 can be described as the opposite to scenario 13. The shelf life percentage owned by UBFN was decreased to 17 percent. The service-level was decreased about one percent, and the total costs went up by four percent. The increase in costs and decrease in service-level are explained by a huge amount of pallets that were removed from the stock due to being too old. The production planner does not take into consideration old items when a production plan is being made. The safety stock is planned to be 1.2 weeks cover, but in reality it is not because lots of the products in stock will be removed due to getting old so they cannot be delivered. So, the production planner has to tell the production lines to produce more each week to build up the safety stock over and over again, which will result in huge costs. Reducing this effect, “the wheel is spinning but the hamster is dead”, can certainly be done by decreasing the safety stock. However this demands further simulations concerning this matter.

9.2.15 Scenario 15

Scenario 15 concerned reducing the forecast error and setting the safety stock to 0.8 weeks cover. The increase in total produced items has the same origin as in scenario 9. Thus, the most interesting aspect of this scenario is that the same service level as the base scenario can be upheld, with a much smaller stock level, only if the case company can become twice as good at forecasting. The costs of capital and storage can be reduced by almost 30 percent. Bad forecasting means that a larger safety stock will be needed.

9.2.16 Scenario 16

The result shows that scenario 16 did not need to be simulated. The only difference between this scenario and the base scenario is the cost of capital, since the agents do behave after the same rules concerning costs. When changing the cost of capital from seven percent to 20 percent per year, the cost of capital is increasing three times, but still does not affect the total cost significantly. Instead this indicates that the cost of stock has a fairly small effect on the total costs.

9.3 Concluding thoughts about the scenarios

In this part the authors summarize some of the thoughts and contemplations that arose during the simulations of the different scenarios. Only the scenarios with what the authors consider novel or interesting aspects will be brought to the readers' attention. Generally every simulation could be seen as the trade-off between service level and costs, where a compromise must be made. The summary will be presented according to input parameters.

9.3.1 Batch size

During simulation of scenarios 1 and 2, the batch size was manipulated to, first, half the normal size and then to double the size. The authors expected the stock level to decrease substantially when the batch size was decreased, but this did not happen and there was only a three percent decrease.

The reasons for this could be many, but an important insight by the authors was that diminishing the batch size is not a universal cure for lowering stock levels. Another important insight was the overcapacity of the factory, since even when the change time doubled (twice the amount of changes) three of the production lines were hardly used. Noteworthy is that even though the stock level shrank the service level rose. The authors believe that this increase in service level is a question of products being available for distribution earlier. As mentioned previously in this paper all margarine products need time to mature so if a product is produced earlier in the week it will also be ready for transportation sooner.

Looking at the sibling scenario, where the batch size was doubled, an interesting insight was made, when observing a two percent increase in service level. This increase can be explained through the increase in stock level, but it could also be analyzed in another way. The products are produced two weeks in advance implying that the safety stock is doubled, but if focusing on one week the safety stock is the same as in the base scenario. What happens is that a buffer is created to handle the forecasting error. UBFN could spread the risk of miscalculating the sales on a two-week period instead of a one-week period. Important to note though is that this risk reduction and service level increase comes at a rather high price, since the cost of keeping stock (including overflow costs) rises by almost 120 percent, increasing the total cost by two percent.

Finally the struggle for local optimization is evident when comparing these two scenarios. In both scenarios there is between one and two percent increase in total cost, but in scenario 1 the cost is carried by an increase in production cost and in scenario 2 the cost is carried by the increase in stock costs. This gives UBFN the possibility of choosing where they would like to place their cost with respect to other factors the company feels play a large role: perhaps flexibility could be an important factor.

9.3.2 Production utility

Changing the utility parameter to 100 percent, as it was done in scenario 6, allows UBFN to work the production lines around the clock. The purpose of this parameter manipulation was to observe if increasing the usage of the machine could raise the service level. The service level was not raised substantially, but it was possible to observe another outcome. If the production planner had the possibility to utilize the entire week for production, three production lines were not employed at all. These three production lines, 312, 314, and 315 could be viewed as a liability for UBFN since they are not used and therefore should be sold to raise money and shrink write offs (which presently has been done by UBFN to some degree when selling production line 315).

