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A simulation model for Supply Chain

- A case study applied at Tetra Pak Carton Ambient AB, Lund, Sweden, for TP A1 TCA Filling Machine -

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Abstract

Title: A Simulation Model for Supply Chain – Case Study applied at Tetra Pak Carton Ambient in Lund (Sweden) for TP A1 TCA Filling Machine

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Introduction: To gain competitiveness, industrial focuses are addressed towards product quality improvement, product time compression, costs and lead-times reduction. Nowadays, these diverse goals cannot be achieved by an isolated organizational switch but throughout an aimed supply policy. In particular, an integrated view to manage physically goods and virtually information from suppliers to customers through all steps there between has taken place: this is what is named “Supply Chain”. Managing the Supply Chain has become one of the most important tasks for managers.
To support it, simulation tools have been developed. The main advantages are in analyzing complex systems and assessing their variations and interdependencies.

Problem Definition: Tetra Pak A1 TCA is a filling machine addressed to emerging markets into which time to market compression and cost reduction are two imperative issues.
The tool should try to figure out:

- Which are best economic order batches to both satisfy customer demand for TP A1 TCA and either to reduce from time to time the capital tied up?
- Which are the impact of inventory, safety stock and reduced lead-time in the supply network?

Purpose: The purpose of this thesis is to develop a tool to manage a complex supply system flow from raw materials to finished products in order to decrease capital tied up in the chain, lead-time to market and identify eventual bottleneck in the flow.

Methodology: The report is mainly a both qualitative and quantitative case study. There is no intention to extend the findings to different companies or different business units within the same company. Information gathering has been done from interviews, internal Tetra Pak’s intranet in combination with secondary sources. Information from secondary sources was collected from literature, books, brochures and articles in addition to the Internet.

Objective: The objectives with the project are:

- To build a user-friendly model to be utilized for the analysis of the supply chain
- Create and evaluate different scenarios
- Eventual indications of improvement areas
- The desired output it to identify the best economic order quantity to squeeze inventory related costs.

Analysis and Conclusions: A simulation program has been developed to imitate the behaviour of the system. This simulation tool, based on Visual Basic for Application (VBA) is able to detect different output scenarios by varying the inputs of the model and assess quantitative values to the related outputs. A further risk analysis – by means of @Risk software- aiming at selecting eventual key-improvement area has been conducted. The program has been run according to the actual inputs of the chain. The purpose is to assess quantitative value to the importance of few inputs on outputs occurring and to qualitatively evaluate the risk related the actual situation.
The suggestions and conclusions of the thesis are:

- review of the agreement for few component suppliers;
- a uniform distribution for the orders joined to an order batch of 80% of agreement seems to guarantee the major benefits for the chain, according to inputs given be TPCA;
- improvement of forecast for the filling machine, since it affects all the planning activities of the supply network;
- the introduction of safety stock in the chain may lead benefits for the global lead-time. Conversely, it increases the tied up capital and the holding cost, because the level of the inventory is higher. The management should decide which the sought task is.

Further developments: The analysis regards only one branch of supply chain for the filling machine and therefore, refers to only one module of the complete filling machine. This is due both to the complexity of describing fully a supply chain of a global company and to the limitedness of time. Anyway, the boundary of the research have been discussed and agreed with Tetra Pak Carton Ambient. A further development could embrace others actors, deliberately omitted in this survey.

Acknowledgements

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Ernesto Beltrame

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Part I – Introduction

Introduction

This first chapter will introduce the background of the thesis. After a brief description of Tetra Pak's background, it will describe the problem framing, the purpose, and the delimitations of the thesis. Finally, the disposition of the chapters will be presented.

1.1 Background

> *"Companies are turning their attention to their inbound shipments and realizing that plenty of money is being left on the table"* [1]
>
> *Adrian Gonzales, senior analyst,*
> *Arc Advisory Group*

1.1.1 Tetra Pak's history[2]

Tetra Pak develops, produces and markets complete processing, packaging and distribution system for food and products.

In 1951 Tetra Pak was founded by *Ruben Rausing* and established in Lund, in the south of Sweden. The first tetrahedron-shaped carton they introduced into markets as a packaging solution gave its curious name. This shape was the result of the attempt to provide package requiring a minimum of material whilst providing maximum hygiene. The innovative idea of an economic and healthy packaging solution had to cross the barrier of the construction of a machine for the tetra-shaped carton. A new packaging system had to be thought and built.

Figure 1.1: *Dr Ruben Rausing, the founder of Tetra Pak*

After 8 years' experimentation, on May the 18th, the cited packaging system was presented to the press, arising a lot of interest and attention. All the intellectual, technical and economical efforts of the founder and his establishment were completely repaid the following year, when the first Tetra Pak machine for tetrahedron-shaped cartons was delivered.
Because of the rapid increase in the demand for packaging solutions, the following decades were spent to empower the production capacity for packaging materials (i.e. in 1959, it reached one billion cartons a year), and to enlarge Tetra Pak market interests by the construction of new productions plants around

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[1] Gonzales, A., (2002), *Inbound logistics drives strong demand for transportation systems.* Warehouse Management Journal, Sep 2002, pg.1

[2] Tetra Pak homepage, www.tetrapak.com, November, 2004

the world. In 1961 the first USA–Tetra Pak factory was established, in 1965 production commences at a new plant for packaging material in Rubiera (Italy).

What is more important, all the Tetra Pak production was accompanied by a continuous attention to research and innovation. In this sense, a real milestone in its history was the launch of the *Tetra Aseptic System*, which enabled producers to do the filling up of, for example, milk in an environment free of bacteria and thereby create products with long shelf life (see Figure 1.3) This innovative introduction allowed the company to satisfy new customer needs and wants and enhanced considerably markets opportunities: in 1987, more than 37 billion packages were produced by Tetra Pak every year. Aseptic packages accounted for 65 per cent of the total.

Figure 1.2: *Tetra Classic*

Figure 1.3: *Tetra Brik Aseptic*

The 1990s represented a decade of change. In 1991, there was the Tetra Pak's acquisition of Alfa-Laval, one of the largest suppliers of equipment and plants to the food industry, processing industries and agriculture. An organization arrangement followed the acquisition: on January 1993, the new company took the name *Tetra Laval.* The *Tetra Laval Group* is at present divided into four industrial groups: *Tetra Pak, Tetra Laval Food, Alfa Laval Agri and Tetra Laval Holding Finance*, which holds overall control of the group.

The Tetra Pak has become one the world's largest suppliers of packaging systems for milk, fruit juices and drinks. It provides integrated processing, packaging and distribution line and plant solutions for liquid foods and manufacturing.
Tetra Pak owns 77 marketing companies across the world, 59 packaging material plants including licensees, and 12 packaging machine assembly factories, which all together guarantee work for more than 20,000 people. With its products, Tetra Pak is present in more than 165 markets all around the world.

1.1.2 Tetra Pak nowadays

At the moment, Tetra Pak is a world market company that offers customers thirteen packaging systems for pasteurised and aseptically packaged products (carton or plastic-based). Tetra Pak' 77 market companies in two regions: Tetra Pak Europe & Africa and Tetra Pak Asia & Americas. The companies within Tetra Pak are organised in three business areas:

- ***Tetra Pak Carton Ambient*** develops and produces packaging systems and distribution solutions for products that can be distributed and stored at ambient temperature. The company has a global coverage and key product development centres in Lund, Sweden and in Modena, Italy. In Lund where Tetra Pak Carton Ambient AB is located it provides product innovation and industrialisation of packaging systems and distribution solutions including world class expertise in raw materials, converting processes and equipment to our customers all around the world.

- ***Tetra Pak Carton Chilled*** is the company providing packaging for refrigerator products. It comprises Business System Tetra Top, Business System Tetra Brik Chilled, Business System Tetra Rex and common Business Area Carton Chilled functions. Tetra Pak Carton Chilled is a supplier of consumer friendly packaging systems based on unique Tetra Pak competence. Tetra Pak Carton Chilled AB is located in Lund, Sweden.
- ***Tetra Pak Processing System*** develops processing systems and supplies complete processing and packaging lines to dairy and beverage industries.

All these three areas cooperate with ***Tetra Pak Market Operations*** international companies which purpose are to collect orders for packaging solutions in the markets and needs for packaging material. From one side, Tetra Pak supplies hundreds of different types of packaging, from cartons to plastic bottles. From the other, it develops new processing solutions and designs and services complete liquid-food plants.[3]

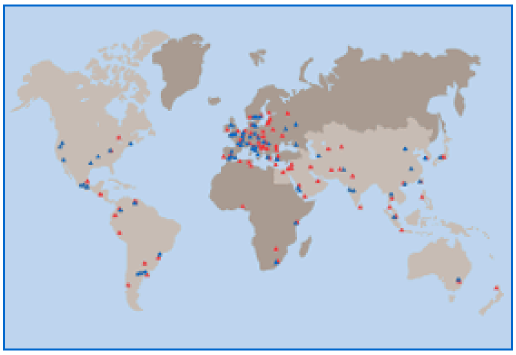

Figure 1.4: *Tetra Pak's 77 Market Companies in the world*

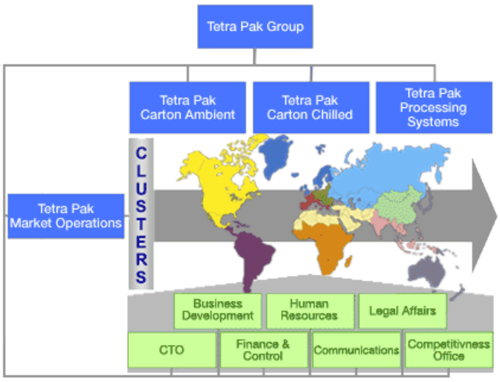

Figure 1.5: *Tetra Pak's Organizational Chart*

This work has been carried out for Tetra Pak Carton Ambient (TPCA) in Lund and, more precisely, for TPCA' s *Emerging Segment*, in the area of Supplier Management. The presentation of this segment, compared to the other, should be useful to better define the surrounding of the project.

Emerging Segment focuses on developing and delivering products that target the value segment in emerging markets and in the lower end of developing markets. Customer priorities here are primarily based on low entry cost, low cost operations and machine and system simplicity. Its strategic mission is to build a secure new customer and consumer base with lower investment and purchasing power capabilities.[4]

Beyond this segment, TPCA consists of other two ones: *Value Segment* and *Premium Segment.* Briefly, the first aims at satisfying customer priorities with

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[3] Tetra Laval 2003, Brochure, Tetra Pak Intranet, Tetra Pak Carton Ambient AB, Lund

[4] Tetra Pak Carton Ambient Intranet and Interview with Industrialization Manager, Emerging Segment, Tetra Pak Carton Ambient AB, Lund.

lowest possible cost and highest possible operational efficiency, while the second put the stress on the need for meeting best customers' requirements for the packaging systems. High differentiation, special solutions and high flexibility are the keywords and targets for this segment.

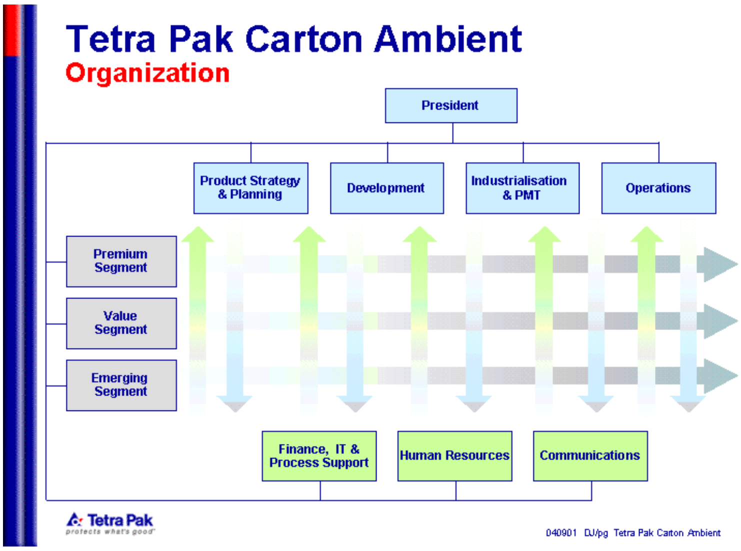

Figure 1.6: *Tetra Pak Carton Ambient Organization, Lund*[5]

1.2 About the project: problem definition and description

Launched in 1952, the Tetra Classic package was the first Tetra Pak's commercial product. Up to this point, both milk and cream had been sold loose over the counter or in glass bottles. When manual service in the shops began to be replaced by self-service, the need arose for a practical, manageable type of package, that could replace glass bottles and loose milk sales. The new packaging system was extremely cost efficient to produce, and enabled an optimal use of material. At the same time the demand for better hygiene increased. As a consequence, Tetra Pak's efforts were directed to the development of systems protecting food against the passing of time and atmospheric damages. The company released its next major innovation in 1961, the world's first aseptic carton. It was identical in appearance to the Tetra Classic package but the innovative introductions were twofold. First, a high barrier aluminium layer was embedded into the packaging material to protect external agents and, second, newly developed short term/high temperature sterilisation was used to treat the product. This combination enabled milk and other perishable liquid foods to remain shelf stable for months without need for refrigerator. The Tetra Classic Aseptic was the result of this new technological introduction. [6]

After a period in which Tetra Pak's attention was directed to the development of new easily handling packaging products, Tetra Classic has recently noticed an enjoying comeback, with serious investments in both new researches and markets. One important strategic step occurred in 1999 when Tetra Pak decided to invest in the *Emerging Markets*, one the segments of actual Tetra Pak's

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[5] Tetra Pak Carton Ambient Intranet, Tetra Pak Carton Ambient AB, Lund

[6] Tetra Pak Homepage, www.tetrapak.com , 2004 – 11 – 15

business. It has become evident that the demand of these new markets can be satisfied by modernisation, revitalization and adjustment of the Tetra Classic system. Its peculiar shape, its historical immediate connection to Tetra Pak's brand and, finally, its particular affection to young people have justified reinforced company commitments towards the development of efficient manufacturing and distributing the Tetra Classic Aseptic.

Nowadays, Tetra Classic is mainly adopted as packaging solution on the school milk segment and beverages for out of home consumption. Other products that are now commonly sold in Tetra Classic Aseptic packages are tomato paste and fruit compotes.[7]

The Tetra Pak A1 filling machine is the machine that produces Tetra Classic Aseptic packages. It is able to package different sized carton cans (from 65 ml to 200 ml), suitable for liquid food in a variety of applications.

- **TCA 65**: 65 ml sized package, ideal for single serve ice lollies, perfect for children, to be opened with scissors or perforation. Most common sales unit are packaged in cardboard boxes or plastic one consisting of 6 – 10 packages.
- **TCA 150 Slim – TCA 200 Slim**: 150 or 200 ml sized product. The target segment is refreshing beverages for on-the-go consumption. It is provided by pre-punched straw hole for easy drinking. To be sold with loose or bundled straws, the cardboard boxes in this case are filled up with 32 – 36 packages.
- **TCA 200 Base**: 200 ml sized package, it's a simple and durable package for UHT milk, particularly suitable for school feeding programmes. It differs from the previous because it respects the original tetrahedron shape (i.e. the TCA 200 Slim has one dimension longer than the other). From a manufacturing point of view the packaging cardboard consists of 21 packages.[8]

TCA 65　*TCA 150 – 200 Slim*　*TCA 200 Base*　*Plastic Crates and Cardboard boxes*

Figure 1.4: *TP A1 TCA Filling machine's packages*[9]

The Tetra Pak A1 represents a robust, reliable and low cost filling machine easy to use. It produces high quality aseptic packages and it is a high capacity packaging machine. The filling machine is the answer that Tetra Pak offers to market request for a low investment system, satisfying both needs for high

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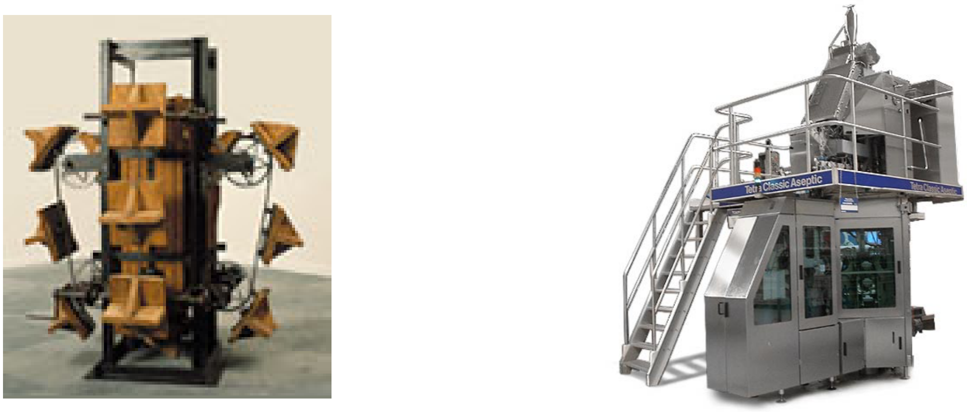
[7] Ibid.

[8] Tetra Pak TP A1 TCA Brochure, Tetra Pak Intranet, January 2005

[9] Ibid.

capacity and elevated quality. In other terms, it is particularly addressed to cost-sensitive customers. [10]



TP Filling Machine for Tetra Classic, 1944

TP A1 for Tetra Classic Aseptic (TCA), 2005

Figure 1.5: *TP filling machines for Tetra Classic*

The requirement of a general cost reduction is to consider the basic input of the investigation has been conducted along with this project. Actually, Tetra Pak Carton Ambient (TPCA) is attempting to improve its performances (concerning the manufacturing of the TP A1 TCA) throughout a twofold direction.

Firstly, TPCA is focusing on an overall time to market reduction. Adopting a supply chain perspective, this will entail deep efforts towards manufacturing lead-time compression. As a result all the policy between TPCA and its suppliers will be revised to align and share a common objective through the chain. Secondly, this goal has to be achieved without increasing costs (mostly, in term of inventory) and eventually with cost reduction. It should not to be forgotten that this machine is addressed to emerging markets where reliability and lost cost are jointly the principal requirements to succeed in competition.

The leading task of the study is to analyse the supply chain for TP A1 TCA filling machine with the scope of evaluating what occurs to costs if lead-times and quantity of TP A1 TCA required from the market change. This survey will be conducted by means of a simulation model, which will imitate the real system of the supply chain. Thus, by varying the inputs (i.e. forecasted demand, lead-times, inventory stock, economic order quantities) different scenarios will be provided and the consequent analysis of outputs (i.e. capital tied up in the chain, average lead-time) will be carefully taken into consideration in order to find factors affecting them the most.

The last step of the work will be a qualitative risk analysis related to the present scenario. A network like TPCA ‘s one is naturally affected by uncertainty. If an investigation aims at describing and realistically simulating the behaviour of a complete supply chain, it must be realized that the business environment is uncertain. Therefore, the decision maker who has to take the decision to boost the company’s effort towards a specific business area for performance improvements has to be conscious of that uncertainty and, possibly, assessed. The risk analysis aims at this.

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[10] Interview with Supplier Manager, Emerging Segment, Tetra Pak Carton Ambient AB, Lund, 2005 – 01 – 21

1.3 Purpose

According to requirements given by Tetra Pak Carton Ambient AB (TPCA)[11], the objective of the master thesis is to develop a tool that describes and simulate the supply chain for a precise Tetra Pak's filling machine, the TP A1 TCA. In particular, the tool should manage flows from sub-assemblies to finished modules and finally to a complete Filling-Machine.
The model should try to indicate suggestions and tendencies on order quantity per each sub-module based on lead-time, agreements between TPCA and its suppliers and demand for the filling machine. It should also be assessed the capital employed in the entire value chain from time to time.
Thus, input data for the model are filling machine orders deliveries over time, production lead-time and costs. The tool should be able to use default values for data that is missing when applicable[12].

As introduced in the previous paragraph, three major stages will be followed:

1. Development of the Model
2. Model transferring into a computer based program
3. Further analysis of current situation by means of inputs collected from TPCA

1.4 Focus and demarcations

Tetra Pak Carton Ambient is a company within Tetra Pak Group which task is to develop, manufacture and deliver complete packaging systems to customers. It provides also the filling machine necessary for the filling up of the carton packaging material. A variation of the type of carton shaped package, it will consequently differ the machine. Thus, Tetra Pak develops and builds many filling machines according to the shape of the package, because the filling up process changes from time to time.

This project precisely focuses on modelling and simulating Tetra Pak's supply chain for TP A1 TCA Filling Machine (i.e. filling machine for the 'Tetra Classic Aseptic' package). Due to its extreme complexity, the studied has been conducted evaluating only one branch of the supply chain for TP A1 TCA: the chain, in effect, is a multi-echelon system consisting of three different tiers before the delivery.

In other words, the connections and activities between Tetra Pak Market Company ("Market"), responsible for the collection of orders from the customers, Fuji Autotech AB ("System Supplier"), providing the final assembly before delivery to the market, Tetra Pak Stålvall AB ("Module Supplier"), responsible for the manufacturing of a precise module of TP A1 TCA (named ASU Infeed) and finally, the Tetra Pak Stålvall's suppliers for the ASU Infeed ("Component Suppliers") have been investigated. The Component Suppliers transform raw materials into first sub-modules. [13]

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[11] Tetra Pak, *Preliminary Draft – Master Thesis Simulation Model Supply Chain Management*, November, 2004 – Appendix II

[12] For information about the input data, see paragraph 6.4.

[13] For more detailed information about the supply chain for TP A1 TCA, see the case study (paragraph 6.2)

The following figure might help for the understanding:

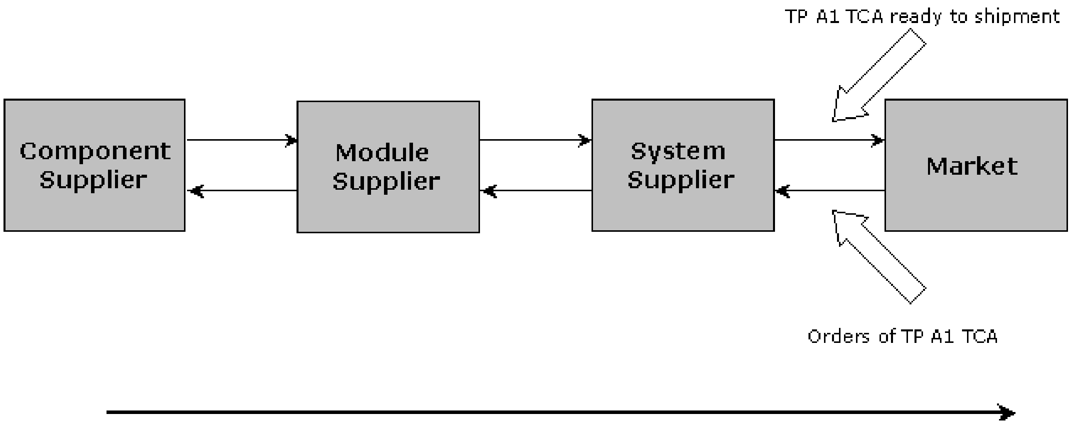

Figure 1.6: *Supply Chain for TP A1 TCA*

It should be explained that Tetra Pak Carton Ambient does not manufacture the TP A1 TCA on its own. The System Supplier is also responsible for the final testing and delivering to the Market. TPCA' s role is to support all the business activities throughout the chain from the order receipt to the shipment to the Market. It manages the economic transaction of the order and it assures the customer requirements satisfaction in the operations along with the suppliers network.

The analysis only evaluates, therefore, the inbound logistics activities (from Component Suppliers to Market). By inbound logistics activities of this chain, it has been meant all it is necessary to manufacture a complete TP A1 TCA filling machine, ready to be delivered. In other words, what occurs after deliveries has not been appraised: all the outbound logistics activities concerning distribution, retailer shipments and final deliveries to customers are out the scope of this thesis. Actually, it is neither a task of TPCA. The Tetra Pak Market Company should be responsible for these activities

1.5 Outline of the thesis

The paragraph aims at illustrating the disposition of the master thesis (see Figure 1.7):

The thesis might be divided into three areas: the *Introduction* (chapters 1,2), the *Theoretical Framework* (chapters 3, 4, 5) and the *Empirical Framework* (chapters 6, 7). The last chapter is dedicated to *Conclusions.*

- The **first** chapter is an introduction to the work: it offers the readers an overall description of the thesis and the following case study. The purpose and the delimitation task are also defined.
- The **second** chapter deals with methodology of the thesis: after a brief description of the approaches existing in literature, it discusses about the chosen approach, the gathering of data and the reliability of the information.

- The **third, fourth and fifth** chapters concern with the theoretical framework the thesis is based upon. A careful overall view on literature is basically presented. The theories, introduced in these chapters, represent the base for the work.
- In the **sixth** and **seventh** chapters the empirical study and its results are revealed. The first one is used to illustrate the case study. The attempt is to make the reader understand what the problem deals with and offer him the coordinates to unravel the following solutions. The findings and outcomes of the case study are carefully analysed in the second one.
- In the last and **eighth** chapter generalisations are made and conclusions are discussed. In this chapter examples of further studies are suggested.

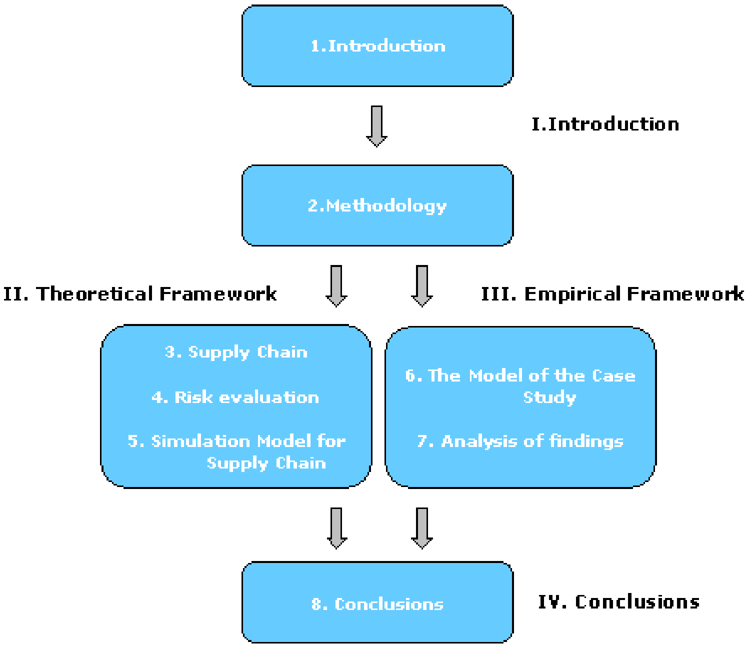

Figure 1.7: *Outline of the thesis*

Methodology

This second chapter will describe the methodology used in the thesis. The methodology is the way to achieve the purpose. It is presented after having introduced the main approaches existing in literature. Along with the description, it is also highlighted the gathering data process and a discussion about information that has been collected. The last paragraph will illustrate the resource distribution during the work.

2.1 Method introduction

According to Glaser[14], methodology is the theory of method with which a research is conducted. Methodological investigations allow the researcher to better understand the previously conducted researches and how to carry them on in future. For Näslund, methodology basically deals with how we gain knowledge about the world. (Naslund, 1999)

2.2 The research approach

A research aims at increasing knowledge, expertise or capabilities in a certain area of interest.

Arbnor and Bjerke (Arbnor and Bjerke, 1997) offer a deep contribution in the description of a research approach. In their work they distinguish between “knowledge” obtained through explanation and “knowledge” obtained through understanding. According to these two types of knowledge they propose three approaches to research: *analytical approach*, *system approach* and *actors approach*. The choice depends on the nature of the work and the personal research’s view of reality.

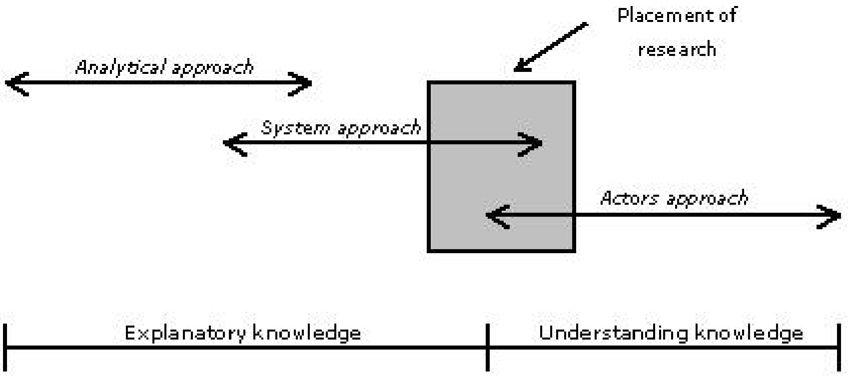

Figure 2.1: *Research approach*[15]

2.2.1 Analytical approach

The analytical approach takes origin from a philosophical branch, positivism. It traces its origins in the social sciences to the great theorists of the

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[14] Glaser, B.G. (1992), Basic of Grounded Theory Analysis, Sociology Press, Mill Valley, CA

[15] Olsson, A. (2003), *The integration of customer needs in e-business systems,* Lund University

nineteenth and early twentieth centuries and especially to Auguste Comte (1896). The positivist seeks the facts or causes of social phenomena apart from the subjective states of individuals. (Taylor, 1998)

Mostly employed in natural science researches, it tries to explain reality in an objective way. A phenomenon is described as a strict relationship between causes and effects: the researcher must stay outside the research object and refrain from interacting with it to avoid exerting an influence on the object, thus distorting the reality he or she tries to disclose. (Gammelgaard, 2004)

The analytical approach is based upon an additive characteristic, according to which the entirety is equal to the sum of different parts. A helpful image is that of a puzzle: the overall picture is given by the sum of each single part.

The results should be generalised and utilized to create new knowledge.

Figure 2.2: *The analytical approach*[16]

2.2.2 System approach

The system approach is a consequence of a reaction against positivism arisen in the late´60ies. In fact, although the system approach's achievement is still describing objectively reality, it differs from the analytical one because it considers reality as a "system", as a part of creation. In this sense, the individual point of view and ideas of the researcher provide the base of his view.

The system approach asserts that reality is arranged in a certain way and entirety is not equal to the simple sum of its parts. The system approach concentrates on the interaction between the different parts in attempt to take all relevant aspects into account. (Checkland, 1993)

The systematist thinks that the components of reality have such features that cannot be evaluated separately: the interactions must be taken into consideration. In other words, the overall picture is due to the interactions of the parts, taking all the system under attention, and not only to the sum of them. For this reason, the system approach is also defined "holistic", in contrast with the "atomistic" view of analytical approach.

A system might be either open or closed: in an open system there are components that can be omitted, even if they affect; in a close system there are no components, affecting the system, that are neglected outside the boundary of the survey.

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[16] Abnor, I., Bjerke, B., (1997), *Methodology for creating Business Knowledge,* Sage Publications, Newbury Park, CA

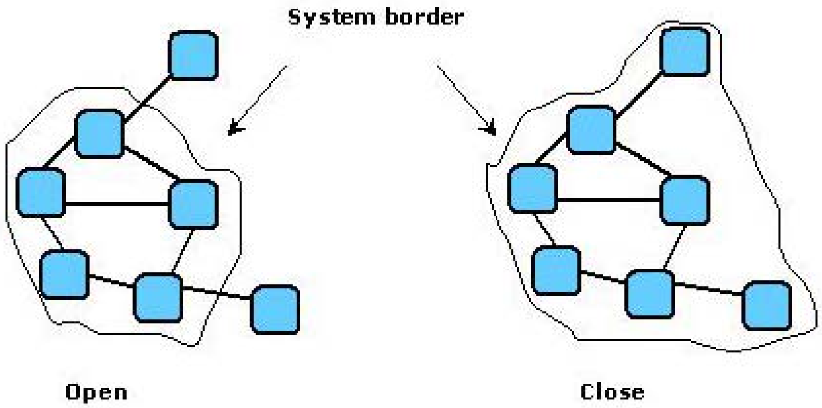

Figure 2.3: *Open and closed systems – The system approach*[17]

2.2.3 Actors approach

The actor approach comes from the second major theoretical perspective: the phenomenologism or interpretetivism. The phenomenologist is committed to understanding phenomena from the actor's perspective; the important reality is what people perceive it to be. (Taylor, 1998)

So, the actors approach differs from the others in their assumption of an objective reality. It considers reality like a social creation where the overall picture is obtained from including also actors and their concepts of reality.

The outcome of a research based upon an actor approach basically consists of subjective observations and in-depth interviewing.

2.3 Quantitative and Qualitative study

There are two different kinds of method for gathering information during a scientific research: the quantitative and the qualitative method. It is important to choose the right method according to the kind of research because they lead to two different kinds of data, although it is sometimes better to try to combine them. Basically the qualitative method is an inductive method and it starts from collected data and tries to build new theories by searching for connections and patterns. Authors usually link it to philosophical trends of phenomenology and symbolic interaction. Linked to positivism, the quantitative method is instead a deductive method; so it starts from previous theories to make hypotheses and then tests them.

2.3.1 Quantitative Study

The quantitative method works on variables supposed measurable and its results are numeric data, objective and quantifiable. In order to obtain such a kind of data the quantitative method uses questionnaires and statistical tools and it is more formalised and standardized, but even more inflexible, than qualitative method.

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[17] Abnor, I., Bjerke, B., (1997), *Methodology for creating Business Knowledge,* Sage Publications, Newbury Park, CA

According to Merriam (1998), quantitative study aims at breaking down a phenomenon in its components, which are transformed in variables that are then studied. The great advantage is that its results can lead to generalisations but, at the same time, there is also the risk that the data collected are irrelevant.

2.3.2 Qualitative study

The qualitative method aims at giving increased understanding of the research object, thanks to the author's particular close contact to that object; it is characterised by flexibility and a low level of formalisation. Another great advantage is that this method can give a deeper understanding in processes, but it is difficult to generalize the results achieved because it is based on a few sources.

According to Merriam (1998), the essential characteristics of qualitative research are:

- the focus is on the interpretation and on the meaning people have constructed, therefore the method studies how all the parts of the object work together to form a whole;
- the researcher is the primary instrument for data collection and analysis and he or she should have important attributes such as tolerance for ambiguity, sensitivity to context and data good communication skills;
- research activities usually involves fieldwork, hence researcher must physically move to go to the field (people, institution...);
- the process is primarily inductive, as quoted above;
- the product of a qualitative study is mostly descriptive, since that study focuses on process, meaning and understanding.

Point of Comparison	*Qualitative research*	*Quantitative research*
Focus of research	Quality (nature,essence)	Quantity (how much, how many)
Philosophical roots	Phenomenology, symbolic interactionism	Positivism, logical empiricism
Goal of investigation	Understanding, description, discovery, meaning, hypothesis generating	Prediction, control, description, confirmation, hypothesis testing
Data collection	Researcher as primary instrument, interviews, observations, documents	Inanimate instruments (scales, tests, surveys, questionnaires, computers)
Mode of analysis	Inductive (by researcher)	Deductive (by statistical methods)
Findings	Comprehensive, holistic, expansive, descriptive	Numerical

Table 2.1: Adapted from *"Characteristics of Qualitative and Quantitative Research"*[18]

2.4 Case study

"Case study is not a methodological choice but a choice of what it is studied"[19].

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[18] Merriam, Sharan (1998) *Qualitative Research and Case Study Applications,* Page 6

[19] Patton, Michael Quinn (2002), *Qualitative Research and evaluation methods*, Page 446

According to Yin (1994), a case study is an in-depth investigation of a phenomenon within his real-life context and it is used when researcher cannot manipulate relevant behaviours of examined events. The main characteristics of a case study are:

- it is used for cases where the descriptions of a phenomenon are focusing on details and deep descriptions;
- the findings concern the examined case: it is rarely possible to draw general conclusions to all reality, if existing;
- direct observation and systematic interviewing are often within the method.

Punch (Punch, 1998) highlights four characteristics of a case study:

- it is a “bounded system”
- the case is the case of something
- the study has an holistic focus
- multiple sources of data and multiple data collection methods will be used.

This should not surprise. Case studies allow for the use of both qualitative and quantitative methods (Ellram, L.M., 1996). As stated afterwards, all these features suggested us the case study as the methodological choice for this thesis.

2.5 Data Collection

Two kinds of data can be collected during a research: primary information and secondary information.

Primary information is data collected for the first time by the researcher himself and it is fundamental to make the study be as close as possible to reality. The problem of this kind of data is that the observer’s influence on an information source, misunderstandings of purposes and inaccurate measurements can affect them.

Secondary information is data already gathered and collected in books, newspapers, databases, etc. However it might not be comparable with a new study because of different purposes or conditions it was collected for.

Primary information can be gathered in three different ways: interviews, observations and experiments.

2.5.1 Interviews

Interviews are a common method to gather qualitative information and sometimes it is the only method used to collect data. Before performing an interview the researcher should have a clear idea of what he or she is looking for, in order to define an objective and structure questions helpful to obtain a special kind of information. According to Dexter (1970), interview can be defined as a “*conversation with purpose*”.

Interview allows the researcher to better understand people’s perspectives and feelings, and it is necessary also when a research regards something happened in the past which can’t be replicated.

Types of interview

Before performing an interview, it is necessary to define what kind of interview is going to be performed. According to Merriam (1998), the type of interview depends on the amount of structure desired and it is chosen from a continuum, as shown in the figure:

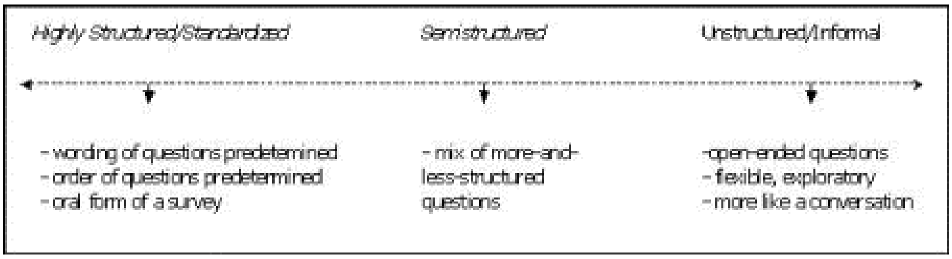


Figure 2.5: *Interview Structure Continuum*

The most part of interviews belongs to the unstructured type, because it assumes that respondents' view of the world are defined in unique ways; moreover, this kind of interview is very useful to explore a phenomenon not enough known in order to have the possibility to ask relevant questions for next interviews. The highly structured type is essentially an oral form of the written survey so questions are predetermined and it is difficult to define respondents' perspectives of the world. The semistructured type is halfway between the previous two ones: the interviews follows a list of questions and issues which have to be explored and the way to do that is not predetermined.

2.5.2 Observations

Observations are another important method to gather information. When primary data are collected, they're called *direct observation*. There are two main differences between interviews and observations:

1) observations take place in the field where the phenomenon of interest exists;
2) observational data are firsthand because the researcher can personally observe the phenomenon while in interviews it is described by respondents'.

Observations can be open or hidden. In open observations the observer affects the setting because people belonging to the group of interest are aware to be observed, so their behaviour may be not the same as usual. In hidden observations people don't know they're observed, but this fact could lead to a conflict. One of the main problems in observation is the relationship between researcher and setting because the one affects the other and it leads to a distortion of the situation.

After having observed the phenomenon it is important to record as many details as possible in order to create the database for analysis.

2.5.3 Experiments

The meaning of an experiment is manipulating reality in order to examine the studied problem: the researcher chooses an experiment variable to manipulate and then analyses effects at the dependent variable. An experiment can take place in a natural environment or in a laboratory and controlling disturbing elements is difficult but determining for a well-made experiment (Yin, 1994).

2.4.4 Literature study

This is a way to gather secondary information and it consists in searching in books, articles and documents. As quoted above, the main problem is that sometimes this kind of information might not fit very well to the context researcher is working in or it could not be useful when the research object is too new and recent.

2.6 Validity and Reliability

During a scientific research, there is another important aspect to be considered, besides method: requirements that results have to meet.

