MASTER

Inventory performance
an integrated approach in an ETO environment

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Inventory Performance: An integrated approach in an ETO environment

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Abstract

In this master thesis project, research is conducted to the performance of inventory management of an engineer to order equipment manufacturer. Analysis conducted in this project showed that the inventory levels in this organization are too high compared to the sales levels which result in undesired inventory performance measured by the inventory turn rate. This undesired performance is mainly caused by a lack of inventory focus in the organizational processes and unreliable supplier delivery. Also sub optimal behavior within the departments involved in the inventory process creates undesired overall performance. An explanatory inventory prediction model is developed to explain the relationship between several factors and their impact on the inventory performance. The main recommendation done in this project is creating an integral consciousness of inventory in all involved departments in the company's processes.

Management Summary

In this research conducted the following research question was investigated: “What are the relevant causes for the performance problem of inventory management at this company?” The project consists of two phases, namely an analysis phase and a design phase. In the analysis phase the development of inventory performance over the last years was researched. Also the factors which have influence on this resulting inventory performance were identified. In the design phase of the project a causal model was developed in order to give an explanation of the relationship between the evolvement of the several selected factors and the resulting inventory level. Also the design phase provided several possible improvements to the inventory management of the company in order to improve performance. The main results of the two research phases are stated into the following four statements as presented below here.

Inventory levels are too high compared to the cost of goods sold levels

A broad quantitative analysis was conducted to all aspects of inventory. This is done in order to investigate if there were special areas in the inventory accounting to the undesired performance. First of all researching the calculation of the inventory performance measure shows that the way in which the sales are included in this measure gives a different performance pattern. Based on this different calculation method the period of performance drop differs. Therefore research must not be restricted to one specific period. Further research showed that the undesired performance is caused by the fact the inventory levels are too high compared to the sales levels.

Further research of the inventory component showed that the inventory increase is mainly caused by the reserved stock and the work in progress. This means that this part of inventory is covered by demand generated from customer orders or by forecasts. Looking at other inventory classifications is can be seen that almost one third of the total inventory is classified in a rest category while normally only a minor part of inventory would be expected in such category. The conclusion of the broad inventory analysis was that on average the inventory increase occurs in all aspects of inventory. No specific areas of attention could be determined accounting for this increase

Sub optimal behavior, unreliable suppliers and a lack of inventory focus in the organization are the main contributors to the undesired inventory performance

The goal of the second part of the analysis phase was to identify all possible factors having impact on the inventory performance of the company. According to the theoretical framework provided by De Vries (2005) inventory performance is a combination of traditional inventory control and its embedding in the organization. Organizational factors can have a large influence on the inventory performance. Therefore an extensive qualitative analysis was conducted in the organization. This analysis consists out of interviews held in all involved departments in the organization. After this qualitative analysis again a quantitative analysis is conducted in order to find data support for the identified factors. For many organizational factors, unfortunately no data could be found.

To answer the research question the main causes for the undesired inventory performance are the lack of inventory focus in the organization, sub optimal behaviors in the involved departments and unreliable delivery by suppliers. The device in the organization was to have material available. Only attention was given to the late availability of this material. Early ordering therefore was no exception in the execution of the inventory processes. Besides that every department involved in the inventory related processes in the organization was assed bases on performance indicators which enhance optimal behavior of that particular department without considering overall inventory performance. Every department was convinced that their way of working was good to the organization. This way of working creates many

reschedules in the production process. In one year there occur 262 reschedule signals on 99 product projects. This indicates an average of 2.6 reschedules for one project in the process. Also early ordering is an issue again. This was due to the fact that the sales department was assed based on timely delivery and savings obtained by ordering a specific number of products. The last point to mention here is the supplier reliability. External as well as internal suppliers have a bad delivery performance. On average only 30% of external suppliers deliver on the arranged delivery date. For internal suppliers this value lies on average on 40% of timely delivery. In order to cope with these uncertain deliveries slack time is added between the internal requirement date and the date arranged with suppliers. Here no distinction is made between good and bad suppliers and all items gets the same slack time. The last point to mention here is the lack of clear defined procedures for effective process execution in the organization. Policies and required knowledge for efficient working are not explicit documented.

An explanatory model explains the inventory increase better than the current used judgmental method.

After the most important factors are identified the goal was to find an explanation for the development of the inventory level in the period of interest out of the development of the selected factors in that period. The current used judgmental method for giving this explanation does not give the desired insights in the causes of the high inventory levels. Also the actions taken to adjust inventory to desired levels based on these method has not an acceptable effect. Since the development of a pure deterministic analytic model was too much time consuming and not directly applicable for several variables statistical multiple regression models were designed in order to find the causal relation between the variables and the resulting inventory level.

The best performing regression model containing the variables cost of goods sold, number of quality rejects, number of reschedules, number of stock keeping units and on time deliveries on requirement date explains 75% of the variance in the difference inventory levels. The selected model was tested on the inventory development at this company in the period of analysis. Here the predicted inventory values are compared to the real observed values in that period. The results show that on average the model has an error of 7%. This means that the predicted inventory level is on average 93% reliable. For statistical models this means high values. So it could be concluded that the constructed causal model is capable to Explain the development of the inventory level out of the selected variables.

Inventory consciousness is the most important improvement to the organization

Based on the conclusions of the analysis phase and the results of the designed model possible improvements to the process are given in the last part of this project.

The most important improvement given to the organization is creation inventory consciousness in all involved departments. Inventory performance is an overall performance indicator for the entire organization. To start all departments have to know which effect their actions have on the inventory position. Reaching desired inventory performance levels can only be reached if all departments are convinced of the importance of inventory and working all together to reach common goals.

Besides that a possible method is proposed to calculate a representative performance measure. This is based on the relation between the inventory development of a particular product project and the sales levels.
The conclusion was that taking the cost of goods sold of the last 6 months multiplied by two for an annual value is approximately a best way to represent this relation.

Also a closer look to the logistics aspects of the inventory is helpful for improving performance. In the current way of inventory classification a large part (on average $1/3^{rd}$ of total inventory) is in the rest category with has no specific function or special attention. A classification based on logistics parameters like usage, demand pattern and uncertainty might give a better representation of the inventory in this situation. With a new classification different inventory control policies could be assigned to different behaving inventory categories.

The last improvement to mention here is the creation of a knowledge repository in which knowledge and procedures are clearly documented. In the current organization much time is lost and inefficiencies occur because knowledge and procedures are not clear and mostly only represented in the mind of persons. Everyone has therefore his own perception which is the best way of working. If everything is clearly defined and documented it is possible for people to take over each other work and new employees could find the information they needed. Also clear procedures create an efficient unified way of working. Now everyone knows how to handle in specific situations.

Preface

The research conducted [redacted] serves as the master thesis project to finish my study Operations Management and Logistics at the Eindhoven University of Technology. This multidisciplinary study was very interesting for me because its combines several disciplines like logistics, human resource management, information systems and organizational design I choose to conduct my master thesis project in the field of logistic management. In this field research is done to the influence of organizational factors on inventory performance.

I worked on this research project from November 2008 to August 2009. In that period I was member of the Operations Planning department [redacted] I experienced a pleasant working climate and working in this department gave me many valuable experiences of functioning in an organization. This would be very helpful for the future.

Before starting with the outcomes of this research study, I want to thank several people for their support during the project. First of all, I would to thank all people at the company who are supporting me in doing my research. I have experienced a supportive climate in the company without any troubles to get the information I needed. Everyone was very helpful to me. Special thanks go to [redacted] They made it possible for me to do my project at this company and supported me during the entire project. They also gave me plenty valuable and critical comments on my work.

Besides my colleagues from the company I want to thank my thesis mentor Karel van Donselaar for his support during the entire project. His comments are also very valuable to me and our conversations leads often to new insights for conducting my research. Further I would like to thank Henk-Jan Pels for his critical approach to my work during the project.

Last but not least I want to thank my parents and friends for their support during my entire study.

Mark Venner
Eindhoven, September 2009

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List of abbreviations

- COGS: Cost of Goods Sold
- ETO: Engineer to order
- ITR: Inventory turn Rate
- JIT: Just In Time
- KPI: Key Performance Indicator
- MAPE: Mean Absolute Percentage Error
- MSE: Mean Square Error
- OP: Operations Planning
- OSP: Outside Processing
- OTD: On time Delivery
- PM: Project Management
- POC: Percentage of Completion
- SKU: Stock Keeping Unit
- WIP: Work in progress

Definition of concepts

The mentioned concepts here are frequently used terms used in the report.

- Total stock: all stock = warehouse stock + WIP
- Warehouse stock: all stock physically stored in warehouses
- WIP: the value of all production orders measured at the end of the accounting period. Here in this company definition of WIP differs from the general definition of WIP. Here WIP consist of the value of all production orders physically placed on the production floor. Also products in the production process of external suppliers count for the WIP level.
- Reserved stock: the value of inventory which is allocated by needs for projects, spare parts or service. This is all stock which has reservations in the system.
- Available stock: This is the warehouse stock which has no reservations in the system. This stock is further categorized in obsolete and (non)excessive stock
- Obsolete stock: value of all items in the available warehouse stock without valid transactions during the accounting period. There are two categories of obsolete stock:
    - Obsolete 50%: Available stock without valid transactions during the last year. The inventory value remains 100% for logistics but for financial 50% of the stock value is taken in the obsolete provision.
    - Obsolete 100%: Available stock without valid transactions during the last two years. For logistics the value remains 100% because stock is physically in the warehouse. For financials the stock value is fully taken into the obsolete provision.
- (non)Excessive stock: the available stock – the obsolete stock. This is divided into two categories based on the average usage over the last two years. Here the usage over the last year has a weigh of two and the usage of two years ago had a weigh of one.
    - Non excessive sock: the available value is smaller than the average usage of the last two years. There is no excessive value
    - Excessive stock: the available value which is lagers than the average usage over the last two years. This value is evenly written of over the coming 5 years.
- Net inventory = value of warehouse stock + value of WIP – (obsolete +excessive stock).
- Inventory Turn: number of times a year the “Net Inventory” is turned over to the cost of sales.
- Promise date: Date which is promised to customers for the delivery of materials or products.
- Requirement date: date at which products or materials must be available for use in the production or delivery processes.
- Schedule date: Date which is scheduled for the availability of products or materials.
- Need By date: date which is arranged with the suppliers for the need of materials. This is the requirement date minus the added slack times in order to deal with supplier uncertainty and the time needed for post processing activities like receiving, quality control and storing.
- Strategic Parts: parts which have a very long expected life time. These parts have also a very long delivery lead time. When a part is unexpectedly broken equipment could be out of order for a long time Company policy is provide this parts only on order.
- Insurance Parts: Parts which have also a very long expected life time but not a long lead time. When a part unexpectedly fails equipment is directly out of order. Also here company policy is to provide these parts only on order.
- Wear Parts: this are parts which has to be replaced on a regularly basis. Due to the material to be processed these parts wear. Company policy is to provide these parts directly to customers. For distributors of spare pats lead time is delivery time.
- Maintenance Parts: these parts are replaced due to preventive maintenance after about 8000 machine hours or a period of two years. the policy is to deliver these parts within one month
- Administrative Parts: these are all administrative parts which determine the structure of the equipment. Mentioned here is all documentation for producing the product.

Part 1: Introduction to the project

1. Problem environment and definition

"Nowadays many concepts and techniques are available for effectively controlling inventories. Despite the value of available concepts, such a one-side approach has its limitations in practice" (Zomerdijk 2003). The point is that for solving inventory control problems more is needed than quantitative models and techniques. The organizational context plays a crucial role on the effectiveness of these methods.

In this report, the impact of several factors throughout the operational process of a specific company, called [redacted] on the performance of the inventory turnover (ITR), are researched.

This chapter starts with an introduction to this research. First of all, paragraph 1 introduces the company at which the project is conducted. The second paragraph deals with the problem situation of the company. Paragraph 1.3 introduces the research assignment for this project. After that, paragraph 1.4 gives the research approach for this project. In paragraph 1.5 the relevant literature, related to the problem, is stated. The last paragraph of this chapter clarifies the further structure of the report.

1.1 Project context

The problem environment of this research project is the organization of [redacted] This company produces equipment for all kinds of applications. The often enormous and high tech products are installed at locations all over the world.

[redacted].

[redacted]

[redacted]

[redacted]

The production program is characterized by engineering to order (ETO). Equipment is engineered and manufactured to specific customer specifications. Due to the material to be processed, the location where the equipment has to be placed and other environmental characteristics, each product has to be reengineered to these circumstances. So in this specific situation the customer order decoupling point lies at the engineering phase. In the second chapter more is elaborated about the company specific organization, processes and their inventory situation.

1.2 Problem statement

In this section the problem the management of the company faces is introduced.
One of the key performance indicators management uses to evaluate the performance of their organization is the Inventory Turnover Rate (ITR). This is defined as the cost of goods sold (COGS) divided by the level of inventory. This rate evaluates how long it takes before the money invested in inventory is earned back. In the third chapter more about the ITR and its importance for business is elaborated.

In Figure 1.1 the development of the ITR, the COGS and the inventory level is graphically presented over the last years. This figure shows that from May 2007 there is a remarkable change in the pattern. From here there is a steep decrease in the ITR level. On the other hand there are increases in inventory levels and COGS levels as well. The conclusion drawn from this figure is that inventory levels are increasing stronger compared to the corresponding COGS levels. This results in lower ITR performance.