There is, though, another aspect that has to be considered. The authors are of the conviction that by selling of the excess production lines UBFN is at the same time selling off their flexibility. The model is a setup without the risk of major breakdowns. If, by some chance, something should happen to any of the production lines it is always good to have a back up production line to minimize the damage.

9.3.3 Forecast deviation

The forecast deviation is an important parameter and by lowering the parameter, as was done in scenario 9, it was the authors' belief that an approximation of the cost of forecast error could be obtained. However, after much deliberation it was concluded that this could not be achieved. Instead other insights were made. A better forecast would lead to higher cost, even though the cost of stock would decrease, because UBFN would simply sell more, which means that a forecast error is equal to loss of sales and therefore loss of income and maybe even the loss of good will. This insight might sound trivial but is a good mental exercise when discussing the cost of forecast deviation.

Another more novel insight was that even though the forecast deviation was zero, the service level did not reach one hundred percent. The reason for this was discussed in chapter 9.1.9, but one continuing line of reasoning could show a structural error in the food industry if the planning procedure is the same as in UBFN. What the authors mean is that the limitations of the produced items are not transferred to the computer planning system. Limitations like maturity time and product life span are not considered when planning production. If they were considered it would be possible to achieve a service level of one hundred percent.

There are in other words great possibilities associated with improving the production planning routine. In addition to the above mentioned there are also improvements to be made concerning the updates of the system as well as the number of planning occasions a week. An increased number of planning occasions with more updated stock information and more recent forecasts could perhaps improve the fit of the whole supply chain even more.

9.3.4 Safety stock

The safety stock parameter is one of the most influential parameters of the model and therefore any manipulation of this parameter is interesting. By reducing the safety stock to 0.8 in scenario 11, which implies a safety stock of five and a half days, the total cost was reduced by one percent while the service level dropped by nine percent. The cost reduction was both due to a lower stock costs and lower production costs, but such a steep drop in the service level would probably be unacceptable by UBFN. Looking at the sibling scenario 12, where the safety stock instead was raised to 1.6, implying eleven days of safety stock, the service level rose by three percent, while costs were raised with one percent. The cost raise originated from both production and stock costs. None of these options are especially good, but manipulating the safety stock together with other parameters could result in interesting insights. Having concluded that the safety stock parameter is one of the most important a focused study should be performed around the parameter.

9.3.5 Shelf life

The scenarios manipulating the shelf life parameter up and down originated from two needs at UBFN. Scenario 13 depicted the situation as it had been in the past when UBFN owned 50 percent of a product’s life span, and UBFN was wondering how much the shift from 50 to 33 percent had cost them. Scenario 14, on the other hand, is a scenario that could be the future for UBFN. Since UBFN’s customers are strong players in the retail industry in Sweden, they could in the future demand a large part of the product life span, leaving UBFN with approximately one sixth of the life span. The first novel insight the authors made was that owning 50 percent of the life span was not as favorable as UBFN had thought. Although the production costs went down the cost of stock rose making the total cost about the same. Once again the futility of local optimization was shown. Furthermore there was no difference in service level which the authors and UBFN had expected there to be. This might however also be a result of the fact that the UBFN supply chain has adapted to the new prerequisites and does not function well with the old settings any longer.

Looking at scenario 14, the possible future, the results were more of the expected kind. Cost of stock shrank due to fewer pallets in stock and that the pallets were in stock for a shorter period of time, while cost of production went up. The service level dropped and the total cost rose with almost four percent. The reason of the rise in costs and drop in service level is the amount of items in stock that become old. As described earlier it is the safety stock that is too large. When the production planner realizes that a large amount of items are old (the planner actually only realizes there are items missing) he prepares a new production plan to cover the forecasted sales and the safety stock. The problem is that the items will become too old again. It is a vicious cycle that is hard to break. The shelf life setting should probably be combined together with the manipulation of other parameters such as safety stock parameter. Important to note though is that UBFN will have to struggle if its customers start to demand a longer period of the product's life span and this insight is important to recall when having a dialog with the customers.