Validity

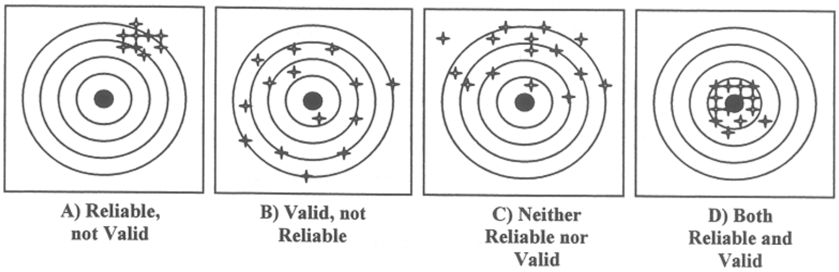
Validity can be described as a way to make sure that the study does not contain any systematic errors. Collected data could be not correct and may not answer central questions of the research: this is the reason why it is basic to have high validity, because results can be as close as possible to reality.

Reliability

After having obtained results from a research, it is necessary to check if those results would be the same if the study is made again with different choices in the population and with different researchers: this is called reliability. The meaning of reliability is making sure that results are well describing the reality, because this reality is only one and if the same study is repeated it has to give the same results (Merriam, 1998): this is due to the lack of random errors.

Relationship between Validity and Reliability

According to Arbnor and Bjerke (1997), validity and reliability are not separate concepts but they are in close relationship, as it is illustrated in the metaphor of the target:



A) Reliable, not Valid

B) Valid, not Reliable

C) Neither Reliable nor Valid

D) Both Reliable and Valid

Figure 2.5: *The relationship between validity and reliability*

There are four possible situations.

A. The study is reliable but not valid: hits are in the target and close to each other, so there are not random errors, but they are far from the centre (that is the central question).
B. The study is valid but not reliable: hits randomly cover almost the whole area of the target and are rarely near the centre; however as average the centre is hit even if shots are quite far from each other.
C. The study is neither reliable nor valid: hits are far each other and as average they are not near the centre.
D. The study is reliable and valid: hits are all near the centre of the target.

Mainly, qualitative method tends to achieve high validity because of the author's closeness to the research object but also to have low reliability. The quantitative method can instead give high reliability because respondents are used in this study.

2.7 The research approach in this study

It might be useful to summarize all the introduced concepts in a table (see Figure 2.6), which allows the reader to understand our methodological choice.

	Analytical approach	**Systems approach**	**Actors approach**
Theory type	Determining cause-effect relations. Explanations, predictions. Universal time and value free laws.	Models. Knowledge about concrete systems.	Interpretations, understanding, contextual knowledge.
Preferred method	Quantitative	Case studies (quantitative and qualitative)	Qualitative
Unit of analysis	Concepts and their relations	Systems: links, feedback mechanisms and boundaries	People and their interaction
Data analysis	Description, hypothesis testing	Mapping, modelling, simulating	Interpretation
Position of researcher	Outside	Preferably outside	Inside – as part of the process

Table 2.2: *The Arbnor and Bjerke framework*[20]

Actually, it should be said that the line between analytical and system approach, or quantitative and qualitative method is not so defined. In the last few years, there has been a rapid increase in the number of scientific essays dealing with the attempt to combine the two research methods.

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[20] Gammerlgaard, Britta, (2001), *School in logistics research? A methodological framework for analysis of the discipline,* International Journal of Physical Distribution & Logistics Management, Vol. 34, N. 6, 2004, pp. 479 - 491

Naslund (Naslund, 2002) argues that “it is necessary to both use quantitative and qualitative methodologies if we really want to develop and advance logistics research”. For instance, the methodological triangulation, trying to arrange qualitative and quantitative methods in a unique research paradigm, is the new management perspective[21]. Triangulation means using different research strategies to obtain different perspectives and so to evaluate in a better way; as a matter of fact the term triangulation is used in land surveying in order to find one’s own position given two landmarks[22]. For other authors, (Mangan, 2002; Ellram 1996) the case study represents one technique allowing the fusion of various research perspectives into a unique research methodology.

Due to limitedness of the research and the focus of the work, this thesis is fundamentally a case study. There is no purpose to generalize the findings to other surroundings (i.e. outside Tetra Pak), eventually it makes sense to extend the survey to other branches A1 TCA filling machine’s supply chain.

The thesis concerns complex flows of material and information among various actors in complex systems. As a consequence the system approach has been adopted as methodological point of reference. Since the different actors in the supply chain interact and create a complex situation, according to which the result is more than the sum of the individual subsystems, the analytical approach was inappropriate. Finally, the actors approach has been avoided. The purpose of the work is to figure out solutions not regarding the social aspects of the involved actors.

As said before, this work deals with flows of information and material along with a multi-step system. To better analyse the interactions between different tiers of this system, a “black box approach” has been adopted. It was no worthy focusing on the specific activities and processes of a single stage of the supply chain. Each company has been considered as a box with upper and lower linkages and relations with other companies. To be more explicit, the inbound and outbound logistics activities and related issues have been deeply appraised. At the contrary, it has been preferred not to take under consideration that ones related to production and manufacturing activities. (see for further specifications chapter 4)

The literature review has been the first step of this report. A panoramic search in EBSCO, Science Direct and Emerald databases has been carried out from various perspectives relating to supply chain management concepts, risk assessment and methodology of a scientific work. Further, a specific investigation in *International Journal of Physical Distribution and Logistics*, *International Journal of Logistics Management*, *International Journal of Operation & Production Management* and *Supply Management Review* Journal has been conducted. This search for relevant information, anyway, has proceeded during the whole process of the project. As well as literature material from international journals, a specific literature from the supervisor has been used.

Finally, the Internet has often represented a profitable source of information.

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[21] For further information, see: Mangan, J., et all., (2002), *Combining quantitative and qualitative methodologies in logistics research,* International Journal of Physical Distribution & Logistics Management, Vol. 34, N. 7, 2004, pp. 565 - 578

[22] Patton, Michael Quinn (2002), *Qualitative Research and evaluation methods*, Sage Publications, New York, p. 247

The gathering data process has been very difficult since the system we had to investigate was complex. It occurred that some type of information was hard to collect, both due to the geographical position which did not allow a direct visit to the company and to the impossibility of gathering them (i.e. costs) because not yet evaluated or typed. Several interviews have been conducted during all the project time. Unstructured/informal interviews and personal meeting, whenever possible, have been preferred. The aim of this choice was to capture all the more details about the topic as possible, to better understand which the issues of the project were and to be adherent time by time to problem requirements.

Totally we performed 20 interviews among company managers, professors, PhD students and master thesis students. Details about these interviews are reported in the References.

Specific or technical information (i.e. Tetra Classic, ASU Infeed A1 TCA) have been gathered through internal Tetra Pak's databases and intranet.

2.8 Time schedule

This paragraph represents briefly the time distribution during the project.

The first time of the project was dedicated to the development of the conceptual model. This part of the work was fundamental, since it represents the basis upon which the dissertation is conducted. In this phase, the explicitness and comprehension of variables affecting the assigned problem was the first focus. The purpose of the conceptual model is to try to describe the reality the researcher is investigating in a simple and immediate way. Defining conceptually a model means to establish which are the most important inputs connected to relevant outputs to consider for the discussion without omitting variables.

Secondly, the data collecting process followed. This stage of the work lasted a lot. The problem was to find out relevant data concerning the work we were developing and to link them in a reasonable manner. Furthermore, the complexity of the reality that had been studied forced to gather different data from different companies along the described supply chain.

Thirdly, the conceptual model was transformed in a real simulating model. The purpose of this thesis is to develop a tool able to manage complex material flows throughout different actors of the chain. It tries to figure out different scenarios varying one or more inputs. In order to guarantee reliable findings to the committee, the model should be characterized by robustness and validity. In order to offer meaningful and operative reports, the model should be optimised. A considerable part of time was due to these activities.

Finally, the last step of the work was the final report. This paper has been written under the unique advertisement to be adherent to the mental generating process of this thesis. The most important part of the essay writing was the analysis of findings of the case study we investigated. It was important to address remarkable considerations to the study. This study attempts to suggest managers possible intervening areas to engage for improvement.

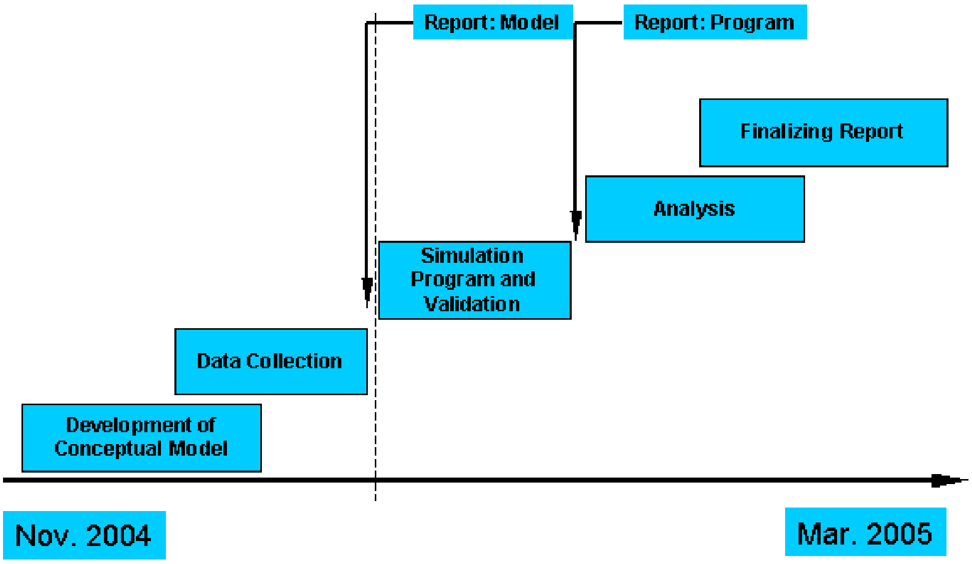

Figure 2.6: Time schedule[23]

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[23] Own

Part II - Theoretical framework

Supply Chain Management

The third chapter will introduce the basic theoretical concepts the work is based upon. After defining what is a supply chain, the chapter deals with the main drivers, facilities and drawbacks behind supply chain management. Finally, there is presented a brief description of information system to support the supply chain management.

3.1 Introduction

Rarely would anyone starting out on a trip just walk out the door with no thought of where to go or what to do. The same is true when beginning a research study. Each activity is best undertaken with some idea of what you want to do and, in the case of research, what you want to know. It is necessary to make a plan for carrying out the survey. This plan or map (research design) helps develop the research from an initial point to a further conclusion. This background from which the research takes origin is the theoretical framework.

3.2 Definition of Supply Chain

"In a time of shortening product life cycles, complex corporate joint ventures and stiffening requirements for customer service, it is necessary to consider the complete scope of the supply chain management (SCM), from suppliers of raw materials, through factories and warehouses, to demand in a store for a finished product". These are the opening words of Tom Davis' s *"Effective Supply Chain Management"* article[24]. Published more than ten years ago, it is striking how he underlined the necessity of a change on the business management towards an integrated view of processes along with the company. For a firm, aiming at gaining a strategic competitive advantage upon the benchmarking, the rethinking of all the company's business processes in term of shared activities within the supply chain has become fundamental.
Historically, companies focused on their own organisation aiming at increasing their profits. They saw themselves as one single company against other companies to exploit market opportunities and enlarge profitability: the relationships with suppliers were adversarial rather co-operative. This focus has been changing and it is more common to hear about supply chains of different companies competing with each other rather than a single company's one. (Christopher, 1998) They have begun seeking to achieve cost reductions or profit improvements through a more competitive global supply chain.

The term Supply Chain Management (SCM) was originally introduced by consultants in the early 1980s and has subsequently gained tremendous attention.[25] SCM' s growth has been observed through the numbers of sessions at the annual Council of Logistics Management, meetings with "Supply Chain" in the title and it has been confirmed since the publishing of two new international

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[24] Davis, T., (1993), *"Effective Supply Chain Management"*, Sloan Management Review

[25] Lambert, D., (1998), *Supply Chain Management: what does it involve?,* The Ohio State University Press

journals dealing entirely with supply chain issues *(Supply Chain Management: An International Journal* and *Supply Chain Management Review*)[26]

Despite of this increasing interest on supply chain opportunities, thus becoming one of the most important tasks for manager in the recent few years[27], sometimes the meaning of these words has been missing.

The Supply Chain Council defines SCM as the *"effort involved in producing and delivering a final product from the supplier's supplier to the customer's customer"[28].*

The Global Supply Chain Forum defines the SCM as *"the integration of key businesses processes from end user through original suppliers that provide product, services and information that add value for customers and other stakeholders"[29]*

This work neither aims at providing the most appropriate definition nor at analysing all the nuances of the concept. Indeed, it has been preferred to summarize the most spread definitions in the table presented below:

Author(s)	***Definition of Supply Chain***
Jones and Riley, 1985	The planning and control of a total material flow from suppliers through manufacturing and distribution to the end–user.
Stevens, 1989	A system whose constituent parts include suppliers of materials, production facilities, distribution services and customers, all linked together via the feed forward flow of materials and the feedback flow of information.
Ellram, 1991	A network of firms interacting to deliver a product or service to the end customer, linking flows from material supply to final delivery.
Christopher, 1992	The network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form products and services in the hands of the ultimate consumer.
Davis, 1993	A network of processing cells with the following characteristics: supply, transformation and demand.
Cooper et al., 1997	The integration of business processes from end-user through original suppliers that provides products, services and information and add value to the costumers.
Christopher, 1998	The network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users.
Handfield and Nichols, 1999	It encompasses all activities associated with the low and transformation of goods from raw materials stage, through to the end user, as well as the associated information flow. Materials and information flow up and down the supply chain.
Schary and Skjott-Larsen, 2001	The entire set of activities involving the organization and flow of material and other resources to produce and deliver the product to the final costumer.

Table 3.1: *Chronological comparison of SC definitions*

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[26] Larson, P.D., Rogers, D.S.,(2002), *Supply Chain Management: definition, growth and approaches,* Journal of Marketing Theory and Practice

[27] Ibid

[28] Supply Chain Council, www.supply-chain.org, 2004/11/25

[29] Lambert, D., (2004), *The eight essential SCM processes,* Supply Chain Management Review, pp. 18 – 26

3.3 Logistics VS Supply Chain Management

The concept of logistics management is surely antecedent to SC' s one and it might be considered as an extension of it. Many logistics practitioners, academics and consultants view supply chain management as an extension of logistics outside the firm to include customers and suppliers. (Handfield and Nichols, 1999) The council of Logistics Management revised the definition in 1998 to reflect that logistics is only a part of the supply chain management: *"Logistics is that part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services, and related information from point-of-origin to point-of-consumption in order to meet customers requirements"*[30]*.* SCM has a much broader scope and considers the effect of functions other than logistics on business processes spanning multiple companies. Actually, there is an open debate upon this topic and not everybody agrees on this point of view.

In this work, Stevens's (Stevens, 1989) theoretical framework, afterward reviewed by Christopher (Christopher, 1998) and Harland (Harland, 1996) have been chosen. They state that the concept of SCM is an extension of the logic of the logistics in the sense that logistics primarily deals with optimising flows within the firm, while SCM philosophy entails a focused analysis of the all processes in the pipeline from the customers to the suppliers. Simply, the internal integration and an optimised process perspective only inward the firm is not sufficient.

Figure 3.1 reports the stages of the evolution in the integration in SCM activities as historically occurred. The first stage represents the basic pipeline of a unique company from purchasing to final distribution. In the second one, companies understand that to minimize buffers (e.g. related inventory costs) between functions within the same firm it is necessary to develop an essential integration. The third stage constitutes the natural subsequent step: all the company activities are focused on the attempt to achieve a linear flow (products/service, information, monetary) through all the functions.
The last stage introduces the distinction between logistics management and SCM. The concept of linkages among all firm activities is extended upstream to suppliers and downstream to customers. To be competitive in a global network market, it must be adopted a perspective not only concerning optimisation from raw materials through the delivery of final products within the organization, but also encompassing all the performers of the supply chain.

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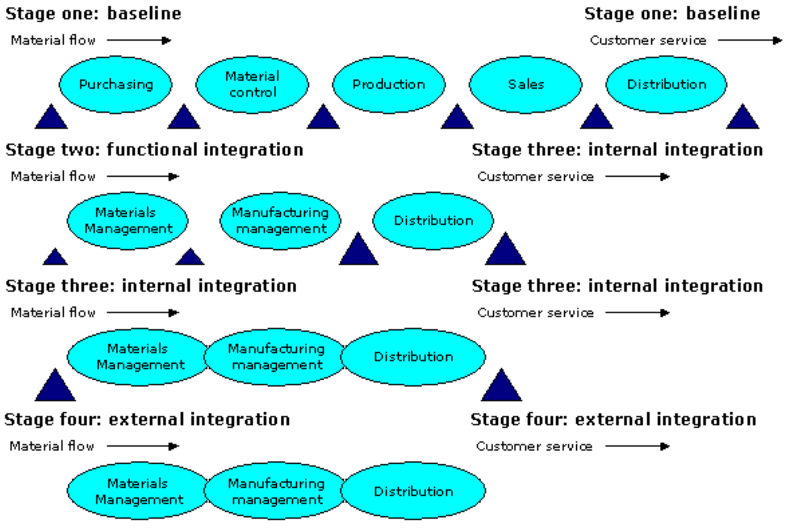
[30] Council of Logistics Management, 1998



Source: Stevens, G.C., "Integrating the supply chain"

Figure 3.1: *Logistics and SC Management*

Seemingly contrasting with Stevens’s analysis, Harland’s survey (Harland, 1996) represents another important contribution in the field. He considers the last two stages of the figure above and he overshoots Stevens’ s research, distinguishing four types of supply chains:

a) Internal supply chain: focuses on internal flow of materials.
b) Dyadic or 2-part relationship: looks at the relationship between a company and its immediate supplier or customer.
c) Entire supply chain including the supplier’s supplier and the customer’s customer.
d) Network of organisations involved in the provision of a product or a service required by the end customer.

3.4 Value Chain

Before embarking on further supply chain’s notions it is important to understand what is at the base of the idea of implementing improved processes to reduce cost and gain strategic competitiveness. The value chain concept (Porter, 1985) it’s the framework to which this work is referring. The value chain provides a systematic way of examining the activities of a company within a supply chain.

Porter argues that the competitive advantage stems from the multiples discrete activities the firm performs. The value chain represents a tool by which it is possible to disaggregate a company into its strategic activities to realize the structure and impact of costs. If the firm is able to manage them better (i.e. through reduction cost strategy, differentiation strategy, focus strategy) than competitors, it will achieve success in the market place.

Hence, Porter subdivides the firm activities into two families: the primary and the support activities. The name `primary’ is due to the fact that all these type of activities contribute directly to the adding-value process. The others, instead, are overall activities embracing the functions within the company.

The difference between the product value from the customer perspective and the product value addressed to manufacture it represents the margin. The goal of the firm is to align all the activities in order to maximize the margin.

Primary activities are:

- Inbound logistics: materials are brought into the organisation
- Manufacturing: materials are converted into final products
- Outbound logistics: activities concerning with the delivery of final products
- Marketing and sales: attempts to place and manage an order
- Service: post-sales activities

Support activities are:

- Firm infrastructure: activities covering costs of for example legal affairs, finance, accounting, etc.
- Technology development
- Human Resources management
- Procurement: purchasing of various inputs for each primary activities.

The value chain concept was initially addressed to one single company activities. Further investigations underline how it is possible to extend this surrounding concept to an entire supply chain, from suppliers to customers. In this thesis, the "extended" value chain concept has been adopted. The figure below explains better the meaning: the original Porter's definition referred to the firm activities whilst the extended version regards the interaction with suppliers and customers.

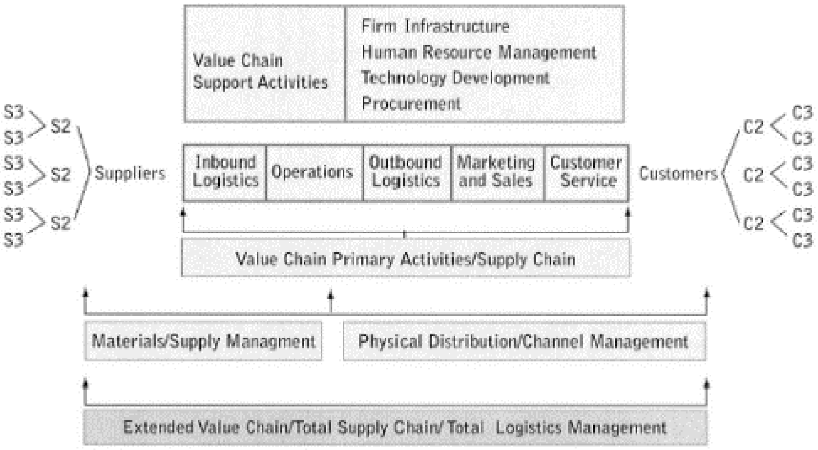


Figure 3.2: *The Extended Value Chain*[31]

3.5 Characteristics of Supply Chain

In this paragraph, there are briefly highlighted the principal features to understand the SC concept.

- **Members involved in the SC**: a complete supply chain can include customers, retailers, distributors, manufacturers and suppliers. Each stage in the SC might not be present. As Chopra and Meindl (2000) suggest, the appropriate design of the SC will depend on both the customer's needs and the roles of the stages involved.
- **Activities involved in the SC**: an ideal view of the activities processed in a supply chain can include purchasing and material releasing, inbound and outbound transportation, warehousing and distribution, inventory control

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[31] Trent, R.J., (2004), "What everyone needs to know about SCM", *Supply Chain Management Review,* Vol. 8, N. 2, Mar., pg. 24

and management, demand and supply planning, order processing, production planning and scheduling, shipping and customer service. (Trent, 2004)

- **SC Flows**: in the SC there are three different flows between the participants: flow of goods (service), information flow and monetary flow.
- The *product flow* consists of the efforts to transfer all the goods from the supplier to its customers. It usually contains decisions as where to manufacture, the location of warehouses, optimising-stock levels, how to ship and deliver the goods.
- The *information flow* is a bi-directional flow, from the firm to the customer (e.g. marketing promotion and information that the customer has to use to place an order), and from the customer to the firm (e.g. demand information, customer satisfaction).
- The *monetary flow* represents the necessary parallel flow that allows the accomplishment of all the activities above cited (Johanson et al., 1997). For example, the monetary flow regards cash-flow, financial operations and accounting activities.

The Figure 3.3 will clarify the concepts:

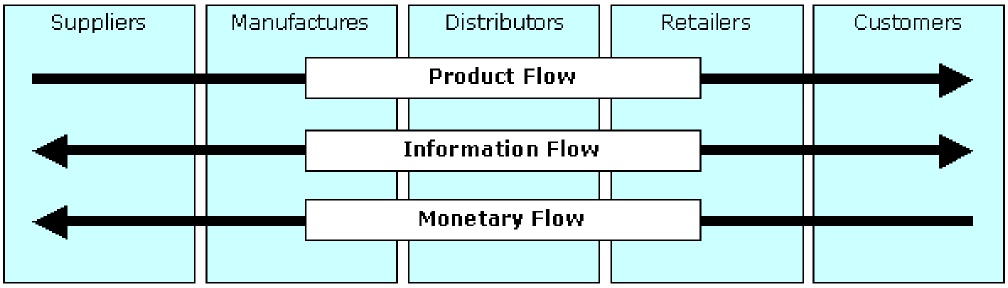

Figure 3.3: *Flows in SCM*

3.5.1 Drivers of Supply Chain

Global competition, faster product development and reducing cost need are only few of the issues SCM tries to achieve. Companies have realized that they cannot be good at everything and if they want to compete, they have to align their businesses with that of the others involved in the same supply chain.
the main drivers to the change in the processes of the company are:

- **Customer orientation** – The main aspect that drives companies to look at the total process is just to become more effective in meeting customer needs and fulfilling the demand. In a wide world market customers have the opportunity to choose the desired product or service among a larger amount of possibilities. The customer satisfaction represents the first target that an entire supply chain strives to achieve.
- **Low cost** – Closely connected to the first objective, the “low cost” motto is almost an obsession for all companies. Not only do companies have to satisfy customer requirements, but they should do it at the lowest price, as well. Thus, if companies aim at being competitive, cost reduction in all the stages of the firm (and supply chain) becomes a “must”. The zero inventory philosophy, strategies of outsourcing in production or assembling and internal transport minimization are, for example, consequent strategic decision related to the absolute need for cost

reduction. In particular, inventory reduction is one of the most relevant items in term of cost savings and on the list of benefits obtained by a supply chain implementation. Indeed, most successful case histories of supply chain management or cycle time compression include inventory reduction (La Londe, Masters, 1994)

- **Time compression** – Both customer orientation and global enlarged competitiveness have forced management to consider the time to market reduction as a primary task to satisfy customers' requirements and consequently to take into evaluation the total order cycle. Moreover, firm performances (i.e. order cycle time reduction) are dependable on supplier and customer performances, even if they are not strictly related. As a consequence, the actors involved in the chain are urged to focus on their dependability and capacity to increase flexibility. The flexibility is the way for the supply chain to cope uncertainty typically characterizing all business environments (Slack et. al, 2004)
- **The development of Information Technologies (IT)** – The continuous improvement in the Information & Communication Technology (ICT) represents the first reason for the necessity of integration in the company activities. In particular, the development of web-based applications (e.g. e-commerce) has lead towards shorter supply chain, characterized by enhanced reactivity, responsiveness and capability to be switch to different scenarios.

It might be curious to highlight that in literature there is a debate on the correct definition of SCM concept. According to previous analysis, Tompkins and Jernigan (1997) argue that "supply chain management" is a misnomer and should be replaced by "demand flow management". "Demand" instead of "supply" to underline the customer approach to the product flow, "flow" rather than "chain" to comprehend that it is characterized by a continuous movement and integrated approach to end user satisfaction.

Schary and Skjott-Larsen (2000) make a clear distinction between supply chain, concerning the first stages of the entire chain (supplier, manufactures) and demand chain, much more dealing with distributors, retailers and customers requirements.

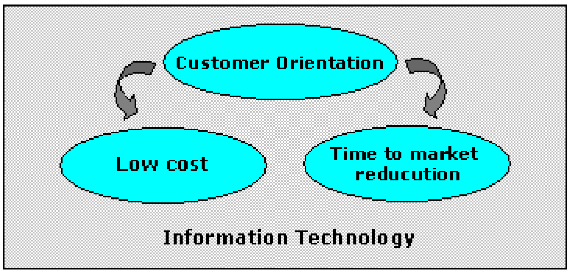

Figure 3.4: *Drivers behind Supply Chain*

3.5.2 Obstacles towards SC orientation

Adopting a supply chain orientation is not immediate, because every actor within it has to align his targets to that of one staying before and later in the supply chain. In other words, SCM requires the coordination of a wide range of activities and flows that extend across functional and organizational boundaries.

The aim of this paragraph is to illustrate which are the main difficulties that a company adopting a SC policy has to face.

- **Supply chain performance** – The supply chain performance is a consequence of each stage performance. For instance, it occurs that sometimes the sites in object have different management teams, missions and operational goals. This implies inefficiencies and resistances for the overall chain. (Lee et al., 1992). In general, it is difficult to define and implement systems for the measurement of performances.
- **Structural and organizational change** – Internal problems, such as loss of employment or acceptance by management and employees of the new orientation might represent barriers to operational alliances within the supply chain. A company that achieve to improve the supply chain's activities should realize that better outcomes derive from an integrated approach. For example, organizational barriers may inhibit coordinated inventory control and lead to disagreements on inventory ownership and higher stock inventory. (Lee et al., 1992)
- **Information flow within SC** – Information is crucial to the performance of a supply chain because it provides the basis upon which supply chain managers execute transactions and make decisions. Sometimes, it is difficult to gather relevant and up-to date information across the supply chain since the lack of adequate databases and integrated information system. (Chopra and Meindl, 2002). Furthermore, the lack of information sharing throughout the actors of the SC is responsible for the fluctuations and uncertainties in the demand. These drawbacks can be overcome by the implementation of information systems (i.e. electronic data interchange (EDI), point-of-sale (POS)) to share the information (Slack et al., 2004)
- **High trust & Responsiveness –** SCM and cycle time compression should be based on high levels of trust not only within the various parts of a given firm (production, distribution or sales) but also they must be established and maintained between the various actors of the SC (suppliers, sellers and warehouses). The members should share effective and sensitive data. Inability or unwillingness to share these data will fail the attempt to accomplish the close coordination implied by SCM strategy. (La Londe and Masters, 1994)

3.5.3 Benefits of SC

Further analysis of SC features would be useless if we don't spend few words to realize the potential opportunities offered by a SC implementation.

Perhaps, many of the SC benefits have already been introduced along with this dissertation or, at least, they are implicitly deducible. Others coincide with the drivers of the SC itself. Anyway, it is worth presenting them hereby by means of a schematic prospect (Christopher, 1998, Lambert, 1998, Chopra, 2002):

- Improved customer service and customer satisfaction
- Competitive advantage
- Reduced demand amplification
- Reduced uncertainties
- Reduced inventory investment
- Reduced stock levels
- Compressed order-fulfilment cycles

- Cost reduction (also through economies of scope and network)
- Improved flexibility
- Major control (cost performances, quality, etc.)

3.5.4 SC trade-offs

Trade-offs result when, for instance, an organization strives to achieve an improved target in one direction obtaining worse performances in another direction. Trade-offs occur again when organizations make choices to accept less of one thing in order to receive more of something else. David Simchi-Levi (Simchi-Levi, 2003) presents five common trade-offs that are present in most supply chains. They constitute a source of conflict among functional groups, particularly when measurement systems encourage narrow behaviour.

Supply Chain Trade-Offs	
Lot size – Inventory	Large lots lead to high inventory in anticipation of demand.
Inventory – Transportation Cost	Aggregating material movements allows fewer and larger shipments and reduces transportation costs. Less frequent material movement however requires holding inventory and possible decreases in customer service.
Lead-Time – Transportation Cost	Transportation costs are lowest when large quantities of items are transported between stages of the supply chain creating longer lead-times
Product Variety – Inventory	Increased variety and features create new part numbers, which affects forecasting complexity, product placement across the supply chain and inventory levels.
Cost – Customer Service	Increased customer service levels usually require higher inventory levels and faster delivery, which increase supply chain costs.

Table 3.2: *Simchi-Levi's framework*[32]

3.6 Supplier Relationship Management

Supplier Relationship Management includes those processes focused on interaction between the enterprise and suppliers that are upstream in the supply chain.

Since the beginning, one of Tetra Pak's core values has been sharing competencies, values and vision throughout its pipeline. To be competitive as a global leader of packaging solution, it had to establish efficient relationships with few confident suppliers.

This paragraph will present some simple concepts about supply relationship management (SRM). As highlighted in previous pages, integration along with SC and information sharing are almost obliged choices in a wide and competitive market. If the importance of creating and maintaining effective supply chain relationships is evident, supply chain professionals also address relevance to determining the appropriate relationship for a particular partner and to selecting

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[32] Simchi-Levi, D., Kaminsky, P., (2003) *Designing and Managing the Supply Chain, Concepts, Strategies and Case studies,* Boston, McGraw-Hill Irwin

the most appropriate supply chain approach (Trent, 2004). The Table below represents the framework of reference for supplier relationship management: the matrix 2x2 reports in one axis the number of suppliers and in the other the value related to that supplier. It asserts that varying the number of items to manage, the strategy of SRM varies, too and different types of SC practices are required.

Segmenting Supply Chain Relationships and Approaches			
Value	High	**Strategic Items** Collaborative Relationship Cost Focus Win/win approaches	**Leverage Items** Cooperative relationships Cost Focus Usually win/win approaches
	Low	**Transaction Items** Transactional relationships Transaction cost focus Win/lose approaches	**Market Items** Competitive relationships Price focus Win/lose approaches
		Few	Many
		Qualified Suppliers	

Table 3.3: *Supplier Relationship Management*[33]

The '*transaction items'* quadrant is representative of companies managing goods and services with a lower total value and a limited supply market. The search for multiple and different suppliers is not proportioned to the value resulting from this effort.

The '*market items'* quadrant is detected by the intersection between many suppliers box and lower value items box. This is a situation of low suppliers-switching cost and relationships are competitive and focused on price.

The *'leverage items'* quadrant is the case of high volume goods manufactured by a group of specified suppliers. This strategy implies the adoption of a cooperative relationship between the provider of items and its customers. Thus, long-term contracts for larger volumes are typically used in this quadrant. In this stage a total cost rather than price oriented vision is the more relevant.

The *'strategic items'* quadrant concerns goods representing products with high value added for customers. A collaborative relationship should be developed to be adherent or eventually differentiate according to customers' requirements.

3.7 Managing the Supply Chain

The first goal of an organization aiming at compete in a global market is to implement actions, techniques or tools allowing it to gain a competitive advantage from competitors (Cigolini, Cozza, Perona, 2004)

3.7.1 SC' s techniques

The SC techniques are the main building blocks through which managers define their supply chain's hard framework and control system, shaping its configuration, its management rules and ultimately determining its performance (Cigolini, Perona, 2004).

There are hereby presented the main techniques universally recognized as principles to adopt an efficient and improved supply chain. Some of them (i.e.

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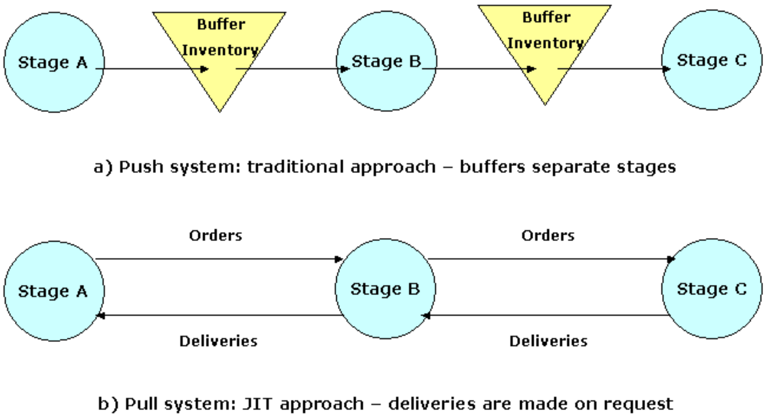
[33] Trent, R. J., (2004), "What everyone needs to know about SCM", *Supply Chain Management Review* , March, Vol.8, N.2, pp. 52 - 59

just in time (JIT), continuous improvement) might be inappropriately called techniques, since they represent out-and-out philosophies or improvement approaches.
The purpose of this paragraph is not to introduce a detailed description of every technique but to offer the reader a simple breakthrough among these widespread and accepted concepts.

- **Just-in-time (JIT)** is popular in the supply side of the chain. Based on the idea that no activity should take place until there is customer demand for it (pull system), JIT is the opposite of traditional push systems, where products are manufactured in batches on the basis of their forecasted future demand (Isaac, 1985). In other words, the pull system is based on the principle that the order will be generated when there is a demand for the final product at the end of the supply chain. This demand will flow backwards through the supply chain and "pull" the products through the system. According to the push system, instead, the order quantities are calculated, products manufactured and then, final products delivered. This approach leads to queues and intermediary inventory stocks because the production is often exceeding the real request. In such this way, the capital tied up in the chain increases. The MRP system is based upon a push system.
  JIT means producing goods and services exactly when they are needed: not before so the have to wait as inventory, nor after they are needed so the customers have to wait (Slack et all., 2004). Not only is JIT connected to low inventory level, but it implies high product quality, as well. Actually, *JIT aims to meet demand instantaneously, with perfect quality and no waste*[34]



a) Push system: traditional approach – buffers separate stages

b) Pull system: JIT approach – deliveries are made on request

Figure 3.5: *Push and pull system*

- Strictly related to Just-in-time there is the **continuous improvement** approach. It implies simple and small incremental improvement steps. The continuous improvement approach stems from the Japanese "kaizen" concept, that means *"continuing improvement involving everyone, managers and workers alike"*[35]
- The JIT principles can be extended from one side to distribution channels (**continuous replenishment program (CRP)**), with the purpose of creating a win – win situation, according to which vendors can improve

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[34] Bichen, J., (1991), *Implementing Just-in-time*, IFS

[35] Imai, M. , (1986), *Kaizen – The key to Japan's competitive Success*, McGraw Hill

inventory control, production planning and customer service, whilst distributors increase inventory turns and improve customer satisfaction (Cigolini et all. 2004). From the other, relationship with supplier can be optimized by **vendor managed inventory (VMI**) technique, by which the supplier controls customer's inventory via electronic data and ensure and adequate level of service (i.e. material amount or response time)

- The **reordering policies technique** (i.e. economic order quantity (EOQ), fixed order quantity ordering (reorder point ROP), periodic reorder, etc.) risks to be not suitable in case of multi-tiers supply chain, since it causes distortions in inventory. These technique tend to share one weakness which is they frequently lead to stock levels being higher or lower than necessary, particularly in those cases whether the rate of demand may change or occurs in discrete 'lumps'. Many firms, in effect, have observed the *"bullwhip effect"* in which fluctuations in orders increase as they move up the supply chain from retailers to wholesalers to manufactures to suppliers (Lee, 1997). Whether demand is fixed for a long time and the variation in supply chain virtually do not exist, the use of this technique is reasonable (Axsäter, 2000).

  In particular, the economic order quantity (EOQ) formulation calculates the best order quantity for each batch order and balances the cost of holding inventory against the costs of placing replenishment orders.

  Defined:

  D = Annual demand of the product
  S = Fixed Cost incurred per order[36]
  H = Holding Cost[37]

$$EOQ = \sqrt{\frac{2 * D * S}{H}}$$

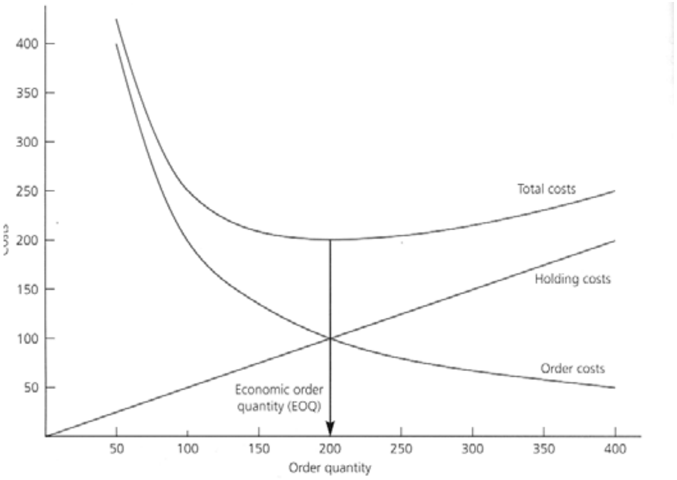

Figure 3.6: *Economic Order Quantity*

When inventory levels falls to a certain point predetermined point (ROP), the order should be placed and the amount to be ordered is fixed by EOQ formula.

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[36] The fixed ordering cost includes all costs that do not vary with the size of the order but are incurred each time an order is placed (e.g. administrative cost, set-up cost, etc.)

[37] The holding cost is the cost of carrying one unit in inventory for a specified period of time. It is a combination of the cost of capital, the cost of physically storing the inventory and the cost of carrying one unit in inventory and the cost that results from the product become obsolete.

Alternative methods include the regular review of stock levels with fixed intervals between orders.

- **Business process redesign (BRP)**, according to Hewitt (Hewitt, 1994) and Hammand (Hammand, 1993) is the redesign of business processes to achieve improvements in critical measures of performances. Typical are shortening lead-times, increasing flexibility and reducing costs.