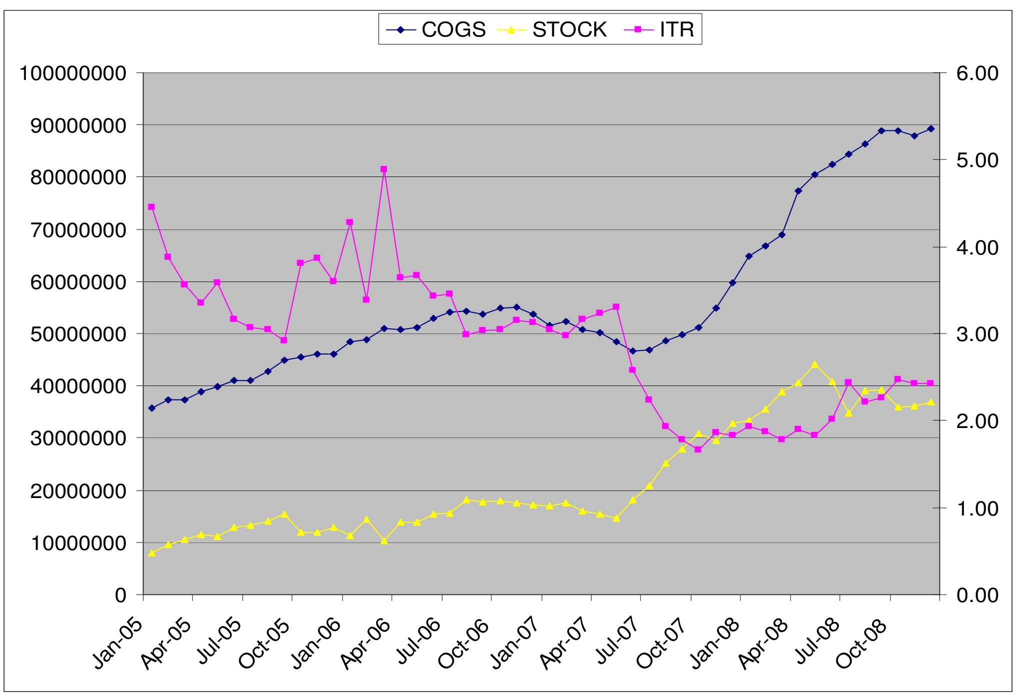

Figure 1-1: ITR vs. Inventory vs. COGS

In highlights the main problems management faces is:

- Inventory levels are significantly increased. A high inventory level creates much inventory holding costs.
- Management does not know if these inventory levels are too high in this specific company setting (increasing sales, ETO environment and current company management)
- Management does not exactly know which factors contribute to the high levels of inventory and in which extend they do.
- The company does not have sufficient grip on the inventory because actions carried out to reduce these inventory levels did not have the expected results

1.3 Assignment formulation

In this section the goal and relevance are stated. After that the assignment is formulated with the relevant research questions.

1.3.1 Goal and relevance

In a research project the goal is to solve a specific practical problem. The solution provided by the project has to be relevant for the satiation in which it is carried out. Since the master's thesis project has a scientific background, theory from the relevant literature is used to solve the problem. This provides guidelines to solve a generally, theoretically formulated problem which is used to come up with a solution for the particular situation. The solutions to the practical problem provide further insights and possible limitations to or confirmations to the scientific literature.
In this project the practical problem to be solved is the question which factors in the organization cause the resulting inventory performance. In order to identify all those relevant factors a theoretical model provided by Zomerdijk and De Vries (2003) is used as a theoretical guideline. The outcomes provided by this model are used to give guidelines to the management for possible solutions of the practical inventory problem. Since this scientific theory is very recent it needs further research in order to become fully developed and generally usable. This research project contributes to the literature by providing a case study to give support for this model in this particular engineer to order situation. It provides also some possible limitations and opportunities for the model due to this practical situation.

1.3.2 Research questions

For this project the main research question could be formulated as: "What are the relevant causes for the performance problem of inventory management resulting in a low Inventory Turnover Rate".
Based on this question four relevant research questions are specified:

1 What has happened in the period from May 2007 leading to the sudden drop in ITR levels and increases in inventory levels?
2 What are the factors contributing to the inventory management performance at this company?
3 To what extend do the identified factors influence the performance of inventory management at the company?
4 Which improvements could be made and to what extend do they contribute to the inventory position of the company in order to meet target performance?

In addition during the execution of the research project a fifth research question is identified. This is stated as follows:

5 What is the best calculation method for the Inventory Turn in this situation? Inventory turn is calculated by dividing the COGS by the inventory level. The question here is how to calculate the ITR so that the inventory level is best related to the corresponding COGS for this company specific situation.

1.4 Research approach

This section describes the approach for this project. First of all the general approach is outlined. Secondly the methods and techniques are briefly introduced and finally the deliverables of the project are identified.

1.4.1 Project approach

The approach of this project is based on the regulative cycle of Van Strien (1997) which is elaborated upon by Van Aken (2005). This cycle is presented in Figure 1.2.

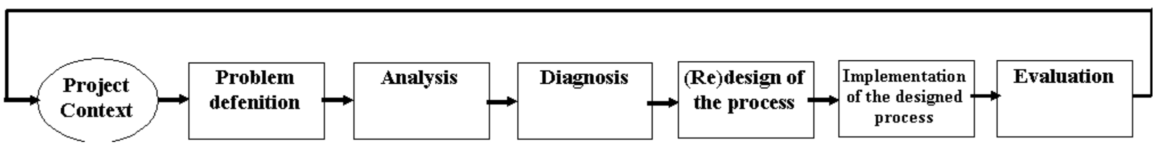

Figure 1-2 Regulative Cycle

First of all the problem is defined. This is already provided in the research proposal by Venner (2009b) and refined in this chapter. After that the process flows into the analysis and diagnosis phase. The theoretical model for the set up of this part is provided by Cooper and Shindler (2003). This model is further explained in Appendix A. Because the time for this project is limited, it is important to reduce the scope. There is no time to include all possible factors and the entire product mix of the organization. Only the most important ones should be further considered. Therefore this project also uses a funnel approach mentioned by Cooper and Shindler (2003). This approach consists of an analysis and a design phase, as shown in Figure 1.3. In the first phase of analysis it is important to use a broad perspective in order to find all possible relevant factors. After the diagnosis, which is the last part of the analysis phase, the perspective will be much smaller. Only a selected number of the most relevant factors and product groups are taken into account.

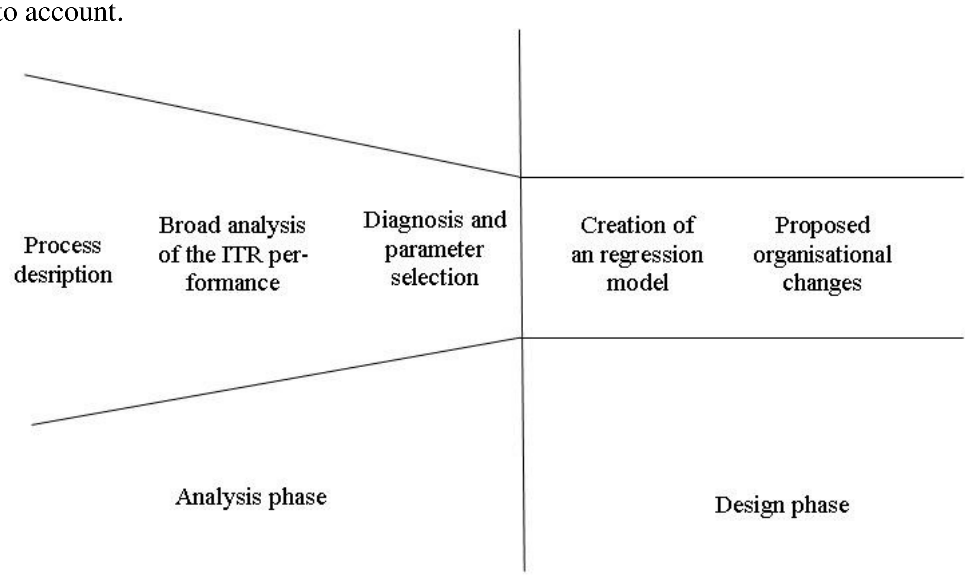

Figure 1-3 Funnel approach

The analysis phase consists of quantitative as well as qualitative research methods. The process starts with a broad analysis of all possible data related to the performance of inventory. This is done to get an unbiased insight in what has happened with the inventory performance in this company. After that the findings are supplemented with a broad qualitative analysis throughout all relevant departments of the organization. Interviews are held in order to identify all possible factors contributing to the resulting inventory performance. After these factors are identified in the qualitative overview, further data analysis is conducted to support these factors with quantitative data.
The broad analysis phase evolves into a diagnosis phase were the conclusion from the analysis phase will be stated. Connections between the factors and inventory as well as between the factors itself are identified. The goal is to get a complete overview of what happened, leading to the resulting performance. The research model by Cooper and Shindler (2003) ends up with a management advice. Since this project does not end after the analysis phase the end of the analysis phase would be an interim assessment of the results so far. The results are discussed with the management in order to get support for identified factors and select the most important ones for the next phase of the project.
After the relevant factors are selected the project moves into the (re)design phase. With a multivariate data analysis technique a model is designed in order to quantify the impact on the inventory level of the selected parameters. The development of this model is further stated in Chapter 5. Also the model is used to predict future values for a given set of parameters.
Because of the lack of data for all relevant factors, the project also provides possible organizational redesign proposals for better inventory performance.
After the design phase of the regulative cycle, the implementation phase follows. The designed model will be tested and validated within the organization Also the performance of the model will be evaluated
The implementation of the proposed organizational improvements is behind the scope of this project. So it is up to the organization to take the proposals of this project into consideration and to choose for implementation

1.4.2 Methods and techniques

Interviews
In order to conduct qualitative research, interviews will be held with all disciplines involved in inventory management. One goal of the interviews is to find out how the actual inventory management processes work in practice at this company. For this project it is important to know how real day to day operations deviate from the official formulated way of operating.
The other goal of the interviews is to find out which problems and obstructions occur for proper inventory performance and which decisions have been taken leading to the drop in ITR.

Data Analysis
All kind of data analysis techniques are used to analyze available company data. Mentioned here are descriptive and analytic techniques as well as statistical techniques. Also graphical interpretation of data is used. Two special techniques are mentioned below here

- **Multivariate data Analysis**
  This technique is suitable to find a relation between a dependent and several independent variables. For the prediction model this technique is used
- **Time Series Analysis**
  Since all data is observed over time special analysis techniques are present in order to deal with those kinds of data.

1.4.3 Deliverables

At the end this project delivers a model which makes it possible to predict the inventory level by a given set of factors. It consists of a multivariate data model which identifies the strength of the chosen factors on the resulting inventory levels and predicts the future inventory values with a given set of factor values. The model and this project give the organization quantitative as well as qualitative insights in their inventory behavior and possible improvements to it.

1.5 Relevant literature

In this project the theory by Zomerdijk & De Vries (2003) and De Vries (2005, 2007) is used for analyzing the inventory performance problem in this specific company

For the analysis of inventory performance problems many literature is available. In the scientific literature two different main streams considered. The first stream consists of the production and operations management disciplines. These are often characterized as individual production systems and dominated by planning and control issues. Examples of such analysis models are mention in articles by Meredith (2001) and Ruffini (2000). The other stream in the scientific literature is dominated by the behavior oriented disciplines. They considered that the organizational setting of inventory control can and should not be disregarded (Zomerdijk & De Vries, 2003). Models to asses these aspects are stated by Kisperska-Moron (2003) and Rabinovich & Evers (2002). The drawback of these methods is they are less technique and method oriented.

“Despite the growing attention for organizational related issues regarding inventory management, the area still seems to lack a clear linkage between planning and control issues on the one hand an organizational behavior on the other hand (De Vries, 2005). Therefore De Vries (2005, 2007) developed a framework to integrate the analysis of both aspects.

In an ETO organization like this one, the performance relies on the flexibility of the organization (Bertrand 1998).The resulting inventory performance depends on the ability of the organization to react to changes in the dynamic environment. This indicates that traditional inventory control factors as well as organizational behavior determine this performance. Therefore the model developed by De Vries (2005, 2007) is suitable in this situation.

1.6 Report outline

After this chapter of introduction, where the outline for the project is stated, the remainder of the report is structured as follows.

The second part of the report consists of the analysis and diagnosis phase. In Chapter 2 the company and its processes are identified as well as the company specific inventory situation. Then the third and fourth chapters consist of a quantitative analysis of the company data and a qualitative research throughout the company to identify all relevant factors relating to the inventory performance. In the fourth chapter also the diagnosis of the analysis phase is conducted and choices are made for the next phase of the project.

After the diagnosis is conducted the third part comes up, which is the design phase of the project. In Chapter 5 a regression model is developed to determine the strength of the chosen factors to predict future behavior. Chapter 6 provides the proposed changes to the current organization and the way in which the ITR could be calculated.

Finally in the last chapter the conclusions, recommendations and limitations for this project are outlined. This chapter also deals with the contribution to the literature of this project.

Part 2: Analysis

2. Research context

The analysis done in this project is based on a framework presented by Zomerdijk & De Vries (2003) and is further developed by De Vries (2005, 2007). This theory is already discussed in the literature study conducted as introduction to this master thesis project (Venner 2009a). Here a short summary of the main purpose of this research is given.

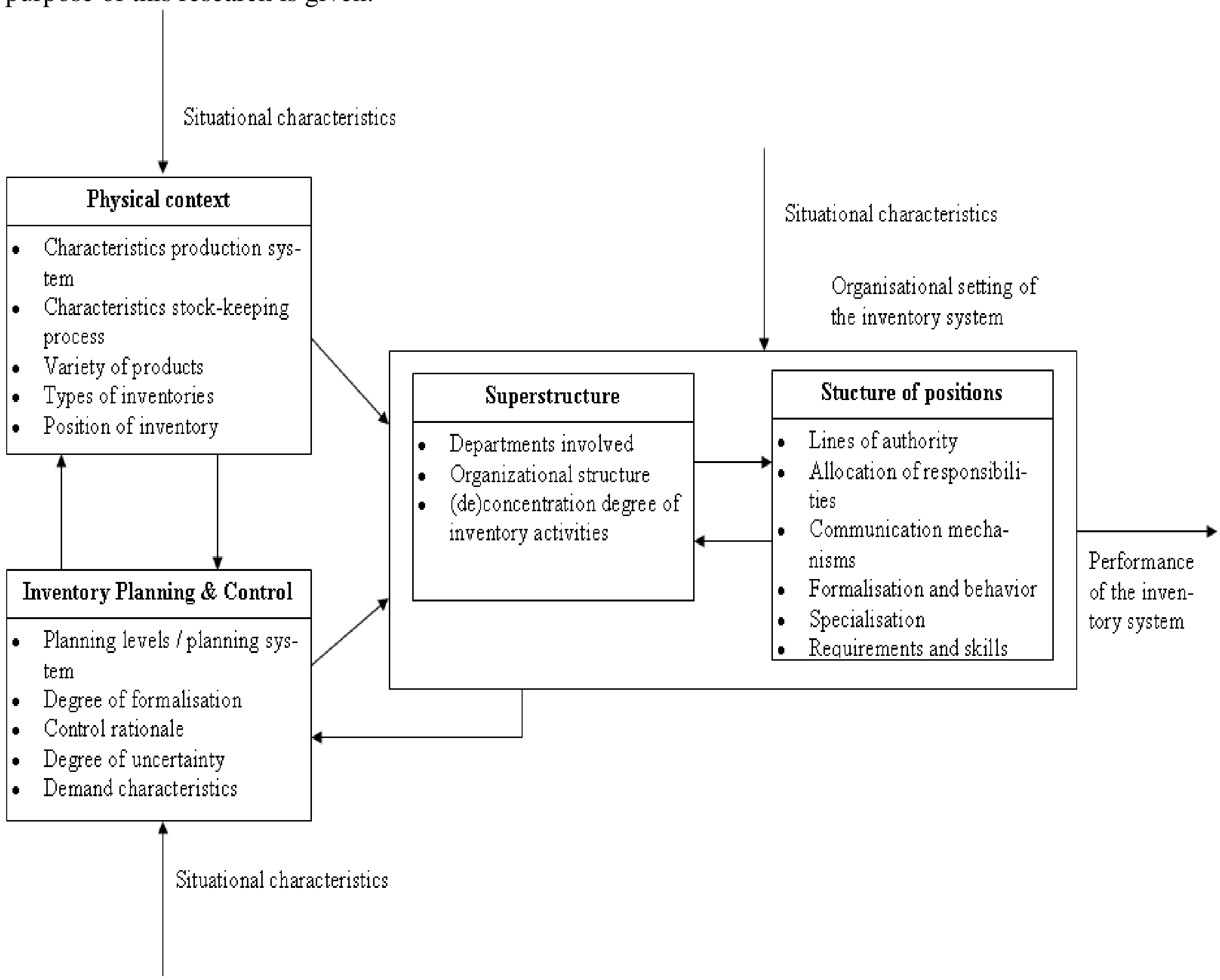

Figure 2-1 Framework for inventory control performance (from De Vries, 2005)