9.4 Achieving the objectives

By finishing this chapter, the authors consider the rest of the objectives in the study, and hence the second part of the purpose as well, to have been achieved:

- An agent-based computer model of the case company was created and verified.
- An analysis of the different tested scenarios answering what-if questions, asked by the case company, was conducted and the analysis can be used as a basis for decisions.

Looking back upon chapters six, seven, eight, and nine the authors certainly feel that the theory can talk the talk AND walk the walk.

10 Concluding the study

"...we are entitled to make almost any reasonable assumption, but should resist making conclusions until evidence requires that we do so." (Steve Allen)

In this chapter the authors will recapitulate the most important findings of this paper. There will also be a part that comments on weaknesses of the study that the authors have discovered during the journey of creation. Finally the authors will suggest fields related to this study in which the world would benefit from further research.

10.1 Conclusions

This study set out to answer two questions, one concerning the applicability of complexity theory on a supply chain and one concerning the making of a decision tool for decision making at UBFN. As to the question of applicability, chapter six of the study compares the UBFN supply chain to a complex adaptive system, a key aspect of complexity theory and comes up with a remarkable resemblance. The parts studied at UBFN display internal properties such as heterogeneous agents: the stock, the markets, the production planner etc. These agents all have different rules guiding them, but have a common boundary, forecast, sales, machine speeds, that control them, making it seem as though the whole system is guided by just a few rules. Also the agents do to some degree have freedom, or dimensionality, which enable them to self-organize.

Even more interesting is what happens when the agents act together, in other words the external properties. The agents struggle to improve their own fitness and at same time change the conditions for other agents. An example of this is the struggle between the production unit, wanting to increase batch sizes to raise the operational efficiency, and the stock unit, wanting to lower batch sizes in order to lower stock levels. The agents are directly or indirectly connected to each other and co-evolve like the planned order in which produced items were developed by the production planning and production lines together.

The emergence at UBFN is highly visible, since no single agent possesses the ability to make sure products are deliverable to UBFN’s customer. Also emergence between agents exist when the production planner makes sure the safety stock increases when it encounters a product that is to be produced late in the week. Another aspect of emergence is the unpredictability of the outcome and as the authors demonstrate in chapters eight and nine the outcome of several scenarios was unexpected. The attempt by the forecasters and planning agent to use historic data to try to predict the future consumption (and, in extension, the production) is an example of agents’ anticipation of the future. And the constant change at UBFN is a clear example of quasi-equilibrium within which all CAS must exist in order to survive.

Bringing all these similarities together makes a pretty strong case, and it is the authors’ belief that UBFN can certainly be viewed as a complex adaptive system.

And even though it cannot be specifically decided that it is valid for all supply chains, UBFN's supply chain includes many common parts, found in most other supply chain, so that it is likely that the theory could be applied to other supply chains.

Moving on to the second purpose where different scenarios were to be investigated and evaluated, it was concluded by the authors that it is possible to create an agent-based computer model and in accordance a model was created. The model was verified through historical data, which is also the only way to make sure that the model is valid and usable for answering what-if questions.

Manipulating input parameters and observing the outcome has strongly convinced the authors that the constructed ABM is suitable as a decision tool since it provided answers to all the authors' what-if questions presented in chapter eight. Furthermore the insights of several of these scenarios were both novel and interesting, indicating that the outcome might have been difficult to predict without ABM as a tool. Even those insights that were not novel are of value because they strengthen the basis for decisions.

Among the insights the authors made were that results when the shelf life of a product was prolonged did not, as the authors and UBFN expected, affect the company in a positive way. Another result was the insight about the safety stock parameter, which turned out to be one of the most important parameters. Together with manipulation of the forecast error it would make for interesting further research. When focusing on batch size, the struggle of local optimization between stock and production became evident and it was also concluded that cutting the batch size in half did not affect the stock level in a significant way.