3.7.2 Tools to implement SC's techniques and measure SC' s performances[38]

One approach that some companies adopt to compare their operations with those of other companies is called **benchmarking**. Benchmarking is almost the process of learning from the others. The goal of this operational tool is regarding both to judge how an internal operation has been done and to investigate different ideas from competitors that might be copied. Thus, two different types of benchmarking are below distinguished (Schary and Skjott-Larsen, 2000):

- Competitive benchmarking: this is benchmarking against direct competitors in your own market. This may involve benchmarking of strategic measures such as market share, return on assets or customer satisfaction. It may also focus on functions or processes. It may stimulate improvement in the company if they can get a detailed view of their competitors' situation. This information is usually hard to get though.
- Non-competitive benchmarking: it is focused on strategic measures, functions or processes of non-competing companies or of functions or processes within the same organization. Frequently, there may occur similarities between processes in companies in different industries. Benchmarking companies in other industries may very well lead to innovative approaches to old problems and conduct to significant improvements

The **key performance indicator (KPI)** is an objective measurement tool for comparing company or project performance in key activities of a business. The key performance indicators provide a benchmark that a project or a company's performance can be measured against. The information provided by a KPI can be used to determine how an organization's move towards best practice.
KPI can be used for a range of activities associated with a business, for example cost and time reduction, cost and time predictability, number of defects, accident records, client satisfaction, productivity and profitability.

Companies need to objectively compare and benchmark their practices and performances so that they can identify areas of improvement. After the comparison the company needs to implement the changes that will lead to performance improvements. The purpose of a KPI is to provide an objective performance measures in a key activity associated with a company or project. This can then be used to compare and benchmark against the range of

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[38] The broadness of this field forced us to choose the reported perspective. It is not the unique. Actually, in literature, a great debate around what consider tools or not could be found. Since the purpose of this paragraph is just to illustrate which are the main existing tools to manage and improve supply chain, we adopt the methodological choice to present the most common tools in agreement to many authors as possible.

performance currently being achieved across other projects, companies or the rest of industry.

3.8 Information Systems within the Supply Chain

Information is crucial to the performance of a supply chain because it provides the basis upon which supply chain managers make decisions. Information Technology (IT) consists of the tools used to gather and collect information, gain awareness of it, analyze this information and act on it to improve the performance of the supply chain. (Chopra et all. ,2000)
The development of IT for managing and communicating transactional data has been a primary focus of computer scientists and information technologists for over 40 years (Shapiro, J.F., 2001). To manage the great amounts of information generated by a companies activities, today **Enterprise Resource Planning (ERP)** System is a widely spread information system adopted all around the world. Born as a development of Manufacturing Requirement Planning (MRP) system, the ERP systems includes software and hardware that facilitate the flow of transactional data in a company relating to manufacturing, production planning and control, logistics, finance, marketing and sales, quality and human resources. In principle all business applications of the company are integrated in a uniform system environment that accesses a centralized database system (Shapiro, J.F., 2001). The enhanced visibility that integrated information gives is the most benefit of ERP.

Other relevant information tools are:

- **On line connections** (electronic data interchange (EDI), Internet technologies) support the transfer of data and other business documents through each tier of the supply chain, providing at the same time accuracy and control. This achievement of paperless transactions between two trading company represents costs saving from logistics and administration. So, the Internet allows customers to reduce search time and transaction costs, permits to access t global market and enables different organizations in a supply chain to share information with each other ain a highly effective way (Christopher, 1998).
  Today, the Internet plays a significant role in many supply chains and companies are using the Internet to conduct a wide variety of supply chain transactions. Examples of e-business are abundant.[39] E-business affects supply chain in term of *responsiveness* and *efficiency.* Impacts of E-business on responsiveness mean for instance major opportunities for direct sales to customer, faster time to markets, personalization, etc. Company savings are, instead, the greatest impact of E-commerce on efficiency.
- **Automated identification systems** (i.e. bar codes, point of sale (POS), radio frequency identification (RFID)) are commonly used to monitor goods movement from throughout the logistics system. Barcoding of products has been the first step towards automated movement. Radio frequency identification, or RFID, is a generic term for technologies that use radio waves to automatically identify people or objects. An RFID system consists of a tag, which is made up of a microchip with an

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[39] Details in Chopra, S. Meindl, P., (2004), Supply Chain Management: Strategy, Planning and Operation, Second Edition, Prentice Hall Edition

antenna, and an interrogator or reader with an antenna. The big difference between the two (bar code and RFID) is bar codes are line-of-sight technology. That is, a scanner has to "see" the bar code to read it, which means people usually have to orient the bar code towards a scanner for it to be read. Radio frequency identification, by contrast, doesn't require line of sight. This is the reason for increasingly interest for RFID systems.[40]

3.9 Resume

This chapter reports the frame of reference of the thesis. Our purpose has not been that to deepen into supply chain's concepts and techniques, but to present a breakthrough of the largest notions adopted. Thus, the definition of supply chain and its major features have been introduced. The main purpose of this paragraph was the historical justification in management for the need of integration activities among different companies.

In order not to run the risk of lose the meaning and opportunities offered by the chain's concept, efficient tools and techniques to manage the supply chain have been reported. Last paragraph dealt with the information systems to support supply chain's activities. Even not fundamental for the task of this thesis, we repute it fundamental to the panoramic comprehension of the subject.

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[40] More detailed information at www.rfidjournal.com

Risk evaluation

Consequently to concepts have been introduced in the previous chapter, this fourth one will present notions regarding the risk analysis within a supply chain. Firstly, the definition of risk and uncertainty will be presented. A theoretical process for the risk management will follow. The description of the features of the software adopted in this thesis to evaluate risk analysis will conclude the chapter.

4.1 Introduction

In many business environments, the need for fast responding to market requirements has become a strategic issue. To satisfy them, companies' networking (i.e. suppliers, manufactures, retailers, customers) has become an inevitable solution. In such this way, companies deepen their relationship with partners along with the value chain, thus becoming more dependent on each other. This solution offers opportunities like cost savings, ability to concentrate on core competencies, improved customer service, but also requires high trust and responsiveness. This implies uncertainty and consequently, risk.
For example, the increasingly growing decisions to outsource production imply inherent risk. Furthermore, in striving for efficiency, companies can introduce risks into their supply chains. Just-in-time for instance, might become "just-too-late" if something goes wrong and there is no safety switch into the supply chain (Hauser, 2003). Risk management in the supply chain means moving efficiently at the lowest total cost and without compromising the quality of the product or customer satisfaction. In evaluating the supply chain of few related companies, it might occur to underestimate the risk and its complexity. One of the management tasks should be the risk assessment. In a global competitive market, nowadays the "risk issue" must be weighed and balanced by the supply chain management. By understanding the characteristics of supply risk, supply chain management professionals can implement better strategies for better managing that risk.

4.2 Risk and Uncertainty

Inadvertently, in the introduction paragraph *uncertainty* and *risk* have been introduced without the necessary definition and distinction.

"*Uncertainty exists whenever one does not know for sure what will occur in the future. Risk is uncertainty that matters because it affects people's welfare. Every risky situation is uncertain, but there might be uncertainty without risk.*"[41]

The Royal Society (Royal Society, 1992) defines the risk as the *"the chance, in quantitative terms, of a defined hazard occurring. It therefore combines a probabilistic measure of the consequence of that/those events".*[42]

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[41] Bodie, Z., Marton, R. C., (1999), *Finance,* Hemel Hempstedad: Prentice Hall

[42] Ibid.

The risk is surely an outcome of our incapability to see the future. Quantitatively, a definition of risk might be the product of the probability of an event and its impact on business.

$$Risk = Probability * Impact \qquad (4.1)$$

This formula might be illustrated by a matrix 2x2, in which the y-axis represents the "Probability" of one event and the x-axis, its "Business impact". The riskiest outcome is when at a high probability of a given event corresponds a relevant impact on the business environment.

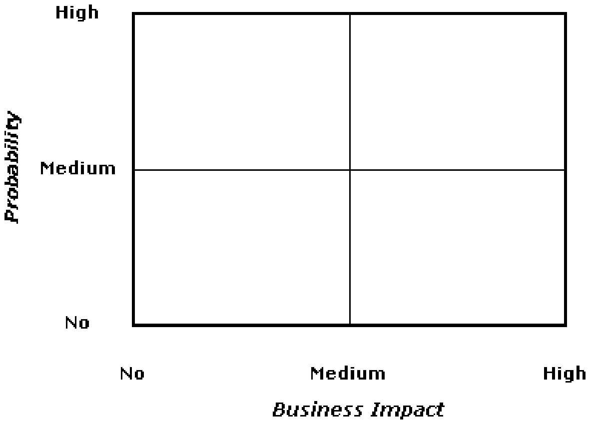

Figure 4.1: *Risk matrix*[43]

4.3 Characteristics of risk

As quoted below, risks derive from our incapacity to predict future situations and a significant degree of uncertainty enough to be relevant for us is related to those.
Firstly, risk can be subjective or objective. While, for instance, flipping a coin should be considered an objective risk (you know exactly the probability and the eventual impact of both equal probable scenarios), a survey about the weather for the next week might be subjected to different points of views. Most risks, however, are subjective and this has important implications for anyone analysing risk or making decision based on risk analysis.

Secondly, risk might be evaluated through qualitative and quantitative approaches. In the first case, supply chain risk map, grid or matrix are tools for the qualitative evaluation of risk how is perceived by decision making manager or groups of decision making managers according to their experience and judgements.
In a quantitative approach, two different calculations of risk should be underlined, thus reflecting two perspectives. Deterministic calculations have a known set of inputs which will result in a unique set of outputs. Stochastic

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[43] Norrman, A., Jansson, U., (2004), "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident", *International Journal of Physical Distribution & Logistics Management*, Vol. 34, N. 5, pp. 434 - 456

calculations have random variables as input. Random inputs leads consequently to random outputs.

4.4 Taxonomy of risk sources

There are different ways of classifying risk (i.e. objective, subjective, commercial, non commercial, etc.), but there are also many ways of categorizing risk sources. Thus, risk and source of risk should not be mixed. As said before risk is the event with a probability and a surrounding effect, the source of risk is the phenomenon that is the cause for uncertainty and, consequently, risk.

Juttner (Juttner, 2002) points out three types of sources of risk:

- Risk external to the supply chain, that means “political risks” (e.g. terrorism, political upheavals, etc.), “natural risk” (e.g. fires, accidents, disruptions, hurricanes, earthquakes, etc.) and “market risk” (e.g. volatility of customer demand)
- Risk internal to the supply chain, that regards, for instance, production (e.g. machine failure), demand planning (e.g. uncertainty) or labor (e.g. strikes)
- Network related risks, referring to risks arising from interaction between organizations within the supply chain (e.g. lack of interaction).

Hallikas (Hallikas, 2002) singles out four different categories of risk sources, leaving out risks external to the supply chain: customer demand, customer delivery, cost management, and weakness in development and flexibility. The first because demand might be too low or inappropriate, the second, since the incapability to answer in time customers’ requirements. But having demand and fulfilling deliveries can be not sufficient for a company: risky situation might outcome from inoculated cost management. Finally, the quickness and mutability of market features could represent drivers of risk for not very flexible companies or supply chain.

Zsidisin (Zsidisin, 2003) focuses his paper on supply risk, defining it as the potential occurrence of incident associated with inbound supply individual supplier failures or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand. Supply risk, therefore, involves the potential occurrence of events concerning inbound supply activities.
This definition and perspective seem to be appropriate according the subject of this thesis. Thus, here below there is reported the classification of the major supply risk sources, adopted from Zsidisin’s grid:

- Capacity constraints: the inability of a system to produce an output quantity in a particular time period.
- Cost reduction capabilities: the act of lowering the cost
- Cycle time: time between purchase request to a supplier and receipt
- Inbound transportation
- Information system: information system capability to transfer timely, accurate and relevant information to buyers
- Inventory management: supplier ability to manage raw materials, work-in-process, and finished goods and inventories
- Process technological changes: the frequency of new ideas and emerging technology

- Quality: the unsatisfactory quality of shipments
- Supplier availability: availability of strategic materials in terms of quality and quantity and relative strength of suppliers
- Volume and mix requirements changes: demand fluctuations in quantity and type for a component or service

4.5 Risk management process

Risk management might be viewed as the process of decisions making about risks and their subsequent implementation. This process begins with the definition of risky situations and stops with the decisions prompted to face them. Likewise, the risk management process focuses on understanding the risks and minimizing their impact. (Norrman et al., 2002). It is thank to risk management that risks are evaluated and managed to reduce them to an acceptable level.

A common risk management process might be divided into four subsequent steps: risk identification or analysis, risk assessment, risk management actions and risk monitoring.

4.5.1 Risk identification

Risk identification is the first step in the risk management process. By identifying the risks, the decision-maker realizes which the cause of uncertainty is. The main goal of this stage of the analysis is to recognize future uncertainties to enable proactive management of risk-related issues. In a supply chain environment, this risk identification entails identifying both direct risk for its operations and the potential sources through each tier along with the supply chain.

A risk analysis is based on uncertainties in the input information. Naturally, this uncertainty will be promulgated throughout the analysis, conducting to corresponding uncertainty in the findings. Nevertheless, this is a feature is not misleading: it is however significant to clearly describe the uncertainty which the analysis and assessments are based upon.

Many could be found in literature to identify risk and its sources. One important is risk mapping: it is developed a map (e.g. grid) to map risk sources and their potential consequences. Other techniques for the research of factors are the “fault tree analysis” (FTA) and the “event tree analysis” (ETA). They are diagrams reported the sequence of failures that may propagate through a complex system (Norrman et al., 2002). The FTA diagram examines all potential events leading up to the initial critical event. It weighs the critical factor and the diagram presentation of findings shows where the system fails. The ETA diagram, instead, reveals all situations it might happen after a critical event. It tries to estimate the outcomes following initiating event by investigating its consequences. Finally, What-if analysis can be conducted to consider which output scenario will be obtained, if the inputs are changed.

4.5.2 Risk assessment

As seen, the first step in risk analysis is the comprehension of the existence of risk and the need for its recognition. But it is not sufficient: it must be quantify.

Quantifying a risky event means determining the relative likelihood of occurrence. Risk assessment provides this type of information.
Yates and Stone (1992) state risk assessment should establish loss potential, identify eventual losses and their likelihood, assign significance of losses and appraise overall risk. In fact, risk assessment and prioritization allow the decision makers to choose the most suitable management action to minimize the impact of risk.

One possibility is to compare different events by assessing them probabilities and consequences of a risk event (Hallikas, 2001). Examples are matrix maps (e.g. Figure 4.1) on a five level class scale (for probability, very unlikely, improbable, moderate, probable, very probable; for impact, no impact, minor impact, medium impact, serious impact, catastrophic impact).

Risk can be assessed through deterministic and stochastic models. Without repeating what stated in the previous paragraph, the main difference between the two approaches is the way in which they take into consideration the uncertainty. In other words, uncertainty, not included in inputs, is propagated throughout the model providing uncertain outputs. Instead, by utilizing stochastic models, the inputs account uncertainty. Thus, the outputs are described by a probabilistic distribution, which illustrates the uncertainty of the result.

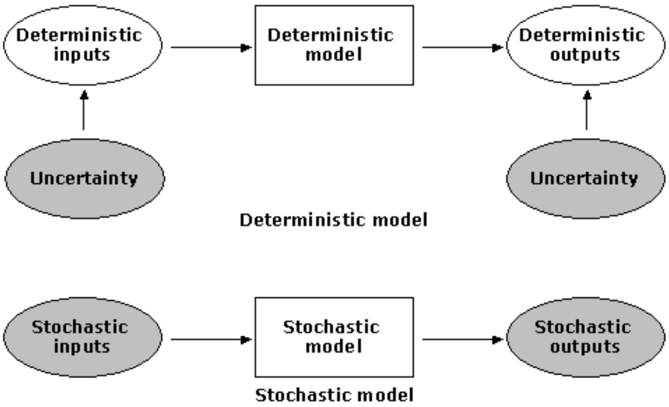

Figure 4.2: *Deterministic and stochastic models*[44]

Finally, software packages are more and more available for the purpose of supporting risk analysis and assessment. They also offer greater opportunities in term of simulation of model affecting risk. The two most commonly used are Crystall Ball and @Risk[45].

4.5.3 Risk management actions

Risk management is the third step of the risk management process. In this stage, considerations dealing the acceptance or not of the risk level are made, decisions facing the assessed risk are taken and eventually, implementation of actions to reduce consequences or probability of occurrence are deeply evaluated.

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[44] Adopted from Svanberg, J., (2004), *A Constructive Approach to the Interaction Between Risk and Logistics*, Lund University

[45] For Crystall Ball, www.decisionengineering.com; for @Risk, www.palisade.com

So, decision maker's task is to estimate whether the risk is sustainable and whether is not, to implement actions to minimize the risk impact. This might be done by means of:

- Sensitivity analyses
- Scenario analyses
- Analysis of distribution

Examples of how to reduce the impact could be for instance an extra safety inventory or having specific risk manager teams. Zsidisin (Zsidisin, 2003) suggests technique as process improvement or buffer strategies. Risk might also be transferred to supply chain partners by changing delivery times of suppliers (e.g. JIT), to customers (e.g. make-to-order, (MTO)) or by outsourcing activities (Norrmann, 2002). Other actions might deal with the development of strategic alliances or increased level of communication and transferring data along with the supply chain.

4.5.4 Risk monitoring

The company and its environment are not static and thus also status changes. The recognized risk factors can be monitored to identify the potential increasing trends in their probabilities or consequences. In addition, new significant risk factors may appear. To identify these, it is necessary to monitor the changes, customer needs, technology, partner strategies and competitors and to update the risk assessment correspondingly.

4.6 Supply Chain Risk Management (SCRM)

Although the most relevant concepts dealing with risk have been presented and the theoretical process for risk evaluation has already reported (according to supply chain perspective), it seems important to focus briefly on supply chain risks management concept.

Supply chain management risk (SCRM) is the collaboration with partners in the supply chain to apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources (Norrmann, 2002).

Important factors that boost supply chain vulnerability are:

- increased use of outsourcing as business strategy;
- more integrated processes between companies;
- reduced lead-times, buffers and inventories;
- increased demand for on-time deliveries
- shorter product life cycles
- compressed time-to-market

Sharing risks between members along with the actors of the supply chain might be a strategy for an appropriate SCRM. In any case, the purpose of the SCRM is to understand and try to avoid the ripple effects that business disruptions can have in a supply chain.

4.7 @Risk[46]

There are different packages to draw risk analysis in the market. In this thesis @Risk has been utilized. With @Risk, the uncertainty present in the estimates is considered in order to generate findings showing all possible outcomes. It is a simulating software based upon the traditional Microsoft Excel environment, capable to combine all the uncertainties to be evaluated in the model and to provide consequent possibilities of outcomes.
@RISK is, precisely, an add-in to Microsoft Excel. As an add-in, @RISK becomes seamlessly integrated with the spreadsheet of work, adding risk analysis to the existing models. The easy way to manage it is one of the main reasons for its use in this thesis.

Risk Analysis in @Risk is a quantitative method that seeks to determine the outcomes of a decision situation as a probability distribution. To make use of @Risk, a model must be developed. This is the first stage of the risk analysis with @Risk. It consists of four steps:

1. **Develop the model**: before utilizing @Risk, it is necessary to build a model as a representation of the real system that has to investigate. This has to be done in a spreadsheet.
2. **Define the uncertainty**: in this step, the uncertainty affecting the model has to be introduced. By using probability distribution functions[47] to represent the inputs of the model, @Risk evaluates this uncertainty. The other task of this stage is to choose and select the outputs which values we are interested in. Of course, the inputs and the outputs must be connected in the model built before.
3. **Analyzing the model with the simulation**: in this stage, the simulation has to be run. It determines all the possible outcomes of the outputs that were selected before. @Risk recalculates the findings thousands of times, entering in turn random values of the input. Thus, each simulation offers a possible combination of uncertain values or a scenario that could outcome. Each finding of the simulation includes statistical information: they are reported in a spreadsheet-window. Finally, through its simple graphical display of outputs, @Risk allows two types of advanced analyses, the sensitivity analysis[48] and scenario analysis.
4. **Making decisions**: the last step of the process is the decision making stage. After having collected the previous analysis, managers or researchers could take their decision to face and manage the assessed risk.

@Risk adopts Monte Carlo simulation to draw the risk analysis. Monte Carlo method is a technique, using random or pseudorandom numbers, for a

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[46] The information reported hereby has been collected from the web-site (www.palisade.com) and from the supervisors.

[47] Probability distributions are statistical graphs representing a stochastic distribution of values. Examples are Normal, Triangular, Poisson, Histogram, etc.

[48] Sensitivity analysis of a model is used to determine which inputs are the most significant. Sensitivity analysis of the inputs to a simulation allows a review of an estimate to concentrate on the specific inputs, most likely to improve the accuracy of the estimate. The resulting outputs are graphed in a tornado graph, which display immediately the inputs that are the most significant. They are identified with longer bars at the top of the graph.

solution of a model. Random numbers are essentially independent random variables uniformly distributed over the unit interval [0,1]. Monte Carlo simulation is a quantitative simulation technique used in many different types of decision analysis models. The model is run repeatedly to determine the possible outcomes of the model. During each run a value for each variable is selected, randomly based on its specified probability distribution. As the Monte Carlo simulation is run, the model calculates and collects the results. The population of results is finally presented as the overall probability distribution for the simulation.[49]
Properly, the simulation in @Risk consists of two distinct operations:

- Selecting sets of values for the probability distribution functions contained in the cells and formulas on the spreadsheet.
- Recalculating the spreadsheet using new random values.

Sampling is defined the selection of values for the simulation from probability distributions. Monte Carlo sampling techniques are entirely random; samples are more likely to be drawn in areas of the distribution that have higher probabilities of occurrence.

Finally, the findings are probability distributions for the probable values occurring. The results are statistics and data reports for both inputs and outputs. By statistics, minimum and maximum calculated values, mean standard deviation and percentiles have been meant.

4.8 Resume

This fourth chapter had the purpose to briefly present the principal concepts of risk analysis. This task has been undertaken throughout a theoretical perspective. Therefore, the main notions of risk analysis, assessment and management have been introduced. Risk analysis and management is a new branch of the overall production management discipline and seems to have continuous growing interest (even more after the catastrophic events we assisted). Moreover, a process description of the risk evaluation has been depicted. The target was to establish a theoretical background for the further dissertation. In effect, for the case study investigated in this thesis, it will follow an evaluation of risk associated to each risky scenario it has been appraised significant of risk evaluation.
The last chapter was totally dedicated to the presentation of the software utilized for the risk analysis. It aimed to comprehensively describe the capabilities, opportunities and ways of working of the software. We are conscious that some details concerning @Risk functions are passed over. But this would be out of scope of this analysis.

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[49] "Why does this technique take its name from the Riviera playground of Monte Carlo? Because Monte Carlo has long been famous for its casino and for such games of chance as roulette, all generating random numbers. The randomness of these casino games is similar to the way the Monte Carlo simulation selects its variable values in the course of creating a model." Hauser, L.M., (2003), "Risk-adjusted Supply Chain Management, *Supply Chain Review,* Vol. 7, N. 6, pg. 69

Simulation Model for Supply Chain

This fifth chapter will introduce the simulation technique for the description of the supply chain. A description of the steps to construct a simulation model will follow. Finally, the characteristics and opportunities of simulation will be highlighted. This chapter will represent the last theoretical chapter to introduce the case study of the thesis.

5.1 Introduction

Supply chain planning is currently one of the hot topics in today's management. Simulation technology is emerging as a new tool to support supply chain management. It allows the researcher to evaluate the variation of a system and its interdependent connections. Thus, simulation permits a decision maker to establish the impact of eventual changes in the supply chain and their reflections on the other system components. Furthermore, simulation is a powerful tool to support estimation of performances of a whole real system.

Since the 1980s simulation has been adopted as tool to help analysis in manufacturing environments. The growth of its use, joint to the availability of simulation packages helped push the tool into many other application areas. The results were that many companies began to expand the utilization of simulation beyond manufacturing systems, looking at the start and finish of these processes, which are raw materials and finished goods. The perspective for the implementation of simulation tools to support decision enlarged the fields of application. (Wyland et al., 2000)

The introduction of supply chain management became a task in the mid-1990s and created a marketplace for tools that could address basic issues surrounding the flow of products from vendor to customer. These tools are capable to collect valid information regarding the four basic processes involved in a supply chain: plan, source, make, delivery. Similar to the success of the simulation market, the supply chain management software has been able to provide a tool that can assist in what had been a time-consuming task of scheduling the entire supply chain from order to delivery (Wyland et al., 2000).

5.2 Simulation

Simulation is a method by means of which it is possible to describe and imitate the behavior of a real system over time. The objects of interest of the system are called entities and the relationship between them might be expressed in mathematical, logical or symbolic terms.
When the simulation model is built, a lot of "What if" analysis can be conducted. What if analysis is applied when the objective is to change a real existing system or to develop new descriptive model. Therefore, simulation can be used as an analysis tool or a design tool (Shapiro, 2001).

5.3 Characteristics of simulation

Here are reported the main features regarding of simulation modeling. It has to be observed that simulation is always to be referred to the concept of supply chain that is the surrounding topic of this thesis.

5.3.1 Terms and demarcations

A system has to be viewed as *“a group of objects that are joined together in some regular interaction toward the accomplishment of some purpose”*[50]. As said the entities are objects of interest, whilst each feature of each single entity is named *attribute*. The period of time, finally, until which the activity is manipulated, is defined as *activity* of the attribute. (Banks, 1996)

Simulation models can be classified as either *static* as either *dynamic*. A static simulation represents a system at a specific point in time. A dynamic simulation model represents a system that changes over the time. In general, the simulation models can be subdivided into deterministic and stochastic models.
In more detail, focusing on supply chain, four categories can be found in literature (Min, Zhou, 2002): *deterministic, stochastic, hybrid* and *IT-driven models*. Deterministic models assume that all the parameters are known and fixed with certainty, whereas stochastic models take into account the uncertain and random parameters. Deterministic ones are splitting into single and multiple objective models, while stochastic are classified into optimal theoretic and dynamic programming. Stochastic models are also more common because reality is seldom deterministic. (Banks, 1996). Hybrid models have elements of both deterministic and stochastic models. These models include simulation models that are capable to deal with both certainty and uncertainty involving parameters. Finally, IT-driven models aim to integrate and coordinate various phases of supply chain mapping on a real time basis using application in order to enhance visibility along with the supply chain (Chopra, Meindl, 2002). This rising interest in IT-driven models is subsequent to the realization that IT development has been recently the major driving force for supply chain innovations (Shapiro, 2001). Examples of this last category are ERP and MRP.

Supply Chain Modeling	
Deterministic models	Single objective Multiple objective
Stochastic models	Optimal control theory Dynamic programming
Hybrid models	Inventory theoretic Simulation
IT – driven models	ERP MRP

Table 5.1: *Supply Chain Modeling*

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[50] Banks J., Carson, J.S., Nelson, B.L., (1996), *Discrete-Event System Simulation*, Prentice Hall International

5.3.2 Advantages

Simulations offer a great deal of opportunities and this is one of the reasons for their increasing role in most supply chain re-engineering efforts. (Shapiro 2001)
Firstly, the most evident advantage given by application of simulation is represented by time compression, since the opportunity of simulating years of the system behavior during few minutes. As underlined before, simulation can be a supportive tool for decision makers. In effect, it is utilized to see what happens when hypothesizing different scenarios. In other words, changing simulation inputs and observing the resulting outputs it could obtain valuable insight into which variables are most important. Using simulation tool, decisions are taken easily. By simulating a number of scenarios, a company might be better prepared for the unpredictability of the future.
Furthermore, in real effective systems mathematical models or analysis cannot be sufficient to describe complex connections or linkages between variables of the system. In such these cases, simulation constitutes a potential and immediate alternative. This last characteristic becomes peculiar when the analysis has to be conducted on short living systems for which time represents the most relevant variable.
Finally, simulation studies help design models describing systems as it is going to operate rather than based on someone's supposition. Decision will be made from objective analysis instead of subjective intuition. Specifications or further requirements in the description can be added. (Banks, 1996)

For all the reasons expressed above, simulation permits to create a model of the supply chain system and to test various levels of input that can emulate real-life inconsistencies. The knowledge gained in adopting a simulation model may therefore be of great value toward suggesting improvement areas (Wyland et al., 2000).

5.3.3 Drawbacks

The principal problem related to implementation of a simulation model is the impossibility to guarantee that the model will provide certain answers. Simulation implies repetitions of sequences that are based on randomly generated occurrences. The reliability of the model might not be assured. Consequently to its necessity for several iterations, a great deal of time and attempts may be spent in the realization and development of a simulation model.

Moreover, the inputs of the simulation must be accurate. Actually, the outputs from a simulation depend on the inputs. Thus, if inputs are not precise, the following findings and analyses could be meaningless. It is important that inputs and outputs are carefully collected (Banks, 2000).

Finally, the complexity of the system could represent a problem for the simulation model. Sometimes, it could occur that the reality to investigate is so connected and interrelated that it is difficult to view it as a whole. Therefore, it is impossible to simulate it. Complexity also affects simulation in term of incapability to interpret the findings. Precisely, the randomness of inputs might cause problem in evaluating the results of the model and to determine relevant observations.

5.4 Steps in a Simulation Project

The process of getting a simulation model consists of a few steps. This is hereby presented a simulation modeling approach according to Persson and Olhager' s framework (Persson, Olhager 2000).

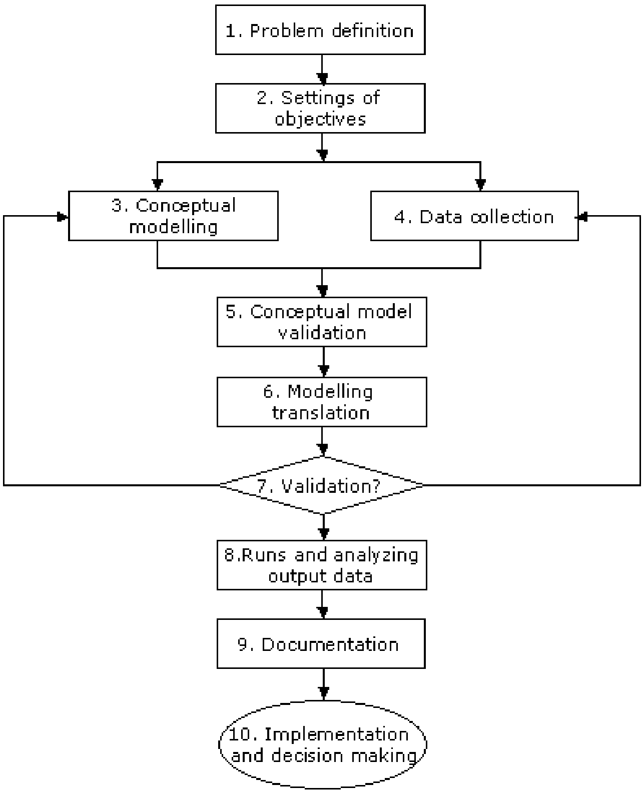

Figure 5.1: *Steps in a simulation project*[51]

1. **Problem definition**: the problem statement is to be considered the first step of each simulation model. It is fundamental that the problem formulation is understood.
2. **Setting of objectives**: the objectives represent the tasks and the goals of the project. By clarifying which are the purposes, it is clear since the beginning, which targets will have to be achieved.
3. **Conceptual modeling**: in this part the simulation model starts taking form. The conceptual model is the result of the attempt to depict the real system and transfer it into a logical description: the part of reality or real system under examination is therefore described in a simple document. It is important for the researcher to have the capability to sort out the parts of the problem, to make correct assumptions, and then to develop the model into a useful approximation of the real system (Banks, 1996). The purpose in this step is to capture the system logic and behind the system.
   In this stage, the constraints of the system have to be taken into consideration. For instance, boundary conditions are to be specified during

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[51] Adopted from Persson, F., Olhager, J., (2002), "Performance simulation of supply chain designs", *International Journal of Production Economics,* Vol. 77, N. 3, pp. 231 –245

the development of the conceptual model. This permits to avoid considering variables out of scope.

4. **Data collection**: the data input in a model is essential to get the correct answers based on objectives. In many simulation situations one has to decide which data that is relevant. The extent of data is usually too vast and some data may also be more relevant than other. To distinguish those products are important for the simulation from those that are not, it should be used specific rules (e.g. the ABC rules or the 80/20% rule). By means of these devices, it can be possible to address a quantitative relevance (e.g. in term of cost) to each variable of system, understanding which are the most responsible for output performances.
5. **Conceptual model validation**: the conceptual model is examined and corrected if it is necessary.
6. **Modeling translation:** after the verification of the conceptual model has been conducted and the data has been collected, the conceptual model can be transformed to a computer-based simulation model. This can be done in a simulation language or in simulation software packages.
7. **Validation:** this stage aims at testing the computer-based model against the conceptual model and the real system. The model must be corrected if necessary. To assess the validity of a model, historical data can be utilized. In effect, if the simulation model is built on an existing scenario, the historical data represent the most reliable inputs for the model. By means of them, the model adherence to the real system it might be checked.

   Validation activity is of vital importance. If it fails to correct all model errors, the result of the simulation might be questionable.
8. **Runs and analyzing output data:** The simulation is run and the output data collected and analyzed. The effect of varying inputs on the output (i.e. sensitivity analysis) is examined. When simulation runs have been carried out, a researcher’s task is to valuate if the findings are reliable or whether more runs are necessary.
9. **Documentation:** the simulating program should be accompanied by essential documentation to explain how to manage it. If the documentation is missing, it will take time for the analyst to utilize the program. Moreover, it will be difficult for him to intervene in the simulation by changing one or more variables of interest if the documentation is not related to.
10. **Implementation:** the analyzed data is used to recommend some decision or help in an implementation. If the model user has been involved in the process and understands how to use the model and the outputs, it is more likely that the implementation will succeed.

5.5 Excel and Visual Basic for Application (VBA)

Microsoft Excel is a spreadsheet application used to calculate, analyse and present information. Excel nowadays is the most important software among spreadsheet applications, with an estimated 90% market share.

Excel files are called workbooks and every workbook consists of worksheets; a worksheet is divided into rows and columns, which compose a matrix: rows are marked with numbers, columns with capital letters; matrix cells can be filled with numerical values or letters and it is possible to create and manage a list by using more cells.

Microsoft Visual Basic for Applications (VBA) is a tool based on computer language Microsoft Visual Basic that works within Excel and other Microsoft Office applications. VBA allows the user to perform actions on cells, ranges of cells, worksheets and workbooks, such us creating buttons and running macros: that is, it is possible to repeat the same actions automatically for many times and through few steps.

Nowadays many companies are taking advantage of supply chain simulation tools and VBA used in conjunction with Excel can develop such tools quickly and with minimum cost. There are other advantages given by the use of VBA in simulation: first of all errors due to manual processing data are highly reduced and it is possible to run many simulation automatically, therefore there is a great benefit in terms of time and people are free for other tasks; secondly, by saving in the same workbook both the input data of the simulation model and its results it is easier to compare them, to do a less error prone analysis and to make conclusions.
Finally, due to the huge diffusion of Microsoft Office (and Excel) it is not necessary to buy further applications to build a simulation model through VBA, hence there are not additional costs.

Excel models are deterministic: input data are known and fixed, they can be recorded in cells, gathered and sorted in lists, and the Application makes available a big range of mathematical functions which can manipulate inputs and calculate results; in order to view alternative results it is necessary to change input values. One way to enhance this situation is to implement functions giving random values; anyway the value of a cell remains unique, while it would be useful to assign the cell a range of values with a particular distribution.
To introduce uncertainty and better simulate the behaviour of real systems there are Excel add-ins available on the market, which use Monte Carlo Simulation. One of these programs is @Risk.

There are other computer languages which work in conjunction with Excel (like C#, C++ and Java) and guarantee faster performances than VBA; however VBA is easier to write and understand, therefore it is preferred to other languages if there are not onerous graphic calculations to implement and it is not required a huge number of simulations.

5.6 Resume

This chapter constitutes a breakthrough in field of simulation modeling for the supply chain. It highlights the opportunities given by a simulating approach to imitate the working of a complex system and to predict its future behavior. Simulations allows also to conduct “what if” analysis by means of which it is possible to draft different scenarios concerning the reality is has been studied.
Finally, a practical process map to build simulation models was reported and the program for the building of the simulation program is introduced.
The following chapter will describe the surrounding of the case study of this thesis and introduce the simulation model adopted to analyze the complex system it has been investigated.

Part III – Empirical study

Model and Program for the Case Study

This sixth chapter will introduce the model and the simulation program that has been built for the case study. This chapter represents the base for the following analysis. After a brief introduction, it will deepen the development of the conceptual model and highlight all the inputs and outputs of it. Then, how the conceptual model has been translated into a computer simulation model and a detailed explanation of how the program works will be reported.

6.1 Introduction

This case study is the result of the *Tetra Pak Carton Ambient*' s (TPCA) attempts to map all of its supply chain activities in order to understand and evaluate its performances. Recently, the necessity for an assessment and distinction between 'value-adding' activities and non 'adding-value activities' has arisen. In a short product life cycle, the continuous efforts to reduce drivers of cost (i.e. lead-time, inventories, capital tied up in the chain, etc.) constitute the way for the achievement and maintenance of a competitive advantage upon competitors. These issues represented the background for the development of supply chain topics as new perspectives to increase business operations efficiency.
As introduced in the first chapter, this project was charged by TPCA in Lund (Sweden). One of its business area concerns the realization and delivery of filling machines, necessary for the filling up of the final package. One of these, the Tetra Pak A1 Tetra Classic Aseptic (hereby, TP A1 TCA), provides the filling up of the Tetra Classic Aseptic, the most traditional and well-known Tetra Pak's packaging solution.

The study has focused on analysing Tetra Pak's supply chain for TP A1 TCA, in order to understand how it works, which drivers in term of cost and time to market for all the chain are more relevant and how to link them together for improvements. The goal of the project was to develop a tool aiming at describing the supply chain and at managing it from raw materials to final products ready for shipment. The tool should also simulate the workings of the chain when a new order for the filling machine is placed. In addition, by imitating its behaviour, the simulation tool should suggest eventual improvement areas to focus on.

6.2 Mapping the Supply Chain for TP A1 TCA

TP A1 TCA is used for the filling up of the Tetra Classic Aseptic package. Tetra Pak Carton Ambient in Lund is responsible for the order management and process from acceptance to delivery to Tetra Pak Market Company (hereby "Market"). This last company instead manages the activities regarding retailers, warehouses for finished products and shipment to final customer. For this reason, the focus on outbound logistics activities overtakes this study: the investigation would be definitively out of scope.

Many efforts have been recently made by TPCA in the attempts to reduce the number of suppliers with whom they have direct contact. In effect the complexity of dealing with many suppliers can be expensive for an operation and might prevent the operation from developing a good relation with a supplier (Slack, 2004). Since it is not easy to get close to different suppliers, it is important to reconfigure the supply side network to render it easier and more ordered. This also implies that some suppliers become increasingly important to their customers. It is not a case that one of the Tetra Pak's core values is partnership with customers, suppliers and colleagues[52]. Tetra Pak seeks to work in partnership with few suppliers that are innovative, financially solid and committed to its businesses. The cooperation enables to protect the quality of supplier's materials. Relationship also involves listening to suppliers and, mostly, sharing core values, competencies and knowledge.

The strict relationship with few suppliers became an obliged choice after the fusion between Tetra Pak AB and Alfa Laval AB in the '90ies. Tetra Pak stopped manufacturing on its own to only carry on exerting its supportive guidance and effective control on the manufacturing process. Since then, Tetra Pak started outsourcing manufacturing and assembling activities towards its suppliers.

At the moment, TPCA is implementing and improving an "ordered supply network" (Slack, 2004) according to which all the activities of manufacturing and assembling are broken down along with the chain.

At the top of the supply chain, there is the Market, which is the final customer for the suppliers' activities. Tetra Pak Market Company is, in fact, responsible for the final delivery and installing to the specific customer.

Secondly, there are the Systems Suppliers. They are few suppliers with well-specified core business, with whom TPCA has developed a strict and strategic cooperation. The System Supplier's task is to assemble the modules of the machine he received from the previous tiers of the chain, to test the complete filling machine and to package it.