De Vries states in his articles that nowadays it is well recognized that the performance of inventory systems not only depends on the planning algorithms on its own but heavily relies on the organizational context of inventory systems. Despite this recognition the field of production and operations management still lacks a comprehensive body of knowledge integrating both control and organizational aspects of inventory systems. This lack of knowledge is due to the complexity of the relationship between inventory control and its organizational design. “The challenges here are to develop a framework from which questions from both the planning and control of inventory systems as well as the organizational embedding of this control can be described and analyzed in coherence” (De Vries, 2005). This developed framework is presented in Figure 2-1.
This project uses this framework to identify the causes leading to the undesired inventory performance at the company. First of all this chapter deal with the Physical context and the inventory planning and control aspects mentioned in the framework. Chapter three gives a more extensive quantitative analysis of

the performance of the inventory system and the types and position of inventory at the company. After that Chapter four deals with the organizational setting of the inventory system.
As stated before, this chapter gives a brief description of the company in order to understand the physical context of the organization and its inventory processes. First an introduction is given to the organization of the company and all relevant departments for this research project are introduced. The next section describes the most important and specific aspects of the production process for this company. The chapter ends with an overview of the specific inventory situation for this process. The information for this part is obtained from [redacted] and identified during the interviews held at several departments. More about the interviews is explained in Chapter 4

2.1 Company Organization

This section gives an overview of the organization of the company. Appendix B1 shows the organizational model. Figure 2-2 shows the relevant logic of steps for the company process from sales to delivery. In the sub-sections the relevant departments for this project are shortly introduced. This overview of the organization and processes is mainly based on product line A. This is done because this line is most representative for the companies business and has by far the largest sales contribution in comparison to the other product lines.

Figure 2-2 [redacted] relevant process steps

Sales

The sales department can be divided into two main units. The first on is the unit for the equipment of product line A. The unit consists out of two streams. First there is the sale of new products. The second stream consists out of spare parts and customer services. The second sales unit is dedicated to the product lines B and C This unit also consists out of new products, spares and services. For the analysis in this project there is a look at the first Sales unit.
Due to the worldwide selling of equipment the sales department consists of three regional managers. In several countries around the world the company has its own area sales managers. These regional salesmen are supported by the applications engineers at the production facility. These applications engineers make the product selection and provide quotations to customers.
Besides the complete new products, they provide spare parts and services to its customers. This department handles all requests for spare parts from customers. They also advise customers which and how much spare parts a customer must have for a smooth usage of their production equipment.

Project Management

The role of Project Management is to control the entire process of product orders from sales to delivery. Project Management determines the critical path for a specific order and gives the delivery times for a quotation to the sales department. One of the main tasks of this department is to plan the orders, especially the assembly and testing part, for the products into a complete project plan throughout the organizational process. An example of such a project plan is given in Appendix B2

Engineering to Order

The main task of the department Engineering to Order is the design for all types of products and product constructions. They provide the detailed drawings and all technical documents for this equipment. Since the company works on an engineer to order base, every produced product is adapted to the customer's specific needs. Engineering translate these specifications into internal instructions for the organization. A main task, which is crucial for the production process is the release of the bill of material for each order.

Purchasing and production processes can only start if the desired materials and their specifications are known and all needed technical drawings are available.

Logistics

The logistics department consists of two sub-departments: Operations Planning and Forwarding. Operations Planning (OP) is responsible for the entire warehouse stock of the company. The main task of OP is to translate the product orders with the given bill of material by engineering into requisitions for the purchasing department and production orders for the machining department. The department Forwarding is responsible for the worldwide transportation of all parts, complete installations and the included documentation.

Purchasing

This department is responsible for the purchasing of all parts needed in the organization.
The company has over 500 different suppliers all over the world. 50% of all these suppliers are from foreign countries.
The department consists of three purchasing teams based on the items for which they are responsible. The first team is responsible for the purchasing of raw materials and castings. These materials need further cultivation in the machining department. The second purchasing team is responsible for the "Buy outs". These are components which are completed sub-assemblies and directly usable in the assembly process. The last purchasing team handles the work that is contracted out. Due to an expected capacity problem in the machining department some work has to be outsourced to suppliers with the same capabilities. Besides that the company makes a strategic choice to contract out 50% of their machining work in order to maintain flexibility in their own machining department.

Production

In the production department there is a distinction made between the Machining and the Assembly. Machining is the largest department of the organization. All machine handlings to remove excess material from metal are carried out by this department. The Machining works in 2 shifts. Recently a third shift is added to this department started voluntary. Employees could join the 3 shift system if they wanted but it is not obligatory at this moment. In the future the plan is towards a full 3 shifts operating machining department.
After all parts are produced and delivered the product is assembled in the assembly department. After the product is assembled it is extensively tested and painted. Since most equipment is too large and heavy for transportation, after testing and painting the products are partly disassembled and packed in special boxes to be prepared for transportation. An example for the production and assembly steps for a typical product are given in appendix B3

2.2 Company Business process

The operational business process for the production of new equipment is visually presented in Figure 2-3

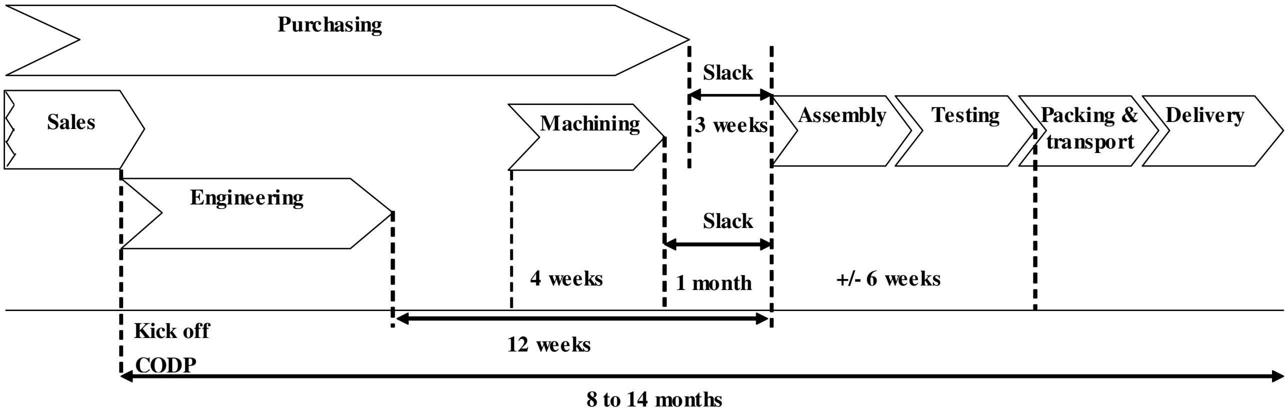

Figure 2-3 [redacted] Process

The starting point is the sales process which can often takes years from the first contact to the final order. In the quotation phase Project Management determines the lead time for the order and from Engineering the cost prices ore obtained. Characteristic for the business environment of this company is the manufacturing critical path. This is shown in Figure 2-4. The path colored in red is the manufacturing critical-path. This is the longest path from the start of production by the supplier to the delivery of the product at the customer. As shown in this figure the paths from several suppliers' parts are much longer than the internal lead time of the company itself. For the illustration the lead time, given by the company to its customers for a product from sales to delivery varies between 8 and 14 months. In contrast to this some parts, such as bearings have lead times up to 600 days. In order to reduce customer lead time the company makes a strategic choice to order several items with very long lead times before a customer order is made final.

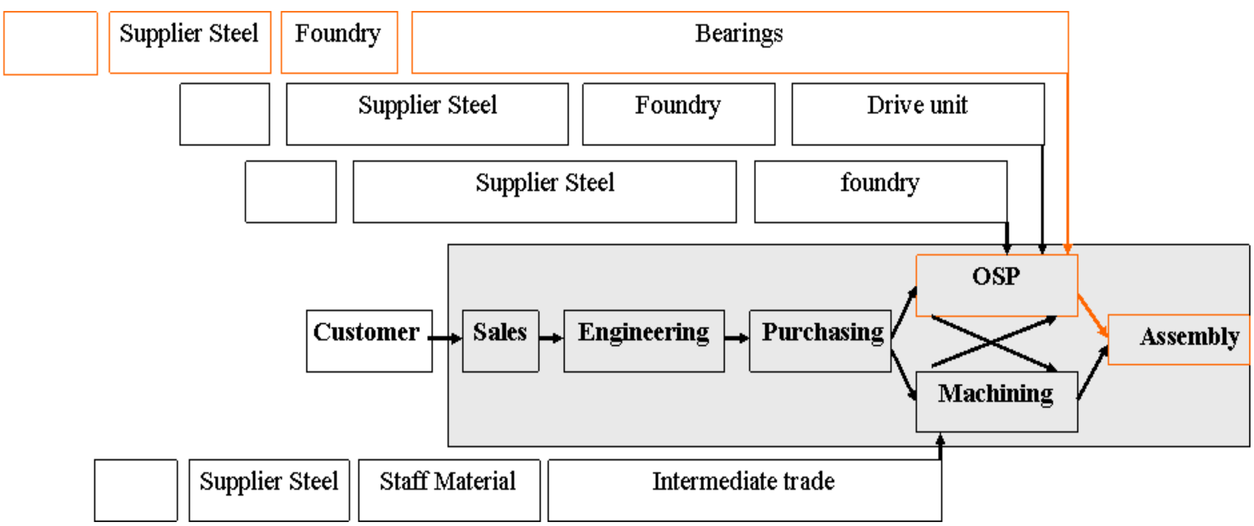

Figure 2-4Critical Path

The sales department makes a monthly forecast for bearings and crankshafts based on expected sales. Due to this the purchasing process already starts during the sales process as presented in figure 2-3. There are framework contracts with several suppliers for the minimum and maximum monthly order quantities.

There are also contracts for the reservation of capacity at suppliers. The capacity is reserved for orders from this company but the technical details for the ordered products can be provided later.
The Customer Order Decoupling Point (CODP) lies at the end of the sales process. This means that besides the parts which are order earlier on forecast the need for all other materials, activities are driven by customer orders. Also the engineering and production activities for new products are completely driven by customer orders.

The process starts with a “Kick off”. At this company there are two kick off moments. In this process description the “Technical Kick off” is used. This is the moment where all technical details are made clear and this is the official starting point for the production process. At this moment Project management makes a complete project plan. The project plan is based on the available capacity in the assembly department. Especially the test phase of the assembly process is determining the planning. Each product is “slotted’ in the assembly process. The start date for assembly is leading for the other activities carried out in the production process.
From this the Kick off also the engineering phase starts. The application engineers of the sales department have already selected the product for a customer from several available basic product modules during the sales process. Engineering chooses a product out of the range of already manufactured products in history which is most likely to be the desired one. This product is adapted to the desired customer specifications.
Because there are parts with long lead times, such as frames and membrane housings, engineering must release these parts 1 week after the kick off in order to receive them in time for the assembly process. The total release (for machining as well as for purchasing) for all parts for a product project is officially set 20 weeks before the start of assembly. Practically a period of 12 weeks before start assembly is used for the total release of all parts. If all materials are released the purchasing and machining process can start. In the machining department all raw materials are manufactured for use in the assembly. The lead time for the machining processes of a product order is about 4 weeks. For the suppliers the need by dates for all material is planned three weeks before the start of the machining or assembly processes. The scheduled date for the requirement for all materials produced by the machining department is planned one month before the start of the assembly process. These slack times are created due to the unreliable delivery performance of suppliers as well as the machining department. Appendix D3 gives a complete overview of the used dates in the supply processes of this company. If all required parts are really available at the scheduled start assembly date the assembly phase starts. Here the product is completely assembled and extensively tested. This process has a lead time of 6 weeks on average. After testing, the product is painted and prepared for transportation. Heavy products are dissembled in to manageable parts which are packed into special boxes for transportation.

2.3 Inventory situation

In this section there is a detailed look at the inventory processes. Figure 2-5 shows the flow for the Material acquirement process. The need for materials starts at three points. First there is the demand generated by sales orders for products. Due to the planning made by Project Management and the Bill of Material (BOM) provided by Engineering the need for materials is generated. OP translates these needs into the company’s MRP system. The second stream of material acquirements consist of the need for spare parts generated by customer orders from intermediate trade. These needs are also entered in the MRP system. The last input stream is the forecast made by the several units of the sales department on top of the customer orders in the first two streams. Spares makes a forecast for the spare parts and sales of new products makes forecast for items with long lead times such as bearings. All order streams together determine the need for material. From this point OP determines, supported by supplier data such as lead times, the order quantities and request dates for the several materials. This results in production orders and requisitions. Requisitions are purchasing orders for internal use between OP and the purchasing department

The production orders are taken by the planning office of the machining department for detailed planning of the production work. OP only determines the middle and long term planning for the production.
The requisitions are picked up by the purchasing department. This department translates the requisitions into specific purchase orders for the several suppliers.