There were, of course, scenarios that did not yield extraordinary or interesting results such as lowering the changeover time or disabling a production line or allowing the production planner to utilize the entire week when making a plan. But even these results are important to UBFN to help it focus its resources on projects that do matter. In conclusion, after six months of targeted studies of CAS and UBFN we, the authors, , believe that ABM has a natural part of and glorious future within the field of logistics due to its properties as a decision-making tool.

10.2 Criticism of the study

When working this close to a particular topic and research object, the authors believe that it is important to step back to obtain some distance and perspective of the ongoing study. By doing so, several issues have been revealed along the way.

One type of criticism concerns the authors' view of ABM as a concept and the fact that other competing theories and approaches were not seriously considered. Even in the beginning of the study when searching for a case company the application of this theory was a prerequisite. Answering the questions asked by UBFN might, in other words, have been carried out with other methods. However, in this case the simulations from, for example, EBM would have to be simplified. This focus on ABM might also have been enlarged by one of our supervisors' enthusiasm for ABM. This has on the other hand given us valuable inspirational guidance, which is always needed when studying areas that are relatively unexplored, such as the area of ABM.

The criticism regarding the model mostly concerns the work behind it or the verification of it. The fact that the model was programmed alongside the process of data collection possesses both pros and cons. The downside might be that the model in some way has maneuvered the process instead of initially collecting all data and then starting developing programming code. This has on the other hand created a natural repeated process between the data collection and the programming, which continuously enlarged the knowledge about ABM and the development of a model.

A last area of criticism is the fact that the authors have only been present at UBFN once or twice a week at certain periods of time. Even though no specific office space in Helsingborg was obtained the authors were always very welcome to visit UBFN at anytime to use the public areas in Helsingborg. This lack of attendance might have influenced the study and is maybe partly a reason behind some of the assumptions presented in chapter seven. However, there have continuously been meetings to follow up the progress of the study, to question the study and to answer questions the authors might have had along the way.

10.3 Suggestions to further research

In this study, we have seen that agent-based modeling can tell a lot about cause and effect in a supply chain network. How exact the reality can be captured in a model can be questioned. However, the authors believe that it is basically a question of time and an effective work method, which will describe the exactness of a model, even if the authors believe that there are behaviors, such as coffee breaks that never will be caught in a model because they are made up by the complexity of the human mind. Even though these complex behaviors can be caught with a statistical correctness, there will be a probability that an event will occur, but *when*, in time, the event occurs is very random and could happen at any time of the day, and furthermore it is not likely it will happen at the same in reality and in a simulation. If such behavior has a large effect on the entire system, it is very likely that a model does not give the correct results when verifying an agent-based model with historical data. In order to catch these behaviors in future, the research on ABM must be more aligned to the research on artificial intelligence.

The authors believe that there is a lot to do in the research field. A number of theoretical studies have been written, but there are relative few models made on existing supply chains. In order to verify the usage of ABM in logistics, more models have to be constructed. When ABM is commonplace in the large supply chain networks, genuine verification can be made, and experiences can be shared.

If a “cook book” in effective working method concerning data collection, political supply chain matters and the modeling itself can be written, it would be a great contribution to the practical part of the research field.

In this study the agent-based modeling is used as a decision tool. In fact, there are examples of existing supply chains that actually use active software agents taking decisions in real-time. The authors believe that there are today several functions in supply chain networks that could be replaced by intelligent agents. The advantages could be; cost reduction, real-time decisions, correctness as well as the decision maker’s availability. However, simplifying human behavior might not be easy, and demands further research in order to make it work on a large scale.

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"When you steal from one author, it's plagiarism; if you steal from many, it's research." (Wilson Mizner)

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Appendix A

Appendix A presents a detailed list of the output parameters from scenario one through four. The output parameters; stock level, production utility and total cost is broken down into further output parameters.