The second tier of the supply network is represented by the Module Suppliers. They specifically work at the manufacturing, assembling and testing of a particular module[53]. After these activities they ship the modules to the System Supplier.

At the bottom, finally, there are the Component Suppliers. They are involved into the transformation process from raw materials to sub-modules for the Module Supplier they refer to.

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[52] Tetra Pak Homepage, www.tetrapak.com, 2005-02-01

[53] For 'module' it should be meant a specific part of the complete filling machine

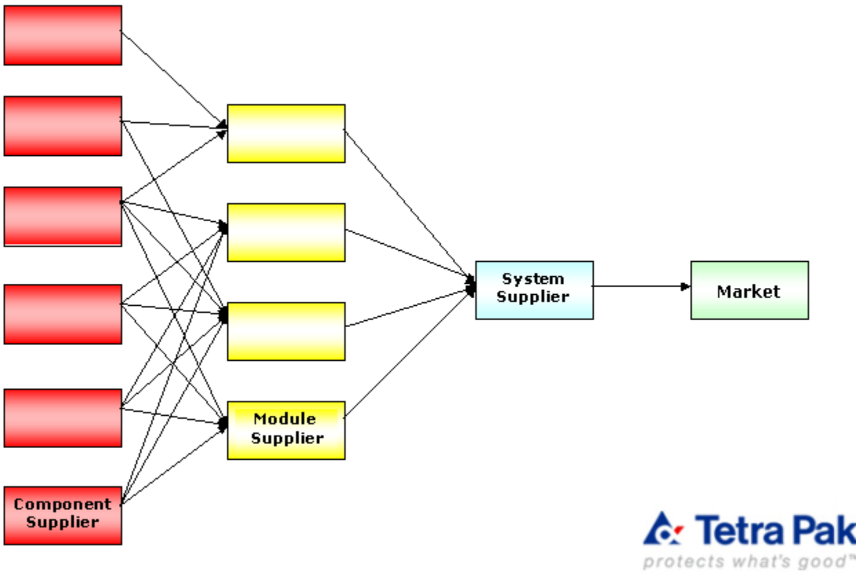

Figure 6.1: *Tetra Pak's supply chain for TP A1 TCA*

In particular:

- System Supplier: Fuji Autotech AB. This company, located in Elsinkrona, assembles the modules coming from the Module Suppliers, tests the filling machine and packages it for shipment. When the System Supplier receives an order from the Market, it forwards it to the following tiers.
- Module Suppliers: for this machine, there are four modules manufactured and assembled by four Module Suppliers. The first is Tetra Pak Stålvall AB, situated in proximity of Göteborg, which designs, projects and constructs a module called ASU Infeed (see Figure 6.5). In this project, this part has been deeply investigated and it is the most relevant part, which this study regards. The others are Fuji Autotech AB (this company also manufactures a module before assembling all), Logstrup AB and Wedholm Komponenter.
- Component Suppliers: they are the actors in the chain responsible for the manufacturing of sub-modules of the TP A1 TCA. Due to limitedness of time and according to requirements given to us by TPCA, the research addresses only to the activities of one Module Suppliers and its connected Component Suppliers. The Module Supplier in object is Tetra Stålvall (TPS).

It would have been impossible to investigate all the actors throughout all the tiers of the network, both to complexity and to impossibility to gather the information the study needed. Hence, in agreement to TPCA it has appraised to consider only one branch of the chain. TPS' s Component Suppliers are several and uniformly distributed over Sweden. According to the fact that the study has entailed to visit the suppliers to understand the dynamics within the firm, the geographical position has therefore influenced the extension of the research.

The choice of the suppliers to take into account was principally consequent to interest in the research for TPCA and availability of data. The study, therefore, has focused on few suppliers representing more or less 80% of the costs for the filling machine.

The following figures highlight the boundary of the research and the geographical distribution of the suppliers (i.e. System, Module, Component). The research entails surveys from when the raw materials arrive at Component Suppliers' plants until the final filling machine packaging, ready for shipment to the Market.

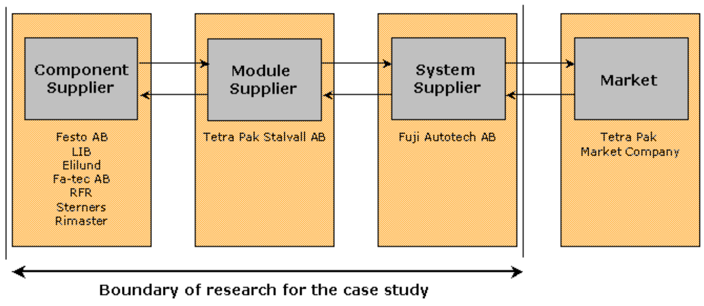

Figure 6.2: *Boundary of the system*

Figure 6.3: *Suppliers disposition*

6.2.1 TP A1 TCA Filling Machine

Here it is presented how the filling machine works:[54]

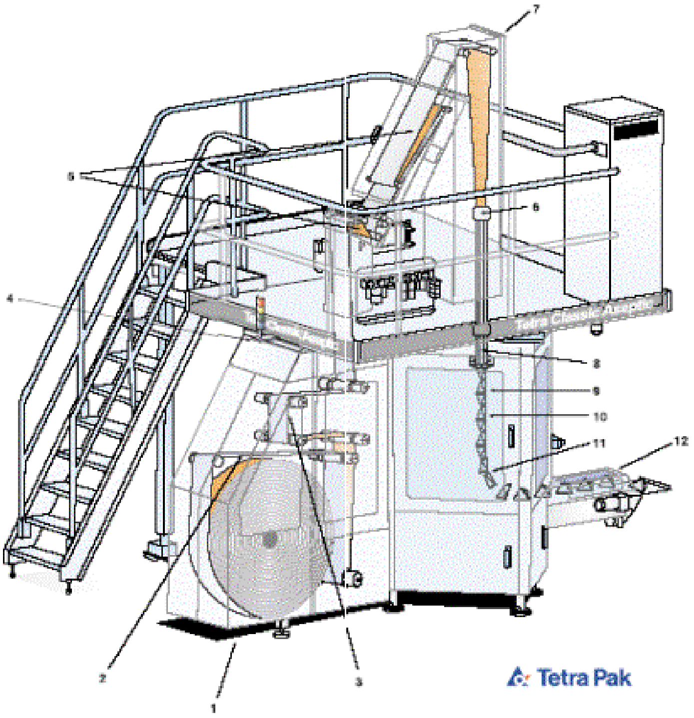

Figure 6.4: *TP A1 TCA*

1. Packaging material infeed: the unit holds a reel of packaging material. Factory splices are supervised here and automatically discarded at the outfeed unit.
2. Automatic splicing unit: when changing reels, the packaging material is automatically heat and pressure spliced. Packages formed at the joint are automatically discarded at the outfeed unit.
3. Longitudinal streep seal strip application: here the seal strip is attached onto the edge of the packaging material.
4. Data code unit performs printing that is correctly positioned on each package.
5. Packaging material sterilisation: passing through a shallow bath, a thin layer of hydrogen peroxide is applied to the packaging material. In the

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[54] Tetra Pak Carton Ambient Intranet, Tetra Pak Carton Ambient AB, Lund, 2005 – 02 – 02

heating chamber all hydrogen peroxide is evaporated producing effectively sterilised packaging material.

6. Tube forming unit: the packaging material passes an upper forming ring precisely shaping it into a tube, then a longitudinal seal is closed using heat.
7. Aseptic chamber: all operations take place in an environment kept sterile by using over pressured sterile air.
8. Production filing ripe: the aseptic product is filled via pipe reaching far down in the previously shaped and sealed tube.
9. Transversal sealing: it takes place beneath the filling product level, ensuring that the packages are always completely filled.
10. Design correction: the design correction system ensures that the print is correctly positioned in each package. The same applies to location of the optional pre-punched straw hole.
11. Package cutting and separation: the continuous packaging tube is precisely separated between two close and parallel transversal seals by a knife in each pair of jaws.
12. Outfeed conveyor: it ejects the separated packages for further transport to manual or automatic packaging units.

As underlined in the previous paragraph, the TP A1 TCA filling machine is manufactured, assembled and packaged throughout different companies. The figure below reports the picture of the filling machine and the module that has been studied:

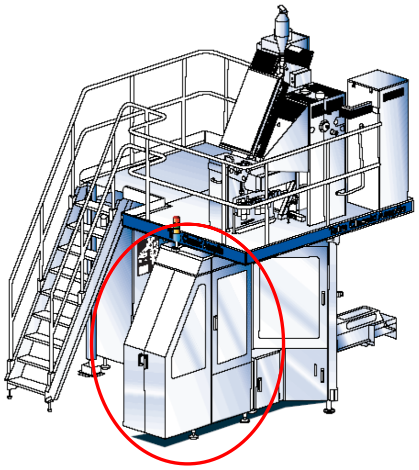

Figure 6.4: *TP A1 TCA*

Fuji Autotech AB, the *System supplier*, assembles together all the modules.

Tetra Pak Stalvall AB (TPS), the *Module Supplier* analysed, assembles, the module named ASU (Automatic Splicing Unit) Infeed TCA (i.e. red circle).

The *Component Suppliers,* considered the studied, supply TPS for the ASU Infeed TCA.

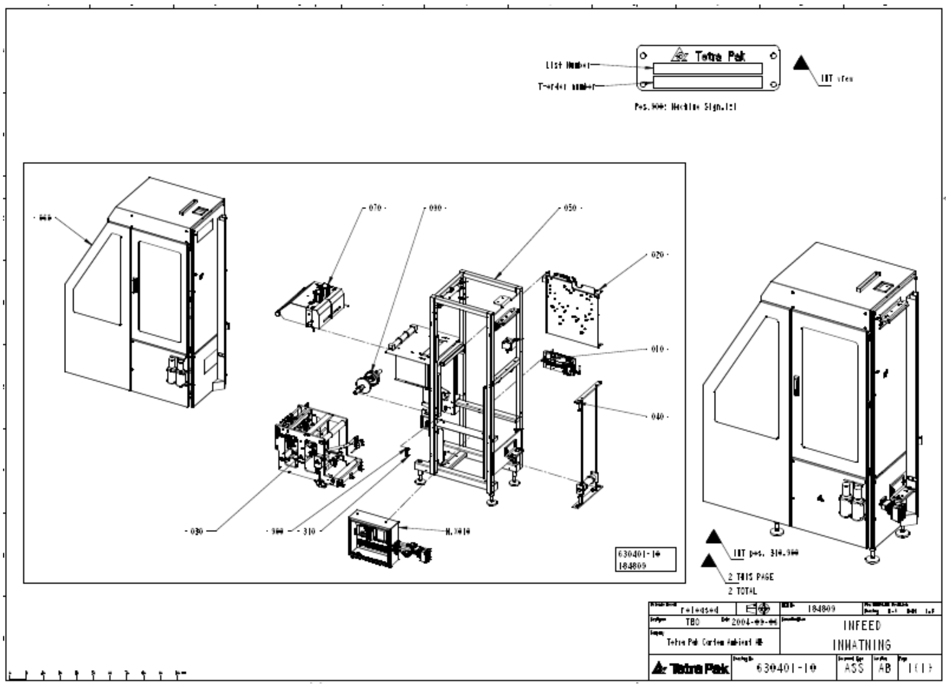

Figure 6.5: *ASU A1 Infeed*

Further demarcations

TPCA and its supplier have established and signed an agreement according to which the suppliers have to manufacture or assemble their respective modules within a certain lead-time. The cost of the module (sold from one tier to another) is also fixed. Moreover, the agreement allows each supplier of the chain to manufacture and put in stock an established number of modules: the modules produced and placed in warehouses in excess are not paid by TPCA.

All these measures have been taken by TPCA into threefold direction:

- firstly, the time-to-market compression is the first purpose of TPCA' s strategies of outsourcing. Instead of manufacturing on its own, TPCA can outsource these activities and requires fixed quality level and reduced lead-time. In effect, each supplier can focus on its best competences, thus increasing efficiency and becoming strategically relevant in the chain;
- secondly, an established level of inventory stock accomplishes to trade-off the necessity for time-to-market compression and the reduction of exceeding costs due to capital tied up. A fixed inventory level represents also a way to balance uncertainty and prevents production operations from stock out;
- last but not least, the total cost for each sub-module, module and the final machine is agreed by TPCA and the suppliers. This avoids speculations among the actors of the chain and hinders excessive payoffs from one tier (the seller) to the following tier (the buyer) of the supply network.

6.3 Problem definition and setting of objectives

As discussed in chapter 5, the first step in the realization of a simulation model is to define thoroughly the problem requirements and to set the objectives of the model. These declarations have already been made along with the dissertation

(i.e. see Chapter 1). The purpose of this paragraph is just to report them briefly from another perspective.
The purpose of the model is the simulation of the supply chain for the filling machine just presented above, since it is necessary to map it in order to understand possible improvement areas. The costs and lead-times related to the filling machine are too high.

More in depth, the two issues that the simulation should specify are:

- known lead-times and costs of the component, which is the best order batch in order to reduce the total keeping cost (i.e. cost related to inventory stock)?
- basing on same inputs, which is the best order batch to trace the best trade-off between the lead-time for the complete filling machine and inventory?

The simulation will attempt to answer these two questions.

6.4 Conceptual model

A model is a representation of a set of components of a system or subject area. The model is developed for understanding, analysis, improvement or replacement of the system. Systems are composed of interfaces or interdependent parts that work together to perform a useful function. The model describes what a system does, what controls it, which things it works on, which means it uses to perform its functions and what it produces (Umeda, 2001).

IDEFØ [55] modelling notation is used to represent relations of processes. IDEFØ is a modelling technique based on combined graphics and text that are presented in an organized and systematic way to gain understanding, support analysis provide logic for potential changes, specify requirements or support systems level design and integration activities. Effective IDEFØ models help to organize the analysis of a system and assist the modeller in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong. Thus, IDEFØ models are often created as one of the first tasks of a system development effort.[56]

In this thesis, the basic elements of an IDEFØ model diagram have been adopted. Further implementations or detailed description would have been out of scope, since in this stage the purpose of the model is just to imitate the behaviour of the real system in the simplest way possible. Perhaps, further developments of this simulation model could enhance the depth and the breadth of conceptual modelling description.
Hereby, there is illustrated the basic IDEFØ syntax for conceptual models.

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[55] IDEFØ Homepage, www.idef.com/idef0.htm 2005 - 02 - 03

[56] Ibid.

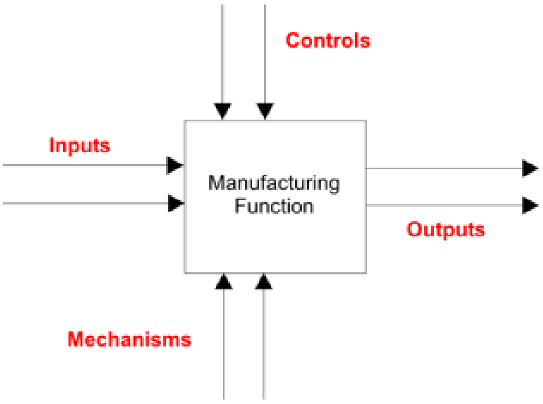

Figure 6.6: *Syntax of IDEFØ diagram*

The "box and arrow" graphics of an IDEFØ diagram show the subject of investigation as a box and the interfaces to or from it as arrows entering or leaving the box. In order to be able to express real-life functions, boxes operate simultaneously with other boxes, with the interface arrows providing "constraints" as to when and how operations are triggered and controlled.
Each side of the function box has a standard meaning in terms of box/arrow relationships. The side of the box with which an arrow interfaces, reflects the arrow's role. Arrows entering the left side of the box are *inputs.* Inputs are transformed or consumed by the function to produce correct outputs. Arrows entering the box on the top are *controls*; controls specify the conditions required for the function to produce correct outputs. Arrows leaving a box on the right side are *outputs*. Outputs are the data or objects produced by the function. Finally, arrows connected to the bottom side of the box represent *mechanisms*.[57]
The branch of the supply chain for the filling machine is analysed as a multi-echelon system, in which each stage represents a specific company (supplier).
Similar to the IDEFØ diagram, the conceptual model, which has been developed in this thesis, considers each tier (i.e. supplier) of the chain as a box. This entails that the investigation does not focus on the processes within the company to transform one input into one output, but it regards as if it was a box. Therefore, the inputs from the previous actor in the chain and the outputs towards the following one are the only variables taken into consideration. This approach is called "black box" approach.
Introduced in the first chapter to display the background of the thesis, the following figure might help comprehend:

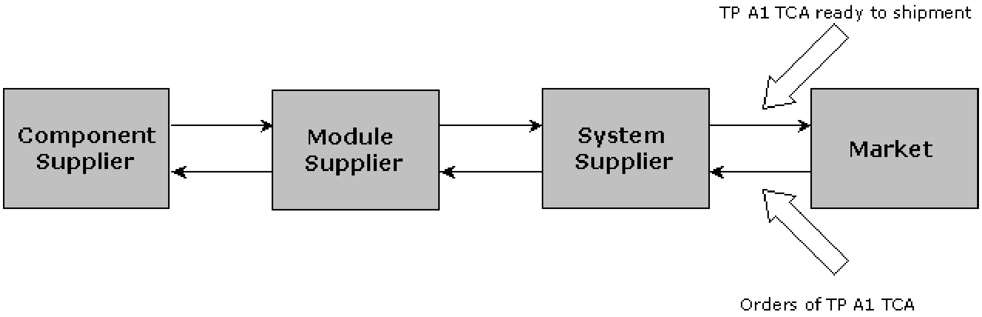

Figure 6.7: *Conceptual model – Black box Approach*

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[57] Training IDEFØ, www.idef.com/idef0.htm, 2005 – 02 – 03

Accurately, if the model aims at describing a real system, input and outputs are not sufficient. The environmental conditions, constraints and uncertainties affecting it should also be appraised. Thus, the final conceptual model has been built presenting, horizontally directed, *inputs* and *outputs* and vertically oriented, *constraints* and eventual *disturbances*.
By constraints, relevant variables that might force the behaviour of the system have been meant and, consequently, they have to be evaluated for the reliability of the analysis. Disturbances refer to uncontrollable variables - variability and unforeseen events (uncertainty) - that a real system may encounter.
Closely similar to IDEFØ standard, this conceptual model has few differences, however not substantial: they are consequent to the implementation of the case study. Hence, the following is the conceptual model depicted for this study. This example is applied to 2-tier of the chain, the Module Supplier. The same approach has to be enlarged to all the actors of the chain.

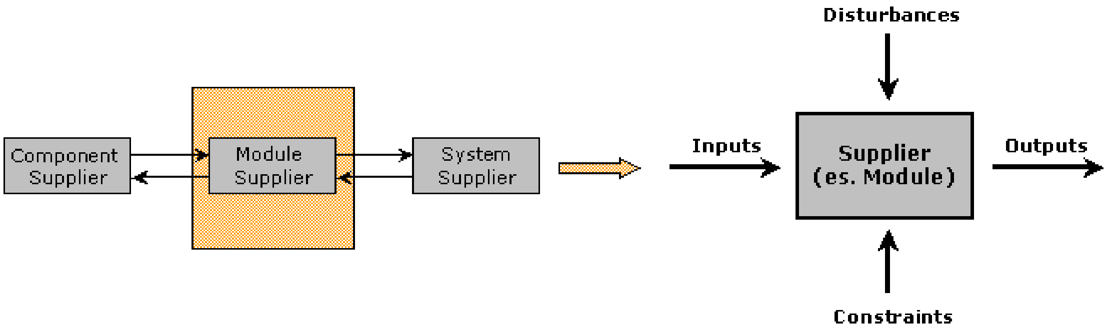

Figure 6.8: *Conceptual Model – Black block approach*

6.5 Inputs

There are reported all the inputs for the simulation model that has been developed. Every input has been anticipated by a brief theoretical introduction. These are the inputs taken into account:

- Lead-times component suppliers' modules;
- Agreement between TPCA and its suppliers on lead-times and EOQ;
- Policy for customer's order cycle;
- Total costs of sub-modules and module;
- Demand for the filling machine distributed over a year;

6.5.1 Lead Time

Lead-time is defined as the time taken from the receipt of a customer's order through to its delivery and includes all the activities within this chain of actions (Christopher, 1998). The lead-time concept is due to the fact that there is a lack of time between when an order is placed and when the same order is satisfied.

Considering the pipeline, the lead-time should be broken down into its components, revealing which activities regard it. At large, all the activities that are processed in a firm to manage a complete order should represent a part of the all order-to-delivery cycle. The following figure highlights the major elements of lead-times.

Commercial and planning lead-times	Material lead-times	Assembly lead-times	Distribution lead-times	Installation lead-times

Figure 6.9: *Lead-time components*[58]

By 'commercial and planning lead-time' should be included for instance the lead-times related to ordering receipt management (i.e. ordering reception, planning and processing lead-time). 'Materials lead-time' is an aggregate name for all activities affecting lead-time regarding the process of manufacturing goods. Thus, examples are material purchase lead-time, supplier lead-time assembly release and order picking lead-time.

The 'assembly lead-time' is logically that time spent for the activities of assembling modules together whilst 'distribution lead-times' includes both transportation time to customer and despatch preparation time (documents, packages, etc.). Finally, the 'installation lead-times' affects post-sales activities in the place into which the goods have been sold.

In this work, the lead-times represent an input for the model. Tetra Pak Carton Ambient and its supplier have given the data about lead-times during the interviews. The lead-times taken into account concern each tier of the supply chain (system, module and component supplier). They compute time from when an order is placed by the company upstream in the chain until when the filling machine or module or sub-module is delivered. Therefore, the lead-time defined in such way also groups ordering receipt and processing lead-times, manufacturing lead-time, assembly lead-time and testing lead-time, respectively for each part of the filling machine we are referring to. It contains also the delivery time, by which is meant the transportation time it takes to transfer the products.[59]

6.5.2 Agreement between TPCA and its suppliers on lead-times and EOQ

As introduced before, TPCA has developed an agreement on lead-times and EOQ among its suppliers to keep under control its activities and to benchmark its performances. The purpose is to stabilize the TP A1 TCA' s time-to-market to satisfy customers' requirements in time and to prevent delays on shipments.

An agreed lead-time means that the filling machine should be ready within that established time. During 2004, the agreed lead-time was 13 weeks (i.e. 91 days, 65 working days): it means that the interval between when the order of the filling machine is placed to when the filling machine is ready to be delivered should have been 13 weeks. In case of multiple orders (i.e. more than one machine ordered) within the same week the agreement let suppliers have an adjunctive week for their operations.

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[58] Christopher, M., (1998), *Logistics and Supply Chain Management: strategies for reducing cost and improving service, Second Edition*, Financial Time Prentice Hall

[59] It should be said that, however, for the supply side of the chain the delivery time is not relevant. As collected from the interviews, it might be appraised as at most one day. In certain cases, it takes only few hours. Compared to manufacturing, assembling and testing lead-time that takes 10 – 20 working days it might be agreed that in the analysis is not so important and, therefore, it is included in the LT, defined as the interval from an order is receipt until the order is satisfied and the machine delivered to the next tier in the chain.

The ‘agreed EOQ’ represents the number of modules that each component supplier is allowed to manufacture and keep in stock that agreed precise number of machine. ‘Agreed’ because TPCA stipulates an agreement with its suppliers according to which when an order of filling machine is placed, Tetra Pak does not pay every further manufactured sub-module *en plus.*

Here is reported the agreed lead-times and EOQ between TPCA and its suppliers for the TP A1 TCA filling machine throughout each step of the chain. The time is expressed in working days: in a seven-days-week, there are five working days.

Agreed LT and EOQ for TP A1 TCA Filling Machine

	Name of Company	**Activity / Part of TP A1 TCA**	**LT**	**EOQ**
System Supplier	Fuji Autotech AB	Assembling & Testing	25	1
Module Supplier	Tetra Pak StalVall AB	ASU Infeed A1 TCA	5	1
Component Supplier	Festo	Valve Ramp Infeed	20	5
	LIB	Strip Magazine	20	5
	Elilund	Strip Applicator	20	10
	Elilund	Paper Magazine	20	10
	Fa-tec AB (and others)	Frame	30	10
	RFR – Rostfria	Doors and Covers	20	6
	Elilund	Splicing Device	20	10
	Sterners	Bobbin	15	5
	Sterners	Bobbin normal reel	5	5
	RIMASTER	Connection Box	25	10

Table 6.1: *Agreed Lead Time and EOQ for TP A1 TCA Filling Machine*

Actually, the tabled values are changing according to TPCA’ s policy of further development into emerging markets. The extreme competitiveness of these markets has forced TPCA to reduce lead-time to gain advantage and maintain leadership in the sector. Thus, since august 2005 this filling machine will have to be ready within 8 weeks against the 13 weeks, as it was during 2004. Consequently, all the values for the component suppliers are switching to new requirements. From August 2005, the lead-time for each component supplier will be considerably shortened.

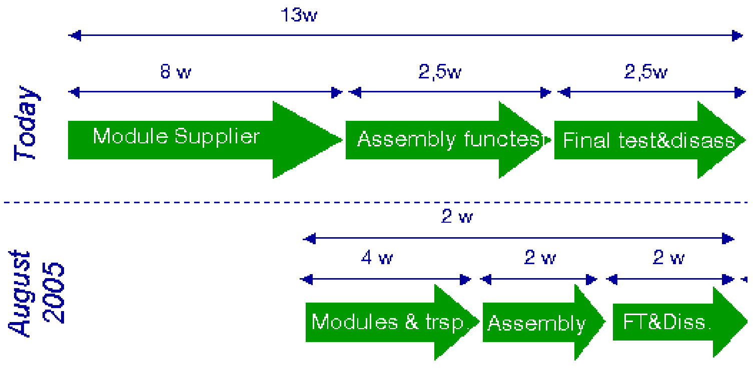

Figure 6.10: Lead-Time Policy for TP A1 TCA – Comparison between policy during 2004 and commitment for 2005[60]

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[60] Tetra Pak Carton Ambient, Supplier Management, Emerging Segment, Tetra Pak Carton Ambient AB, Lund. It should be added that, during the first months of 2005 (i.e. the same period the analysis of this thesis is referring) the agreement was 12 weeks.

Concerning lead-time, the last issue that has been taken into account is the high variability affecting the historic data. The interaction and effects of a variable lead-time will be deeply explained later in the chapter, because it is strictly related to uncertainty of demand.[61] As a result, uncertainty forces companies to produce goods in advance, in order to be on time in delivery and to satisfy customer requirements.

For many suppliers TPCA represents their best or at least, one of the most prestigious customers. This subaltern condition presses suppliers to be willing to TPCA' s requests. It occurred therefore that some firms had to reduce inventory stock level, or change policy of replenishment or increase productivity in the name of the satisfaction of one their most important customers.

Transferring to the practice, suppliers keep items in stock in order to ship their products on time: without inventory, it would not be possible for them respect the agreement. Therefore, this study also wants to assess the impact of stocks in terms of final outputs.

The existence of inventory also changes the time to manufacture the modules, which is reasonably inferior to normal lead-time. According to the interviews and meeting set during the collecting data phase, a further lead-time, named 'lead-time for stock items' has to be considered. This particular time is that the company needs to finish the sub-module it keeps in stock (e.g. WIP = work in progress), test, package and deliver it to the customer. This lead-time is intuitively lower than the normal time to manufacture the item from the beginning.

Thus, the distinction between lead-time and lead-time for stock items plays a role only when there are sub-modules in stock.

The value for 'lead-time for stocked items' has been evaluated by means of interviews to component suppliers. The gathering of this type of information has been difficult, since the incapability of the firms to indicate a precise and fixed value. Simply, it might change from time to time. In the model, we assumed a standard, but reasonable value of 60% of lead-time.

In conclusion, there are three voices of lead-time embedded in the simulating model:

- agreed lead-time;
- lead-time for stocked items, that is used when there are modules available in inventory;
- actual lead-time (called only lead-time), that is different from the agreed one because of the uncertainty introduced in the model, reflecting the real complexity and uncertainty that exists in a real system.

6.5.3 Policy for customers' order cycle

In dependence of the ratio between the customer's order cycle (i.e. the length of time the customer is prepared to wait) and the time taken to complete the good transformation process until delivery, a company might choose among different policy to customer's order cycle satisfaction: (Forza, 2002)

- **MTS = Make to Stock**. This strategy is adopted by firms into which forecast represents the basis for sourcing, manufacturing and assembling activities. Normally, the way to manage the gap between customer's

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[61] Tetra Pak Stålvall AB, Hans Soberg, Purchasing Manager, 2004 – 12 – 10

order cycle and lead-time to product the final good is by carrying inventory. Hence, the way most companies address this problem is by seeking to forecast the market's requirements and then to build inventory. The lead-time is reduced only to time for shipment to customers. Conversely, the holding cost (costs related to keep items in stock) is high. According to this policy, companies using MTS strategy usually manufactures standard goods.

- **ATO = Assemble to Order**. In the companies adopting this policy, sourcing and manufacturing activities are based on forecast, while the assembly is consequent to the actual demand for goods. In this case, the time for the customers corresponds to the time for assembly and delivery and it is possible to satisfy customers' requirements throughout a wide range of final goods, thanks to the possibility of diversifying final products in the last steps of the order process. This strategy represents a good trade-off between standardization and customization, since the possibility to assemble many final products from few manufactured modules.
- **MTO = Make to Order**. All the activities of manufacturing, assembling and delivering are here base on effective customers' orders, while the purchasing is still based on forecast. The MTO strategy allows the firm to deploy a great variety of final products to satisfy customer requirements.
- **PTO = Purchase to Order**. There is no forecast and order planning. All the goods are produced as soon the company receives the order from the market. In this case the time for the customer is the highest. On the other hand, PTO permits an extreme opportunity of customization.

About the case study, the System Supplier, Fuji Autotech AB places the suppliers order whenever it receives orders from the Market. Fuji doesn't have any stock for this machine. It operates just-in-time according to a pull system[62].
Tetra Pak Stålvall AB, as Module Supplier, receives the order from the System Supplier and forwards it to Component ones. It has no stock. TPS operated a MTO policy[63].
The Component Suppliers have to manufacture a sub-module of ASU Infeed of the filling machine TP A1 TCA. They adopt a MTS strategy[64]. As a consequence, they attempt to either reduce lead-time to respect the agreement with TPCA or to prevent them from uncertainty of the demand for the filling machine.

6.5.4 Total Cost

After the time necessary for the operations, TPCA buys the Filling Machine from the System Supplier at an established price. Naturally, this price encompasses all the cost sustained throughout the chain's activities, from raw material purchasing to first sub-module manufacturing to module assembling to final assembling and testing in system suppliers' plant. Labour costs, transportation costs packaging costs and, general order-processing costs are also included in the final price for the filling machine.

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[62] Fuji Autotach AB, Goran Lindh, Industrialization Manager, 2005 – 02 – 08
[63] Tetra Pak Stålvall AB, David Bohman, ASU Product Center, 2005 – 02 – 08
[64] Fa-tec AB, Lars-Uno Andersson, Industrialization Manager, 2005 – 02 – 09

Due to the order structure of the supply chain, the total cost of the filling machine is broken down into each tier of the chain. In effect, every supplier is a different company, which buys raw material/work-in-progress from another company downstream in the pipeline and sells a sub-module/module to the upstream actor.

In TPCA, supplier managers periodically revise their calculation about the filling machines according the Pareto's rule. Their purpose is to understand which are the parts of the filling machine that influence mostly the total cost of the machine. In this way it is possible to narrow the field of investigation: there might be no interest in focusing in drivers of cost that represent only a small percentage of the final cost. It should be reasonable, instead to focus on the major cost drivers.

The table below reports the costs of the sub-modules and module for ASU Infeed manufactured by Tetra Pak Stalvåll. There is no reason for reporting also the price for the final machine, since it depends on all other System Suppliers' performances, which are out of scope for this thesis.

	Company	**Part of TP A1 TCA**	**Total Cost**
Module Supplier	Tetra Pak Stalvåll AB	ASU Infeed A1 TCA	161900 SEK
Component Suppliers	Festo	Valve Ramp Infeed	6977 SEK
	LIB	Strip Magazine	12811 SEK
	Elilund	Strip Applicator	11741 SEK
	Elilund	Paper Magazine	260 SEK
	Fa-tec AB	Frame	30498 SEK
	Rostfria RFR	Doors and Covers	22266 SEK
	Elilund	Splicing Device	12420 SEK
	Sterners	Bobbin	5130 SEK
	Sterners	Bobbin Normal Reel	0 SEK
	RIMASTER	Connection Box	9497 SEK

Table 6.2: *Costs for ASU Infeed A1 – TP A1 TCA*

The tool developed should also help management to keep under control the trend of costs. In this moment, for instance Module Supplier sells System Supplier the ASU Infeed at a price (183558 SEK) that is less than the cost sustained to produce it (more than 190000 SEK). The study aims also at highlighting possible reasons for this inefficiency or suggests eventual key-improvement.

6.5.5 Demand

One of the biggest problems that this simulation tool has had to take into account has been the uncertainty of the demand. The following figure represents the distribution of orders for TP A1 TCA from January 2003 to September 2004. It can be observed how there was an extreme variability in the demand, shifting for instance, from very few order batches to significant ones. The diagram reports the time (i.e. January 2003 – September 2004) in x-axis and the number of filling machine ordered in the y-axis

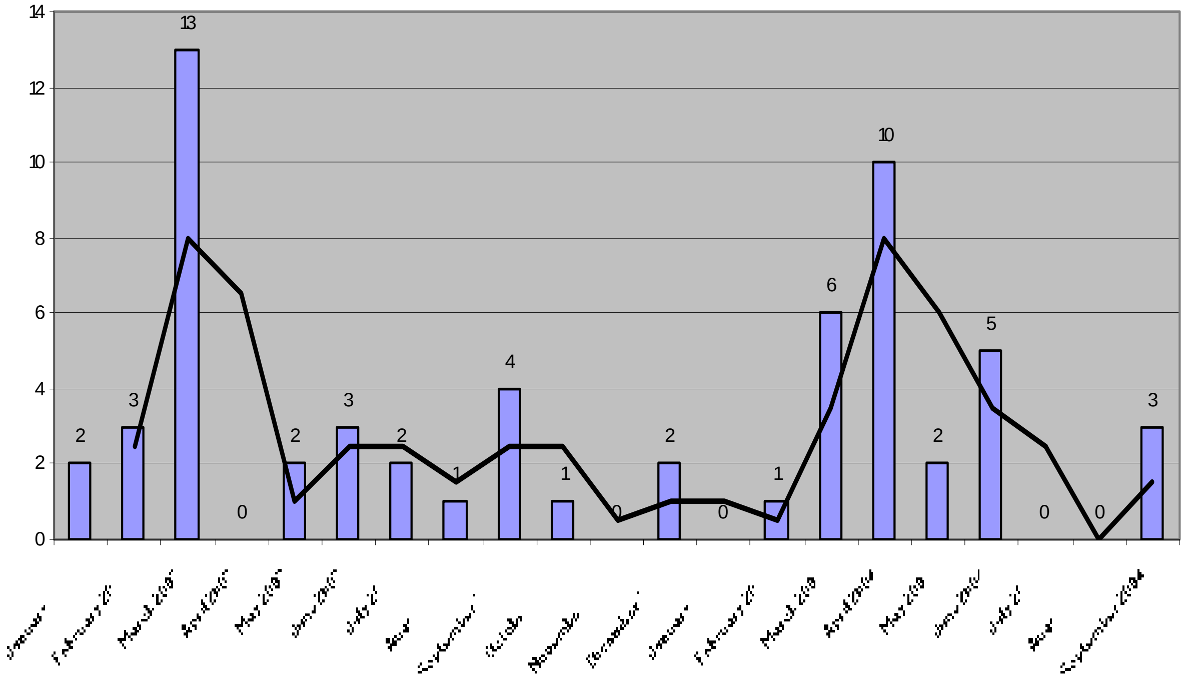

Figure 6.11: *Orders for TP A1 TCA distributed over 21 months*[65]

As can be noted, the demand results to be very uncertain: it can vary, for example, from 13 machines one month (i.e. March 2003) to zero the next one. Thus, this 'lumpy' demand causes a great deal of problems, since the incapacity to predict future orders and, therefore, to plan the production activities. The bad quality of the forecasts represents the first big obstacle towards a 'lean management' of the chain.

Moreover, a continuous rotating demand is one of the causes of delays in delivery. The suppliers, in these cases, cannot manufacture within the agreed time and unfortunately they are responsible for eventual timing delays. Thus, it can be assessed that a reliable forecast is a fundamental input not only for the production planning in term of inventory management, but also in term of time-to market compression.

The Figure 6.11 highlights the lead-time delays: it can be qualitatively noted how an increase in the demand entails an increased lead-time: during March and April 2004 the lead-time varied from 58 days of first March's order to 96 and 101 days of April's. The actual lead-time results 'out of agreement', although the adjunctive week for multiple orders in the same week has been considered.

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[65] Tetra Pak Carton Ambient, Supplier Management, Emerging Segment, Tetra Pak Carton Ambient AB, Lund

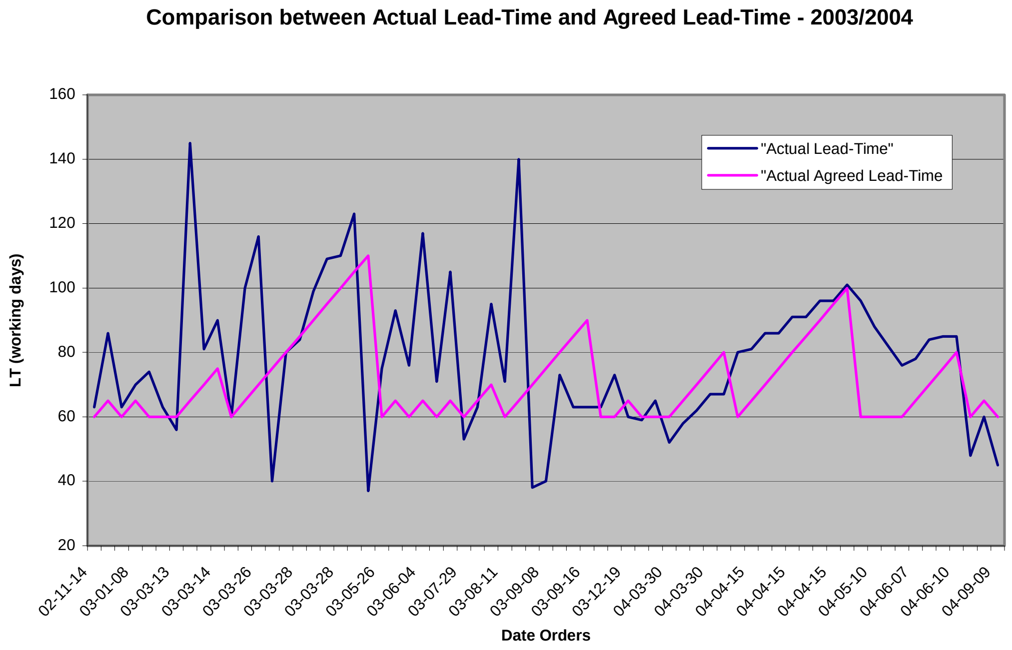

Figure 6.12: *Comparison between actual lead-time and agreed lead-time – Historic data 2003 – 2004*[66]

In the simulation, the uncertainty of the demand has been evaluated by the use of probabilistic distributions for the orders of the filling machines. The tool offers the possibility to conduct the simulation with 5 different distributions:

- Normal distribution
- Binomial distribution
- Poisson distribution
- Uniform distribution
- Forecast distribution

In order to be as strict as possible to Tetra Pak's requirements, the simulation tool includes the possibility to utilize another distribution for the filling machine order. The function 'User's Order' allows users to introduce the number of the orders and the time in which they are supposed to be placed according to their needs. This opportunity provides the program with the possibility to customize the working of the tool, and to simulate the behavior of the supply chain in case of specific situations. In other words, the tool can be used to predict qualitatively what will happen to the system by introducing own values of the demand. For example, by introducing the forecast values as orders number it can be depicted a scenario about future prediction and understood which problems the supply network might have to face.