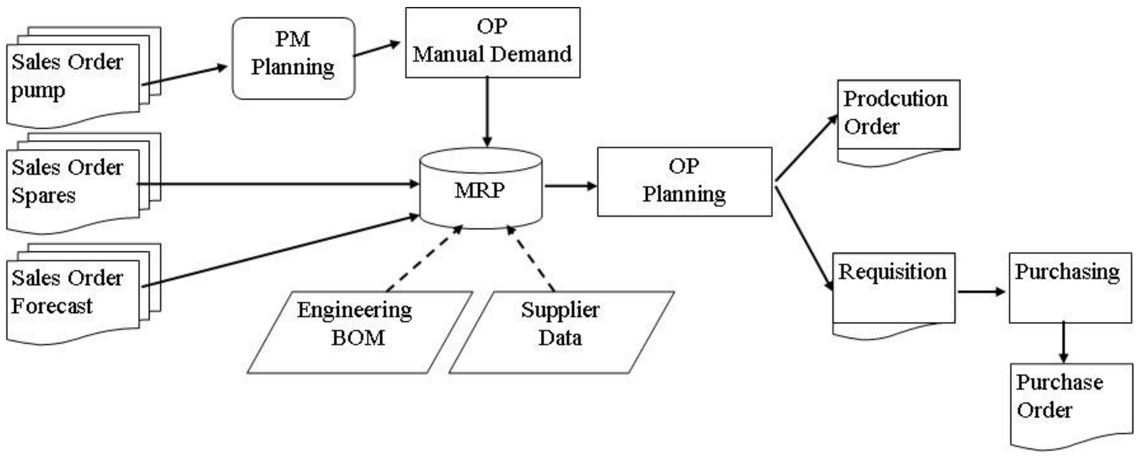

Figure 2-5 Material acquirement process

Figure 2-6 shows the various physical inventory points used in the company. A remark here is that the model shows the internal warehouse stock at the company which is under consideration for the project. Inventory which is in transportation or consigned at customers is outside the scope of this project.

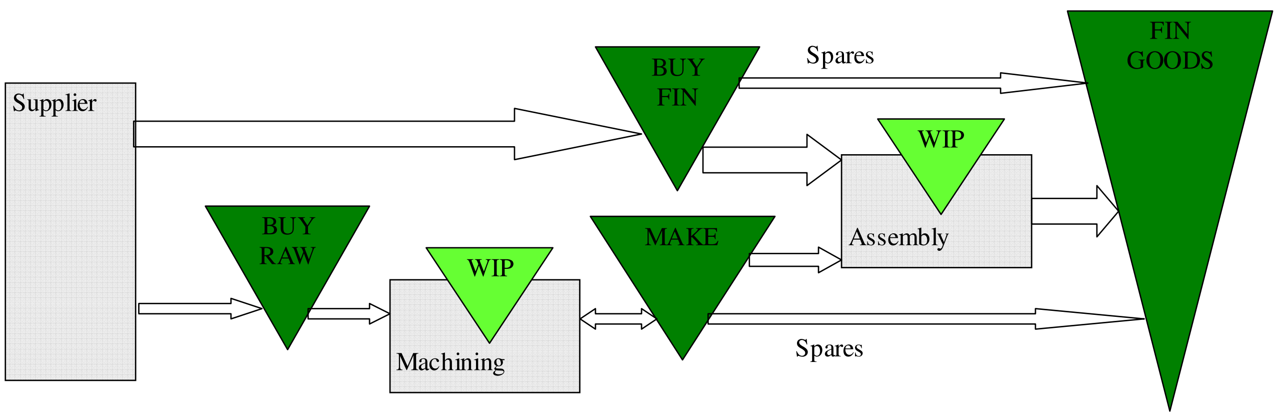

Figure 2-6 Material Flow

Starting at the several suppliers there are two main streams of materials distinguished. First there are the complete parts that are directly usable in the assembly. The second stream is the delivery of raw materials needed for the machining department. The Work In Progress (WIP) machining consists of all materials that are handled by the machining department at the moment. Also the processes that are contracted out are included in the WIP machining level. Inventory which is waiting between two machining handlings does not count for the WIP level but is temporally stored in the warehouse and so counts on the Make inventory level. After production in the machining department the material flows in the Make stock point. From the make and buy stock points inventory flows in the WIP of the assembly department. Besides material for assembly the stock points make and buy also consist of spare parts. Finished goods are the complete products out of the assembly department ready for transport. Also the completed spare parts are physically in the finished goods stock point.

2.4 Inventory control

This section gives a short overview of the inventory controls policy used in the company.

The first important remark is that inventory is “blind”. This means that in the inventory no distinction can be made between spare parts and parts for projects. Also no distinction can be made between parts for the different projects. Only the aggregated reservations (caused by orders or forecasts) for several parts are shown in the inventory database without allocation to specific projects or spare parts.

A second important remark, which has a great impact on the company’s inventory control, is that the demand pattern for the largest part of inventory is fluctuating. Due to the varying product mix no stationary demand patterns could be identified. Historical demand for product types cannot be used as predictor for future demand for those types. Therefore most basic inventory control policies like reorder points and base stock are usable but not optimal for this situation (Hopp and Spearman, 2001). An exception here is a small part of the spares, which is controlled by a Kanban system and has a more stationary demand pattern.

Concluding inventory control is driven by the needs for materials created by sales orders, by forecasts for spare parts, and forecast for items with very long lead times. More about inventory control for an engineer to order organization like this one is explained in chapter 6.

3 Inventory turn performance analysis

This chapter deals with the performance of the inventory system of the company over the last years. The first paragraph is about the performance measure the company uses to evaluate their inventory management effectiveness. As stated before in the problem definition in the first chapter the performance of inventory is below the desired target level. It especially drops since May 2007 as can be seen in Figure 1-1. In the second paragraph the Inventory component of Inventory Turnover Rate is further investigated.

3.1 Inventory Turn Rate

This paragraph presents an analysis of the Inventory Turn Rate. First of all a definition is given for the ITR and its importance for business is elaborated. This is followed by the specific way of calculation of the ITR in this company. After that the two components of the measure are analyzed. This paragraph ends with a performance overview of the ITR over the last years.

3.1.1 Definition and importance

According to Garrisson (2003) the inventory turn rate is one of the elements to evaluate the performance of a company based on the return on investment (ROI). The ROI is defined as the operating profit divided by the operating assets. The higher the return on investment of a company, the greater the profit generated per Euro invested in operating assets. The inventory turn rate measures the relation between the sales (expressed in the cost of goods sold) and the investment in inventory to reach these sales. The higher the inventory turn rate, the less investment in inventory is realized.

In many companies like this one inventories form a large part of the operating assets. Therefore much of the working capital of the company is invested in inventories. Money invested in inventories could not be used for other investments or payables. Lower inventory turn rate levels means that it takes longer before money invested in inventory is earned back.

3.1.2 ITR in the company situation

In this chapter the inventory turn rate is analyzed based on the way it is calculated in the company over the period of analysis. Besides that the ITR is also analyzed based on the parent company's headquarters' policy of calculation which is also used in the company from March 2009. In Chapter 6 the way of calculation of this COGS parameter is further discussed and improvements for calculating this measurement are given. At the company the Inventory Turn Rate is defined by dividing the sum of the COGS of the last 12 months (because the COGS have to be an annualized value for ITR calculation) by the inventory level. The ITR is calculated at the end of every month. Equation 3-1 gives the ITR calculation for a particular month T.

$$ITR_T = \frac{\sum_{T-11}^{T} COGS_T}{INVENTORY(ITR)_T}$$

Equation 3-1 ITR calculation

Headquarters' policy prescribes to calculate the ITR level by dividing the COGS of the last three months times 4 (for annualizing) by the inventory level. This calculation is presented in Equation. 3-2

$$ITR_T = \frac{(\sum_{T-2}^{T} COGS_T) * 4}{INVENTORY \quad (ITR)_T}$$

Equation 3-2 Headquarters' Policy for ITR calculation

The explanation of these two equations consists out of two parts. First there is the COGS component. The monthly COGS are based on the current projects in the production program. Based on the size and the lead time of a product each month (within the lead time of a particular product type) a part of the total COGS of a product is taken and reported. For example for a particular product with a lead time of 8 months and has the status of 3 months before delivery 20% of the total COGS is taken and counts for the COGS for that month. This profile for the administration of the COGS is further explained in chapter 6. The COGS for a particular moth is the sum of all partial COGS from the current projects in the production program and the sales of spares for that month. For this chapter it is important that in the period of analysis nothing is changed in the way the COGS are reported for ITR calculation.
For the explanation of the inventory term for calculation first some concepts have to be introduced. In this paragraph a brief introduction for these concepts is given. This description is also given in the Definition of concepts.

- WIP: the value of all production orders measured at the end of the accounting period. Here in this company definition of WIP differs from the general definition of WIP. Here WIP consist of the value of all production orders physically placed on the production floor. Also products in the production process of external suppliers count for the WIP level.
- Reserved stock: the value of inventory which is allocated by needs for new products, spare parts or service. This is all stock which has reservations in the system.
- Available stock: This is the warehouse stock which has no reservations in the system. This stock is further categorized in obsolete and (non)excessive stock
- Obsolete stock: value of all items in the available warehouse stock without valid transactions during the accounting period. there are 2 categories of obsolete stock
  - Obsolete 50%: Available stock without valid transactions during the last year. The inventory value remains 100% for logistics but for financial 50% of the stock value is taken in the obsolete provision.
  - Obsolete 100% Available stock without valid transactions during the last two years. For logistics the value remains 100% because stock is physically in the warehouse. For financials the stock value is fully taken into the obsolete provision.
- (non)Excessive stock: the available stock – the obsolete stock. This is divided into two categories based on the average usage over the last two years. Here the usage over the last year has a weigh of two and the usage of two years ago had a weigh of one.
  - Non excessive sock: the available value is smaller than the average usage of the last two years. there is no excessive value
  - Excessive stock: the available value which is lagers than the average usage over the last two years. This value is evenly written of over the coming 5 years.

Equation 3-3 shows how the stock level for the ITR formula is calculated. So for ITR the reserved stock, the total WIP and the available stock minus the excessive part is considered. Also the stock level is compensated for a burden percentage which is set at 5% for all product lines. The company also makes the choice to subtract the value of finished products out of their inventory level for ITR calculation. The values of finished products are sometimes very high and often due to administrative reasons they remain some months in the Inventory registration. The stock level is measured at the end of every month.

$$\mathrm{STOCK(ITR)} = \frac{\mathrm{TotalStock} - \mathrm{CompleteProducts} + \mathrm{WIP} - \mathrm{Obsolete100\%} - \frac{\mathrm{Obsolete50\%}}{2} - \mathrm{ExcessiveStock}}{1 + \mathrm{Burden\%}}$$

Equation 3-3 Calculation of the Inventory component for ITR calculation

3.1.3 Inventory levels & Cost of Goods Sold levels

As stated before the ITR consist of two components. The first one is the Cost of Goods Sold. Table 3-1 shows the levels of COGS from January 2006 to January 2009. A complete monthly overview of the COGS over the last years is given in appendix C1. In this table the half year evolvement is given. Especially the months May 2007 and May 2008 are given in this table because this is the period in which the ITR drops and inventory increases. The table shows the COGS levels for the five used product lines at the company based on the ITR calculation given in equation 3-1. The mentioned percentages are the relative contribution of each product line to the total COGS. It can be identified that the Product line A1 has by far the largest contribution to the company's sales of 80 to 85%.

% of total COGS per product line								
	January-06		July-06		January-07		May-07	
Product line B1	€ 4,868,000.00	10%	€ 4,293,833.33	8%	€ 3,963,833.33	8%	€ 5,986,833.33	12%
Product line B2	€ 267,000.00	1%	€ 258,000.00	1%	€ 312,000.00	1%	€ 370,000.00	1%
Product line A2	€ 1,553,000.00	2%	€ 1,875,833.33	3%	€ 1,924,833.33	3%	€ 2,280,833.33	5%
Product line A1	€ 41,005,000.00	85%	€ 46,711,000.00	86%	€ 44,367,000.00	86%	€ 38,806,000.00	80%
Product line C	€ 747,000.00	2%	€ 1,063,000.00	2%	€ 1,042,000.00	2%	€ 973,000.00	2%
TOTAAL	€ 48,440,000.00		€ 54,201,666.67		€ 51,609,666.67		€ 48,416,666.67	
	January-08		May-08		January-09			
Product line B1	€ 8,031,000.00	12%	€ 7,035,000.00	9%	€ 10,702,000.00	12%		
Product line B2	€ 376,000.00	1%	€ 380,000.00	0%	€ 368,000.00	1%		
Product line A2	€ 2,864,000.00	4%	€ 3,319,000.00	4%	€ 3,834,000.00	4%		
Product line A1	€ 52,482,000.00	81%	€ 68,817,000.00	86%	€ 71,604,000.00	82%		
Product line C	€ 1,032,000.00	2%	€ 877,000.00	1%	€ 554,000.00	1%		
TOTAAL	€ 64,785,000.00		€ 80,428,000.00		€ 87,062,000.00			

Table 3-1 COGS term of the ITR calculation for the five product lines

Table 3-2 shows the second component of the ITR measure. Here the values for the inventory level of the five product lines are given for the same periods of the COGS in Table 3-1. A complete overview of the evolvement of the inventory over the last years is given in appendix C1. Also from this table can be identified that Product line A1 has by far the largest contribution in inventory levels: about 75 to 80%. Remarkable is that for product line B1 the contribution to inventory is higher than the contribution to sales. Because product line B1 is leaving from the production facility at the end of 2009 this line is not used for further analysis in this project. The other three product lines has such a small contribution to the COGS as well to the inventory levels (no more than 5%) that, given the time for this project it is not desirable to analyze all these product lines separately. In order to reduce the scope for this project, further analysis is only conducted for product line A1

% of total Stock per product line								
	January-06		July-06		January-07		May-07	
Product line B1	€ 1,054,462.03	9%	€ 2,642,510.83	17%	€ 2,960,060.45	18%	€ 2,610,111.76	18%
Product line B2	€ 119,710.29	1%	€ 187,904.41	1%	€ 199,087.19	1%	€ 178,137.08	1%
Product line A2	€ 491,579.78	4%	€ 476,138.56	3%	€ 803,081.72	4%	€ 779,251.53	5%
Product line A1	€ 9,336,624.07	83%	€ 12,267,619.34	78%	€ 12,641,076.36	75%	€ 10,683,079.19	73%
Product line C	€ 310,966.64	3%	€ 107,316.16	1%	€ 301,658.45	2%	€ 367,602.45	3%
TOTAAL	€ 11,313,342.82		€ 15,681,489.30		€ 16,904,964.16		€ 14,618,182.01	
	January-08		May-08		January-09			
Product line B1	€ 4,313,704.05	13%	€ 8,878,095.04	20%	€ 7,325,813.22	19%		
Product line B2	€ 152,514.00	0%	€ 130,147.72	0%	€ 71,567.58	0%		
Product line A2	€ 892,144.55	3%	€ 1,491,515.59	3%	€ 1,801,878.69	5%		
Product line A1	€ 27,995,758.53	84%	€ 33,346,676.72	77%	€ 28,474,164.57	76%		
Product line C	€ 106,668.66	0%	€ 206,697.07	0%	€ 59,679.80	0%		
TOTAAL	€ 33,460,789.79		€ 44,053,132.14		€ 37,733,103.86			