Output parameter	S 1	S 2	S 3	S 4
Pallets in stock	-2,8%	15,7%	0,0%	0,5%
Pallets in overflow	-55,0%	84736,4%	345,5%	200,0%
Service level Total	0,9%	1,9%	-0,1%	-0,3%
302 Utilization	1,9%	0,0%	-0,3%	-0,3%
305 Utilization	0,0%	-11,8%	-13,0%	-2,4%
306 Utilization	6,0%	-7,2%	-7,2%	-0,6%
307 Utilization	4,2%	-1,9%	-5,5%	0,0%
309 Utilization	6,8%	-11,9%	-6,5%	-0,1%
310 Utilization	9,0%	-19,9%	-6,2%	0,0%
311 Utilization	10,8%	-0,6%	-10,1%	-0,6%
312 Utilization				
313 Utilization	0,6%	1,1%	-1,5%	0,8%
314 Utilization	0,0%	18600,0%	0,0%	0,0%
315 Utilization	20,0%	-60,0%	0,0%	40,0%
Average utilization	5,2%	0,0%	-5,5%	-0,1%
Raw material cost	-0,3%	0,7%	-0,1%	-0,5%
Pack material cost	-0,1%	1,1%	-0,2%	-0,3%
Labor cost	5,3%	0,0%	-5,5%	-0,1%
Cost of washes	115,8%	-46,9%	-0,2%	-50,2%
Cost of product changes	31,8%	-47,1%	0,2%	-50,0%
Cost of storage	-3,2%	115,8%	1,8%	0,6%
Cost of outbound pallets	0,2%	-0,5%	-0,1%	-0,4%
Cost of capital	-3,3%	39,5%	1,4%	0,5%
Cost of melting down	-14,6%	93,6%	-1,1%	-0,7%
Total cost per week	0,9%	1,8%	-0,3%	-1,0%
Yearly cost	0,9%	1,8%	-0,3%	-1,0%

Table 22 Results from simulating scenario 1 – 4 compared to the base scenario

Appendix B

Appendix one presents a detailed list of the output parameters from scenario five through eight. The output parameters; stock level, production utility and total cost is broken down into further output parameters.

Output parameter	S 5	S 6	S 7	S 8
Pallets in stock	0,3%	0,9%	0,0%	0,6%
Pallets in overflow	627,3%	272,7%	109%	700,0%
Service level Total	0,9%	0,4%	-0,5%	0,0%
302 Utilization	-3,1%	-0,6%	-0,6%	-2,8%
305 Utilization	-13,0%	0,0%	0,6%	-12,4%
306 Utilization	-8,7%	-0,9%	-1,2%	-7,5%
307 Utilization	-6,5%	0,0%	0,6%	-6,1%
309 Utilization	-6,6%	0,1%	0,4%	-6,2%
310 Utilization	-6,2%	-0,3%	0,0%	-6,1%
311 Utilization	-10,8%	-0,6%	-0,6%	-10,8%
312 Utilization				
313 Utilization	-1,5%	1,1%	0,8%	-1,7%
314 Utilization	0,0%	-100,0%	0,0%	-100,0%
315 Utilization	0,0%	-100,0%	-100,0%	-100,0%
Average Utilization	-6,2%	-0,3%	-0,1%	-6,0%
Raw material cost	-0,5%	-0,5%	-0,3%	-0,3%
Pack material cost	-0,3%	-0,2%	-0,2%	-0,1%
Labor cost	-6,2%	-0,2%	-0,1%	-6,0%
Cost of washes	-50,1%	-0,5%	-0,5%	-50,1%
Cost of product changes	-50,0%	0,0%	-0,1%	-50,0%
Cost of storage	2,5%	1,1%	0,2%	2,6%
Cost of outbound pallets	-0,3%	-0,4%	-0,3%	-0,3%
Cost of capital	1,9%	1,0%	0,1%	1,9%
Cost of melting down	0,1%	1,1%	3,3%	2,3%
Total cost per week	-1,1%	-0,4%	-0,3%	-1,0%
Yearly cost	-1,1%	-0,4%	-0,3%	-1,0%

Table 23 Results from simulating scenarios 5 – 8 compared to the base scenario

Appendix C

Appendix one presents a detailed list of the output parameters from scenario nine through twelve. The output parameters; stock level, production utility and total cost is broken down into further output parameters.