Overview on Statistical Distribution used in the model[67]

- *Binomial Distribution*: orders are placed according to a Binomial distribution every 3 months; therefore there are 4 Binomial Distributions

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[66] Tetra Pak Carton Ambient, Supplier Management, Emerging Segment, Tetra Pak Carton Ambient AB, Lund

[67] http://mathworld.wolfram.com

during one year. This method was chosen so that it simulates different picks of order demands during the year.

This type of distribution gives the discrete probability distribution $P_p(n \mid N)$ of obtaining exactly n successes out of N Bernoulli trials (where the result of each Bernoulli trial is true with probability p and false with probability (q=1-p). The theoretical formula is $P_p(n \mid N) = \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n}$.

- *Normal Distribution*: orders are placed like a Normal Distribution every 3 months therefore there are 4 normal distributions during one year. The Normal Distribution is an approximation to the binomial distribution when the number of Bernoulli trials becomes large. Retrieving Bernoulli notation quoted before, means and variance of the Normal Distribution are:

$$\mu = Np$$
$$\sigma^2 = Npq$$

- *Poisson Distribution*: orders are placed like a Poisson Distribution every 3 months. This distribution, as the Normal one, is given by the limit of a binomial distribution when p«1 so that:

$$\mu = Np$$
$$\sigma^2 = Np$$

- *Uniform Distribution*: using this distribution, all the days in the simulation year have the same probability to have an order placed thus there are not high picks of orders demand during the year.

- *Forecast Distribution*: it is a distribution that tries to simulate the actual distribution of orders during the year. Basing on historic data (i.e. orders distribution 2004), the 'Forecast Distribution' aims to predict the demand for the following year: it consists of a Normal Distribution during the first semester and a Uniform Distribution during the second one. The distribution chosen is the Normal one because it results the best approximation to the actual historic data.

6.6 Outputs

The outputs of the analysis should instead be focused:

- Total keeping cost
- Tied up Capital
- Average lead-time
- Eventual delay of suppliers in delivering
- Out of Agreement and Penalty Value

6.6.1 Tied up capital and total keeping cost

Material that is stored as work-in-progress or as finished goods, ties up capital. The cost for this tied up capital depends on various factors. Surely, the mere cost of capital is one important voice of cost but, additionally, cost for warehouse

area, material handling equipment and personnel, eventual insurance for material in stock and obsolescence all add up to the cost of stored stuff.
Reducing the storage of finished goods might intuitively minimize the capital tied up in the chain. The risk connected with decreasing the storage level is to increase the likelihood of delayed or not fulfilled orders, leading to unsatisfied customers. From one side, the solution may reasonably be to find an acceptable trade-off between inventory level and number of delays in delivery. From the other, efforts to improve processes to shorten lead-times and reduce the need for storage of goods should be engaged.

In the model, the tied up capital is estimated as the correspondent value (in term of money) of the items that are stocked in the warehouses. To satisfy Market's orders, the suppliers use stocked sub-modules or modules, which need few operations to be ready for packaging and shipment. Therefore, they should be considered as work-in-progress. According to interviews that have been conducted, the value of items in stock are the 85 – 90% of the total cost of them. Hence, this percentage, called 'Material Intensity' is used in the program to assess the tied up capital value for each component.
Instead, the total keeping cost cell is calculated as the cost that the supply chain has daily to sustain to keep modules/sub-modules of the filling machine in inventory. The total keeping cost estimates a cost; the tied up capital appraises a value for the items in stock. The total keeping cost is determined as a range (i.e. 20 - 40%) of the total cost for each module/sub-module of the filling machine. This figure is calculated daily: the total annual cost is determined as the sum of daily values for a year of simulation.
In particular, for each supplier, the daily tied up capital and the daily keeping cost are calculated as:

$$T.U.C. = Total\ Cost * \%\ Material\ Intensity * N.\ of\ items\ in\ Inventory \qquad (6.1)$$

$$K.C. = Total\ Cost * N.\ of\ items\ in\ Inventory * \%\ KC\ Daily \qquad (6.2)$$

6.6.2 Average lead-time

The analysis has also the purpose to investigate which is the average lead-time during a year-simulation throughout all the chain. In fact, Tetra Pak always aims at reducing the general lead-time for delivery filling machines to market. Hence, the model should also try to appraise which is the convenient number of machines to order from time to time both to optimise the tied up capital and to decrease lead-time to market.

6.6.3 Eventual delay of suppliers in delivering

Lack of fulfilment or eventual delays on orders are consequences of various variables. The inventory level, the strategy adopted for the customer's order cycle, the existence of safety stock and uncertainty of the demand are all factors that affect delays or non-delays in shipments of sub-modules, modules, and, finally, complete filling machines. The system has its maximum efficiency when there is no delay and its objective should be to drastically pull down the number of delays.
During the simulation, the tool is able to calculate and to assert which the supplier is that for each order is the last to ship its products and which is the eventual one exceeding the lead-time agreement. By simulating a great amount

of iterations, the program provides how often a supplier's operations are late and, can therefore suggest an immediate area of improvement to focus on.

6.6.4 Out of Agreement and Penalty Value

Although all the deliveries from component suppliers to module supplier should be in time, the behaviour of the chain is sometimes far from this ideal situation. It occurs that the time from the order is received to the shipment to customers overtakes the agreed time.

Therefore, it is important to evaluate how often the system takes longer than the time that is agreed. This offers an indication about the efficiency of the supply chain. The simulation program provides the number of deliveries out of the agreement.

Related to this issue, a Penalty value is also assessed. The 'Penalty' is an estimated value for the items remaining in stock because of the shipment delay. It allows the users to comprehend how much value is stocked in the chain en plus than it is necessary, according to the agreement. The lead-times hereby cited, refer to the time to manufacture, assemble and test a complete filling machine. Thus, these values encompass all the echelons of the chain.

$$Penalty = (LT - Agreed\ LT) * Total\ Cost\ ASU\ A1\ Infeed \qquad (6.3)$$

6.7 Constraints

The main 'constraints' that have been considered in the model are the inventory level day by day for each supplier and the existence or not of safety stock. It has already been introduced that the purpose of inventories is to fill the gap between the logistic lead-time and the time customers are prepared to wait for the products (Christopher, 1998). If there is a stock, this will mean that there is a difference in the timing or rate of supply and demand. If supply of any item occurs exactly when it is demanded, the item will be never stocked (Slack, 2004).

The decision to stock or not stock represents a strategic decision, which can sensibly have effect on costs. For instance, the higher the inventory level, the higher is the probability to reduce manufactured lead-time and conversely, the higher is the holding cost estimation. In general there are pros and cons to this decision.

Inventory plays an important role in enhancing quality for some products, supports speed objectives, in the sense that allow the company to fast respond to demand and it is sometimes necessary in many operations to keep their processes working. Although inventory supports effectively operations performance objectives, there are a number of reasons that managers will not excess inventory. The foremost is that inventory is an asset that ties up money (increased tied up capital), which might have an elevated opportunity cost and cannot be considered as direct add value (Slack, 2004). Other drawbacks related to inventory are represented by the risk of obsolescence or damage, additional administrative costs to manage them and necessity for large plants for the storage of the products.

Sometimes, in particularly risky business environments, it might be taken into account the possibility to have an additional stock for unforeseen events, usually called safety stock. Safety inventory is carried for the purpose of satisfying

demand that exceeds the amount forecasted for a given period. Safety inventory is carried because the demand forecasts are uncertain and a product shortage may result if actual demand exceeds forecast demand (Chopra et al., 2002).
The advantages and disadvantages of using safety stock are the same as normal inventory. On one hand, existence of safety inventory increases product availability, but on the other increments inventory holding costs and the tied up capital, as well.

In the simulation model, two different strategies have been adopted: the first, deals with no safety stock, in order to minimize the total keeping cost; the second, establishes a fixed safety stock for each component supplier to prevent production from uncertainty in the demand and delays in the lead-time from tiers downstream in the supply network. For each strategy, the simulation has been run for a large number of iteration to evaluate their different impacts.

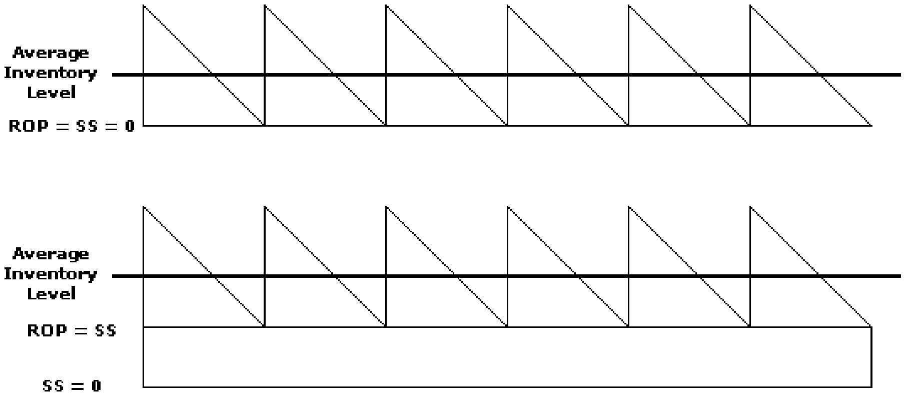

Figure 6.13: *Inventory with and without safety stock*

6.8 Disturbances

Variability and uncertainty are the most important problems that the TP A1 TCA’s supply chain has to tackle. The previous paragraph has already discussed the lumpiness of the demand. A lumpy demand, therefore, is the first source of unpredictability. Moreover, a probability distribution on lead-times has been introduced to render the system more adherent to reality according to historic data that have been collected. In particular, the figure 6.11 reports lead-times values during 2003-2004: upon those values the distribution has been traced. The purpose has been to appreciate how was the tendency in the last few years in order to introduce it in the simulation program. These two conjoint factors (i.e. lumpiness of the demand and lead-time distribution) have consequences on the system behaviour in term of delays in the delivery. In particular, the program underlines which supplier is the last supplier that ships the products it manufactures, which supplier is not able to deliver within the agreed time and assess a quantitative value for the items remaining in stock because of the shipment delay. As introduced before, this adjunctive value is named ‘Penalty’: and it represents an indicative information about how much value is stocked in the chain en plus than it is necessary, according to the agreement.
The user can control this issue in the program by setting the interested value of variability. As described in the handbook attached to the program, a value, varying between 0 (there is no variability and uncertainty in the chain) and 1 (variability according to historic data 2003 – 2004) should be introduced. The program is able to work even if the user enhances the unpredictability of the

system increasing the value to 1,5 or 2. This action would be interesting whether the user aimed to simulate an instable environment or a very uncertain year.

6.9 Modelling translation: the logic of the program

Once defined, the model has to be translated into a simulation program. The following figure resumes the logic of the program and represents the base for it. It is referred to a generic Component Supplier. This presentation omits few details of secondary importance: only the guidelines of how the system works are presented.

When an order is receipt from the Module Supplier, the order management process consists of few steps. Initially, the availability of sub-modules in stock is checked. If so, the order is processed and the sub modules delivered after the 'lead-time for stock items'. Otherwise, a new order of replenishment to restore the inventory has to be placed. This stock is made up of sub-modules, which are missing of few operations of the process of goods transformation. To be finished, these sub-modules need operations only for a brief interval of time and this is why 'lead-time for stock items' is lower.

Henceforth, the program works according two possibilities. Firstly, a control of lead-time is set. Whether the foreseen lead-time is longer than that agreed, the system makes use of safety stock. The safety stock, in fact, is that adjunctive part of inventory, which purpose is to prevent company from stock-out, incapability to deliver on time and business uncertainty. Conversely, if the firm does not utilize safety stock a replenishment order will be released. A replenishment order is also placed in the case that lead-time is lower than lead-time agreement. In effect, all the operations should be on time and therefore, there is no reason for using safety stock. Then, the order can be finally processed. At the end, a feedback flow is introduced to keep under control the working of the system.

The following figure resumes the logic of the program. It is based on Component Supplier activities.

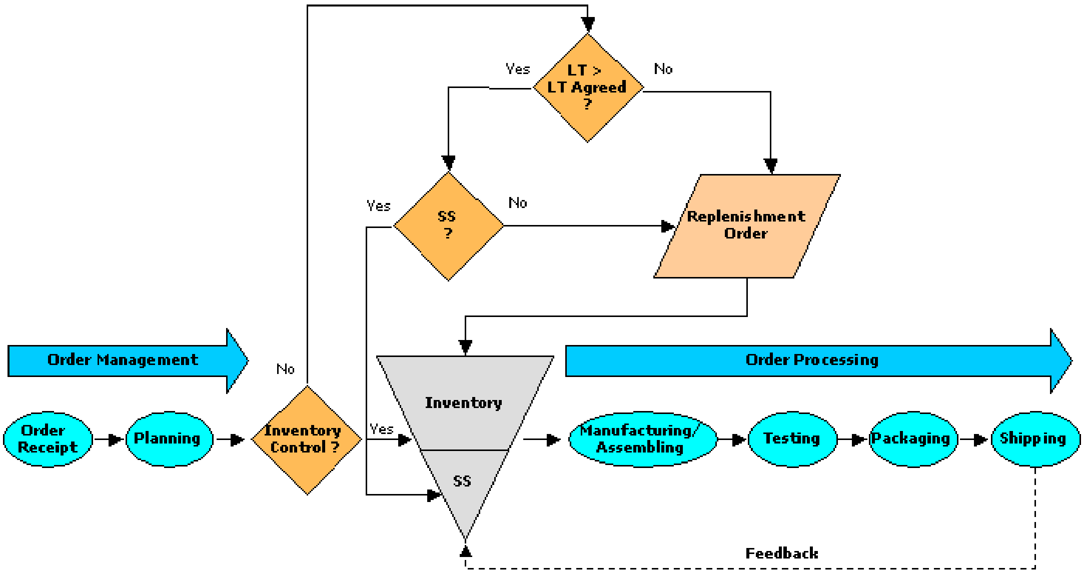

Figure 6.14: *The logic behind the simulation model – Component Supplier's perspective* [68]

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[68] Own

6.10 Validation of the model

The principal way to validate a model is to collect historic data and to use them as input for the simulation tool. If the outcomes are consistent with the real system and precisely, the outputs of the simulation are in line with the output values of the last business years, it will be clear that the simulation tool is reliable and describe realistically the system it has been built for.
The validation process has been done thoroughly to assure reliability and validity to the simulations. Lead-time has been the issue according to which drawing the comparison for the validation. Actually, the suppliers' deliveries are often overcoming the agreed deadline for the filling machine. The reasons are various and mostly, out of scope of this master thesis. It has been however imperative to introduce this variability of lead-time in the simulation to respect the system behaviour. To do it, a careful analysis of historic lead-times has been conduct. In particular, the difference between the actual lead-time and the agreed lead-time has been appraised both in term of absolute value and in term of percentage gap. Percentage gap is calculated as:

$$\%GAP = \frac{(actual\ \ LT) - (agreed\ \ LT)}{agreed\ \ LT} \qquad (6.4)$$

All the percentages related to delays of lead-time have been utilized to draw a distribution that could represent the trend. Then, this distribution has been set in the model in order to introduce lead-time variability in the model and it was applied to every tier in the chain. These below are graphs describing the trend for percentage gaps for both actual and simulation lead-time. A Normal distribution interpolates each graph.

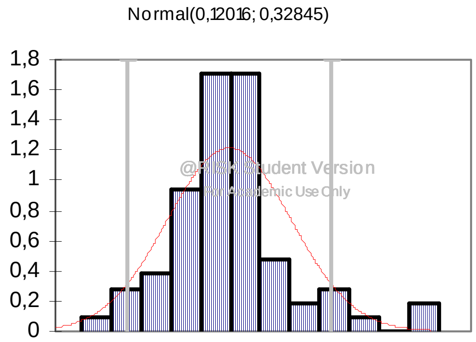

Figure 6.14: *Distribution for actual percentage gaps*

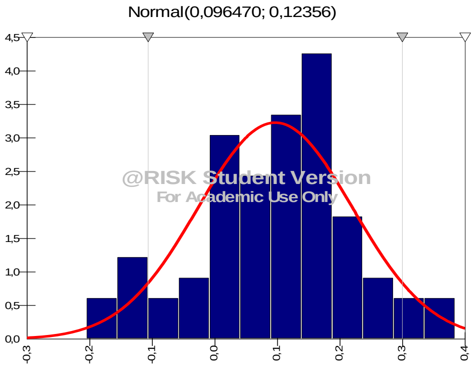

Figure 6.15: *Distribution for simulations percentage gaps*

Two issues are remarkable:

- Percentage gaps graphs are similar: mean values of Normal distributions are very close;
- Variance is smaller in the model: this is due to unpredictable events happening in actual situation that cannot be forecasted and are out of the scope of this work.

In the figure below, historic lead-time distribution compared to the lead-time distribution of a particular simulation is shown. In this case, trends are really alike but two picks which cannot be represented by the distribution chosen for the lead-time.

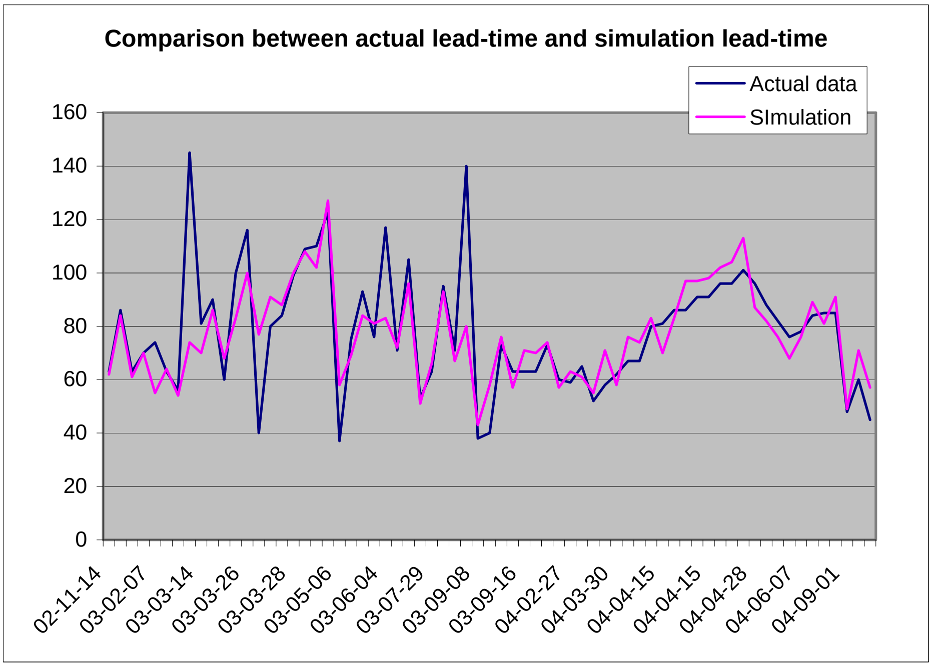

Figure 6.15: *Comparison between lead-times*

6.11 Simulation Running

The simulation program allows the user to evaluate different scenarios from the selection of opportune inputs. It can be used also to predict the behaviour of the system in relation to particular condition that the user is interested in investigating. Finally, the program presents a final sheet in which al the findings of a unique iteration or of a set of iterations are displayed. In particular, this final sheet also reports the average values of a set of simulation, both for the global chain and each single supplier.[69]

After having introduced the inputs (paragraph 6.5) in the opening workbook, the users should choose the demand distribution (paragraph 6.5.5) in the apposite sheet ("Orders"). Hence, all the information for the simulation running are introduced. The only thing missing is to state how many iterations the program is supposed to work. It is obvious that the larger is the amount of iterations, the lower is the effect of the variability and uncertainty in the system.

6.12 Documentation and Implementation

During the work, the steps to create the model have been discussed with TPCA and recorded. Furthermore, the simulation program is embedded with an initial

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[69] For all the documentation, see Appendix IV

sheet that allows the users to understand how the program works, which are the variables to change for a new simulation running and which are assumed as default.

Finally an extended practical handbook has been attached to the simulation program. The readers might find it in Appendix IV.

The purpose of the manual book is to help the user to make use easily of the simulation program and to eventually take reference in case of doubt. How the program works, which are the steps to run a successful simulation and where setting all the inputs the simulation model needs, are thoroughly reported in the practical handbook.

Anyway, the program has been built according to TPCA requirements and during the implementation all the feedbacks offered by TPCA have been considered as "input" for the improvement of the model.

6.13 Resume

This chapter concerned the simulation model that has been developed for the thesis. After an initial description of the background and the delimitations of the survey, the process to build a simulating model and program has been presented, as already theoretically introduced in the previous chapter. Hence, the conceptual model, the inputs and outputs, the logic of the program and the steps to assure it reliability and validity have been thoroughly reported.

The first goal of this master thesis was to develop a simulating tool for the TP A1 TCA's supply chain. This objective has been achieved and the purpose of this sixth chapter was to illuminate the reader about all the stages have been performed to succeed in. The following chapter will introduce a further analysis that this simulation program permits to conduct: once obtained a fitting simulation model, the next goal is to analyse it in order to find possible issues of improvements to focus on.

Analysis

The previous chapter dealt with the definition and description of the simulation program. This seventh chapter will present the results of the analysis that has been conducted, hence the inputs introduced. Due to the complexity of the system and to the impossibility of considering all the effects of the multi-variable model, a further risk analysis with @Risk software will follow. The goal is to detect the most important inputs affecting the outputs of the system. A few graphs concerning the analysis will be presented to support the discussion.

7.1 Introduction

A simulation model needs to run many times with different input values in order to find precise relationships between inputs and outputs and to give results useful to draw conclusions. At the end of every simulation output values change, but different inputs do not affect them with the same relevance; hence the need to alter model parameters properly and to avoid connections among them has arisen.

The intent of the simulation model is to emulate the actual system. Experiments, then, can be conducted to determine the effects of altering model parameters on performance measures. Conducting experiments on an actual system like a complex supply chain is infeasible, because it is time consuming and expensive. Actually, simulation provides the ability to experiment on a representative model, thus yielding information previously unattainable in any reasonable amount of time (Porcaro, 1996).
After having constructed a great simulation model of the system, the point is to determine which the best combination of changes is to provide the best results. A systematic approach to do it is the *Design of Experiment (DOE)* tool. The DOE method is a recipe for setting factors and levels for inputs in a simulation model. The utilization of DOE allows performing simulations with different inputs levels in order to study them independently and to investigate their interactions. When the experiments are run and the response data is collected, the effect of factors and their interaction can be determined. Conversely, it is also guaranteed the possibility to pick and choose the levels of the factors to achieve the desired response.
The simulation model has some inputs and consequently some related outputs. But, what is unknown is the linkage existing between them, the quantitative relation connecting inputs and outputs. The DOE accomplishes this task. The DOE and relative regression analysis will provide the equations relating inputs and outputs of the model.
It is easy why DOE and simulation are adopted at the same time. DOE provides the recipe for the experiments and a method for analysing the results, while the simulation supplies a mean to run the experiment. Together, they constitute a very powerful tool (Porcaro, 1996).

At the same time, it is very important to pay attention to the number of inputs to deal with because the bigger is that number the more expensive in terms of time is the DOE because for every new input it doubles the number of simulations to perform. After having interpolated results of DOE experiments, by the use of

regression analysis it is possible to relate outputs to inputs through equations. Those equations refer to a static and deterministic model, therefore it is important to perform a risk analysis to understand better which parameters are affecting the most model's performances under uncertainty.
Finally, after all those procedures, it is possible to draw conclusions and making suggestions on the basis of analysis output.

7.2 Analysis using Design of Experiment[70]

A design of experiment is a structured method for determining the relationship between factors affecting a process and the output of that process. DOE uses purposeful changes of input variables in order to observe and relate change to the output variables. The purpose of DOE in effect is to obtain the maximum amount of information using a minimum amount of resources.
DOE also permits to:

- Determine which factors shift the average response and which have no effect at all
- Build empirical models relating to the response of interest to the input factors
- Find factor settings that optimise the response and minimize the cost[71]

In particular, DOE is a statistical technique that allows the researcher to evaluate the interactions existing between variables of the model and it highlights which inputs are relevant to outputs and which have no affection. The greatest weapon of DOE is that users and analysts can avoid changing only one input at time, because changing only a single input at a time does not enable the estimation of interaction among factors. Changing one separate factor at time does not lead to the real optimum, and gives different implications with different starting points.[72]
Moreover, the statistical accuracy is higher and the variances of estimated effects are narrower[73].
The design of experiment adopted in this thesis aims at isolating the "vital few" from the "many" inputs have been introduced in the model.
Without embarking on difficult explanation about how DOE is constructed, there is hereby reported the basics about a design building. To run the experiment, Six Sigma Excel add-in[74] has been used. As described in the latter chapter, the choice of Microsoft Excel add-in applications are due to easiness related to Excel implementation and to Excel overwhelming diffusion.
Each input is described by two opposite values (-1; +1), representing two opposite alternatives that this input can assume in the real system. Each input is then multiplied with another input, which assumes two opposite values (+1; -1). The outcomes will be therefore related.
If N is the number of factors to take into account, the number of interactions should be considered will be $2^{n.}$ This type of design is named *Full Factorial Design,* since the characteristic of mapping all the possible combination between values. When the number of factors is relevant, the design of experiment should

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[70] *Design of Experiments*, Basic Course, Umetrics Academy, 2004
[71] Six Sigma Concept, Johansson Consulting, www.johansson-consulting.com
[72] *Design of Experiments*, Basic Course, Umetrics Academy, 2004
[73] Six Sigma Concept, Johansson Consulting, www.johansson-consulting.com
[74] Ibid.

involve a very large number of iteration to consider all the possible outcomes and its complexity considerably increased. To reduce it, *Fractional Factorial Design* can be used. While in the full factorial design all factors and interaction effects can be estimated independently of each other, in the fractional factorial factors and interaction effects are mixed up, thus reducing the number of experimental runs.
The Table 6.3 below helps understand:

Full Factorial Design - 3 factors A,B,C; 8 runs							**Fractional Factorial Design - 3 factors A,B,C) 4 runs**						
A	B	C	AB	AC	BC	ABC	A	B	C	AB	AC	BC	ABC
-1	-1	-1	1	1	1	-1	1	-1	-1	-1	-1	1	1
1	-1	-1	-1	-1	1	1	-1	1	-1	-1	1	-1	1
-1	1	-1	-1	1	-1	1	-1	-1	1	1	-1	-1	1
1	1	-1	1	-1	-1	-1	1	1	1	1	1	1	1
-1	-1	1	1	-1	-1	1							
1	-1	1	-1	1	-1	-1							
-1	1	1	-1	-1	1	-1							
1	1	1	1	1	1	1							
No correlation between matrix columns exists. This means that all main effects and interactions can be estimated independently.							Several columns are correlated e.g. A=BC, B=AC, C=AB. This means that the cause of a visible effect cannot be clearly identified. Interactions however are less likely than main effects.						

Table 7.1: *Full Factorial Design vs. Fractional Factorial Design*[75]

The design that this study needs is just a tool as a "screen" for the understanding of really important factors. It allows sensible reduction in the amount of interactions between factors.
In the simulation model of this thesis, a reduction of the system complexity has been sought. As introduced in the previous paragraphs inputs are various (e.g. EOQ, LT, demand, uncertainty, stock levels) and broken down along with the numerous tiers of the supply chain. For this reason, the model investigates into the existing relations among 26 inputs to produce 5 outputs of interest. If a full factorial design had been run, it would have entailed a huge number of iterations (i.e. 2^{26} iterations). The need for a reduction in the simulation runs it is immediate to understand.
The design of experiment of this thesis performs 1024 different simulations. Moreover, additional 10 simulations were run in order to evaluate center points: the center point is an experiment which is run with all input values set to level 0, in order to investigate the interior space, limited by +1 and –1 values. The number of center points will not affect the estimation of main effects or interactions[76].

Resuming what already introduced in chapter 6, there are 26 factors to consider:

- 10 EOQ agreements between Tetra Pak and its suppliers
- 12 Lead-Time agreements
- Demand, meant as number of orders per year

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[75] Six Sigma Concept, Johansson Consulting, www.johansson-consulting.com

[76] Six Sigma Concept, Johansson Consulting, www.johansson-consulting.com

- Safety stock level, meant as the same for each supplier in order to simplify the analysis
- Variability of Lead-Time affecting the whole supply chain
- Percentage of Keeping cost, meant as the same for each supplier

Levels selected for every input are listed here below:

Input / Level	EOQ (referred to agreement)	LT (referred to agreement)	Demand (orders/year)	Variability	Keeping Cost %	Safety Stock
+1	+33%	+33%	45	1	0,4	4
0	=	=	35	0,5	0,3	2
-1	-33%	-33%	25	0	0,2	0

Table 7.2: *DOE levels chosen to perform the analysis*

7.2.1 Outcomes of the analysis

After having performed 1034 simulations according to the DOE, the following step is the regression analysis, which consists of writing an equation for each output depending on inputs.

There are three main types of polynomial models:

- Linear (e.g.: y= $\beta_0 + \beta_1 x_1 + ... + \varepsilon$)
- Interaction (e.g.: y= $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 .... + \varepsilon$)
- Quadratic (e.g.: y= $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 .... + \varepsilon$)

In this case the linear model has been chosen because of the high number of inputs and equations have been calculated through Six Sigma. In order to simplify the reading of those equations, variables names used in the program are quoted below:

	EOQ agreement	Lead-time agreement
Valve Ramp Infeed	X01	X13
Strip Magazine	X02	X14
Strip Applicator	X03	X15
Paper Magazine	X04	X16
Frame	X05	X17
Doors and Covers	X06	X18
Splicing Device	X07	X19
Bobbin	X08	X20
Bobbin normal reel	X09	X21
Connection Box	X10	X22

Table 7.3: *X value for inputs in the regression equations given by DOE*

Lead-time System Supplier: X11
Lead-time Module Supplier: X12
Demand: X23
Variability: X24

Daily keeping cost percentage: X25
Safety stock level: X26

One of the most significant parameters is the *R-Squared*[77], also called the coefficient of determination, which is the proportion of variability in the output variable taken into account. In other words, R-Squared measures how well we can reproduce current runs and it assumes values between 0 and 1 (i.e. for 1-values the model is perfect). However, if a variable is added to the equation, R-Squared value will get larger even if the added variable is of no real value, therefore it is calculated also the *R-Squared adjusted*, which compensates for this glitch.

Here below there are presented the interpolation results for each output.

7.2.2 Average Lead-time

The equation found is the following:

$$\text{Mean Lead-time} = 63.196 - 0.243*X01 - 0.284*X02 - 0.730*X05 - 0.439*X06 + 8.135*X11 + 2.014*X12 + 0.488*X13 + 0.452*X14 + 2.605*X17 + 0.509*X18 + 0.157*X19 + 0.881*X22 + 2.520*X23 + 1.551*X24 - 1.313*X26 \qquad (7.1)$$

R-Squared and R-Squared adjusted values are slightly above 90% hence this equation is well-describing simulation results.
It is remarkable that, according to this equation, the factor of the regression equation affecting the most this output is the System Supplier's lead-time (X11); other important factors are Module Supplier lead-time (X12), 'Frame' supplier's lead-time (X17), which is the longest lead-time agreed of all, and the number of orders per year. Safety stock level and lead-time variability are relevant as well.

7.2.3 Tied Up Capital

$$\text{Tied Up Capital} = 563401.680 + 3633.477*X01 + 8200.838*X02 + 12433.888*X03 + 32703.862*X05 + 10461.854*X06 + 14850.282*X07 + 4125.931*X08 + 10538.985*X10 + 2815.727*X14 + 11215.253*X17 + 5945.566*X18 + 2759.399*X19 + 52834.028*X23 - 24833.628*X24 - 23347.078*X25 + 145696.724*X26 \qquad (7.2)$$

R-Squared and R-Squared adjusted values are close to 95% therefore this equation is well-describing simulation results.
The most important factor according to this interpolation is the Safety Stock level; other inputs to be taken into consideration are the Demand, the Frame supplier's EOQ, the Lead-time variability and the Daily Keeping Cost percentage.

7.2.4 Total Keeping Cost

$$\text{Keeping Cost} = 196127.501 + 1270.948*X01 + 2896.731*X02 + 4554.309*X03 + 11386.818*X05 + 3486.596*X06 + 5008.073*X07 + 1678.568*X08 + 3578.621*X10 + 4012.964*X17 + 2229.104*X18 + 18433.582*X23 - 8695.663*X24 + 58037.725*X25 + 50706.062*X26 \qquad (7.3)$$

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[77] Six Sigma Concept, Johansson Consulting, www.johansson-consulting.com

R-Squared and R-Squared adjusted values are about 93%: this equation too is well-describing simulation results.

There are two main factors affecting the most this type of output: the Keeping Cost Percentage and the Safety Stock level. Besides, Demand and Frame supplier's EOQ are important for evaluating results regarding this output.

7.2.5 Out of Agreement

$$\text{Out of Agreement} = 5.049 - 0.210 \cdot X01 - 0.317 \cdot X02 - 0.220 \cdot X06 - 0.333 \cdot X08 + 2.253 \cdot X23 + 4.149 \cdot X24 - 1.845 \cdot X26 \tag{7.4}$$

R-Squared and R-Squared adjusted values are about 69%; hence this equation is less reliable than the previous ones.

The most important inputs are the Lead-time variability, the Safety Stock level and the Demand. This result is reasonable.

7.2.6 Penalty

$$\text{Penalty} = 70940.232 - 4183.768 \cdot X01 - 6942.148 \cdot X05 - 3364.426 \cdot X06 + 59696.990 \cdot X11 + 15592.279 \cdot X12 + 3104.305 \cdot X13 + 21277.752 \cdot X17 + 3297.666 \cdot X18 + 5591.447 \cdot X22 + 28310.156 \cdot X23 + 22797.506 \cdot X24 - 13511.789 \cdot X26 \tag{7.5}$$

Like the previous output, R-Squared and R-Squared adjusted values are about 69%. The input affecting Penalty Cost the most is System Supplier's Lead-time, after that Demand, Lead-time variability and Frame supplier's Lead-time are critical as well. It is difficult to describe accurately this output through a linear function because it is based on the same logic as "Out of Agreement" hence it is characterised by the same problems.

7.3 Inputs and Outputs Matrix

In order to resume what showed until now, here below a table representing the relationship between inputs and outputs according to the Regression analysis is reported. The purpose is to have a better overview on what reported in this chapter.

Inputs/Outputs	**LT**	**T.U.C.**	**T.K.C.**	**O.A.**	**P.C.**
EOQ Valve Ramp Infeed	X	X	X	X	X
EOQ Strip Magazine	X	X	X	X	
EOQ Strip Applicator		X	X		
EOQ Paper Magazine					
EOQ Frame	X	X	X		X
EOQ Doors and Covers	X	X	X	X	X
EOQ Splicing Device		X	X		
EOQ Bobbin		X	X	X	
EOQ Bobbin Normal Reel					
EOQ Connection Box		X	X		
LT System Supplier	X				X
LT Module Supplier	X				X
LT Valve Ramp Infeed	X				X
LT Strip Magazine	X	X			
LT Strip Applicator					
LT Paper Magazine					
LT Frame	X	X	X		X
LT Doors and Covers	X	X	X		X
LT Splicing Device	X	X			
LT Bobbin					
LT Bobbin Normal Reel					

LT Connection Box	X				X
Demand	X	X	X	X	X
Variability	X	X	X	X	X
Keeping %		X	X		
Safety Stock	X	X	X	X	X

Table 7.4: *Input-Outputs relationships*

It is easier now to understand which factors are critical for one or more outputs: for instance, Demand input and the existence of variability result important factors for every output taken into consideration. The following risk analysis will weigh the relevance of those factors to determine the few really fundamental.

7.4 Analysis with @Risk[78]

Once determined the equations existing between inputs and outputs of interest of the model, the goal of the risk analysis it to investigate what occurs if, for a precise scenario, constant values of inputs are substituted with stochastic distributions. Secondly, a sensitivity analysis is conducted for the assessment of the most important inputs affecting the outcomes. In effect, the equations that have been found are still function of too many variables and therefore, it is still impossible to address quantitative importance to the different factors of the equations. The sensitivity analysis aims at accomplishing this task. Moreover, it is also easy to conduct and assess, since the use of tornado graphs (see Figure) offers an immediate idea of which are the main components of the outcomes occurring.

Definition of inputs and outputs. To run simulation with @Risk, firstly a model has to be implemented. Our model satisfies this request. Secondly, the second step implies to substitute deterministic (constant) values of the inputs with a probability distribution. A probability distribution is a device for presenting the quantified risk for a variable. @Risk uses probability distributions to describe uncertain values in the Excel worksheets and to present results. Consequently, the outputs are probability distributions of possible values that could occur instead of unique value, like in a normal deterministic model.

The table below reports the distributions have been used for the sampling:

Input	**Probability Distribution**	**Values**
EOQ	Discrete Uniform	+/- 33% Agreement
LT	Exponential	+/- 33% Agreement
Demand	Discrete Uniform	[25; 45]
Variability	Triangular	(0; 0,9; 1)
Safety Stock	Discrete Uniform	[0; 4]

Table 7.5: *Probability distribution adopted in the @Risk analysis*[79]

The choices of these distributions are consequence of the impact of inputs in the real system and have been discussed with the supervisors. The values, instead,

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[78] All the graphics, statistics and data of the analysis with @Risk are reported in Appendix III

[79] Anyway, other @Risk analyses have been conducted to evaluate the impact of different input distributions on output. No remarkable affection has been appraised.

correspond to the same value we decide for the design of experiment (Table 7.2). Hence, the EOQ and the lead-times can vary from -33% of agreement to +33%. Instead, for the Demand, the allowed values are beneath an interval of 25 to 45 orders of filling machine per year. Furthermore, if a discrete uniform distribution has been chosen, this means that the distribution assumes integer values from 25 to 45 with the same likelihood. For the other distribution graphs used for the inputs see Appendix V.

Here below there is reported the frame of inputs and outputs of the model that have been introduced into @Risk:

Simulation explanations and setting. Once defined the distribution for the inputs, declared which are the outputs the analysis accomplish to investigate, the @Risk simulation might begin. @Risk simulation in based upon Monte Carlo simulation. Monte Carlo sampling refers to the traditional technique for using random numbers to sample from a probabilistic distribution. Monte Carlo sampling technique is entirely random. Samples, of course, are more likely to be drawn in areas of the distribution, which have higher probability of occurrence. Monte Carlo sample uses a new random number between 0 and 1. With enough iterations, Monte Carlo sampling recreates the input distributions through sampling. To assure reliable analysis a huge of iterations has to be run: for this purpose, @Risk performed 10000 iterations.

Findings. For each output, there will be hereby presented the results of the simulation running with @Risk:

- **Average Lead Time:** The @Risk distribution for the average lead-time shows a mean value (i.e. 55 working days) that is under the agreement, with no multiple orders in one week (i.e. 60 working days, equal to 12 weeks)[80]. The probability of average lead-time within the standard agreement is around 75%, which means 1 filling machine upon 4 is delivery exceeding the agreed lead-time. Consequently to how the program has been thought, this delay implies a penalty value for the chain, because the machines are stocked in inventory more than they should be. A percentile of 90% corresponds to 80 working days: that means that the chain has 10% of probability to deliver the complete machine beyond 80 working days. With sensitivity analysis, sampled input variable values are regressed against output values, leading to a measurement of sensitivity by input variable. The results can be displayed as “tornado” type chart, with longer bars at the top representing the most significant input variables. In this case, it could be noticed that System Supplier gives the principal contribution with a standard coefficient of 0,897. Secondly, X17 (LT Frame, Fa-tec) and the Module Supplier’s lead-times are respectively the most affecting, with a value of 0,286 and 0,227.

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[80] It is useful to remember the reader that the agreed LT is 12 weeks, whether in the same week only one order is released. This value will increase of a week for each order is placed within the same week.