Table 3-2 Inventory Term of the ITR Calculation for the five product lines

3.1.4 ITR Performance

This sub-paragraph deals with the performance of the ITR for product line A1 over time. The first remark to make here is that the company not only uses another ITR calculation as prescribed by the parent company. Also the target level for ITR set by the company differs from the headquarters' target level. The company uses an ITR target of six while headquarters of the parent company sets a target level of ten. Figures 3-1 and 3-2 show the ITR development over time based on Equations 3-1 and 3-2.
Both figures shows that company's as well as parent company's target levels are never reached (except from the incidental value of august 2006)

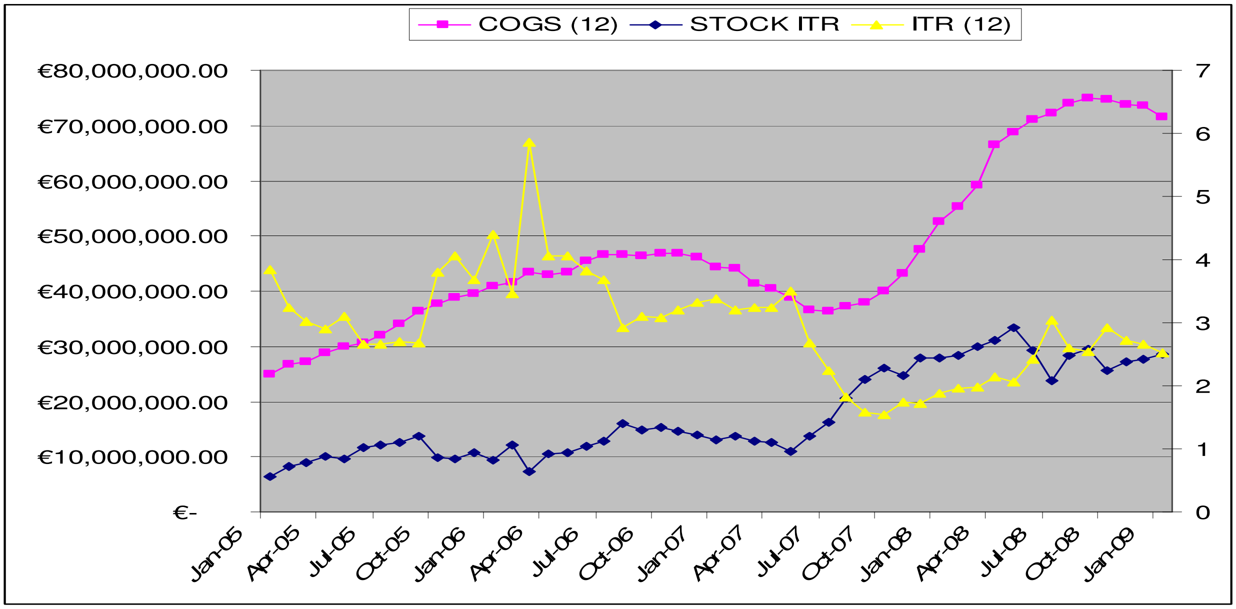

Figure 3-1 ITR performance based on Equation 3-1

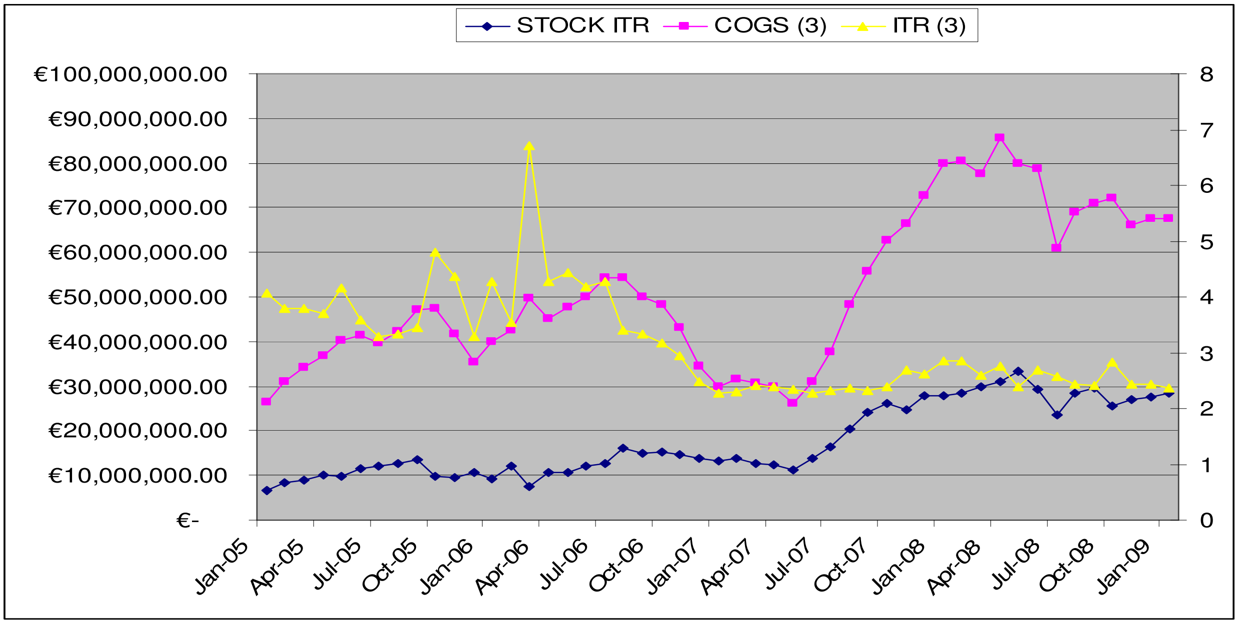

Figure 3-2 ITR performance based on Equation 3-2

From both figures it becomes obvious that the way of COGS calculation has a large impact on the resulting ITR levels. Especially in an environment where sales values are dynamically increase and decreases over different months this effect is strengthened. From September 2006 both figures shows significant different ITR behavior. Especially the period from September 2006 to May 2007 a remarkable difference can be seen. The effect of the lower sales in that period is larger due to Equation 3-1 than by Equation 3-2. In Equation 3-1, a month counts for 1/12th of the COGS, whereas in Equation3-2 a single month accounts for 1/3rd of the COGS Due to this COGS effect the period of ITR decrease differs depending on the method of calculation, as illustrated in Figures 3-1 and 3-2. In Figure 3-1 the ITR drop exists into two periods. The first period lies between July 2006 and Ocktober2006. After that it stabilizes and shows a slight increase in the beginning of 2007. From May 2007 the second period of drop occurs and stops in July 2008. After this period ITR shows again a slight increase. On the other hand in Figure 3-2 there is one period of drop and falls between July 2006 and January 2007. After that period ITR stabilize and remains on average on the same level. From this it can be concluded that it is not obvious that the problems are restricted to the period from May 2007 as stated before.
The resulting ITR is interaction between the COGS and the inventory levels as formulated in the equations. If the COGS decrease the inventory level also should decrease in order to remain the same ITR level. For example if the COGS drop from 12 to 8 million the inventory level should drop from 3 to 2 million in order to remain an ITR of 4. In both figures is can be seen that the ITR drop is caused by a decrease in COGS which is higher compared to the Inventory levels. In figure 3-1 the COGS decrease while the Inventory is increasing from May 2007 which causes the ITR drop. Figure 3-2 shows that the decrease in COGS is steeper than the inventory decrease. (COGS decreases from 55 million to 30 million Euros while inventory decreases from 18 million to 11 million Euros).
Because the company works on an engineer to order base and the lead time for new product projects is quite long (8 to 14 months) the sales for the coming months are known (Except form the spare parts sales which are no more than 15% of monthly COGS). Therefore the COGS levels for the coming months could be predicted quite well due to the COGS administration profiles and due to the fact that calculated cost prices for the projects are known. Since sales are known also the need for materials is known. So inventory levels should be adapted to the COGS levels in order to reach target ITR levels. It could be concluded that the resulting low ITR levels are due to the fact that the inventory levels are too high compared to the corresponding COGS levels.

3.1.5 Inventory holding costs

The inventory holding costs are costs made for storing and handling the items in the warehouses. But also the cost of loosing interest is included in the holding costs. This means that money invested in inventories also could be stored on a bank account and yield interest over this money. This loss in interest due to inventory investment is also included in the inventory holding costs. For this company the inventory holding cost are set on a yearly rate of 12.5 percent of the inventory level.
Figure 3-3 illustrates the monthly inventory holding costs over the period of analysis. Here 12.5% of the monthly inventory level is taken and divided by 12 in order to obtain the monthly value. The figure shows that monthly holding costs are doubled from around 150000 Euros to around 300000 Euros.

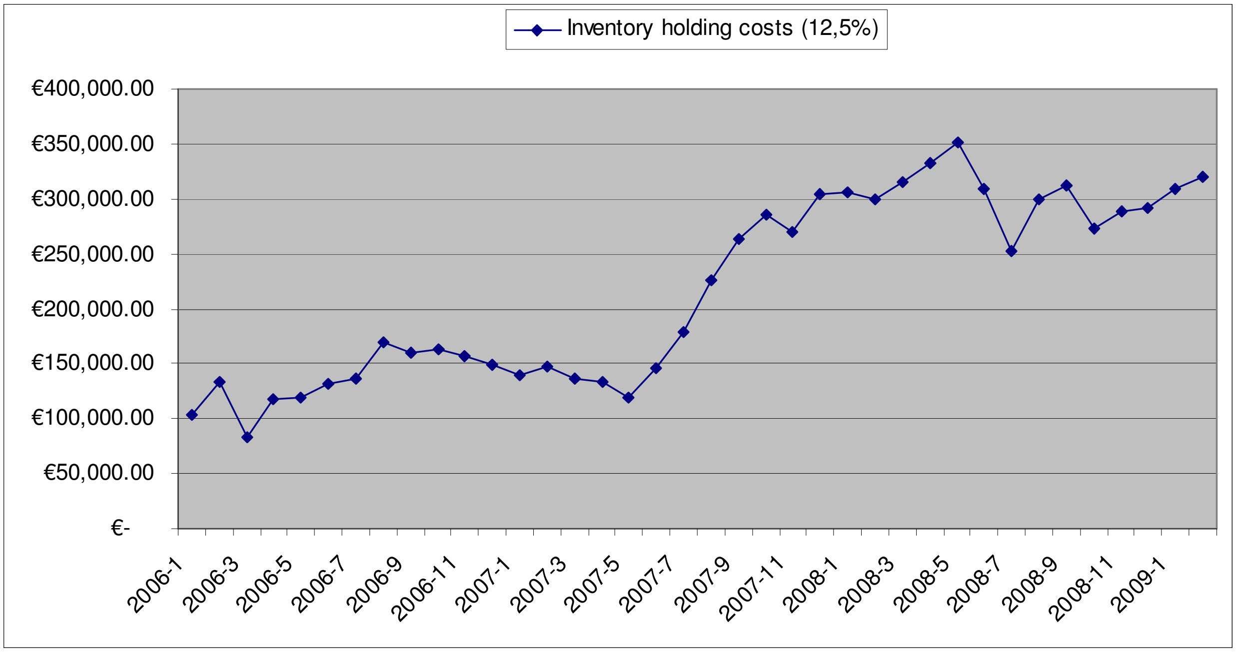

Figure 3-3 Inventory holding costs

3.2 Inventory Analysis

This paragraph deals with the analysis of the inventory component of the ITR for the product line A1. As seen in the previous paragraph the inventory levels are too high compared to the corresponding COGS levels. The goal of this analysis is to discover whether specific parts of the inventory contribute significantly to the total inventory increase. Therefore four possible categorizations of the inventory of this company are analyzed to identify important contributors. The categories are: Inventory structure, warehouse Place, inventory function and item category.

3.2.1 Analysis based on inventory Structure

The first categorization of interest is the inventory structure of the company. As mentioned before the stock here is categorized by Reserved, Available, Obsolete and excessive Stock and the WIP. The evolvement of the several stocks is presented in table 3-3. In this table the half year evolvement of the stock levels is presented Appendix C2 shows the total evolvement for every month of this stock structure over the given period. The months May 07 and May 08 are included in the table because this are the months where the inventory increase starts and stops as shown in Figure 3-2. The table shows that the WIP and the reserved stock are the main contributors in the inventory. In the first half of 2007 a Kanban system is introduced in the assembly. This means that parts are stayed in the warehouse until they are needed in the assembly process. Before all parts are counted for the WIP level from the start of the assembly process. This declares this decrease in WIP contribution and the increase in reserved stock in 2007. Therefore the total level (Inventory + WIP) increased about 200% between January 2006 and January 2009 while WIP level only increased 100% and reserved stock level with 300%. Looking at the period the inventory increased from May 2007 to May 2008 the reserved stock would be the main contributor to this increase. This means that for the largest part of inventory there is a need created by sales orders or forecasts

Stock structure											
	January-06			July-06			January-07			May-07	
Reserved	€	3,854,659.01	37%	€ 6,028,616.49	44%	€	6,501,585.55	38%	€	6,465,906.65	53%
Available	€	795,460.24	8%	€ 575,889.86	4%	€	1,449,522.51	9%	€	1,629,981.43	13%
Excessive	€	77,229.49	1%	€ 100,053.31	1%	€	101,234.71	1%	€	121,064.19	1%
Obsolete	€	362,764.56	3%	€ 420,661.03	3%	€	417,344.58	2%	€	444,875.26	4%
WIP	€	5,514,237.76	52%	€ 6,747,619.23	49%	€	8,657,698.90	51%	€	3,550,865.48	29%
Total	€	10,527,121.57		€ 13,772,786.61		€	17,026,151.54		€	12,091,628.82	
	January-08			May-08			January-09				
Reserved	€	18,762,573.78	61%	€ 20,006,459.37	56%	€	15,174,259.80	48%			
Available	€	2,149,919.87	7%	€ 2,655,900.24	7%	€	4,834,487.14	15%			
Excessive	€	167,246.24	1%	€ 214,670.82	1%	€	924,346.48	3%			
Obsote	€	484,612.83	2%	€ 462,148.51	1%	€	713,252.31	2%			
WIP	€	9,597,100.14	31%	€ 12,464,921.87	35%	€	10,602,771.11	34%			
TOTAL	€	30,994,206.62		€ 35,589,429.99		€	31,324,770.36				

Table 3-3 Stock Structure for product line A1

3.2.2 Analysis based on warehouse place

In figure 2-5 of Chapter two the physical stock points are presented. The second categorization would be based on this stock structure. Table 3-4 presents the results for this analysis January 2008 is replaced by December 2007 in this analysis because the database for this analysis for this month is missing.