Output parameter	S 9	S 10	S 11	S 12
Pallets in stock	-4,7%	0,1%	-26,2%	15,6%
Pallets in overflow	-100,0%	-100,0%	-100,0%	41681,8%
Service level Total	6,3%	-0,2%	-9,1%	3,2%
302 Utilization	4,1%	1,6%	-0,3%	0,6%
305 Utilization	-3,0%	0,6%	-0,6%	0,6%
306 Utilization	3,6%	-0,6%	-0,3%	-0,3%
307 Utilization	1,6%	0,0%	-0,3%	1,6%
309 Utilization	2,5%	0,1%	-1,0%	0,4%
310 Utilization	5,7%	-0,5%	-0,7%	0,0%
311 Utilization	0,6%	-0,6%	-1,9%	0,6%
312 Utilization				
313 Utilization	2,5%	0,8%	-0,4%	2,3%
314 Utilization	-100,0%	0,0%	100,0%	0,0%
315 Utilization	-60,0%	20,0%	40,0%	40,0%
Average Utilization	2,8%	0,2%	-0,5%	0,8%
Raw material cost	3,5%	-0,2%	-0,6%	0,4%
Pack material cost	3,9%	-0,2%	-0,7%	0,5%
Labor cost	2,7%	0,1%	-0,5%	0,8%
Cost of washes	2,4%	0,3%	-0,1%	-0,2%
Cost of product changes	2,5%	-0,1%	-0,6%	0,0%
Cost of storage	-4,4%	0,0%	-25,6%	64,5%
Cost of outbound pallets	4,7%	-0,1%	-0,5%	-0,1%
Cost of capital	-3,9%	0,1%	-25,9%	26,3%
Cost of melting down	-80,7%	-1,2%	-20,8%	44,7%
Total cost per week	3,6%	-0,2%	-1,0%	1,3%
Yearly cost	3,6%	-0,2%	-1,0%	1,3%

Table 24 Results from simulating scenario 9 – 12 compared to the base scenario

Appendix D

Appendix one presents a detailed list of the output parameters from scenario thirteen through sixteen. The output parameters; stock level, production utility and total cost is broken down into further output parameters.

Output parameters	S 13	S 14	S 15	S 16
Pallets in stock	1,0%	-7,2%	-28,9%	0,3%
Pallets in overflow	263,6%	-90,9%	-100,0%	81,8%
Service level Total	0,3%	-1,5%	0,1%	0,0%
302 Utilization	-0,9%	3,8%	3,1%	0,3%
305 Utilization	0,0%	4,1%	-1,8%	0,0%
306 Utilization	-1,2%	1,5%	2,1%	-0,3%
307 Utilization	-1,3%	9,7%	0,3%	-0,6%
309 Utilization	0,0%	2,9%	1,3%	0,0%
310 Utilization	-0,3%	5,0%	2,4%	-1,0%
311 Utilization	-2,5%	10,8%	0,6%	-0,6%
312 Utilization				
313 Utilization	-4,2%	13,6%	-0,2%	1,1%
314 Utilization	0,0%	300,0%	100,0%	0,0%
315 Utilization	20,0%	180,0%	-20,0%	0,0%
Average Utilization	-1,2%	6,5%	1,3%	-0,1%
Raw material cost	-0,7%	4,6%	1,3%	-0,4%
Pack material cost	-0,6%	5,5%	1,5%	-0,2%
Labor cost	-1,2%	6,5%	1,3%	-0,1%
Cost of washes	-1,6%	2,9%	1,9%	0,0%
Cost of product changes	-1,3%	2,2%	1,3%	0,1%
Cost of storage	1,4%	-6,5%	-28,1%	0,5%
Cost of outbound pallets	-0,2%	-0,6%	2,2%	-0,3%
Cost of capital	1,2%	-6,0%	-28,2%	170,9%
Cost of melting down	-42,1%	594,6%	-80,3%	1,6%
Total cost per week	-0,6%	3,7%	1,0%	0,0%
Yearly cost	-0,6%	3,7%	1,0%	0,0%

Table 25 Results from simulating scenarios 13 – 16 compared to the base scenario