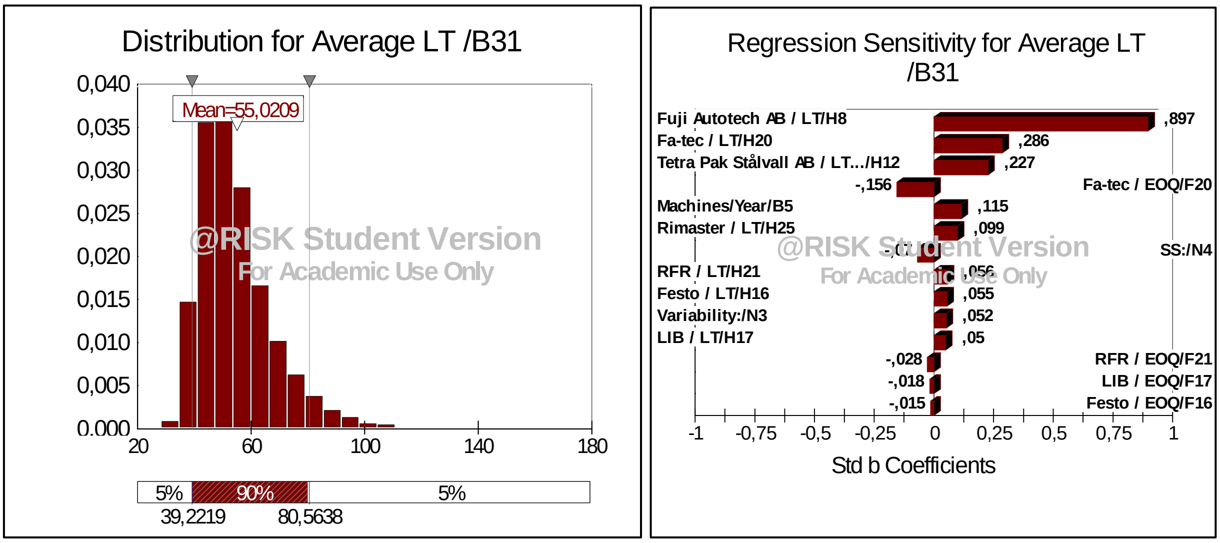

Figure 7.1: *@Risk analysis for Average Lead Time*

- **Tied Up Capital:** The graph dealing with 'Tied Up Capital' output is similar to a normal distribution according to which the outcomes are spread around the mean value. The graph presents an indicative mean value of 580000 SEK corresponding to almost three complete 'ASU A1 Infeed TCA's in the chain. The queues of the graph inform us that 90% is the likelihood that output values range from 390000 SEK until 770000 SEK, corresponding almost to four ASU complete modules. This value is significantly high and it is mostly related to the contribution of Safety Stock (Tornado Graph, Regression coefficient = 0,879). Reasonably, a constant presence of items in stock leads to increase the value of the tied up capital. An interesting effect on the system is exerted also by X05 (EOQ Frame, Fa-tec, Std coefficient=0,285) and by the distribution of the orders of machines (Demand, Std coeff. =0,273). Then, the LT for the Frame and the EOQ of Splicing Device follow (Std coefficient of 0,14 and 0,13).

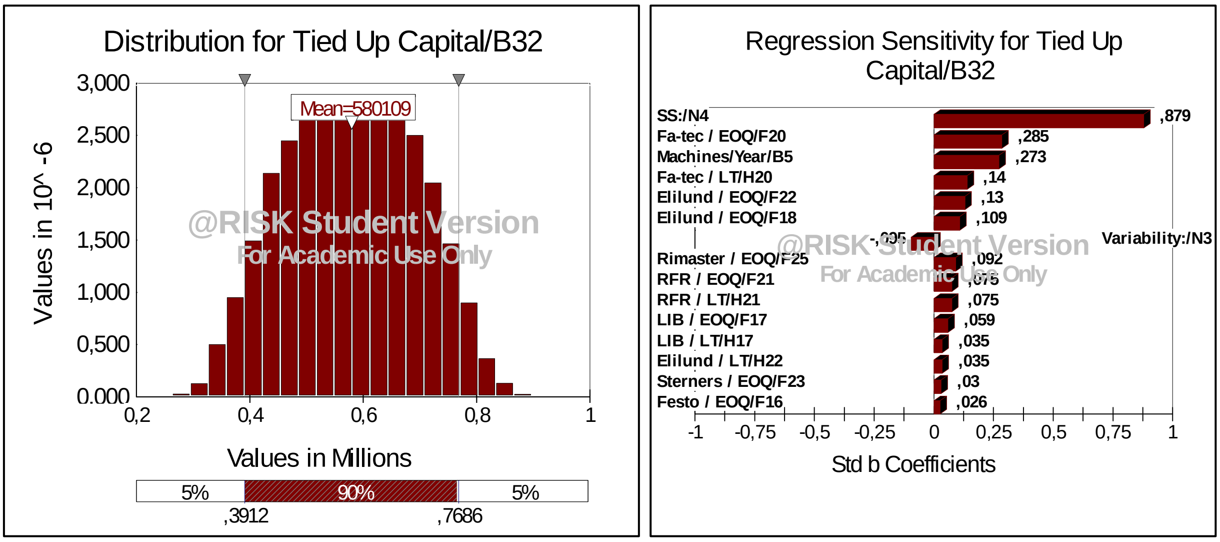

Figure 7.2: *@Risk analysis for Tied Up Capital*

- **Total Keeping Cost**: As a consequence of what asserted above, even for the total keeping cost the level of Safety Stock results to be critical. This is meaningful, moreover if the definition of total keeping cost is reviewed. The keeping cost is calculated day by day as the product between the daily inventory level in each day and the holding cost of the module that is in stock. Thus, if there is a high level of inventory, the cost of holding them in stock will therefore increase. The EOQ of ‘Frame’ component and the ‘Demand’ are still influencing the outcomes.

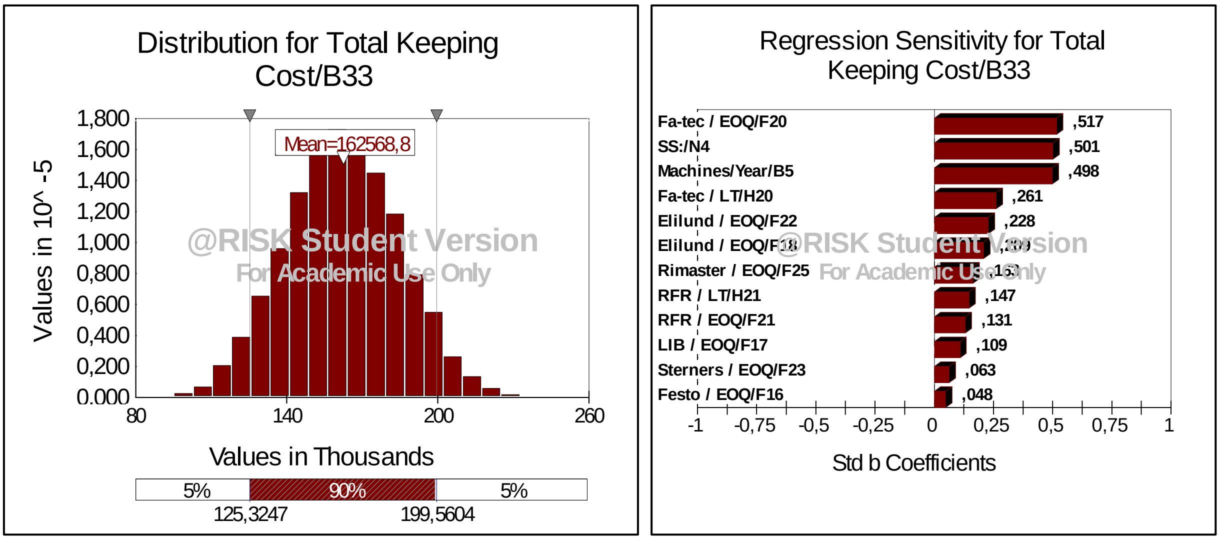

Figure 7.3: *@Risk analysis for Total Keeping Cost*

- **Out of Agreement:** The simulation program tries to predict the behaviour of the chain for a year. Regarding the number of times in which the system is in late and therefore, the filling machine cannot be delivered in time, this value is about 6 times/year. The probability that deliveries are less than twice a year is only 5%; 90% of occurrences are between 2 and 10 deliveries in late. There is a percentage of 10% corresponding to a number of ‘out of agreement’ that are superior to 10 times/year. This figure is considerably high, even more if compared to the average orders number of filling machine during a year (i.e. 35 A1 TCA). The ‘Out of Agreement’ value is significant, because it aims at offering a quantitative assessment of the delays in the supply chain. The reduction of this value should be considered fundamental for a company in term of customer satisfaction and strategic advantages on competitors. Even more important is that this figure is related to the potential loss (e.g. opportunity cost, tied up capital value exceeding the necessary, etc.) that a company has to sustain in this case. The @Risk output distribution shows that the system is not almost able to deliver the modules according to the agreement of 12 weeks. This is due particularly to the relevant variability and uncertainty affecting the lead-times in the model. The ‘tornado graph’ helps evaluate this effect. To increase the Out of agreement figure also contributes the Demand (number of orders of filling machine per year). A high level on the demand or a very uncertain and lumpy distribution of orders increases the risk for delayed deliveries.

However, it is meaningful to notice that if the variability and the demand affect in a negative way the output, the existence of safety stock mitigates their effects. The purpose for the introduction of an additional stock (named safety) is to prevent the system from stock-out, due to unpredictable factors or uncertain situations occurring in the system. The positive contribution of the stock balances the negative one of the demand.

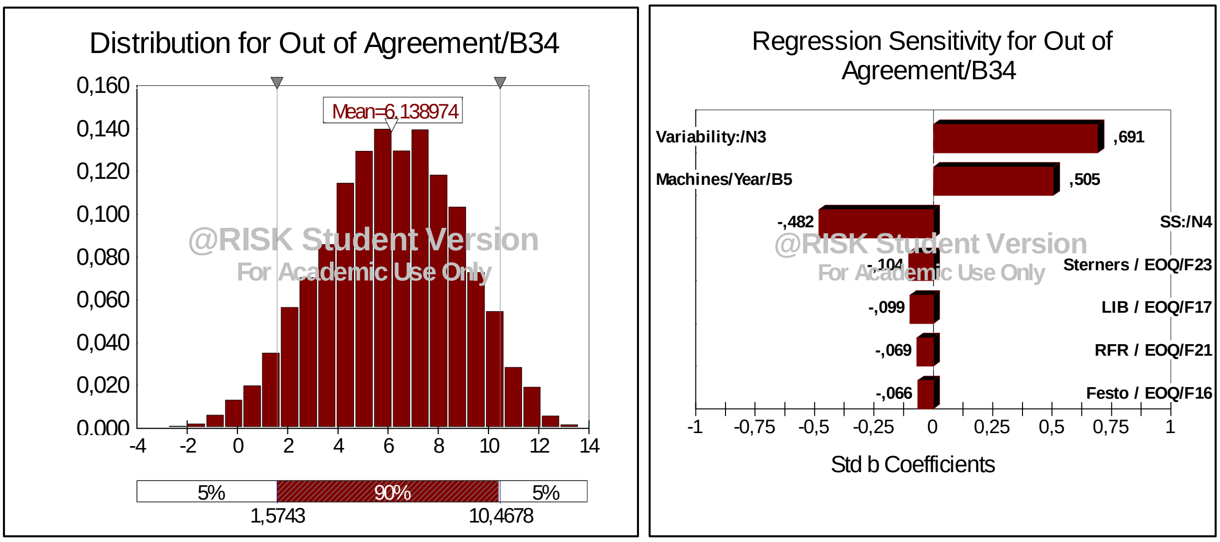

Figure 7.4: *@Risk analysis for Out of Agreement*

- **Penalty:** The meaning of the Penalty value has already defined. It occurs whether the global chain is not efficient and does not fill the agreement. The penalty is calculated how the sum of each daily value corresponding to the time that filling machines (or parts of them) are stocked in inventory instead of being delivered within the scheduled time.

The first graph shows that the penalty value is around 49000 SEK/year, corresponding more or less to 30% of the ASU value. The main input affecting it is surely the System Supplier's lead-time, since the highest standard coefficient of the regression analysis. This finding should not surprise excessively, because it is one of the most relevant lead-time in the chain and since it concern the average lead-time as well. Inputs like the lead-time for the 'Frame' sub-module and that one of Module Supplier also are important in term of this output. The standard coefficients are respectively 0,313 and 0,236. Finally, the Demand and Variability affect the penalty value.

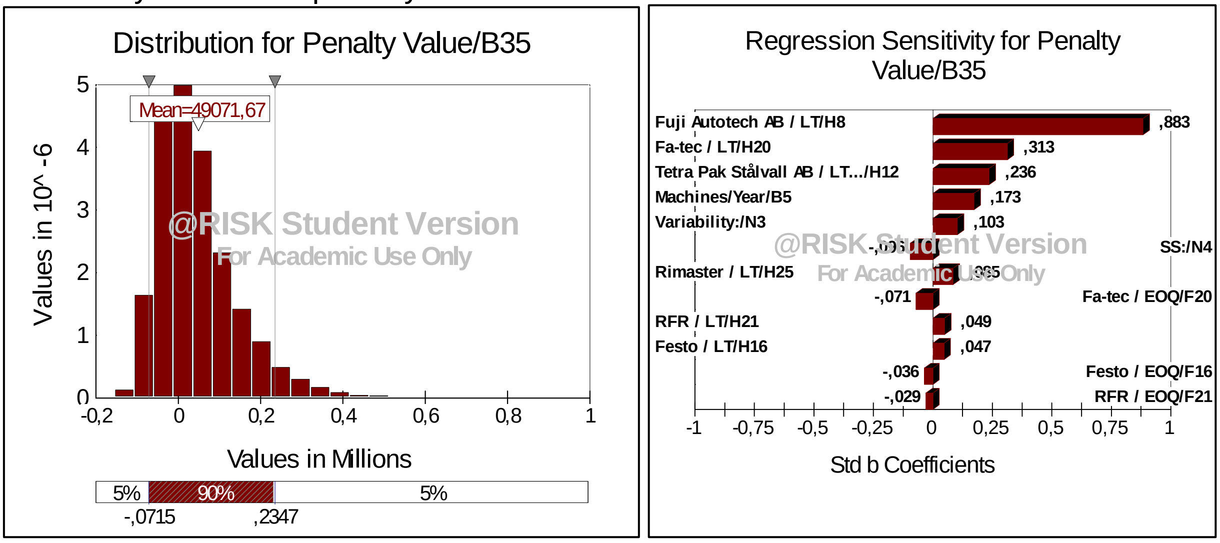

Figure 7.5: *@Risk analysis for Penalty Value*

7.5 Inputs and Outputs Matrix after @Risk Analysis

The table below reports the linkages between inputs and outputs after the risk analysis. It is immediate to note how the complexity of the model has been drastically decreased. There are some factors occurring many times in the outputs. Therefore, the impact of these inputs should be proficiently evaluated.

Inputs/Outputs	LT	T.U.C.	T.K.C.	O.A.	P.C.
EOQ Valve Ramp Infeed					
EOQ Strip Magazine					
EOQ Strip Applicator					
EOQ Paper Magazine					
EOQ Frame		X	X		
EOQ Doors and Covers					
EOQ Splicing Device		X	X		
EOQ Bobbin					
EOQ Bobbin Normal Reel					
EOQ Connection Box					
LT System Supplier	X				X
LT Module Supplier	X				X
LT Valve Ramp Infeed					
LT Strip Magazine					
LT Strip Applicator					
LT Paper Magazine					
LT Frame	X	X	X		X
LT Doors and Covers					
LT Splicing Device					
LT Bobbin					
LT Bobbin Normal Reel					
LT Connection Box					
Demand	X	X	X	X	X
Variability				X	X
Keeping %					
Safety Stock		X	X	X	

Table 7.5: *Input-Outputs relationships after @Risk analysis*

For instance, the distribution of the orders during the year has effects on all the outputs of the system. Other important factors are surely the existence or not of Safety Stock, which from one side mitigates the effects of the variability and the peaks in the demand distribution, decreasing the average lead-time and the penalty due to delays of the chain; on the other hand, it highs the tied up capital in the chain and total keeping cost, because the average level of inventory is increased.

Another interesting issue to remark is the impact of the impact of 'Frame' Component suppliers. It affects both in terms of EOQ and in terms of LT, since it figures are the highest in the supply chain. Finally, the System and Module suppliers concern the outputs, in particular the average lead-time and the penalty.

7.6 Graphs Report

After the identification of the most important factors for each output, it is also interesting to graphs what obtained whit the previous analyses. To accomplish this task, few simulations have been run.

These graphs have been obtained by altering only one input at time while keeping the others fixed. It is not a mistake to perform such analysis because it is based on DOE results: it is not another research for mathematical relationships between inputs and outputs but it is a test to understand in which way the most important inputs can affect the output they are referring. Furthermore, a graphical figure can help the user to address attention to the main key-factors.

The analysis, when possible, takes into account different types of orders distribution during the year.

In order to investigate the principal effects for the system, some values have to be set as default. Ten simulation runs have been performed: the average values of the output have been utilized for tracing the graphics. The table below summarize the information and the inputs for the simulation analysis:

Factors	Values
N. of iterations	10
N. of Orders per year	35
Type of Distribution	Forecast – Uniform
Order Batches	50% - 80% - 100% - 130% Agreed
Safety Stock	SS=0 – SS=3
% of Total Cost per Year	30%

Table 7.6: *Inputs for the following graphs*

7.6.1 Lead-time

The most important factor affecting the global Lead-time in the chain according to the equation is System Supplier's Lead-time, because it is one of the longest among all the agreement and because it is situated at the last tier before the Market, hence System Supplier's delays are critical. However it is more interesting to trace graphs linking global Lead-time to other factors different from other Lead-time agreements.

At first sight, Figure 7.6 highlights that the Uniform distribution is the desirable condition to minimize lead-time, while Binomial and Poisson Distribution, which are distributions with not a big variance and high concentration around the mean value (that is, they are characterised by high picks of orders demand) are the worst cases for the average lead-time in the supply chain. Normal Distribution (which is a smoother distribution than Binomial and Poisson) and Forecast Distribution are between the two previous cases. Afterwards, only Forecast Distribution and Uniform Distribution will be shown because they represent the most interesting cases: the first is the interpolation of the actual Market demand, the second represents the best situation.

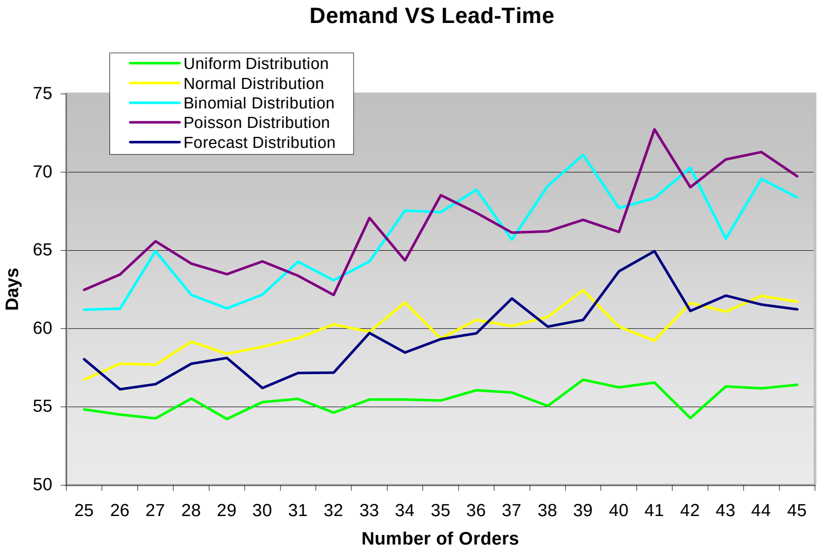

Figure 7.6: *Demand effects on Lead-time*

In figure 7.6 it is represented the lead-time trend in consequence to the variation of the number of orders per year. Generally, lead-time is increasing when the number of orders rises.

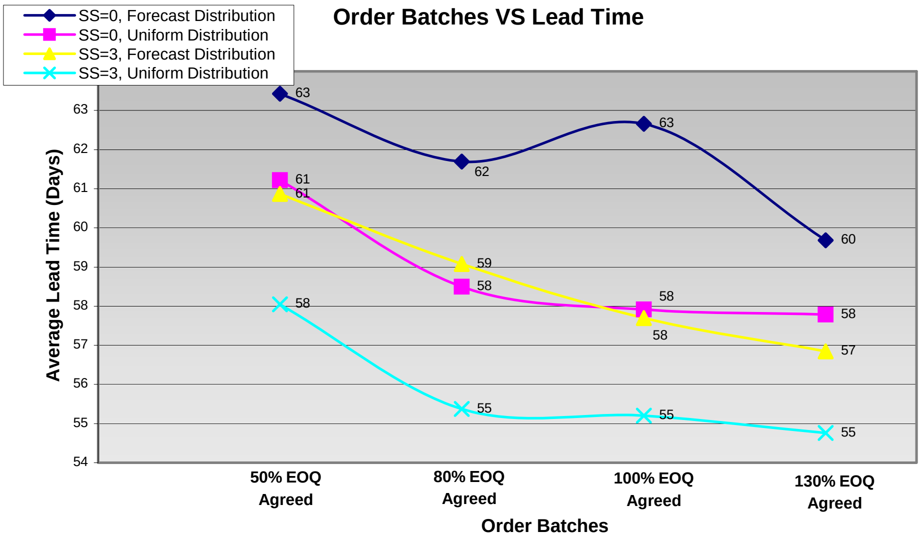

Figure 7.7: *Order batches effect on Lead-time*

In figure 7.7 it is shown how different order batches can affect the global lead-time. In order to draw a significant graph without exceeding in too many simulations, experiments were performed with the same EOQ variation applied to every supplier instead of using different levels for different suppliers. However, an obliged choice since the impossibility to vary one input each time: it is, in effect, a multi variable system and therefore, two dimension graphs do not suit properly. It is important to notice that simulation runs with order batches equal to 80% EOQ agreement do not differ so much in terms of Lead-time from simulations with full EOQ agreement used, there is at most one day of difference more or less. This is an important consideration because if other outputs improve using smaller order batches then it is possible to enhance the actual situation.
Finally, it is useful to give an overview on how the lead-time changes for component suppliers.

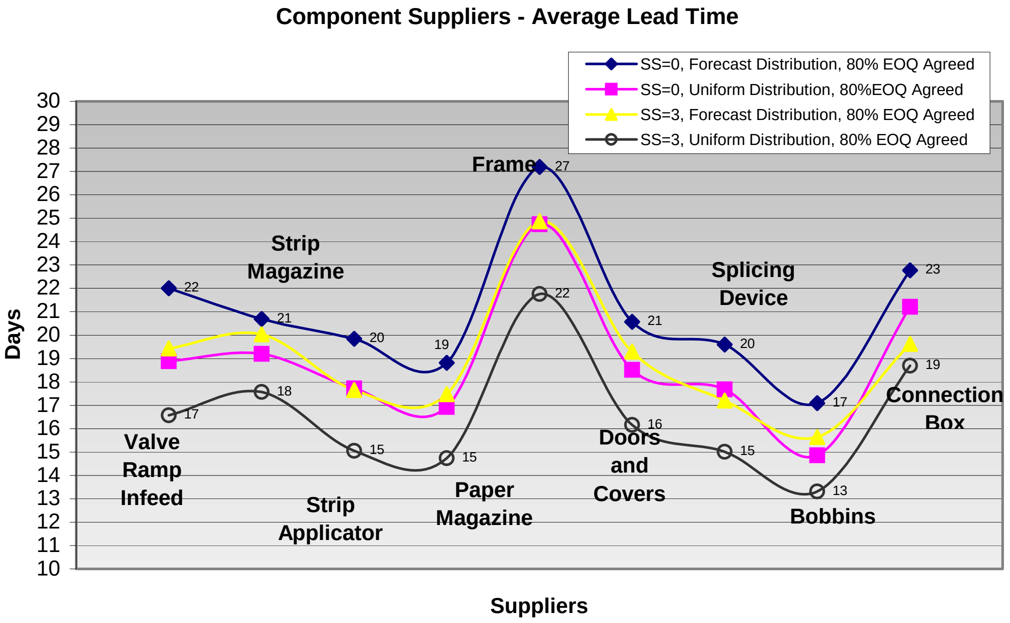

Figure 7.8: *Average Lead-time for Component Suppliers*

Trends are similar for every supplier, even if the type of distribution changes or Safety Stock level changes. Here it is reported once again how much is important the type of Demand on the Lead-time: Uniform distribution (purple line) and Forecast distribution (yellow line) have really similar shapes and values, but the first one needs am high Safety Stock level, while the second one does not use Safety Stock.
Longest average Lead-time belongs to Frame supplier. It is due to its lead-time agreement, which is the longest among all the suppliers.

7.6.2 Tied up Capital

Tied up Capital depends on the average inventory level, hence on the safety stock, which is by far the most important factor. The graphs describe the relationship between Order Batches and Tied up Capital: they precisely evidence how Tied up Capital changes when EOQ different levels are used, compared to

Uniform and Forecast distribution. There are reported four types of scenarios: SS=0, Forecast Distribution; SS=0 Uniform Distribution; SS=3, Forecast Distribution, SS=3, Uniform Distribution. About Safety Stock the choice of these values is because the relationship between Safety Stock and Tied Up Capital is almost perfectly linear, so it makes sense to draw graphs taking into account only two extreme values for the Safety Stock. Concerning demand distributions, the two most relevant distributions have been selected.

As already stated Uniform and Forecast distribution are the most interesting cases to compare because they represent the actual situation and the best situation regarding orders distribution.

Tied up Capital is surely related to EOQ level because the higher EOQ batch is the bigger quantity of material is in stock. It is important to understand which type or relationship exists between these two factors (e.g.: linear) in order to draw conclusions.

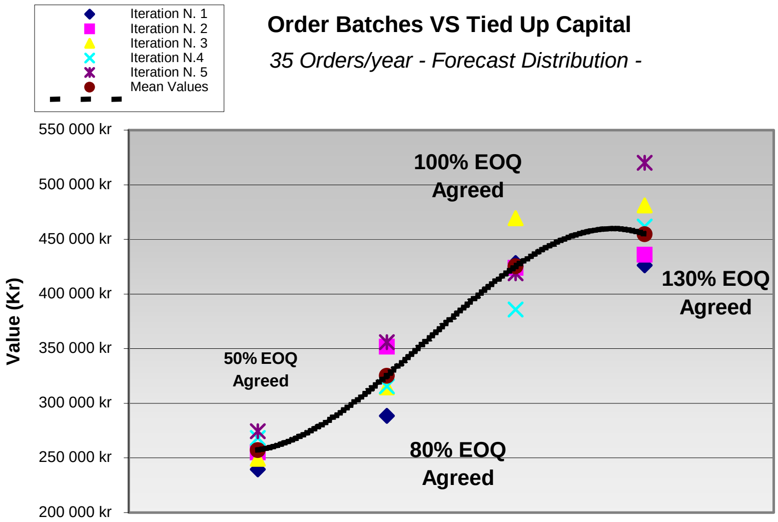

Figure 7.9: *Order batches effects on Tied up Capital(1)*

The first graph above is just an interpolation of 10 simulation runs to compare four different EOQ levels: 50% actual agreement value, 80% actual agreement, actual agreement and 130% actual agreement. Distribution chosen is the Forecast one and there is not Safety Stock. The relationship tends to be linear; therefore increasing or decreasing EOQ batch means automatically to increase or decrease Tied up Capital.

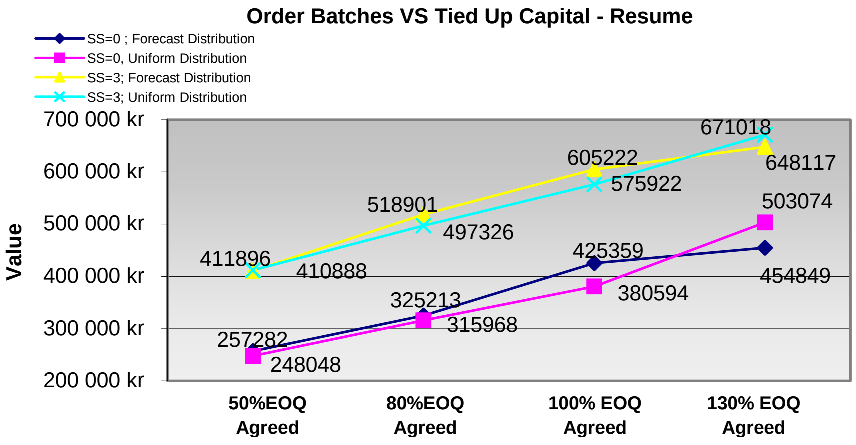

Figure 7.10: *Order batches effects on Tied up Capital*(2)

In the second graph it is shown the same kind of linkage between EOQ batches and Tied up Capital, but now there are two different Safety Stock levels and two different types of Demand distribution. It is easy to guess that Safety Stock just shifts the lines but does not change their shapes, while distributions do not seem to give very different results.

Generally there is a linear-like relationship between safety stock and EOQ level and in any way it is a function always growing. It is correct to assert that an EOQ batch size equals to 80% agreed EOQ level involves a lower tied up capital than the full agreed EOQ level.

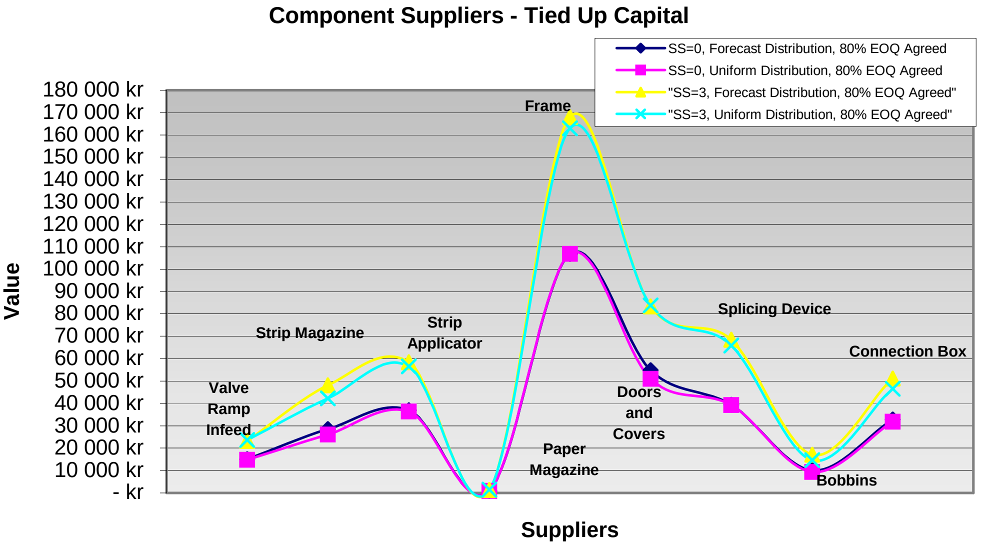

Figure 7.11: *Tied up Capital for Component Suppliers*

Graph in Figure 7.11 shows how the Tied up Capital changes for Components Suppliers, with the same EOQ batch variation, two different types of distribution and two different safety stock levels. As shown before, the two distributions have almost exactly the same trend, while safety stock just shits the line without changing its shape. The supplier that mostly ties up capital in the chain is the Frame supplier: the reason is that it provides Module supplier the most expensive sub-module of all.

7.6.3 Total Keeping Cost

The most important factors related to this output are Daily keeping cost percentage and Safety Stock Level. While the percentage naturally affects the output because it is defined as a percentage of the total cost, safety stock is important because it makes the average inventory level increase: hence keeping cost grows up. Therefore, it is interesting to show how they are related:

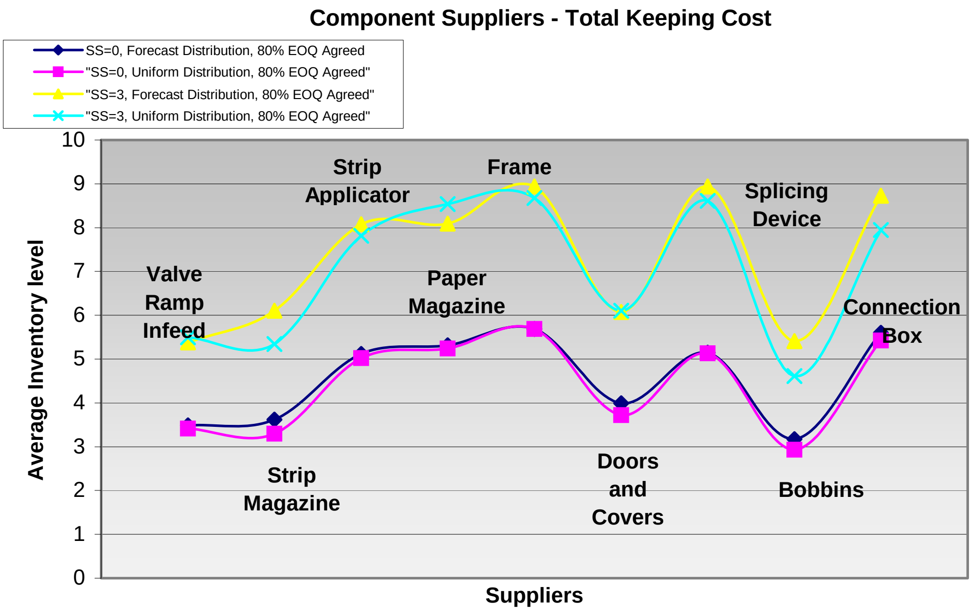

Figure 7.12: *Average inventory level for each Component Supplier*

It is clearly visible that the type of Demand distribution does not play an important role, even if Uniform distribution always assumes lightly lower values than Forecast distribution, while Safety Stock increases average inventory level and shifts the curves up. 'Frame' supplier is characterised by the higher average level: since it provides the most expensive sub-module, it is the supplier affected by the higher Keeping Inventory Cost.

7.6.4 Out of agreement

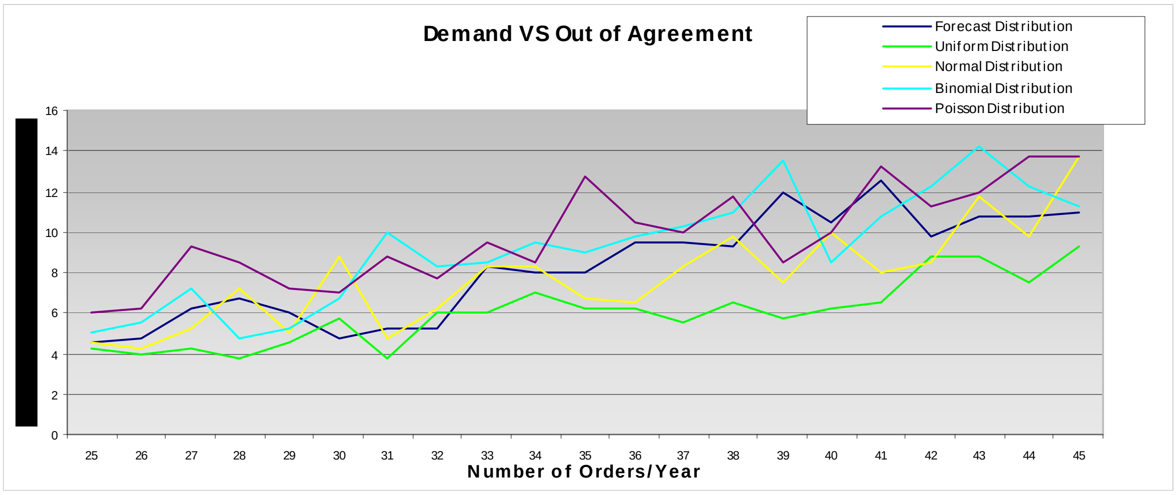

Figure 7.13: *Demand effects on number of Out of Agreement*

This graph represents the trend of the number of times the whole chain exceeds the agreement on lead-time in reliance on the number of orders per year. Generally, every type of distribution has not a smooth curve, except for the Uniform distribution, and there are several picks: this is the reason why linear regression is not reliable as in the previous cases. Anyway, two main conclusions can be clearly drawn by this graph: firstly, increasing annual Demand makes the number of Out of Agreement rise up; secondly, Uniform Distribution is once more the best situation since it leads to the lowest number of outs of agreement.

Next graph relates order batch sizes and the number of Out of Agreement:

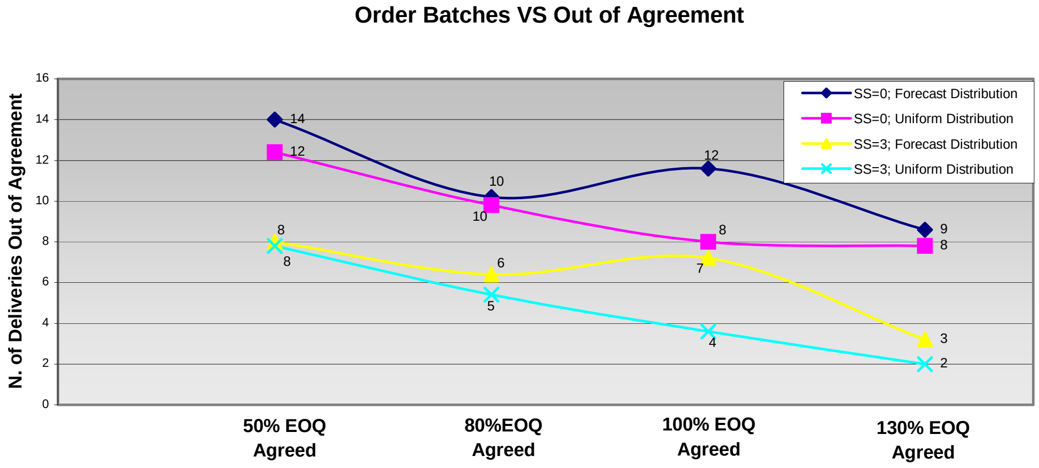

Figure 7.14: *Order batches effects on number of Out of Agreement*

Safety Stock level improves the situation but it does not change the shape of the curves, it just shifts them. As already written, the Uniform distribution returns better values than the Forecast one. Trends are quite similar, except for 100% EOQ value. After having compared the two cases (80%EOQ and 100%EOQ), one remarkable comment is that there is not a great difference in number of Out of Agreement: actually, in Forecast distribution there is a global worsening shift from 80%EOQ value to 100%EOQ values.

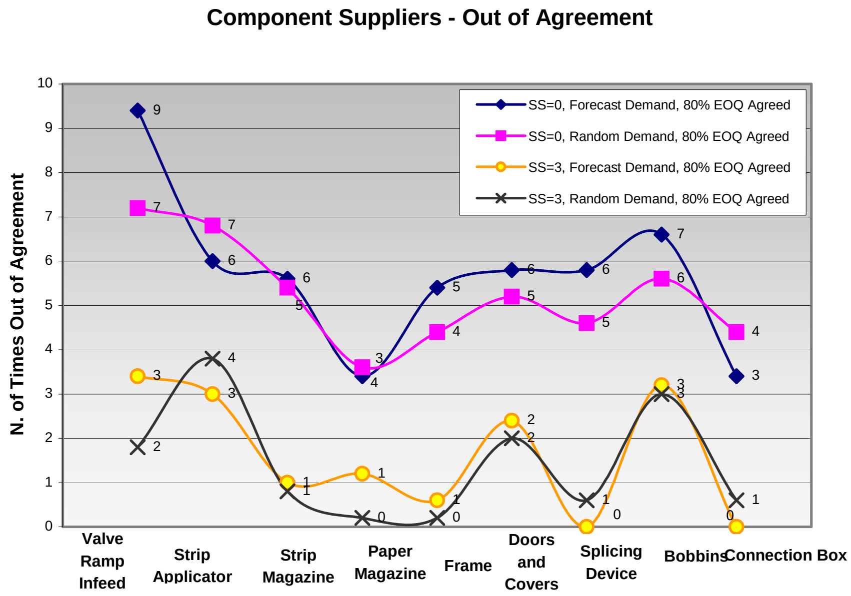

Figure 7.15: *Component suppliers' trend*

In the last figure it is showed the number of Out of Agreement for each supplier comparing two different distributions and two different safety stock levels. In presence of safety stock the two curves are more similar than in absence of safety stock. Valve Ramp Infeed, Strip Applicator and Bobbins suppliers are the most critical ones.