Physical stock structure								
	January-06		July-06		January-07		May-07	
BUY RAW	€ 940,446.29	9%	€ 1,521,979.41	11%	€ 810,623.00	5%	€ 991,548.00	9%
BUY FIN	€ 1,907,774.66	19%	€ 3,880,166.86	29%	€ 4,214,652.00	27%	€ 5,179,675.00	45%
MAKE FIN	€ 1,695,205.17	17%	€ 1,464,501.80	11%	€ 2,165,351.34	14%	€ 1,862,437.00	16%
WIP MACH	€ 2,011,940.35	20%	€ 2,995,546.53	22%	€ 1,997,762.30	13%	€ 2,263,170.66	20%
WIP ASSY	€ 3,502,297.41	35%	€ 3,752,072.70	28%	€ 6,659,936.60	42%	€ 1,287,694.82	11%
Total	€ 10,057,663.88		€ 13,614,267.30		€ 15,848,325.24		€ 11,584,525.48	
	December-07		May-08		January-09			
BUY RAW	€ 1,329,844.00	5%	€ 2,594,750.00	8%	€ 2,320,768.00	8%		
BUY FIN	€ 10,645,175.00	40%	€ 14,175,074.00	41%	€ 13,507,480.00	44%		
MAKE FIN	€ 6,958,362.63	26%	€ 4,997,424.14	15%	€ 3,991,807.18	13%		
WIP MACH	€ 3,228,410.25	12%	€ 4,951,185.09	14%	€ 5,513,680.44	18%		
WIP ASSY	€ 4,782,603.48	18%	€ 7,513,736.78	22%	€ 5,089,090.67	17%		
TOTAL	€ 26,944,395.36		€ 34,232,170.01		€ 30,422,826.29			

Table 3-4 Physical Stock Structure for product line A1

From this analysis it could be obtained that Buy Finish is the largest part of the inventory.
A significant change is that the contribution of the WIP ASSY decreases significantly in 2007. As said in the previous sub-paragraph this is due to a Kanban system which is introduced in the Assembly department from that moment. This means that material is taken out of the warehouse when it is needed in the assembly department and no longer at the start assembly date. Material stays longer in the Make FIN and BUY FIN stock points because all materials are still order based on the start assembly date. Further no significant changes in this structure could be identified

3.2.3 Analysis Based on inventory function

A third possibility to categorize the inventory is the inventory function.
The company has the following categories

- Administrative: all administrative parts which define the structure of a product. Mentioned here are user manuals and other documentation for a product.
- Insurance: parts with an expected long life time. But when broken they threaten the availability of the equipment immediately

- Strategic: parts which have a very long life time. But when these parts are broken the availability of equipment is threatened for a long time due to the very long lead time of these parts
- Maintenance: parts which have to be replaced by preventive maintenance of the equipment after 8000 working hours or two years
- Products: all complete equipment
- Rest: all parts not included in the other categories
- Wear: all parts which need regular replacements due to the abrasive working of the processed materials

The Insurance and strategic parts seems to be very similar in inventory function. Both parts have an expected very long life time and threaten the availability of the equipment when broken. The strategic parts are the ones with a very long lead time (such as frames, bearings an crankshafts) and therefore is takes a long time before a broken part can be replaces. Insurance parts have shorter lead times and could be replaced more quickly.

Table 3-5 shows the values for this categorization over the given months. Appendix C4 shows the complete evolvement for this categorization It is shown that the Products category have a very fluctuation pattern. The company leaves these values out of their ITR calculation because they would be very disturbing for the ITR performance. Mostly these values are remained in the system due to administrative reasons.

From this categorization it could be obtained that the Strategic parts have the largest contribution (around 40%) to the stock and therefore to the stock increasing. For example in January 2009 the strategic contribution would be 44% if the products category is not included in the inventory level.

It is remarkable that the Rest category is the second largest contributor. The contribution of this category is 20 to 30% of monthly inventory levels. This means that about 1/4th of the inventory consist of parts which have no specific inventory holding function.

Functional stock category												
	January-06			July-06			January-07			May-07		
Insurance	€	312.415,17	7%	€	650.440,84	9%	€	487.094,02	7%	€	608.015,68	8%
Maintenance	€	682.913,84	15%	€	1.046.889,77	15%	€	1.209.074,30	17%	€	1.211.302,07	15%
Rest	€	1.174.352,01	26%	€	1.751.621,70	26%	€	1.733.040,52	24%	€	1.015.078,33	13%
Strategic	€	1.462.468,17	32%	€	2.664.912,91	39%	€	2.678.596,50	37%	€	3.972.927,11	49%
Wear	€	513.364,16	11%	€	574.043,37	8%	€	955.533,90	13%	€	1.205.442,28	15%
Administrative	€	396.005,50	9%	€	23.103,14	0%	€	8.429,86	0%	€	16.234,27	0%
Products	€	1.907,27	0%	€	156.605,57	2%	€	116.355,47	2%	€	-	0%
TOTAL	€	4.543.426,12		€	6.867.617,29		€	7.190.410,98		€	8.033.660,38	
	December-07			May-08			January-09					
Insurance	€	1.599.414,18	7%	€	1.542.375,99	7%	€	769.610,72	3%			
Maintenance	€	2.047.313,52	9%	€	1.923.337,86	8%	€	2.185.427,93	9%			
Rest	€	4.183.233,14	19%	€	7.753.366,89	33%	€	4.047.820,65	17%			
Strategic	€	8.536.678,11	39%	€	7.866.982,49	34%	€	8.262.434,69	34%			
Wear	€	2.116.951,74	10%	€	2.411.753,64	10%	€	3.249.208,80	13%			
Administrative	€	17.242,29	0%	€	37.035,00	0%	€	76.668,58	0%			
Products	€	3.337.808,22	15%	€	1.743.128,36	7%	€	5.389.749,70	22%			
TOTAL	€	21.866.811,89		€	23.397.599,27		€	24.115.467,72				

Table 3-5 Functional stock categorization for product line A1

3.2.4 Analysis Based on Item category

The last categorization on the inventory is based on the item categories. The levels of these item categories are presented in table 3-6. Appendix C5 show the total evolvement for this categorization. Also the remark here is that the products category is a very fluctuation and disturbing item category. Except from some incidental changes no significant differences in inventory contribution could be obtained based on the item category

Stock item category								
	January-06		July-06		January-07		May-07	
Frame	€ 266.394,75	6%	€ 69.044,44	1%	€ 375.722,08	5%	€ 159.825,85	2%
Project	€ 96.682,45	2%	€ 384.794,19	6%	€ 444.142,20	6%	€ 130.024,88	2%
Cross head pen	€ 85.395,98	2%	€ 166.955,03	2%	€ 219.473,73	3%	€ 183.091,89	2%
Crankshaft	€ 406.274,00	9%	€ 1.139.172,00	17%	€ 1.247.552,05	17%	€ 2.554.022,21	32%
Brearing	€ 381.158,71	8%	€ 598.883,86	9%	€ 717.270,86	10%	€ 764.616,33	10%
Membrane	€ 279.190,28	6%	€ 320.931,51	5%	€ 397.889,20	6%	€ 468.163,26	6%
Membranehousing	€ 206.976,63	5%	€ 247.511,06	4%	€ 222.265,02	3%	€ 162.150,34	2%
Parts valve unit	€ 561.418,30	12%	€ 625.338,98	9%	€ 938.409,35	13%	€ 1.256.161,25	16%
Rest	€ 2.119.192,13	47%	€ 3.149.912,49	46%	€ 2.579.679,36	36%	€ 2.234.160,18	28%
Complete products	€ -	0%	€ -	0%	€ -	0%	€ -	0%
Shock absorber	€ 140.742,90	3%	€ 165.288,62	2%	€ 48.007,13	1%	€ 121.444,20	2%
Total	€ 4.543.426,12		€ 6.867.832,17		€ 7.190.410,98		€ 8.033.660,38	
	December-07		May-08		January-09			
Frame	€ 746.689,36	3%	€ 288.603,20	1%	€ 567.765,22	2%		
Project	€ 772.014,50	4%	€ 4.907.073,00	21%	€ 1.509.109,47	6%		
Cross head pen	€ 209.925,05	1%	€ 272.712,13	1%	€ 712.069,50	3%		
Crankshaft	€ 4.392.178,82	20%	€ 4.160.027,19	18%	€ 4.029.527,56	17%		
Bearing	€ 1.289.780,55	6%	€ 1.356.210,23	6%	€ 2.039.367,03	8%		
Membrane	€ 684.618,85	3%	€ 632.831,32	3%	€ 656.207,45	3%		
Membranehousing	€ 929.782,29	4%	€ 763.213,11	3%	€ 391.758,53	2%		
Parts valve unit	€ 2.305.323,07	11%	€ 2.575.660,67	11%	€ 3.439.328,79	14%		
Rest	€ 7.202.247,28	33%	€ 6.195.266,23	26%	€ 5.980.082,01	25%		
Complete Products	€ 2.905.560,37	13%	€ 1.608.430,86	7%	€ 4.304.413,82	18%		
Shock absorber	€ 428.691,76	2%	€ 637.571,33	3%	€ 485.838,35	2%		
Total	€ 21.866.811,89		€ 23.397.599,27		€ 24.115.467,72			

Table 3-6Stock based on item categories for product line A1

For example the crankshafts category shows a high contribution in May 2007 but return to usual levels in December 2007. The project category has an exceptional contribution in May 2008. This was due to a very large project in that period. This was a project of 12 products for one customer for which all specific project parts are ordered at the same time for all products. After May 2007 the project category has again its usual contribution levels.

Remarkable here is that the rest category has one of the largest contributions to the inventory levels. Item categorizations are usually used to cover the largest part of all material used in the organization by specific categories and give them special attention. The rest category then consists of a minor part of the inventory without specific attention and inventory policies. In this company a large part of inventory (up to 40%) is indicated as rest which means no specific attention is given to it.

3.3 Conclusion Inventory performance analysis

To conclude this chapter on inventory performance analysis the first research question will be answered. The first remark to make here is that the research question specific ask what happened in the period from May 2007. Analysis shows that based on the way in which the COGS are calculated the period of ITR decrease differs. So the focus should not be based on a specific period but on the relation between the COGS and inventory levels and the resulting performance expressed in the ITR level. The conclusion would be that the inventory levels are too high compared to the corresponding COGS levels to reach the target performance.

Analysis of the inventory component shows that far the largest value is covered by the reserved stock.

Further analysis of the inventory shows that due to a Kanban control in the assembly department there was a shift in values from the WIP to the Sock levels WIP contribution to inventory decreased while stock contribution increased. Also this analysis shows that a large part of the inventory is covered by rest categories. Around 40% of the inventory value has no specific inventory holding function or belongs to a category of attention. To conclude except from some incidental deviations the inventory shows an integral increase over time. No specific parts could be identified which contributes significantly different to the overall inventory increase.

4 Underlying factors

This chapter deals with the second step of the analysis. In the first part of the analysis looks of the physical context and the planning and control context of the inventory system as shown in Figure 2-1 Also there was an extensive quantitative analysis the resulting inventory performance. This first analysis made clear that the inventory levels are too high compared to the corresponding COGS levels. Further the high inventory levels are caused by an integral increase of all aspects of the inventory. The goal of this second step of analysis is to find all relevant causes which are responsible for the increased inventory. The first paragraph presents the results of the broad qualitative analysis of the organization. After that in the second paragraph quantitative data is used to support the results found during the qualitative analysis. This chapter ends with a diagnosis which answers the first and second research question of this project.

4.1 Qualitative analysis

In this paragraph the outcomes of the qualitative analysis will be presented. This qualitative analysis focus on the organizational setting of the inventory system as presented in the framework of figure 2-1. As stated by De Vries (2005) organizational factors could hardly be expressed with quantitative data. Therefore an extensive qualitative analysis which consists out of interviews was conducted. The goal of this qualitative analysis was to find the relevant factors of the organizational setting of the inventory system at this company contributing to the inventory performance. Besides that this research project also provides evidence that inventory performance indeed relies on several organizational factors outside traditional inventory control. It shows that the developed framework is a powerful tool to access these aspects.

4.1.1 Interview setup

The qualitative analysis consists of a series of interviews conducted at all relevant departments at the company affecting the inventory performance. Therefore first of all the relevant departments should be identified. The points mentioned in the superstructure part of the framework of Figure 2-1 are helpful to determine the scope of the interviews. All departments which are more or less involved in the inventory process must be subject for an interview. After that the relevant questions are formulated. To set up an effective interview the theory provided by Emans (1990) was used. The set up for these effective interviews is further explained in Appendix D1

The questions asked during the interviews are based on structure of positions part of the framework by De Vries (2005) as presented in figure 2-1.

- What are the tasks and responsibilities for the department or position which is subject of the interview?
- What are the Key Performance Indicators (KPI) for the department and how has the performance evolved over the period of interest? This in order to identify possible sub-optimization behavior in the organization
- Which important decisions have been taken in the period of interest affecting the inventory position?
- Is the communication structure at the company effective for good inventory control?
- Are the procedures and work instructions clear to everyone in order to achieve an effective execution of the task? What is the degree of formalization in the organization?
- Has everyone the right requirements and skills to do the job he or she is responsible for?
- What behavior is expected in the organization?
- How does the department react on changes in the process?
- If a reschedule signal arises, what are the actions taken by this department?

The detailed questionnaire used during the interviews is presented in appendix D1

4.1.2 Interview outcomes

This sub-paragraph presents the outcomes of the interviews. The list presented in this sub-paragraph is a summary of the information obtained from the interviews. The list presents the identified factors out of this information. At first the factors which are specific for each department involved are given. After that the factors which are general for the organizational process of this company will be provided.

➢ **External factors:**

- *Customers*: Customers are sometimes a distorting factor during the process. During the project they may want changes to their products or decide to have the product at a later moment.
- *Suppliers market*: During the last years, especially 2007 and the first half of 2008 there was a "Suppliers Market". The demand for materials was higher than the supply. There was a saturated market which caused high purchasing prices, long lead times, reduced flexibility at suppliers and uncertain deliveries.
- *Lead time uncertainty*: The lead time for supplied goods is varying over time. The lead times for bearings for example vary between 16 and 35 months. This makes the order and inventory control processes difficult and uncertain because these items with very long lead items are ordered on forecast
- *Delivery performance*: Some suppliers have an uncertain and bad delivery performance. Late deliveries as well as early deliveries are no exception.

➢ **Sales**

- *Forecast reliability*: Sales makes forecasts for long lead items such as bearings and spare parts. Forecasts and resulting sales sometimes have deviations. Also if sales made a forecast in month X they will change or eliminate this forecast in month X+1. This makes the need for materials unstable from month to month
- *Sell as much as we can:* The sales department is assessed based on the resulting sales. The device was to sell as much as possible in order to not disappoint customers. This sub optimization was not always feasible in the organization and agreed customer delivery times were not always met
- *Products sold outside standards:* Products are sold completely to customer specifications. For some parts this is not always necessary. This creates much extra engineering work and more different Stock Keeping units (SKU).

➢ **Project Management**

- *Reschedules:* The way Project Management plans the orders is not optimal from a logistic point of view. Each order is not planned based on agreed delivery time but to fill up the planning scheme. Incoming new orders very often induce rescheduling in this planning. Project Management is assessed by the occupation rate of the assembly capacity and this way of planning make sure no unnecessary assembly "slots" are lost.

➢ **Engineering**

- *Late releases*: Due to the many deviations from standards, which are not always necessary the engineering department has very much work. Understaffing of this department makes that the release dates for materials are not met and creates reschedules. Materials that not need engineering or which are already released will now be available early due to these reschedules.

➢ **Operations planning**

- *Requirement dates*: The requirement dates for all parts needed in the assembly are set at the start of assembly. But some expensive parts are just needed halfway the assembly process. This creates inventory which is not needed.

- *Order more than needed*: On top of the needed quantities OP orders some extra material due to expected uncertainties or defects in materials. This is based on the planners "feeling" and not supported by data.

➢ **Purchasing**

- *Framework contracts***:** Due to contracts with suppliers there are obligations to order a minimum or maximum amount of goods in a given period. Products therefore have to be ordered when not necessary needed.
- *On time delivery*: Due to the uncertainty in supplier delivery, slack times are added between the requirement date arranged with suppliers (need by date) and the internal requirement date. Since the department is assessed by the on time delivery (OTD) performance products are ordered way too early. This is because the OTD measure is only affected by late deliveries and not by early ones.
- *Order more than needed*: Another performance indicator of this department is the savings they achieve. Therefore more than needed is ordered or orders are combined with future orders to get these savings. The Sales department is convinced that this way is working benefits the organization. But there is no match with the extra inventory holding costs it caused. Besides that savings have no direct influences on the inventory values because these are based on fixed cost prizes
- *Unreliable c data*: The purchasing department often uses unreliable data. Promised delivery dates for goods from which it is known they will not be met still remains in the system. This creates unnecessary reschedules
- *Quality control***:** Many of the goods the company purchases have to meet high quality standards. Quality control inspects these receiving goods before stored in the warehouses. Products deviating from required quality have to be fixed or a complete new product has to be delivered. This creates reschedules because material is not available at planned dates.

➢ **Production**

- *On time delivery*: The delivery performance of the machining department was and still is not on the desired level. Due to late deliveries of the machining department extra slack time is added between production and assembly which creates extra inventory for products which are delivered on time.
- *Overproduction*: One of the performance measures of the machining department is the machine occupation rate. This sub optimization creates overproduction if no orders are present in order to reach a high occupation rate. Also here the production department is convinced that their way of working benefits the organization.

➢ **Organizational factors**

- *Organization structure*: Due to engineering to order every product order is a separate project in the production process. Besides that the organization is still functional organized. Therefore inventory is not dedicated to specific projects which make analysis more difficult. This is no direct reason for high inventory levels but makes analysis and problem solving more difficult.
- *Responsibilities and decision process*: In the organization several departments make decisions which have impact on the inventory performance. These decisions are regularly optimal for the department but not for the entire inventory performance. This sub-optimization exists because departments are assessed by conflicting performance measures. OP is responsible for the inventory performance but does not control all decision making. For example forecasts are set by the sales department but not controlled by OP
- *Communication process*: There is much communication within the company but this is still very informal. No clear procedures and protocols are available on how to act in several situations. Due to a growing company this makes communication very time consuming.
- *Company policy and attitude:* the company policy in the period of interest was to sell products and make sure materials are available for production. From the highest management levels of the

company the desired number of products to sell in a year was set very high. The organization's focus was to reach that number. The overall's company attitude was "Make sure material is available at the warehouses and it doesn't matter how early" No focus was set to the impact of this policy to inventory performance.

- *Behavior:* The organization is very informal and many employees work already for a long time for the company. Therefore much knowledge is in the heads of persons and not made explicit. Without this knowledge it is difficult for other employees to take over work efficiently. Therefore every department works on its own without knowing the impact of their sub-optimal "departmental" behavior on the overall company's inventory performance.
- *Company growth:* the company has an increase in sales over the last four a five years. After a little sales decrease at the end of 2006 and the beginning of 2007 sales increased strongly From May 2007 to May 2008. The sales development over time is further illustrated in Appendix D2. The company grows from 2007 to 2008 almost with one third from 300 to about 400 employees. Due to this growth the company had real problems of understaffing in that period. Especially Purchasing and Engineering have a real shortage of workers. Due to this there was no time for a proper introduction of new employees in their task execution. In combination with the informal way of working and a lack of available, well documented procedures and work instructions this caused several inefficiencies

4.2 Quantitative analysis

In this paragraph data analysis is conducted in order to support the findings of the qualitative analysis. Due to a lack of historical data several factors could not be supported quantitatively. Further it is very hard to find data support for many organizational factors which is also stated by De Vries (2007). For the most important factors for which data is available, the quantitative support is presented in the sub-paragraphs below here.

4.2.1 Supplier performance

In order to evaluate the supplier performance the measure of interest is the on time delivery (OTD) based on need by date. This is the delivery date which is agreed between the company and its suppliers.

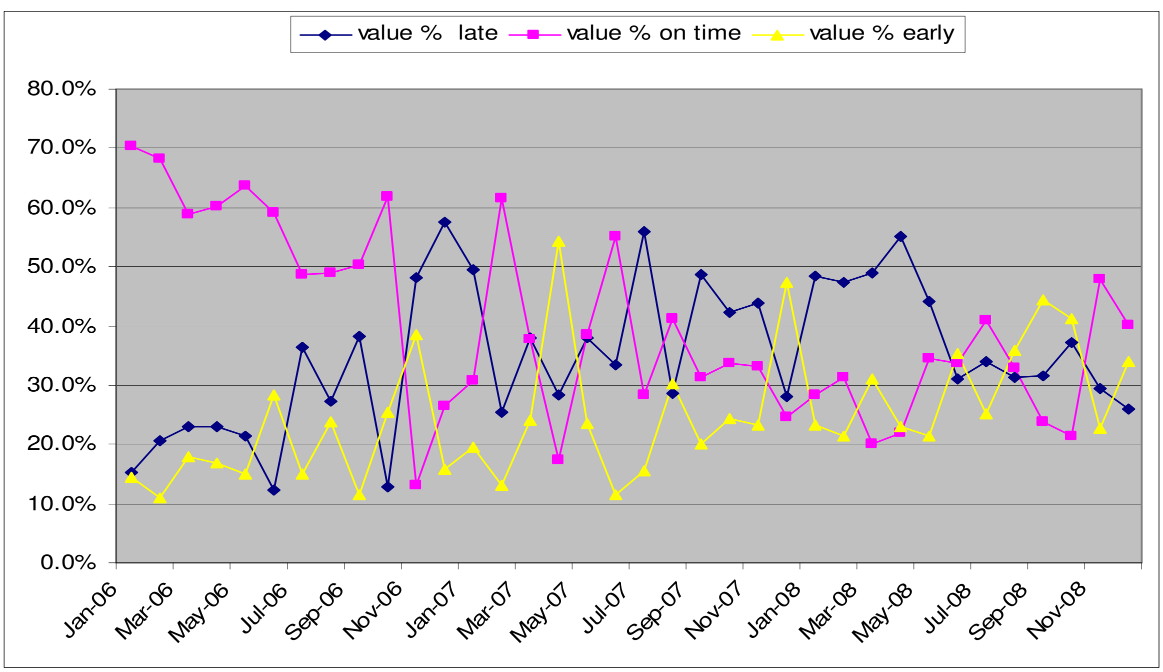

Figure 4-1 on time delivery suppliers

Appendix D3 shows graphically the used dates for the delivery of external and internal orders. Figure 4-1 presents the supplier performance over time. Assessing this figure shows a decreasing trend of the values for the OTD. For example in May 2007 the on time value is 40% and this decreased to about 20% one year later on. The value for late delivery increases from about 30% in May 2007 to 55% in May 2008.
The underlying data for this performance measure are stated in appendix D3. One important remark from this measure is that especially high cost items (cost price over 100000 Euros) are far too late according to the need by date. The average difference between the need by date and the receipt date for these items increased from around 5 days to over 50 days (late) from the end of 2007 to the first half of 2008. Standard deviations in the same period doubled from around 20 days up to 40 days for all items. This indicates highly uncertain supplier reliability.
In order to cope with these uncertain deliveries slack time is added between need by and requirement dates. The requirement date is the date at which the material is internally needed. The figure for the OTD based on requirement date is also presented in appendix D4. This measure also indicates high values (up to 40%) of late deliveries in the period from May 2007 to May 2008. After May 2008 the values of early deliveries increased up to 70% at the end of 2008

4.2.2 Internal performance

Similar to the evaluation of the external suppliers the internal supplier can be evaluated on OTD performance. The OTD performance for the machining department is shown in Figure 4-2. This figure shows a decreasing trend in on time delivery from 50% to 30%. The late deliveries from this department increased from 15% to 35%

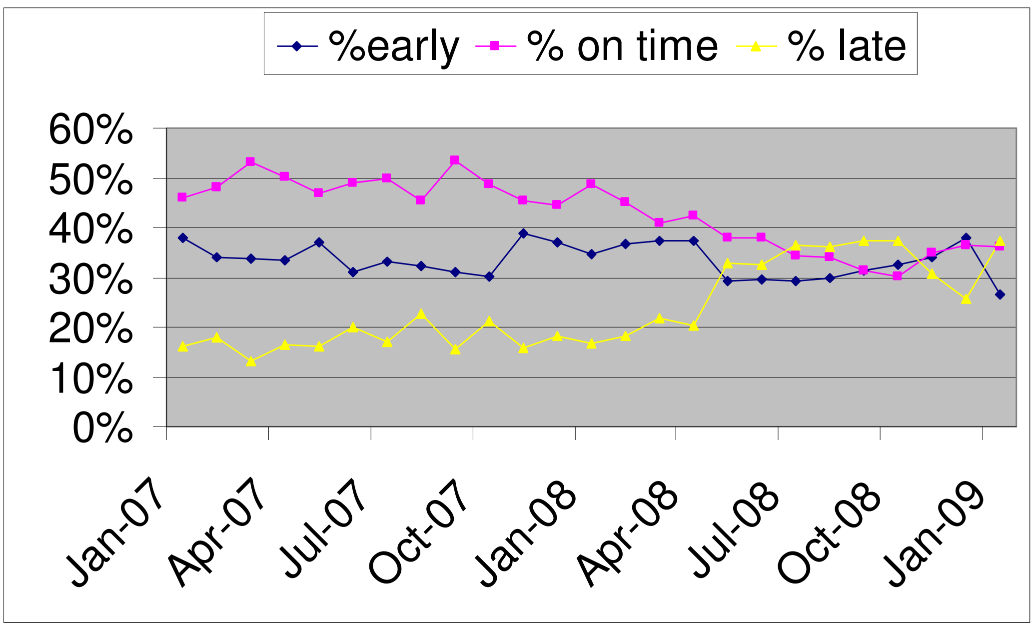

Figure 4-2 on time delivery machining department

4.2.3 Reschedules

Figure 4-3 presents the reschedule signals for product line A1. As can be seen from this figure there is an increasing number of reschedules from May 2007 to very high values in the first half of 2008.
In the first half of 2007 the number of reschedules fluctuates between 10 and 30. After that this number increases up to over 70 reschedule signals in May 2008. From April 2008 to February 2009 262 reschedule signals are measured over 99 product orders. This means that on average each product order is rescheduled 2.6 times.

From April 2008 the causes of reschedule signals are also registered. This data shows that 40% of the signals are due to the way how orders are planned by project management. After that 24% is caused by problems in other projects, 12% by capacity problems of the assembly department and 10% by Quality rejections. A complete overview of the reschedule causes is given in appendix D5.
Further about 75% of the signals are reschedules to future dates. In 2007 and 2008 no or very little action was taken to these signals. Due to understaffing there was a lack of time to handle all these signals.
Also no clear policy and instructions how to deal with these signals were available. Most of the time parts ordered for products which are rescheduled to future dates remain the original delivery dates. This creates much unnecessary inventory

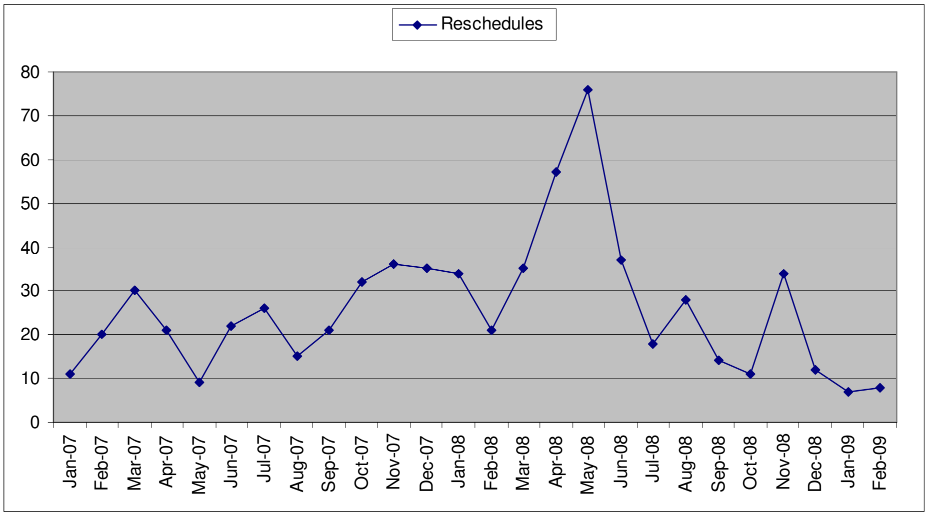

Figure 4-3 Reschedules

4.2.4 Quality control

Figure 4-4 shows the number of quality rejections over the period of analysis the figure shows that the number moves around 60 to 100 monthly quality rejections before July 2007. After that period the number of quality rejections shows a step increase. From that moment on the values varies between 100 and 140.

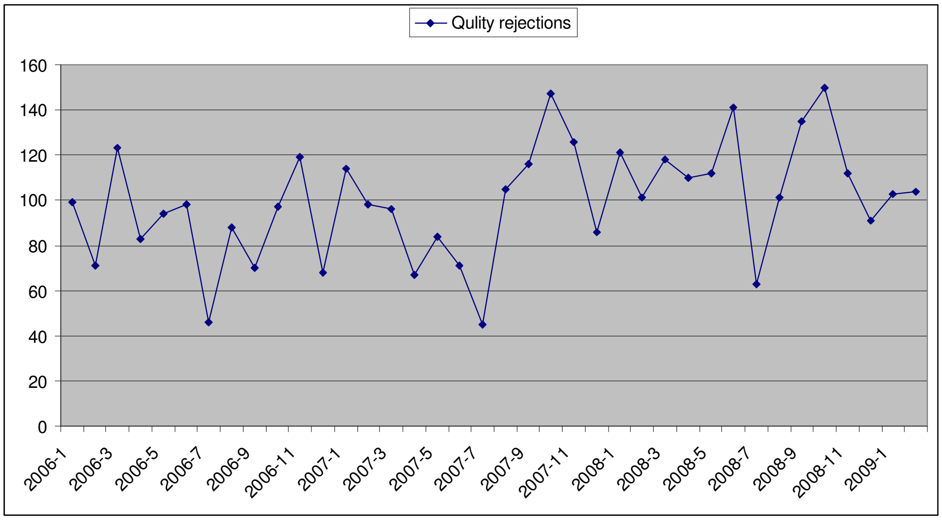

Figure 4-4 Quality rejections

4.2.5 SKU

Table 4-1 provides the number of SKU's for the product line A1 over the period of interest. It shows that in the period from May 2007 to May 2008 the number of items increased almost 750 SKU's. 60% of the SKU's consist of items from the rest category and 25% comes from the maintenance category. All the other categories account for 4 to 7 percent of the items. This is consistent over the entire period.