7.6.5 Penalty

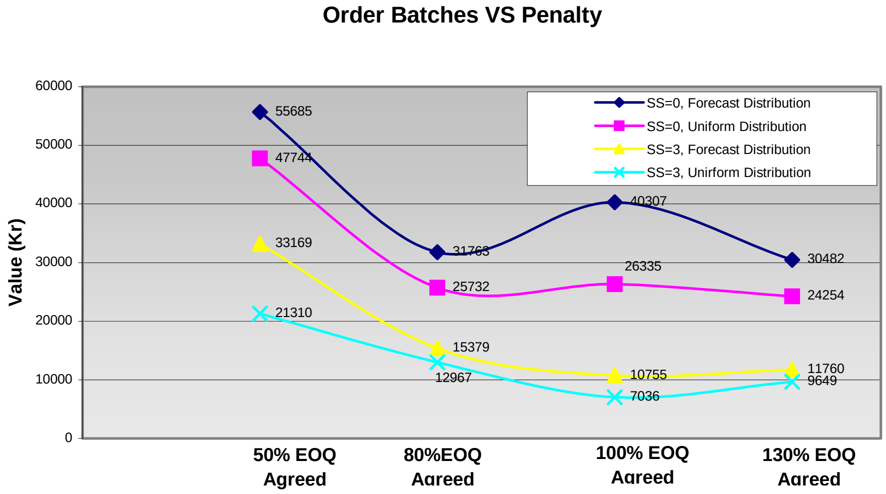

Figure 7.16: *EOQ batch sizes effects on Penalty value*

Penalty is logically linked to the output "Out of Agreement" hence this curves are similar to previous ones showed. It is visible that the presence of safety stock makes curves more similar and improves the situation. Moreover, without Safety Stock there is a change of curves trend between 80% agreed EOQ level and 100% agreed EOQ level, the 80% EOQ agreed batch is more convenient than the actual batch.

7.7 Resume

This chapter presented the analysis of the case study. All the stages in this process were focused on reducing the complexity of the system: the inputs of the model that have been considered are 26, whilst the outputs 5. The risk analysis helps towards this direction: by means of sensitivity analysis and ‘tornado’ graphs, the most significant factors have been evaluated.

The sixth chapter introduced the description of the model and program for the supply chain. This chapter, instead, went beyond: once obtained the simulating program, it aimed at analysing it to detect possible improvements. Few evidences have been highlighted. The following and final chapter will report the conclusion of the project and eventual ideas for further development.

Part IV – Conclusions

Conclusion

This final chapter contains the conclusions of the work.

8.1 Introduction

Analysis results presented in the previous chapter are here discussed, main findings are reported and in the end there are final suggestions for possible ways to improvement.
Afterwards a presentation of pros and cons regarding this model takes place, in order to give an overview on possibilities and limits of the model. Finally, possible developments for this model are suggested.

8.2 Conclusions

According to the inputs given by TPCA, one of the most remarkable results achieved is the importance of a certain demand level: this factor affects all the outputs taken into consideration hence it is a base point for the supply chain improvement. A smooth and regular orders distribution is even more critical than the number of orders placed during the year because demand uncertainty does not permit to plan a correct purchasing policy therefore penalty value and out of agreement too are affected by it. A continuously varying demand is cause od distortion along with the chain.

The lead-time variability is another input that highly affects global results because it is stiff to predict the behaviour for a highly unstable system; unfortunately, information about variability causes were not collected so this case study deals only with its effects. Our suggestion is therefore, to investigate the causes that lead to this uncertainty in the system: by reducing it, general benefits will follow for all the chain.

According to the pieces of information collected, system supplier behaviour affects a lot overall supply chain performances. Its lead-time is relevant for the average global lead-time of the chain. However, we do not assert that the improvements should be addressed to this direction, because we know neither how the system supplier work, nor its strategic relevance for the supply chain.

Another meaningful finding is the average inventory level for each supplier: its value can be managed according to the trade-off existing between lead-time and tied up capital. In the simulation, it is also affected by the safety stock. Its presence depends on strategic objectives set: that is, attaching more importance to lead-time, it will lead to use of safety stock to prevent company from stock out or if the reduction of the tied up capital is the imperative issue, we will advise against the safety stock implementation.

Other interesting outcomes from the analysis are:

- it might be reasonable review agreements policy: suppliers characterized by long lead-time agreements or big EOQ batches agreements with a high cost for the sub-module provided (e.g.: Frame supplier) are necessarily critical for global lead-time and tied up capital;

- the suggestion for the policy to be adopted for the inventory management should be an average level of EOQ batches equal to 80% of the actual agreement, since this level does not significantly raise the global lead-time while tied up capital goes down.

8.3 Pros and Cons of the work

There are several pros regarding the utilization of this model:

- It describes quite well a complex system, it is cheap and user-friendly;
- It is less time consuming if compared to performing a real experiment in the system;
- It allows to test new policies without interfering with reality: this is the main purpose of a simulation model;
- Analysis regards a certain types of input levels, but it is possible to change inputs in order to simulate different scenarios;
- To build this model many interviews to suppliers took place in person, by phone or by e-mail. There had been periodical contacts with TPCA during the development of this work;
- TPCA requested only the simulation tool, in this report there are analysis results too.

There are three main disadvantages regarding this model:

- Internal activities are not taken into consideration: every company is studied by the black-box approach. This approach does not allow focusing on the reasons of problems; it just considers their effects.
- Only one Module supplier was taken into account
- It is difficult to build a simulation program for a multi-echelon system since effects are related one to each other and a large amount of pieces of information is needed. Many times it was hard to gather necessary information.

8.4 Further developments

A complex system like a supply chain needs a great amount of information and perhaps, to include how many actors affecting the outputs as possible. It is worth to build a model considering all the Module Suppliers in order to define with better accuracy troubles and difficulties occurring to the supply chain. This statement does not imply that the work lacks of reliability, because the boundary of the research was previously discussed and agreed with TPCA.

Another breakthrough to address particular attention could be the new agreement policy starting the next August 2005, according to which lead-time agreement is reducing to 8 weeks. This choice is due to the increasing attention paid by TPCA to the Tetra Classic Aseptic package and consequently, to the performances of the filling machine, which manufacture it. The needs for cost containment and time to market compression seem are to parallel issues Tetra Pak is focusing on. Hence, the performances of the filling machine should be aligned to the TPCA's objectives. The simulation tool might be used to figure out new scenarios occurring by means of the introduction of the new input values.

References

Books and Articles

Abnor, I., Bjerke, B., (1997), *Methodology for creating Business Knowledge,* Sage Publications, Newbury Park, CA

Bodie, Z., Marton, R. C., (1999), *Finance,* Hemel Hempstedad: Prentice Hall

Checkland,P., (1993), *Systems Thinking, System Practice*, John Wiley & Sons, Chichester

Cigolini, R., Cozzi, M., Perona, M., (2004), "A new framework for supply chain management – Conceptual model and empirical test", *International Journal of Operations & Production Management,* Vol. 24, N.1, pp. 7 - 41

Christopher, M., (1998), *Logistics and Supply Chain Management: strategies for reducing cost and improving service, Second Edition*, Financial Time Prentice Hall

Chopra, S. Meindl, P., (2004), *Supply Chain Management: Strategy, Planning and Operation, Second Edition*, Prentice Hall of India Edition

Cooper, M.C., Lambert, D.M. and Pagh, J.D., (1997a), "Supply Chain Management more than a new name for logistics", *International Journal of Logistics Management,* Vol. 18 N. 1, pp. 1 - 13

Cooper, M.C., Elram, L.C., Gardner, J.T. and Hanks, A.M., (1997b), "Meshing multiple alliances", *Journal of Business Logistics*, Vol. 18 N. 1, pp. 67 - 88

Davis, T., (1993), "Effective Supply Chain Management", *Sloan Management Review,* Summer 1993, pg. 35

Ellram, L.M., (1991), "Supply Chain Management - the industrial organisation perspective", *International journal of Physical Distribution & Logistics Management,* Vol. 21, N. 1, pp. 13 – 22

Ellram, L.M., (1996), "The use of case study method in logistic research", *Journal of Business Logistics*, Vol. 17, N. 2, pp. 93 - 138

Forza, C., (2002), *L'impresa e le sue aree funzionali,* Libreria Progetto, Padova, pp. 121 - 122

Gammerlgaard, Britta, (2001), "School in logistics research? A methodological framework for analysis of the discipline", *International Journal of Physical Distribution & Logistics Management*, Vol. 34, N. 6, 2004, pp. 479 - 491

Global Supply Chain Forum (2000), "Issue in supply chain management", in Lambert, D.M. and Cooper, M.C., *Industrial marketing Management,* Vol. 29, pp. 65 - 83

Hewitt, F., (1994), “Supply chain redesign”, *The International Journal of Logistics Management*, Vol. 5, N. 2, pp. 1 – 10

Isaac, G.A., (1985), “Creating a competitive advantage through implementing just-in-time logistics strategies” in Christopher, *Logistics and Supply Chain Management: strategies for reduction cost and improving service*

Johansson, A., Rodenstedt, K., Selander, G., (1997), *Supply Chain Management: a third part perspective,* Business Administration, Uppsala University

Jones, T.C., Riley, D.W., (1985), “International supply chain management”, *International Journal of Physical Distribution & Materials Management*, Vol. 15, N.5, pp. 15 –26

Juttner, U., Peck, H., Christopher, M., (2002), “Supply Chain Risk Management: outlining an agenda for future research” in Norrman, A., Jansson, U., (2004), “Ericsson’s proactive supply chain risk management approach after a serious sub-supplier accident”, *International Journal of Physical Distribution & Logistics Management*, Vol. 34, N. 5, pp. 434 - 456

La Londe, B.J., Masters, J.M., (1994), “Emerging Logistics Strategies: blueprints for the next century”, *International Journal of Physical Distribution & Logistics Management,* Vol. 24, N 7, 1994, pp. 35 - 47

Lambert, D., (2004), *The eight essential SCM processes,* Supply Chain Management Review, pp. 18 – 26

Lee, Hau L., Corey Billington, (1992), “Managing Supply Chain Inventory: Pitfalls and Opportunities”, *Sloan Management Review*, Vol. 33, N 2, pp. 65 - 73

Lee, Hau L., Pamanabhan, V., Whang S., (1997), “The Bullwhip Effect in Supply Chains”, *Sloan Management Review*, Spring.

Handfield, R.B., Nichols, E.L., (1999), *Introduction of Supply Chain Management*, Upper Saddle, NJ, Prentice Hall Inc., p. 7

Hauser, L.M., (2003), “Risk-adjusted Supply Chain Management, *Supply Chain Review,* Vol. 7, N. 6, pp. 64 - 71

Hokey, M., Gengui, Z., (2002), “Supply chain modelling: past, present and future, *Computers & Industrial Engineering,* Vol. 43, pp. 231 - 249

Mangan, J., et all., (2002), “Combining quantitative and qualitative methodologies in logistics research”, *International Journal of Physical Distribution & Logistics Management*, Vol. 34, N. 7, 2004, pp. 565 - 578

Merriam, S., (1998), *Qualitative Research and Case Study Applications*, Jossey-Bass, San Francisco

Näslund, D., (1999), “Logistics needs qualitative research”, *International Journal of Physical Distribution & Logistics Management*, Vol. 32, N. 5, 2002, pp. 321 - 338

Norrman, A., Jansson, U., (2004), “Ericsson’s proactive supply chain risk management approach after a serious sub-supplier accident”, *International Journal of Physical Distribution & Logistics Management*, Vol. 34, N. 5, pp. 434 - 456

Patton, M.Q., (2002), *Qualitative research and evaluation methods,* London, Sage, 2002

Persson, F., Olhager, J., (2002), “Performance simulation of supply chain designs”, *International Journal of Production Economics,* Vol. 77, N. 3, pp. 231 – 245

Porcaro, D., (1996), “Simulation Modelling and DOE”, *Industrial Engineering Solutions Magazine,* September 1996, pp. 1- 10

Porter, M.E., (1985), *Competitive advantage*, The Free Press, New York

Rubinstein, R, (1995), *Simulation and Monte Carlo method,* Wiley, Boston

Schary, P. B., Skjott-Larsen, T., (2000), *Managing the Global Supply Chain*, Copenhageh Business School Press

Shapiro, J.F., (2001), *Modeling the Supply Chain,* Duxbury Press

Simchi-Levi, D., Kaminsky, P., (2003) *Designing and Managing the Supply Chain, Concepts, Strategies and Case studies,* Boston, McGraw-Hill Irwin

Slack, N., Chambers, S., Johnston, R., (2004), *Operations Management*, Fourth Edition, FT Prentice Hall, Financial Times Edition

Stevens, G.C., (1989), “Integrating the supply chain”, *International Journal of Physical distribution and Materials Management*, Vol. 19, N. 8, 1989

Taylor, S. J., (1998), *Introduction to Qualitative Research Methods: a guidebook and Resource*, Wiley, Chichester

Tompkins, J., Jernigan, B., (1997), *Goose Chase: capturing the energy of Change in Logistics*, Raleigh, NC, Tompkins Press

Trent, R. J., (2004), “What everyone needs to know about SCM”, *Aupply Chain Management Review ,* March, Vol.8, N.2, pp. 52 - 59

Wyland, B., Buxton, K., Fuqua, B., (2000), “Simulating the supply chain”, IIE SOLUTIONS Magazine, pp. 37 - 42

Yin, R., (1994), *Case study research – Design and Methods*, Sage Pubblications

Zsidisin, G.A., (2003), “Managerial perceptions of Supply Risk”, *Journal of Supply Chain Management*, Vol. 39, N. 1, pp. 14 - 16

Internet Information

www.tetrapak.com

www.palisade.com

www.designengineering.com

www.supplychain.org

www.supply-chain.org

Interviews

Anders Ekberg, Purchasing Development Manager, Tetra Pak Global Technical Support, Lund, 2004 – 12 – 07

Johan Rasmusson, LTH student, master thesis developed at Tetra Pak Global Technical Support, Lund, 2004 – 12 – 07

Anders Jonsson, Industrialization – Emerging Segment, Tetra Pak Carton Ambient AB, Lund, 2004 – 12 – 09

Hans Soberg, Purchasing Manager, Tetra Pak Stålvall AB, Partille, 2004–12– 10

Richard Enander, Purchasing Division,Tetra Pak Stålvall AB, Partille, 2004–12–10

Lof Soren, Industrialization Manager, Tetra Pak Stålvall AB, Partille, 2004–12– 16

Mats Johnsson, Professor, Department of Design Science, Division of Packaging Logistics, LTH, Lund University

Friedrick Olsson, Patrick Tydesio, Phd Students, Department of Engineering Logistics, LTH, Lund University

Thomas Wernesson, Key Account Manager, Rimaster AB, 2005 – 01 – 04

Henrik Larsson, CEO, Larsson I Bjarred Mekaniska Verkstad AB, 2005 – 01 – 18

Lennart Aveling, Anders Jonsson, Supplier Management, Emerging Segment, Tetra Pak Carton Ambient AB, Lund, 2005 – 01 – 21

David Bohman, ASU Product Center, Tetra Pak Stålvall AB, Partille, 2005–02–08

Karl-Uno Andersson, Industrialization Manager, Fa-tec AB,Halmstad,2005–02–09

Goran Lindh, Industrialization Manager, Fuji Autotech AB, Eskilstuna,2005–02–08

Vocabulary[81]

Benchmarking: The systematic comparison of process performance, practices, and attributes for the purpose of process improvement.

Bill of materials: (BOM) a list of the components parts required to make up the total package for a product or service together with information regarding their level in the product or component structure and the quantities of each component required.

Bull-whip effect: the tendency of supply chains to amplify relatively small changes at the demand side of a supply chain such that the disruption at the supply end of the chain is much greater.

Demand management: an approach to medium-term capacity management that attempts to change or influence demand to fit available capacity.

Demand side: the chains of customers, customers' customers, etc. that receive the products and services produced by an operation.

Economic batch quantity: (EBQ) the amount of items to be produced by a machine or process that supposedly minimizes the costs associated with production and inventory holding.

Economic order quantity: the quantity of items to order that supposedly minimizes the total cost of inventory management, derived from various EOQ formulae.

Enterprise resource planning: (ERP) the integration of all significant resource planning systems in an organization that, in an operation context, integrates planning and control with the other functions of the business.

First-tier: the description applied to suppliers and customers who are in immediate relationships with an operation with no intermediary operations.

Inventory: also known as stock, the stored accumulation of transformed resources in a process; usually applies to material resources but may also be used for inventories of information; inventories of customers or customers of customers are usually queues.

Material requirements planning: (MRP) a set of calculation embedded in a system that helps operations make volume and timing calculations for planning and control purposes.

Operations management: the activities, decisions and responsibilities of managing the production and delivery of products and services.

Performance measurement: the activity of measuring and assessing the various aspects of a process or whole operation's performance.

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[81] From APICS, the Educational Society for Resource Management

Pull control: a term used in planning and control to indicate that a workstation requests work from the previous station only when it is required, one of the fundamental principles of just-in-time planning and control.

Push control: a term used in planning and control to indicate that work is being sent forward to workstations as soon as it is finished on the previous workstation.

Regression Analysis: a general statistical technique used to analyse the relationship between a dependent variable and independent variables. The objective is to predict a dependent variable from one or more independent variables.

Reliability: when applied to operations performance, it can be used interchangeably with ‘dependability’, when used as a measure of failure it means the ability of a system, product or service to perform as expected over time, this is usually measured in terms of the probability of it performing as expected over time.

R-Squared, or Coefficient of Determination: a number produced in regression analysis that indicates the goodness of fit of a linear model. R squared also indicates the proportion of the variation in the dependent variables explained in the model.

Re-order level: the level of inventory at which more items are ordered, usually calculated to ensure that inventory does not run out before the next batch of inventory arrives.

Safety stock: amount of stock that has to be kept in order to protect the system from stock outs, which may occur as a consequence of either forecast errors or deviations from average demand during average lead-time.

Simulation: the use of a model of a process, product or service to explore its characteristics before the process, product or service is created.

Stock: alternative term for inventory.

Supply chain risk: a study of the vulnerability of supply chains to disruption.

Time to market: (TTM) the elapsed time taken for the whole design activity, from concept through to market introduction.

Trade-off theory: the idea that the improvement in one aspect of operations performance comes at the expense of deterioration in another aspect of performance, now substantially modified to include the possibility that in the long term different aspects of operations performance can be improved simultaneously.

Work-in-process: (WIP) the number of units within a process waiting to be processed further (also called work-in-progress).

Tetra Pak Carton Ambient
Supplier Management
Lennart Aveling - 4185

MEMO

November, 2004

To Mats Johnsson and Ola Johansson
LTH Division of Packaging Logistics

Copy to

Preliminary Draft –
Master Thesis Simulation Model Supply Chain Management

Objective:
To develop a tool that manages complex material flows from single parts to sub-assemblies to C- groups (number of sub ass.) to finished modules and finally to a complete Filling Machine.

The tool should be able to identify bottlenecks in the material flow and calculate best Economic Order Quantity per article and minimum/maximum levels based on material lead-time, setting cost when applicable, financial cost and transport cost.
It should also be able to calculate the capital employed in the entire value chain from time to time.

Input for the tool should be filling machine orders/deliveries over time e.g. list of orders with ready date.

The data input will be per article:
Lead-time
Price broken down to material, setting cost, manufacturing and assembly when applicable
Transport cost

The tool should be able to use default values for data that is missing when applicable e.g. setting cost, material etc.

Regression Analysis

Regression Statistics	
R^2	0,947642311
R^2-adjusted	0,946818591
S	38842,15077
Observations	1034

ANOVA

Source	df	SS	MS	F	p-value
Regression	16	2,7771E+13	1,73569E+12	1150,442576	0
Residual Error	1017	1,53436E+12	1508712676		
Total	1033	2,93054E+13			

Regression Equation:

Tied Up Capital = 563401.680+3633.477*X01(EOQ_Valve Ramp Infeed)+8200.838*X02(EOQ_Strip Magazine)+12433.888*X03(EOQ_Strip Applicator)+32703.862*X05(EOQ_Frame)+10461.854*X06(EOQ_Doors and

Dependent Vars	Coefficient	Standard Error	T	p-value
Constant	563401,6798	1207,933429	466,4178227	0
X01(EOQ_Valve Ramp Infeed)	3633,477214	1213,817211	2,993430296	0,002825285
X02(EOQ_Strip Magazine)	8200,838486	1213,817211	6,756238425	2,37998E-11
X03(EOQ_Strip Applicator)	12433,88813	1213,817211	10,24362483	1,67269E-23
X05(EOQ_Frame)	32703,86195	1213,817211	26,94298749	4,1717E-121
X06(EOQ_Doors and Covers)	10461,85421	1213,817211	8,618970066	2,55176E-17
X07(EOQ_Splicing Device)	14850,28215	1213,817211	12,23436445	3,30383E-32
X08(EOQ_Bobbin)	4125,930751	1213,817211	3,3991368	0,000702225
X10(EOQ_Connection Box)	10538,98473	1213,817211	8,682513837	1,51908E-17
X14(LT_2)	2815,726943	1213,817211	2,319728965	0,020552805
X17(LT_5)	11215,25275	1213,817211	9,239655397	1,40516E-19
X18(LT_6)	5945,565558	1213,817211	4,898237974	1,12439E-06
X19(LT_7)	2759,398605	1213,817211	2,273323017	0,023214555
X23(Demand)	52834,0283	1213,817211	43,52717015	1,5918E-234
X24(Variability)	-24833,62767	1213,817211	-20,45911645	3,46531E-78
X25(%KC)	-23347,07776	1213,817211	-19,23442635	1,46775E-70
X26(SS)	145696,7237	1213,817211	120,0318485	0

Regression Statistics	
R^2	0,906699361
R^2-adjusted	0,905324597
S	3,050113841
Observations	1034

ANOVA

Source	df	SS	MS	F	p-value
Regression	15	92036,17615	6135,745076	659,5309939	0
Residual Error	1018	9470,651941	9,303194441		
Total	1033	101506,8281			

Regression Equation:

Mean LT = 63.196-0.243*X01(EOQ_Valve Ramp Infeed)-0.284*X02(EOQ_Strip Magazine)-0.730*X05(EOQ_Frame)-0.439*X06(EOQ_Doors and

Dependent Vars	Coefficient	Standard Error	T	p-value
Constant	63,19608976	0,094854028	666,2457131	0
X01(EOQ_Valve Ramp Ir	-0,243434738	0,095316058	-2,553974056	0,010794829
X02(EOQ_Strip Magazine	-0,283804451	0,095316058	-2,977509332	0,002974818
X05(EOQ_Frame)	-0,730403251	0,095316058	-7,662961208	4,22305E-14
X06(EOQ_Doors and Co	-0,438722577	0,095316058	-4,602819176	4,69409E-06
X11(LT_A)	8,135460267	0,095316058	85,35246294	0
X12(LT_B)	2,014134509	0,095316058	21,13111433	1,81562E-82
X13(LT_1)	0,488417377	0,095316058	5,124187777	3,574E-07
X14(LT_2)	0,451970289	0,095316058	4,741806371	2,41977E-06
X17(LT_5)	2,605335484	0,095316058	27,33364715	8,2903E-124
X18(LT_6)	0,509008838	0,095316058	5,340221277	1,14491E-07
X19(LT_7)	0,157223011	0,095316058	1,649491339	0,099355522
X22(LT_10)	0,8808866	0,095316058	9,241743976	1,37785E-19
X23(Demand)	2,519885279	0,095316058	26,43715387	1,1167E-117
X24(Variability)	1,551148694	0,095316058	16,27373954	4,20423E-53
X26(SS)	-1,31323982	0,095316058	-13,7777396	1,00208E-39

Regression Statistics	
R^2	0,932174514
R^2-adjusted	0,931242662
S	21949,68272
Observations	1034

ANOVA

Source	df	SS	MS	F	p-value
Regression	14	6,74738E+12	4,81956E+11	1000,346504	0
Residual Error	1019	4,90943E+11	481788571,7		
Total	1033	7,23832E+12			

Regression Equation:
Keeping Cost = 196127.501+1270.948*X01(EOQ_Valve Ramp Infeed)+2896.731*X02(EOQ_Strip Magazine)+4554.309*X03(EOQ_Strip Applicator)+11386.818*X05(EOQ_Frame)+3486.596*X06(EOQ_Doors and

Dependent Vars	Coefficient	Standard Error	T	p-value
Constant	196127,5006	682,6026621	287,323082	0
X01(EOQ_Valve Ramp Ir	1270,948436	685,9275851	1,852890106	0,064187055
X02(EOQ_Strip Magazine	2896,730963	685,9275851	4,223085681	2,62528E-05
X03(EOQ_Strip Applicato	4554,308676	685,9275851	6,639634816	5,10462E-11
X05(EOQ_Frame)	11386,81786	685,9275851	16,60061223	5,84989E-55
X06(EOQ_Doors and Co\	3486,595814	685,9275851	5,083037757	4,41774E-07
X07(EOQ_Splicing Devic	5008,072853	685,9275851	7,301168463	5,73936E-13
X08(EOQ_Bobbin)	1678,567679	685,9275851	2,447149983	0,014567075
X10(EOQ_Connection Bc	3578,621343	685,9275851	5,217199922	2,20006E-07
X17(LT_5)	4012,964137	685,9275851	5,850419526	6,60203E-09
X18(LT_6)	2229,103738	685,9275851	3,249765407	0,001192794
X23(Demand)	18433,58161	685,9275851	26,87394705	1,0951E-120
X24(Variability)	-8695,663438	685,9275851	-12,67723245	2,64721E-34
X25(%KC)	58037,7249	685,9275851	84,61202925	0
X26(SS)	50706,0625	685,9275851	73,92334642	0

Regression Statistics	
R^2	0,69092251
R^2-adjusted	0,688813794
S	3,407099249
Observations	1034

ANOVA

Source	df	SS	MS	F	p-value
Regression	7	26624,34277	3803,477539	327,6508404	1,826E-256
Residual Error	1026	11910,14175	11,6083253		
Total	1033	38534,48453			

Regression Equation:
Out of Agreement = 5.049-0.210*X01(EOQ_Valve Ramp Infeed)-0.317*X02(EOQ_Strip Magazine)-0.220*X06(EOQ_Doors and Covers)-0.333*X08(EOQ_Bobbin)+2.253*X23(Demand)+4.149*X24(Variability)-1.845*X26(SS)

Dependent Vars	Coefficient	Standard Error	T	p-value
Constant	5,049323017	0,105955746	47,65501812	2,515E-262
X01(EOQ_Valve Ramp Ir	-0,209960937	0,106471852	-1,971985407	0,048879542
X02(EOQ_Strip Magazine	-0,317382812	0,106471852	-2,980908173	0,002941751
X06(EOQ_Doors and Co\	-0,219726563	0,106471852	-2,063705659	0,039296666
X08(EOQ_Bobbin)	-0,333007813	0,106471852	-3,127660576	0,00181168
X23(Demand)	2,252929687	0,106471852	21,15986202	9,39119E-83
X24(Variability)	4,149414063	0,106471852	38,97193486	1,3344E-204
X26(SS)	-1,844726563	0,106471852	-17,32595551	3,46333E-59

Regression Statistics	
R^2	0,696434158
R^2-adjusted	0,692866293
S	50752,82499
Observations	1034

ANOVA

Source	df	SS	MS	F	p-value
Regression	12	6,03356E+12	5,02796E+11	195,1963344	2,3981E-254
Residual Error	1021	2,62994E+12	2575849244		
Total	1033	8,6635E+12			

Regression Equation:

Penalty Cost = 70940.232-4183.768*X01(EOQ_Valve Ramp Infeed)-6942.148*X05(EOQ_Frame)-3364.426*X06(EOQ_Doors and

Dependent Vars	Coefficient	Standard Error	T	p-value
Constant	70940,23211	1578,337777	44,94616623	3,1782E-244
X01(EOQ_Valve Ramp Ir	-4183,767578	1586,025781	-2,637893802	0,008469132
X05(EOQ_Frame)	-6942,148437	1586,025781	-4,377071622	1,32655E-05
X06(EOQ_Doors and Co	-3364,425781	1586,025781	-2,121293249	0,034137572
X11(LT_A)	59696,99023	1586,025781	37,63935678	3,6911E-195
X12(LT_B)	15592,2793	1586,025781	9,831037732	7,45001E-22
X13(LT_1)	3104,304688	1586,025781	1,957285137	0,050586105
X17(LT_5)	21277,75195	1586,025781	13,41576676	6,47455E-38
X18(LT_6)	3297,666016	1586,025781	2,079200764	0,037848046
X22(LT_10)	5591,447266	1586,025781	3,525445382	0,000441534
X23(Demand)	28310,15625	1586,025781	17,84974531	3,10772E-62
X24(Variability)	22797,50586	1586,025781	14,37398189	8,39952E-43
X26(SS)	-13511,78906	1586,025781	-8,519274545	5,69366E-17

Simulation Summary

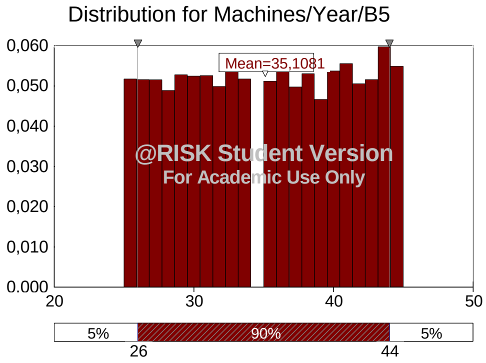
Summary Information	
Workbook Name	@Risk_1.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	26
Number of Outputs	5
Sampling Type	Monte Carlo
Simulation Start Time	2005-03-11 18:14
Simulation Stop Time	2005-03-11 18:14
Simulation Duration	00:00:18
Random Seed	1835521544

Output		Statistics						
Name	**Cell**	**Minimum**	**Mean**	**Maximum**	**x1**	**p1**	**x2**	**p2**
Average LT	Inputs@Risk!E	29	55	168	39	5%	81	95%
Tied Up Capital	Inputs@Risk!E	264890	580109	962485	391169	5%	768570	95%
Total Keeping Cost	Inputs@Risk!E	87919	162569	255895	125325	5%	199560	95%
Out of Agreement	Inputs@Risk!E	-3	6	14	2	5%	10	95%
Penalty Value	Inputs@Risk!E	-153417	49072	894010	-71480	5%	234692	95%

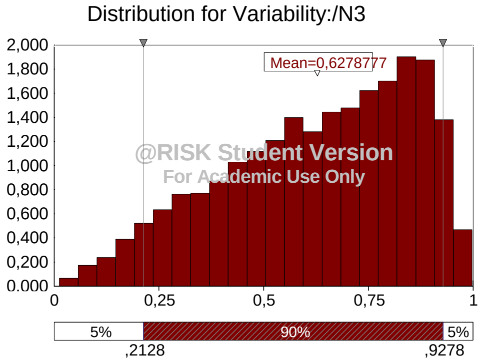
Input		Statistics						
Name	**Cell**	**Minimum**	**Mean**	**Maximum**	**x1**	**p1**	**x2**	**p2**
Machines/Year	Inputs!B5	25	35,1081	45	26	5%	44	95%
Variability:	Inputs@Risk!N	0,012548215	0,627877714	0,997485876	0,212767556	5%	0,927765846	95%
SS:	Inputs@Risk!N	0	2,0001	4	0	5%	4	95%
Machines/Year	Inputs@Risk!E	25	35,1618	45	26	5%	45	95%
Fuji Autotech AB / LT	Inputs@Risk!H	22,50006866	24,9780681	49,30334091	22,6349659	5%	29,92110062	95%
Tetra Pak Stålvall AB / LT	Inputs@Risk!H	2,500062227	4,98855355	36,66342163	2,631600857	5%	9,920250893	95%
Festo / EOQ	Inputs@Risk!F	3	5,0273	7	3	5%	7	95%
Festo / LT	Inputs@Risk!H	17,50014687	20,01512646	37,94299698	17,63276482	5%	25,01126099	95%
LIB / EOQ	Inputs@Risk!F	3	5,0123	7	3	5%	7	95%
LIB / LT	Inputs@Risk!H	17,50001717	19,97899731	45,80555725	17,62330818	5%	24,80577469	95%
Elilund / EOQ	Inputs@Risk!F	8	10,5228	13	8	5%	13	95%
Elilund / LT	Inputs@Risk!H	17,50016022	19,95739565	41,18631744	17,63083458	5%	24,83555603	95%
Elilund / EOQ	Inputs@Risk!F	8	10,5076	13	8	5%	13	95%
Elilund / LT	Inputs@Risk!H	17,50039673	20,04930922	43,99629211	17,62819099	5%	25,13144684	95%
Fa-tec / EOQ	Inputs@Risk!F	8	10,5371	13	8	5%	13	95%
Fa-tec / LT	Inputs@Risk!H	27,50055122	29,98997579	54,792099	27,62973213	5%	34,79717636	95%
RFR / EOQ	Inputs@Risk!F	4	5,9771	8	4	5%	8	95%
RFR / LT	Inputs@Risk!H	17,50023079	20,00207583	40,5926857	17,62948608	5%	25,04755402	95%
Elilund / EOQ	Inputs@Risk!F	8	10,5308	13	8	5%	13	95%
Elilund / LT	Inputs@Risk!H	17,50062561	19,98937049	39,40623093	17,64192963	5%	24,93479729	95%
Sterners / EOQ	Inputs@Risk!F	3	5,0239	7	3	5%	7	95%
Sterners / LT	Inputs@Risk!H	12,50007629	14,98440919	31,8561306	12,6282196	5%	19,8999424	95%
Sterners / EOQ	Inputs@Risk!F	3	5,0021	7	3	5%	7	95%
Sterners / LT	Inputs@Risk!H	2,500658751	4,995500082	24,71100426	2,642208338	5%	9,883594513	95%
Rimaster / EOQ	Inputs@Risk!F	8	10,4981	13	8	5%	13	95%
Rimaster / LT	Inputs@Risk!H	22,50011063	24,99808835	49,94693375	22,63079453	5%	29,93118668	95%

@RISK Input Graphs

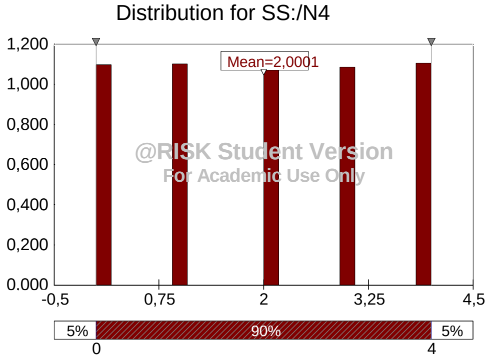
Simulation: 1 / Input: 1



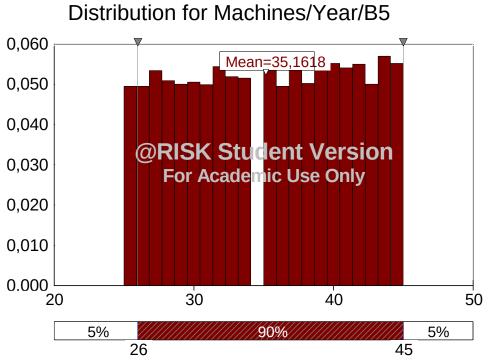
Simulation: 1 / Input: 2



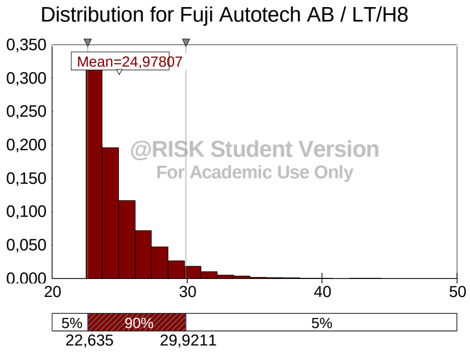
Simulation: 1 / Input: 3



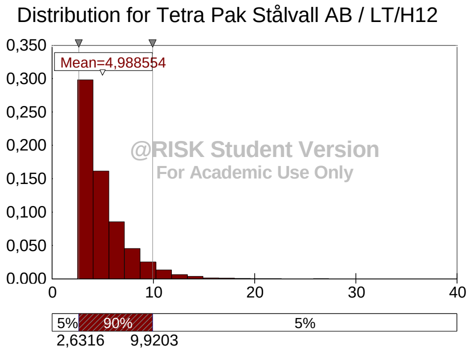
Simulation: 1 / Input: 4



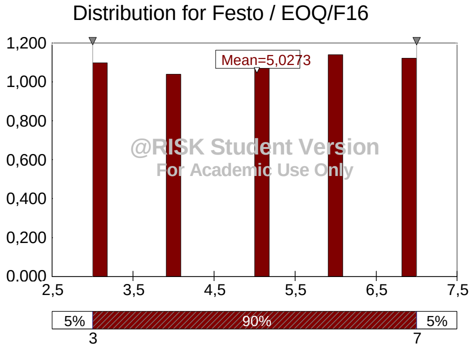
Simulation: 1 / Input: 5



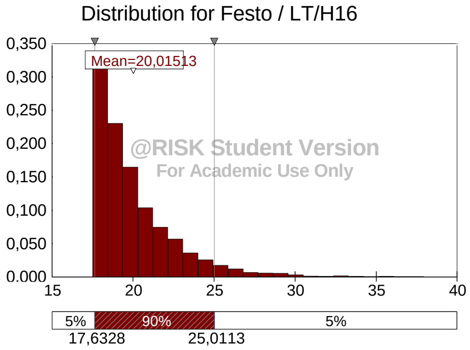
Simulation: 1 / Input: 6



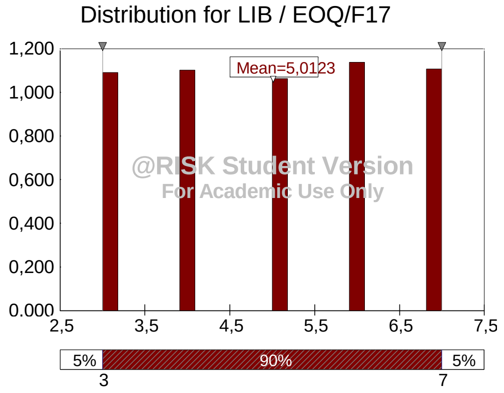
Simulation: 1 / Input: 7



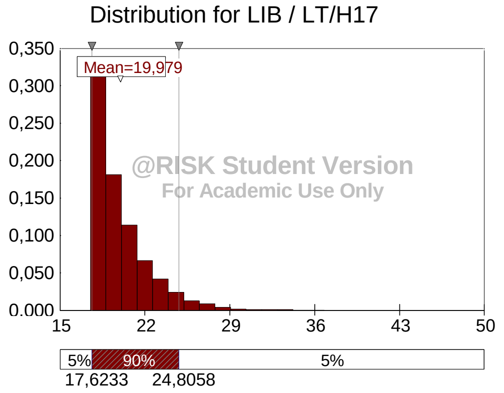
Simulation: 1 / Input: 8



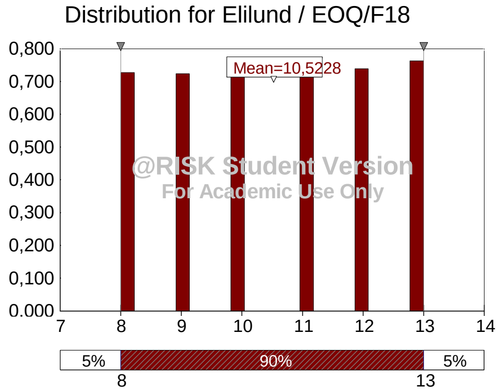
Simulation: 1 / Input: 9



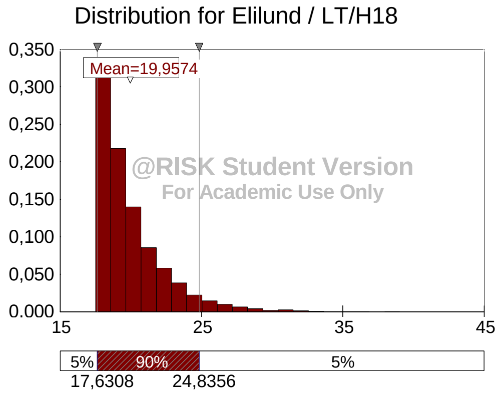
Simulation: 1 / Input: 10



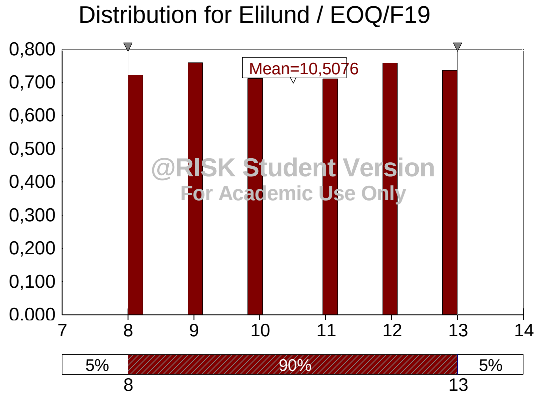
Simulation: 1 / Input: 11



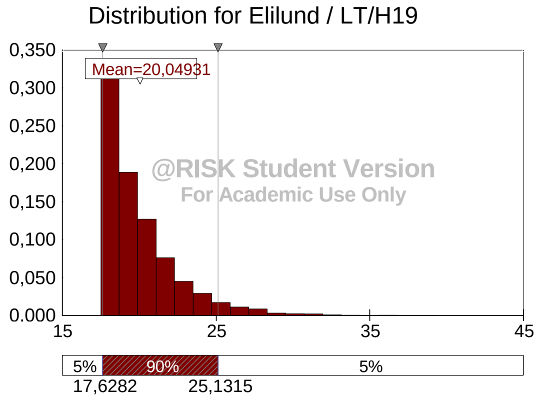
Simulation: 1 / Input: 12



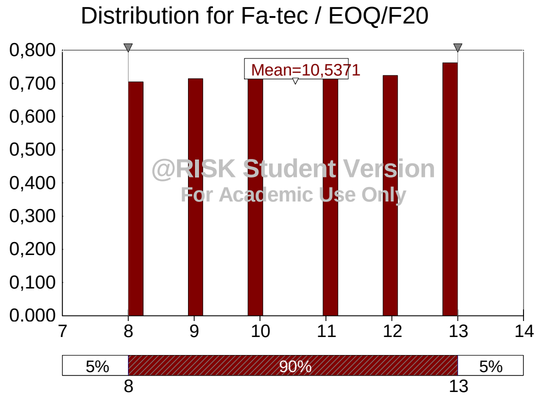
Simulation: 1 / Input: 13



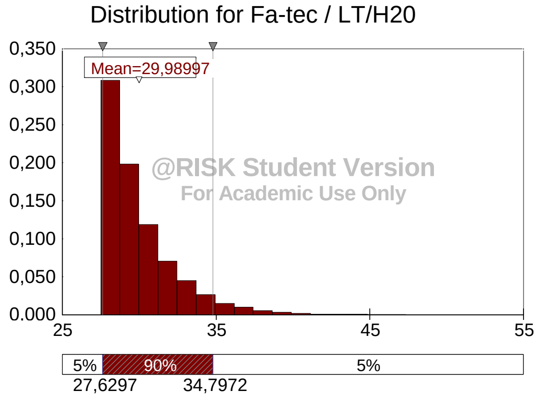
Simulation: 1 / Input: 14



Simulation: 1 / Input: 15

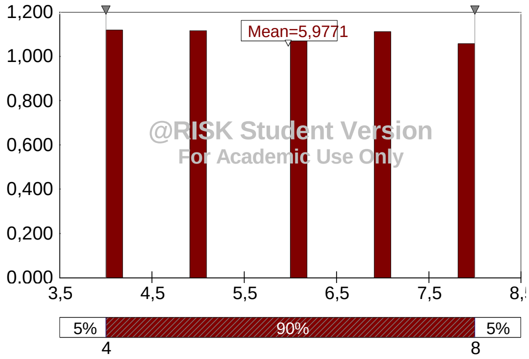


Simulation: 1 / Input: 16



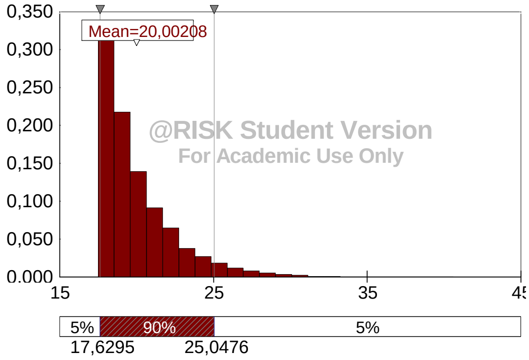
Simulation: 1 / Input: 17

Distribution for RFR / EOQ/F21



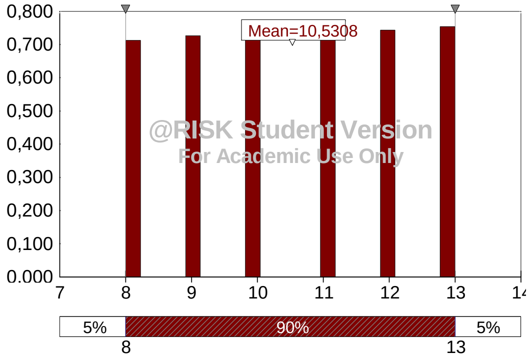
Simulation: 1 / Input: 18

Distribution for RFR / LT/H21



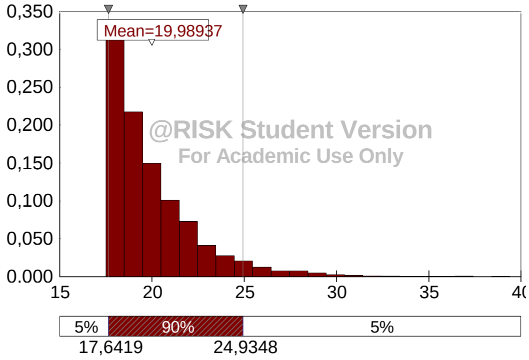
Simulation: 1 / Input: 19

Distribution for Elilund / EOQ/F22



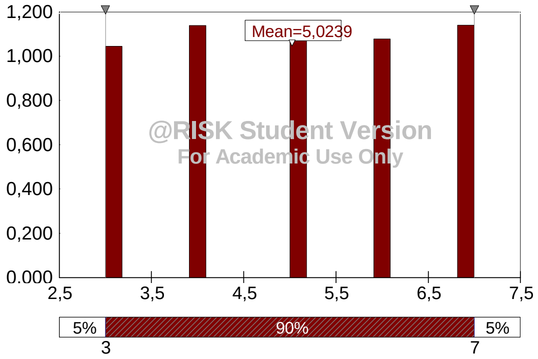
Simulation: 1 / Input: 20

Distribution for Elilund / LT/H22



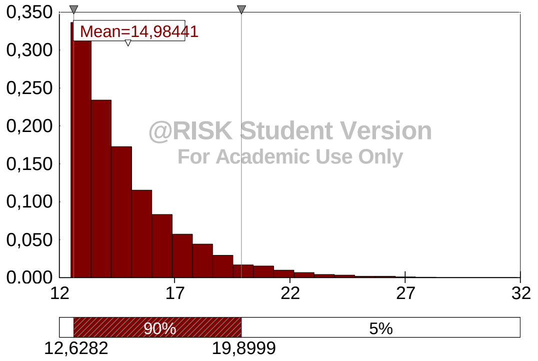
Simulation: 1 / Input: 21

Distribution for Sterners / EOQ/F23



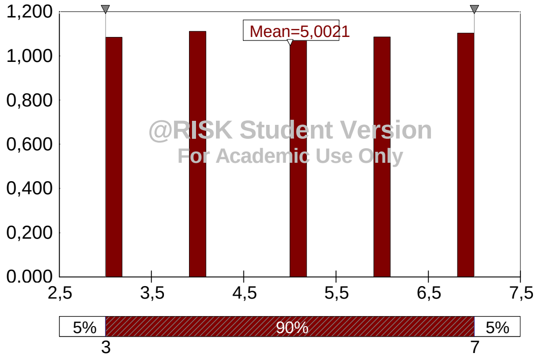
Simulation: 1 / Input: 22

Distribution for Sterners / LT/H23



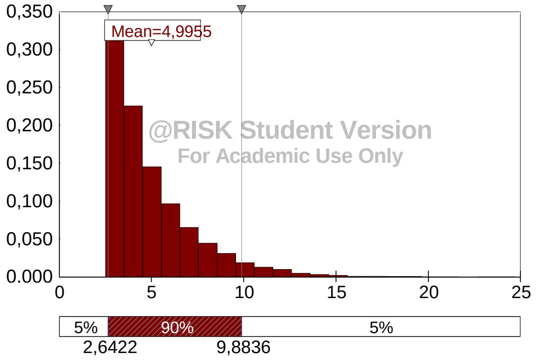
Simulation: 1 / Input: 23

Distribution for Sterners / EOQ/F24

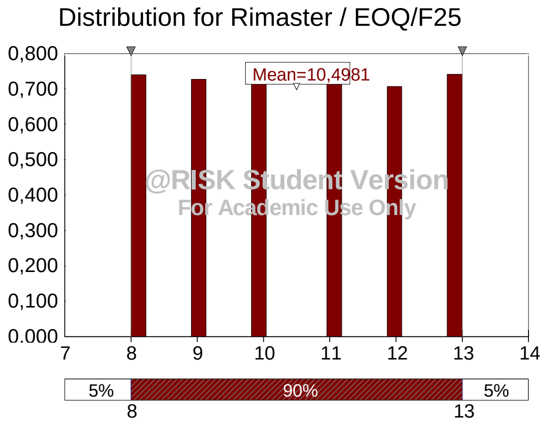


Simulation: 1 / Input: 24

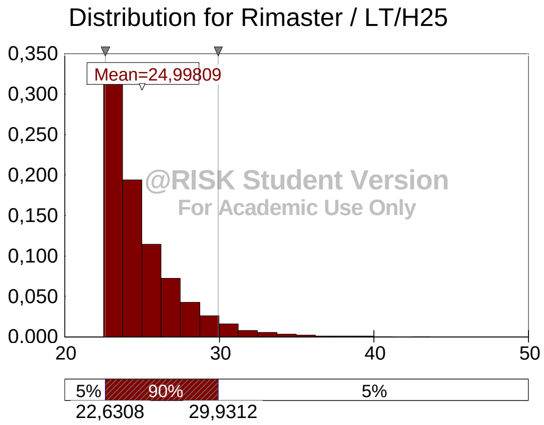
Distribution for Sterners / LT/H24



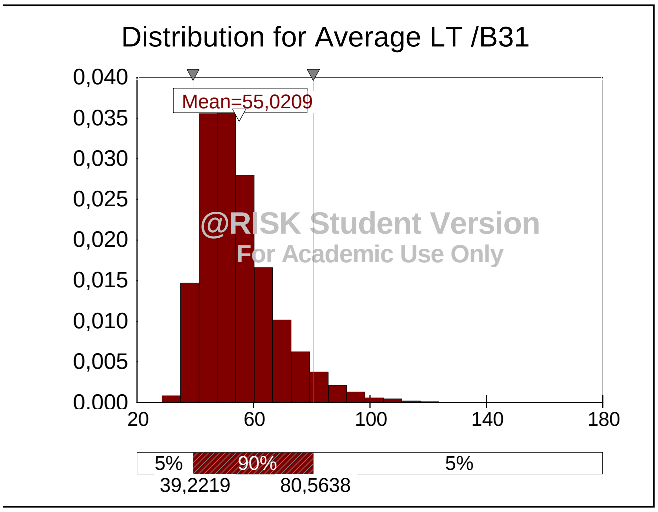
Simulation: 1 / Input: 25

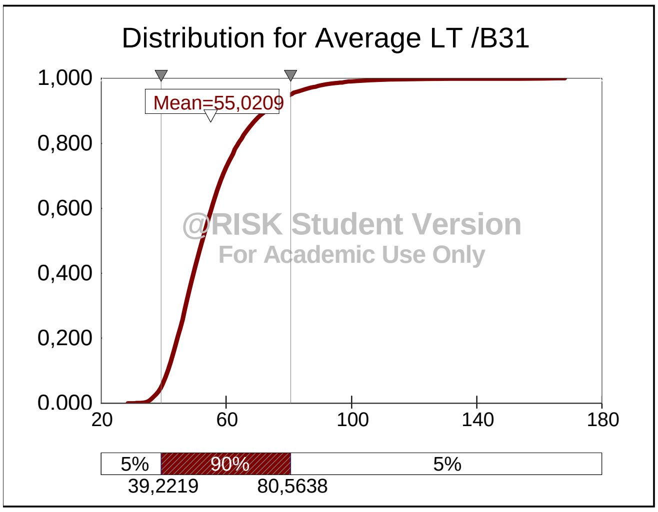


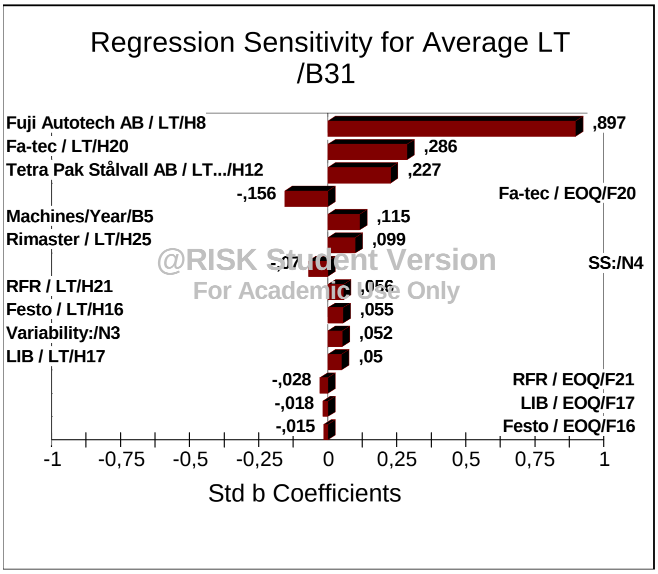
Simulation: 1 / Input: 26



Simulation Results for Average LT





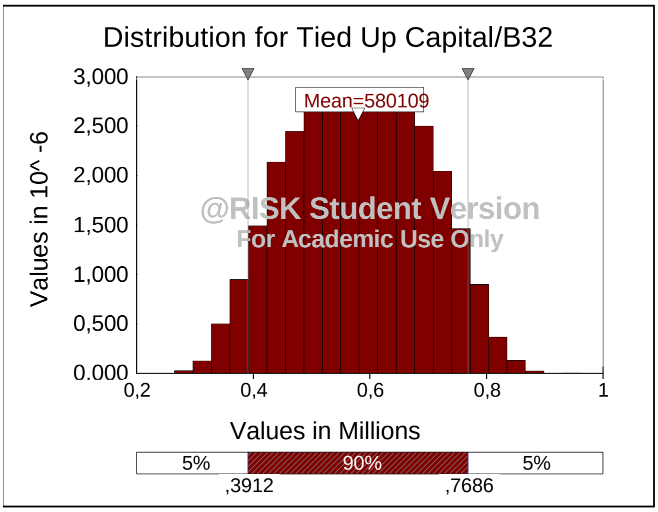


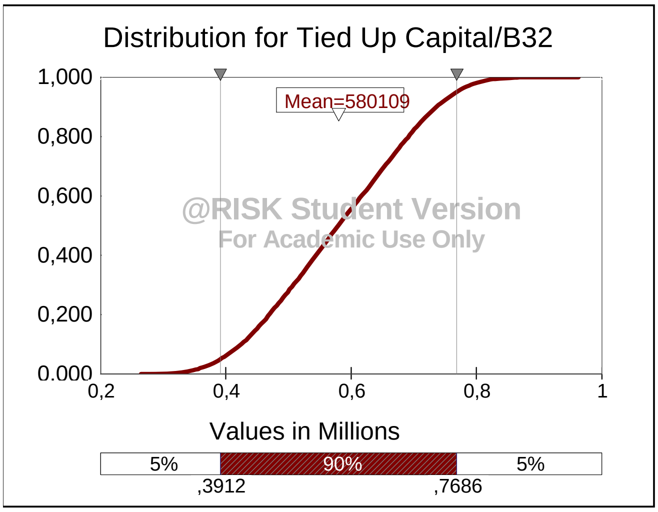
Summary Information	
Workbook Name	@Risk_1.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	26
Number of Outputs	5
Sampling Type	Monte Carlo
Simulation Start Time	2005-03-11 18:14
Simulation Stop Time	2005-03-11 18:14
Simulation Duration	00:00:18
Random Seed	1835521544

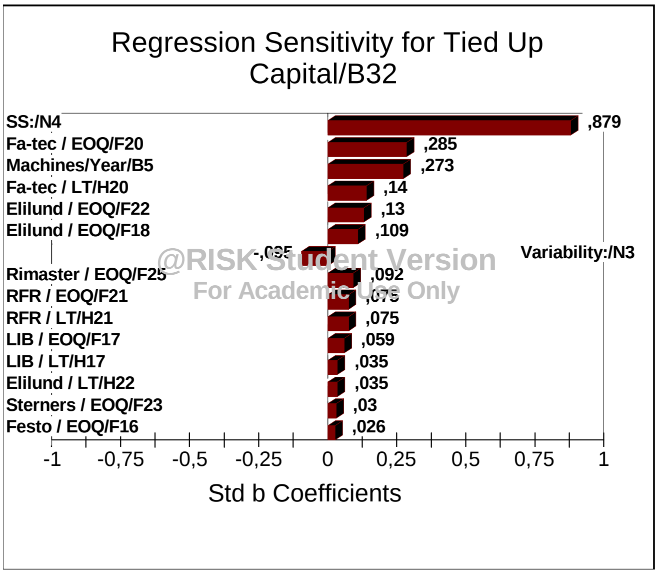
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	29	5%	39
Maximum	168	10%	41
Mean	55	15%	43
Std Dev	13	20%	44
Variance	177,9400936	25%	46
Skewness	1,54345327	30%	47
Kurtosis	7,393317632	35%	48
Median	52	40%	50
Mode	44	45%	51
Left X	39	50%	52
Left P	5%	55%	54
Right X	81	60%	55
Right P	95%	65%	57
Diff X	41	70%	59
Diff P	90%	75%	61
#Errors	0	80%	64
Filter Min		85%	67
Filter Max		90%	72
#Filtered	0	95%	81

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Fuji Autotech A	0,897	0,817
#2	Fa-tec / LT / $H	0,286	0,282
#3	Tetra Pak Stålva	0,227	0,230
#4	Fa-tec / EOQ / $	-0,156	-0,191
#5	Machines/Year /	0,115	0,136
#6	Rimaster / LT / $	0,099	0,085
#7	SS: / $N$4	-0,070	-0,089
#8	RFR / LT / $H$2	0,056	0,045
#9	Festo / LT / H	0,055	0,060
#10	Variability: / N	0,052	0,055
#11	LIB / LT / $H$17	0,050	0,047
#12	RFR / EOQ / $F	-0,028	-0,043
#13	LIB / EOQ / F	-0,018	-0,036
#14	Festo / EOQ / $	-0,015	-0,019
#15	Elilund / EOQ / $	0,000	-0,011
#16	Sterners / LT / $	0,000	-0,003

Simulation Results for Tied Up Capital





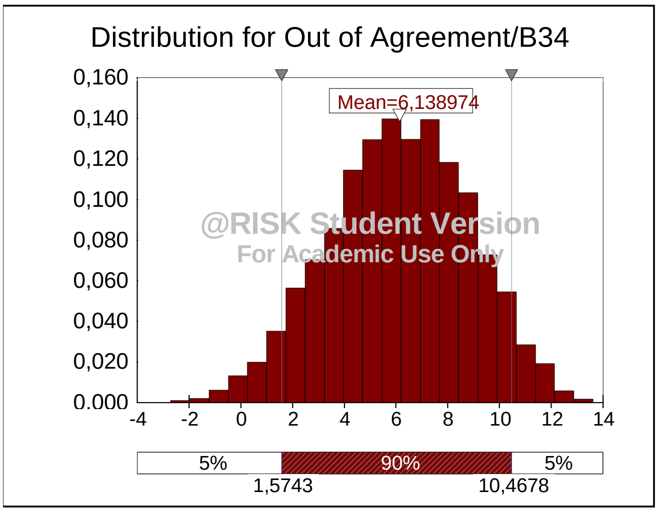


Summary Information	
Workbook Name	@Risk_1.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	26
Number of Outputs	5
Sampling Type	Monte Carlo
Simulation Start Time	2005-03-11 18:14
Simulation Stop Time	2005-03-11 18:14
Simulation Duration	00:00:18
Random Seed	1835521544

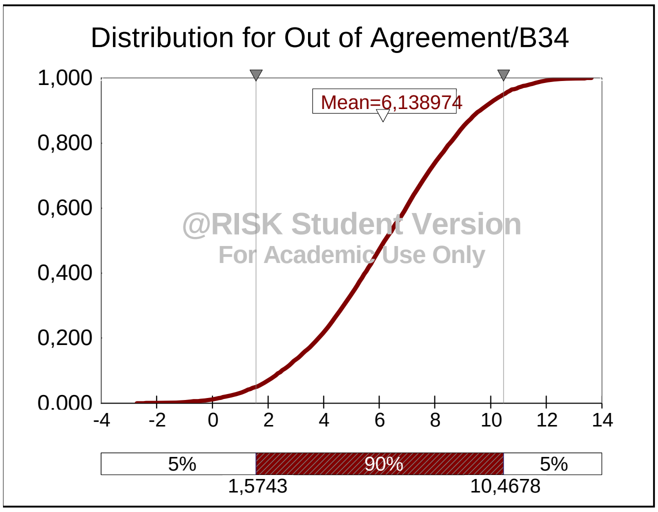
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	264890	5%	391169
Maximum	962485	10%	424349
Mean	580109	15%	448011
Std Dev	117214	20%	468644
Variance	13739073279	25%	489181
Skewness	0,001285128	30%	507468
Kurtosis	2,222853974	35%	526385
Median	579065	40%	543633
Mode	467456	45%	561735
Left X	391169	50%	579065
Left P	5%	55%	597751
Right X	768570	60%	616447
Right P	95%	65%	635622
Diff X	377401	70%	653516
Diff P	90%	75%	672239
#Errors	0	80%	691535
Filter Min		85%	711515
Filter Max		90%	735401
#Filtered	0	95%	768570

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	SS: / $N$4	0,879	0,883
#2	Fa-tec / EOQ / $	0,285	0,260
#3	Machines/Year /	0,273	0,245
#4	Fa-tec / LT / $H	0,140	0,111
#5	Elilund / EOQ /	0,130	0,107
#6	Elilund / EOQ /	0,109	0,115
#7	Variability: / N	-0,095	-0,088
#8	Rimaster / EOQ	0,092	0,083
#9	RFR / EOQ / $F	0,075	0,080
#10	RFR / LT / $H$2	0,075	0,076
#11	LIB / EOQ / F	0,059	0,039
#12	LIB / LT / $H$17	0,035	0,013
#13	Elilund / LT / $H	0,035	0,004
#14	Sterners / EOQ	0,030	0,045
#15	Festo / EOQ / $	0,026	0,017
#16	Rimaster / LT /	0,000	0,019

Simulation Results for Out of Agreement

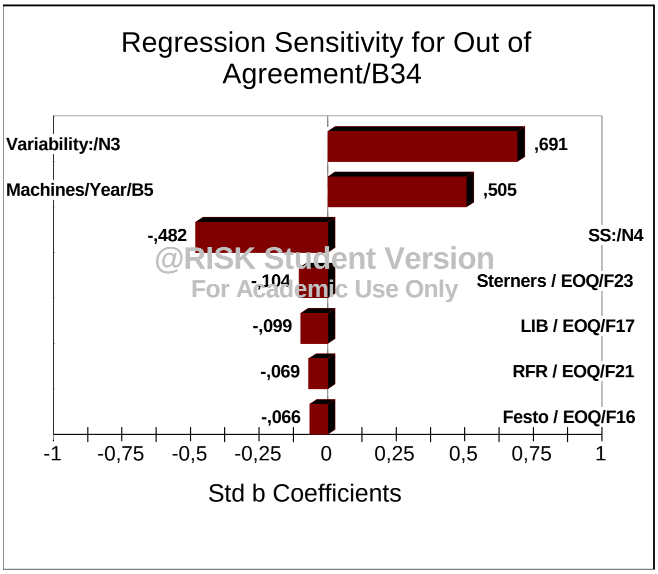


Summary Information	
Workbook Name	@Risk_1.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	26
Number of Outputs	5
Sampling Type	Monte Carlo
Simulation Start Time	2005-03-11 18:14
Simulation Stop Time	2005-03-11 18:14
Simulation Duration	00:00:18
Random Seed	1835521544



Summary Statistics

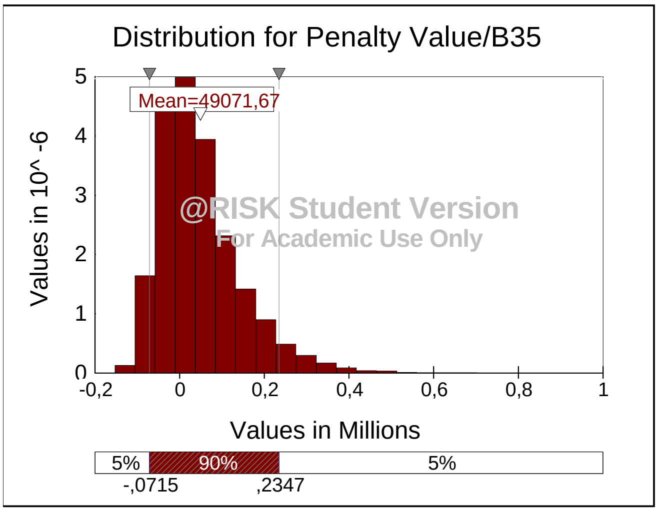
Statistic	Value	%tile	Value
Minimum	-3	5%	2
Maximum	14	10%	2
Mean	6	15%	3
Std Dev	3	20%	4
Variance	7,319933489	25%	4
Skewness	-0,145139715	30%	5
Kurtosis	2,641836346	35%	5
Median	6	40%	5
Mode	5	45%	6
Left X	2	50%	6
Left P	5%	55%	7
Right X	10	60%	7
Right P	95%	65%	7
Diff X	9	70%	8
Diff P	90%	75%	8
#Errors	0	80%	9
Filter Min		85%	9
Filter Max		90%	10
#Filtered	0	95%	10



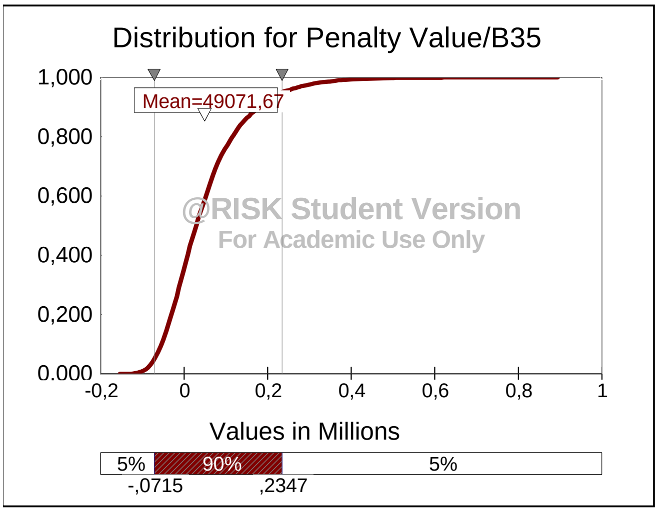
Sensitivity

Rank	Name	Regr	Corr
#1	Variability: / N	0,691	0,679
#2	Machines/Year /	0,505	0,505
#3	SS: / $N$4	-0,482	-0,481
#4	Sterners / EOQ	-0,104	-0,101
#5	LIB / EOQ / F	-0,099	-0,087
#6	RFR / EOQ / $F	-0,069	-0,070
#7	Festo / EOQ / $	-0,066	-0,045
#8	Elilund / LT / $H	0,000	0,018
#9	Tetra Pak Stålva	0,000	0,001
#10	Fa-tec / LT / $H	0,000	-0,020
#11	Elilund / EOQ /	0,000	-0,009
#12	RFR / LT / $H$2	0,000	-0,002
#13	Elilund / EOQ /	0,000	0,008
#14	Sterners / EOQ	0,000	-0,011
#15	Rimaster / EOQ	0,000	0,011
#16	Elilund / LT / $H	0,000	-0,018

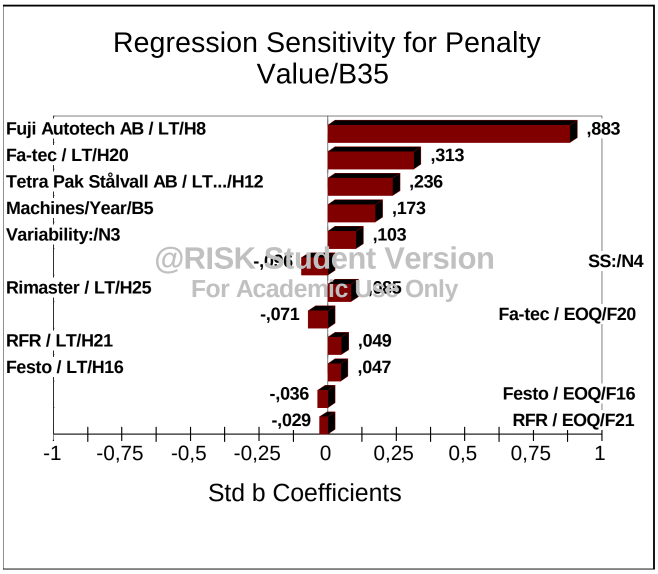
Simulation Results for Penalty Value



Summary Information	
Workbook Name	@Risk_1.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	26
Number of Outputs	5
Sampling Type	Monte Carlo
Simulation Start Time	2005-03-11 18:14
Simulation Stop Time	2005-03-11 18:14
Simulation Duration	00:00:18
Random Seed	1835521544



Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	-153417	5%	-71480
Maximum	894010	10%	-53950
Mean	49072	15%	-41293
Std Dev	99429	20%	-30313
Variance	9886134048	25%	-19561
Skewness	1,501875497	30%	-10284
Kurtosis	7,247491712	35%	-1084
Median	29245	40%	8421
Mode	-5756	45%	18270
Left X	-71480	50%	29245
Left P	5%	55%	40766
Right X	234692	60%	52053
Right P	95%	65%	63870
Diff X	306172	70%	77303
Diff P	90%	75%	94447
#Errors	0	80%	116354
Filter Min		85%	141632
Filter Max		90%	178996
#Filtered	0	95%	234692



Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Fuji Autotech AE	0,883	0,799
#2	Fa-tec / LT / $H!	0,313	0,305
#3	Tetra Pak Stålva	0,236	0,236
#4	Machines/Year /	0,173	0,204
#5	Variability: / N	0,103	0,115
#6	SS: / $N$4	-0,096	-0,122
#7	Rimaster / LT / $	0,085	0,071
#8	Fa-tec / EOQ / $	-0,071	-0,085
#9	RFR / LT / $H$2	0,049	0,035
#10	Festo / LT / H	0,047	0,053
#11	Festo / EOQ / $	-0,036	-0,040
#12	RFR / EOQ / $F	-0,029	-0,041
#13	LIB / EOQ / F	0,000	-0,013
#14	Sterners / LT / $	0,000	-0,001
#15	Elilund / EOQ / $	0,000	-0,009
#16	Elilund / LT / $H	0,000	0,005

@RISK Scenario Report

Scenario Report

Cell	**Name**	**Actual**	**Pecentile**	**MedianSD**	**Actual**	**Pecentile**	**MedianSD**	**Actual**	**Pecentile**	**MedianSD**
		Sim 1 for Average LT with Target >75%			*Sim 1 for Average LT with Target <25%*			*Sim 1 for Average LT with Target >90%*		
Inputs!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$3	**Variability:**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$4	**SS:**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$8	**Fuji Autotech AB / LT**	28	87,3100%	1,401957989	-	-	-	30	94,8800%	2,304335833
Inputs@Risk!$H$12	**Tetra Pak Stålvall AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$16	**Festo / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$16	**Festo / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$17	**LIB / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$17	**LIB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$18	**Elilund / EOQ**	-	-	-	-	-	-	10	49,6500%	-0,582461953
Inputs@Risk!$H$18	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$19	**Elilund / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$19	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$20	**Fa-tec / EOQ**	10	49,1100%	-0,586925447	-	-	-	10	49,1100%	-0,586925447
Inputs@Risk!$H$20	**Fa-tec / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$21	**RFR / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$21	**RFR / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$22	**Elilund / EOQ**	-	-	-	-	-	-	10	49,1700%	-0,585532367
Inputs@Risk!$H$22	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$23	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$23	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$24	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$24	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$25	**Rimaster / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$25	**Rimaster / LT**	-	-	-	-	-	-	-	-	-
		Sim 1 for Tied Up Capital with Target >75%			*Sim 1 for Tied Up Capital with Target <25%*			*Sim 1 for Tied Up Capital with Target >90%*		
Inputs!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$3	**Variability:**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$4	**SS:**	4	100,0000%	1,414744258	0	19,9400%	-1,414744258	4	100,0000%	1,414744258
Inputs@Risk!$B$5	**Machines/Year**	-	-	-	-	-	-	40	75,3300%	0,824935436
Inputs@Risk!$H$8	**Fuji Autotech AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$12	**Tetra Pak Stålvall AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$16	**Festo / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$16	**Festo / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$17	**LIB / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$17	**LIB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$18	**Elilund / EOQ**	-	-	-	10	49,6500%	-0,582461953	-	-	-
Inputs@Risk!$H$18	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$19	**Elilund / EOQ**	-	-	-	10	49,8600%	-0,584222674	-	-	-
Inputs@Risk!$H$19	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$20	**Fa-tec / EOQ**	-	-	-	10	49,1100%	-0,586925447	12	82,6800%	0,586925447
Inputs@Risk!$H$20	**Fa-tec / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$21	**RFR / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$21	**RFR / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$22	**Elilund / EOQ**	-	-	-	10	49,1700%	-0,585532367	-	-	-
Inputs@Risk!$H$22	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$23	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$23	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$24	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$24	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$25	**Rimaster / EOQ**	-	-	-	10	49,8200%	-0,584876478	-	-	-
Inputs@Risk!$H$25	**Rimaster / LT**	-	-	-	-	-	-	-	-	-
		Sim 1 for Total Keeping Cost with Target >75%			*Sim 1 for Total Keeping Cost with Target <25%*			*Sim 1 for Total Keeping Cost with Target >90%*		
Inputs!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$3	**Variability:**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$4	**SS:**	3	79,9100%	0,707372129	1	39,9400%	-0,707372129	3	79,9100%	0,707372129
Inputs@Risk!$B$5	**Machines/Year**	40	75,3300%	0,824935436	30	27,6400%	-0,824935436	41	80,2500%	0,989922523
Inputs@Risk!$H$8	**Fuji Autotech AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$12	**Tetra Pak Stålvall AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$16	**Festo / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$16	**Festo / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$17	**LIB / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$17	**LIB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$18	**Elilund / EOQ**	-	-	-	10	49,6500%	-0,582461953	12	82,6600%	0,582461953
Inputs@Risk!$H$18	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$19	**Elilund / EOQ**	10	49,8600%	-0,584222674	10	49,8600%	-0,584222674	-	-	-
Inputs@Risk!$H$19	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$20	**Fa-tec / EOQ**	12	82,6800%	0,586925447	9	32,2500%	-1,173850894	12	82,6800%	0,586925447
Inputs@Risk!$H$20	**Fa-tec / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$21	**RFR / EOQ**	-	-	-	-	-	-	7	80,7600%	0,709170938
Inputs@Risk!$H$21	**RFR / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$22	**Elilund / EOQ**	-	-	-	10	49,1700%	-0,585532367	-	-	-
Inputs@Risk!$H$22	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$23	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$23	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$24	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$24	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$25	**Rimaster / EOQ**	-	-	-	10	49,8200%	-0,584876478	-	-	-
Inputs@Risk!$H$25	**Rimaster / LT**	-	-	-	-	-	-	-	-	-

		Sim 1 for Out of Agreement with Target >75%			*Sim 1 for Out of Agreement with Target <25%*			*Sim 1 for Out of Agreement with Target >90%*		
Inputs!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$3	**Variability:**	1	77,7319%	0,769842565	0	18,2200%	-1,176089048	1	83,0950%	0,887252033
Inputs@Risk!$N$4	**SS:**	1	39,9400%	-0,707372129	3	79,9100%	0,707372129	0	19,9400%	-1,414744258
Inputs@Risk!$B$5	**Machines/Year**	40	75,3300%	0,824935436	30	27,6400%	-0,824935436	42	85,2500%	1,154909611
Inputs@Risk!$H$8	**Fuji Autotech AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$12	**Tetra Pak Stålvall AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$16	**Festo / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$16	**Festo / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$17	**LIB / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$17	**LIB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$18	**Elilund / EOQ**	10	49,6500%	-0,582461953	-	-	-	10	49,6500%	-0,582461953
Inputs@Risk!$H$18	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$19	**Elilund / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$19	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$20	**Fa-tec / EOQ**	-	-	-	10	49,1100%	-0,586925447	-	-	-
Inputs@Risk!$H$20	**Fa-tec / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$21	**RFR / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$21	**RFR / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$22	**Elilund / EOQ**	-	-	-	10	49,1700%	-0,585532367	10	49,1700%	-0,585532367
Inputs@Risk!$H$22	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$23	**Sterners / EOQ**	-	-	-	-	-	-	4	39,7000%	-0,708538055
Inputs@Risk!$H$23	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$24	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$24	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$25	**Rimaster / EOQ**	-	-	-	10	49,8200%	-0,584876478	-	-	-
Inputs@Risk!$H$25	**Rimaster / LT**	-	-	-	-	-	-	-	-	-
		Sim 1 for Penalty Value with Target >75%			*Sim 1 for Penalty Value with Target <25%*			*Sim 1 for Penalty Value with Target >90%*		
Inputs!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$3	**Variability:**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$N$4	**SS:**	-	-	-	3	79,9100%	0,707372129	-	-	-
Inputs@Risk!$B$5	**Machines/Year**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$8	**Fuji Autotech AB / LT**	28	87,2400%	1,395157695	-	-	-	30	94,8200%	2,298245907
Inputs@Risk!$H$12	**Tetra Pak Stålvall AB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$16	**Festo / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$16	**Festo / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$17	**LIB / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$17	**LIB / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$18	**Elilund / EOQ**	-	-	-	-	-	-	10	49,6500%	-0,582461953
Inputs@Risk!$H$18	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$19	**Elilund / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$19	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$20	**Fa-tec / EOQ**	10	49,1100%	-0,586925447	-	-	-	10	49,1100%	-0,586925447
Inputs@Risk!$H$20	**Fa-tec / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$21	**RFR / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$21	**RFR / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$22	**Elilund / EOQ**	-	-	-	-	-	-	10	49,1700%	-0,585532367
Inputs@Risk!$H$22	**Elilund / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$23	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$23	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$24	**Sterners / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$24	**Sterners / LT**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$F$25	**Rimaster / EOQ**	-	-	-	-	-	-	-	-	-
Inputs@Risk!$H$25	**Rimaster / LT**	-	-	-	-	-	-	-	-	-