	Jan-06	Jul-06	Jan-07	May-07	Jan-08	May-08	Jan-09
SKU	3801	4189	4332	4200	5069	4937	4813

Table 4-1 SKU level for product line A1

4.2.6 Forecast

The forecast accuracy may play an important role in the increase of inventory. Unfortunately historical forecast data and corresponding realizations in sales are not available. Previous forecast data in the database is overwritten by the new one. One possibility to give some indication about the forecast accuracy is the development of available stock. At the company the top 50 items with the highest value in the available stock are registered. Also the source which caused this value is registered. In April 2009 the available stock value was 6.5 million Euros. In the top 50 items 1.3 million was identified as caused by the change of forecast. This is 20% of the available stock.
Another way to asses the forecast is to look at the forecast values that appear in the inventory system. Figure 4-5shows the forecast and inventory values for the Wear and Strategic parts. These two categories make up over 90% of the forecast registered in the system. Remarkable is the step pattern the forecast of the Wear parts shows from end 2006 to the beginning of 2008. In that period forecast for these items is increased from 1 million Euros in September 2006 to over 7 million Euros in May 2007. After January 2008 these values decreased stepwise back to values between 1 and 2 million Euros. The forecast for Strategic (especially bearings) parts shows a very large step increase at the end of 2008 from 2 million Euros to 7 million Euros. Due to the large step increase in forecast also a step increase in wear part inventory would be expected. Inventory of Wear parts indeed shows an increase from the end of 2006 but this is a more gradual increasing over time For the Strategic parts the strong increase occurs at the end of 2008. Since these are items with long lead times the effect could not be assessed from this analysis.

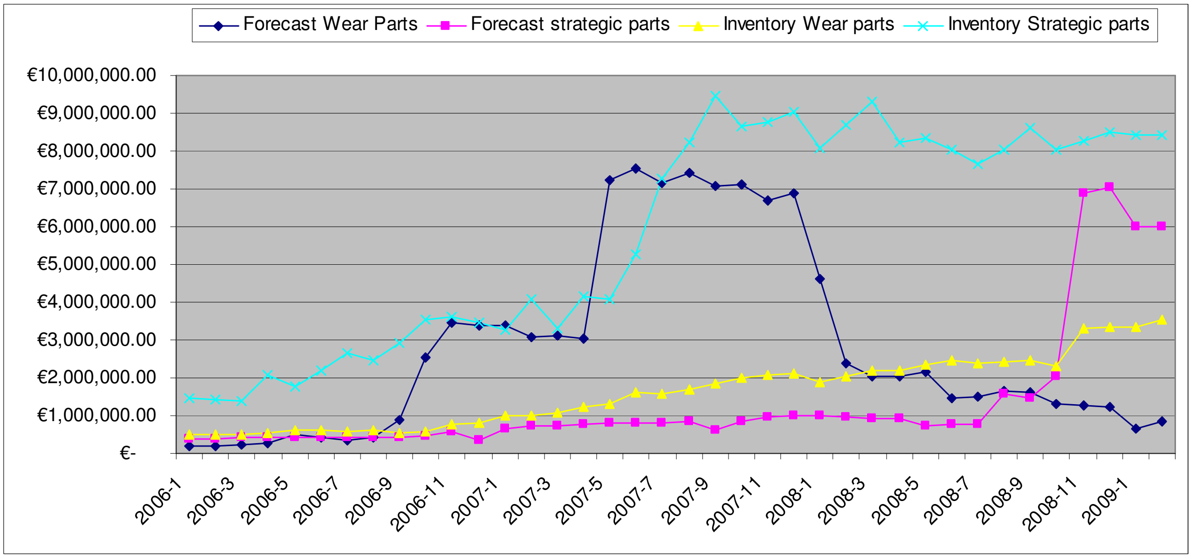

Figure 4-5 Forecast development

Out of these data no significant relations could be made between the forecast and the inventory levels. The limitations of this data make further analysis on the effect of forecasts not possible. The inventory database only shows the number and values of the forecast. Valuable information about the planning horizon and requirement dates for these forecasts is not available due to the fact that historical data is overwritten every time.

4.3 Diagnosis

The last paragraph of this chapter presents the conclusions and a summary of the outcomes of the analysis phase in a problem diagnosis. The Problem diagnosis is based on a model presented by De Vries (2007) for solving inventory performance problems. This model is given in Figure 4-6. The model starts with a performance measurement of the inventory system. At the company the inventory performance is measured by the inventory turn rate. Internally the target level (standards) was set at a level of six and was later adjusted to four. As said before the parent company's headquarters prescribes a target level of ten. The realized performance of the inventory is far below these targets (deviation from standards). In the period of interest this dropped form values around 3.5 to values below 2. The first analysis shows that the inventory component of this measure is the cause of the deviation from target performance. Inventory levels are too high compared to the corresponding COGS. In order to find the underlying causes of high inventory levels a broad qualitative as well as a quantitative analysis was conducted whit a special focus on organizational factors as given in Figure 21

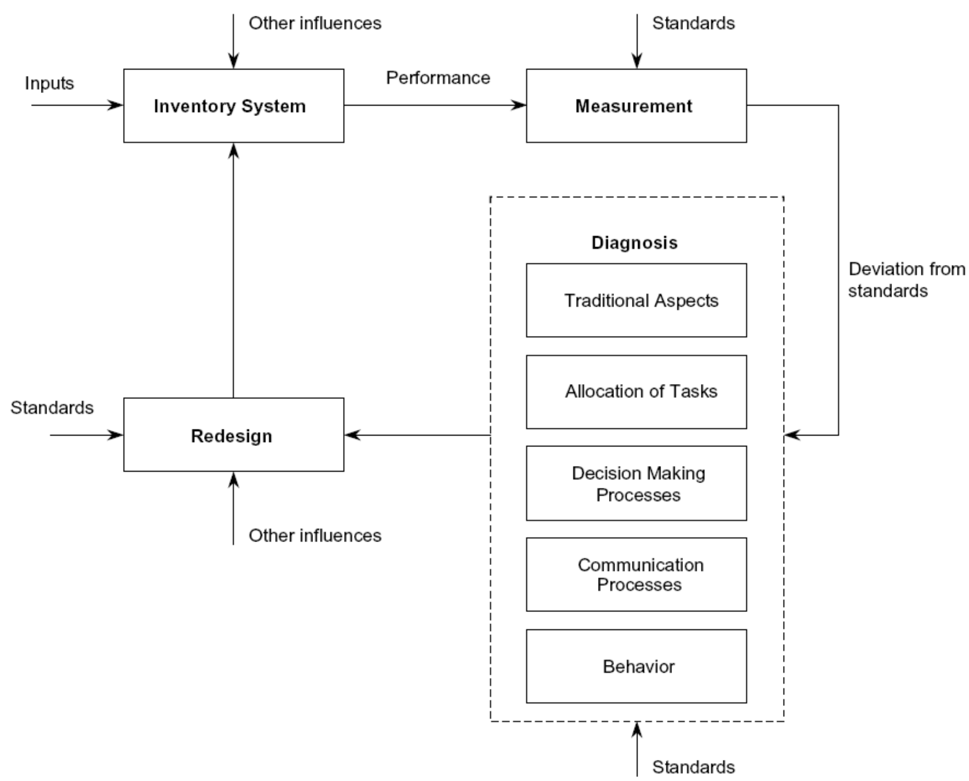

Figure 4-6 Integrated Framework for solving inventory performance problems (from De Vries, 2007)

The diagnosis part of the model in Figure 4-6 comes up with 5 areas of interest for assessing the deviations from targets. The traditional aspect relates to the physical context and the inventory planning and control parts of the framework in figure 2-1. The other four diagnosis areas relates to structure of positions part from the framework and therefore to the organizational factors. The concluding diagnosis consists out of a summary of the main results obtained in the analysis phase of the project. This is stated below here.

At the company from May 2007 the sales increased by 77% measured in costs of goods sold. The company itself grows with one third from 300 to around 400 employees (353 FTE). Due to economical welfare in that period the suppliers market for the material the company needed for their production and assembly was saturated. Demand was higher than supply resulting in high prices, long lead times and uncertain delivery times. This is a factor which is external to the organization and is part of the business environment. Slack time between internal and external used delivery dates is added to deal with this uncertainty. Since this slack time is added for all items no distinction is made between good and bad performing suppliers.
Looking at the internal organization the following can be stated. Several departments are involved in the inventory process. Only the department OP is responsible for the inventory performance. Remarkable is that not al decisions related to inventory are taken by this department. For example forecast is entered by the sales department without consultation with OP. Also the purchasing department decides how to order based on savings they could receive and not considering the inventory cost this caused. All these decisions are taken by these departments based on the performances measures they are assessed by. In many situations this leads to sub-optimizations which are good for the department of interest but not for the performance of the entire organization. There was no consciousness of the impact of actions taken by a person or department on the company's inventory position. For example Project Management creates many reschedule signals by the way they plan orders in the process. This has a large impact on the planning and purchasing department and therefore on the inventory position.
Besides that the company policy was to sell as much as possible and make sure to have the materials to sell. The policy was to make sure materials are available and it doesn't matter how early they are available.
Another factor is the informality of the organization. Communication within the organization is very informal and sometimes very time consuming. This is due to the lack of well documented and used protocols and procedures. Much knowledge is in the minds of persons and it is not well documented why things are done in practice. This makes it difficult for employees to take over each others work and for new employees for an effective introduction on their jobs.
The growth of the company also causes several problems. Due to understaffing at the engineering and purchasing department orders are released late which creates reschedules and there was no time to do purchasing activities as affectively as possible, fore example there was no time for strategic supplier selection or efficient ordering.
The last point is the engineering to order way of working. Products are adjusted to customer needs which create even more work for the engineering department due to the growing number of orders. Another effect of these adjustments is the increasing number of SKU's appearing in the inventory levels.

Nowadays caused by the economical situation growth is somewhat stabilized at the company and more time is available for structuring processes and take a look at the inventory position of the organization. There is more and more attention for the impact of actions on the company's inventory position. According to Chikan (2004, 2008) the acknowledgement by management of the strategic impact of inventories on the organization is an important step forwards. More about this is elaborated in Chapter 6

In this conclusion the answers were given to the second research question. Now it is clear which factors are responsible for the resulting inventory performance. In the redesign part of this project a model is developed to identify the relative contribution of several factors to the inventory levels and possible solutions are given in order to improve the ITR performance.

Part 3: (Re) design

5 Prediction Model

From the analysis phase the main outcome was that the inventory levels are too high compared with the corresponding COGS levels resulting in lower ITR performance. Several factors are identified which contributes to ITR performance. In the (re)design part of the project the identified factors are linked to the inventory development. This gives the management of the company insight in which decisions to take in order to improve ITR levels. In t his chapter a model is developed to identify the most important factors and its relative impact on the inventory level. In chapter 6 several possible organizational improvements are given for the organization which would help to increase their inventory performance.

In this chapter, a model is designed which predicts the impact of several factors on the resulting inventory performance. Paragraph 5.1 gives an overview of the several available forecasting techniques and explains which technique is most suitable for this project. Paragraph 5.2 deals with the specific data issues for the models and introduces the variables used to build the model. In paragraph 5.3 the model is build and paragraph 5.4 gives the validation for the model. The conclusions for the modeling part are stated in paragraph 5.5.

5.1 Model selection

For the development of the model several techniques are available. This paragraph introduces these ways of modeling methods, which are most relevant for operations management and selects the most suitable one for this project.

5.1.1 Technique selection

First of al the choice has to be made between an analytic of a statistical technique. The benefit of an analytic technique is that is more deterministic and more accurate results could be reaches. A drawback of this method is that it is sometimes time consuming to determine the exact impact of a factor. Also the interaction between several factors is difficult to determine in an analytic method. For example in this project take the factor supplier reliability based on the available OTD measure. The direct impact of this factor on the resulting inventory level is difficult to determine exactly. The OTD measure is based on orders and not on individual items. The items in an order could have requirement moments. Due to the blindness of inventory these items are not allocated to projects or spares. Therefore it could not be easily determined what time an item of an early delivery stays in inventory. In order to make an analytic model each order and each item in these orders should be analyzed in. With 3000 to 5000 items in the product line this method would be to much time consuming for this project.

The other possibility is to take a statistical prediction technique. This is less precise compared to an analytic technique but makes it possible to relate the development of several factors to the inventory performance. Also the interaction between the several factors could be assessed by a statistical technique. Since the goal of this project is to give management insight in the relative importance of several factors to the inventory performance a statistical technique would be suitable.

5.1.2 Available prediction methods

The first distinction to be made is between qualitative and quantitative methods (Ballou, 1999). The quantitative methods could be further divided into causal models and time series models (Hopp and Spearmann, 2001). The three methods will be briefly explained below and the advantages and disadvantages of these methods for this project will be stated.

First of all there is the qualitative prediction method which is based on human judgment. “Qualitative prediction methods attempt to develop likely scenarios by using the expertise of people, rather than precise mathematical models”. (Hopp and Spearmann, 2001). The most important problem of these methods is that they are based on subjective judgments by people. Also the nonscientific nature of these methods makes it difficult to standardize and validate for accuracy.

More scientific are the quantitative methods divided in time series models and causal models. “Time series models predict a parameter as a function of past values of that parameter”. (Hopp and Spearmann, 2001). The most important assumption for these models is that past results are a good indicator for future outcomes. Although these models are able to work with several sources of variation within the data, these models assume an underlying stationary pattern within the time series, when all these sources of variation such as trends and seasonal patterns are removed (Chatfield, 2004).
While time series models are based on the predicted parameter itself, causal models predict a parameter as a function of other parameters. (Hopp and spearman, 2001). According to Ballou (1999) the basic premise of these models is that the level of the variable to be predicted is derived from the level of other related variables. Causal prediction models are also more accurate when non-stationary time series have to be forecasted (van den Heuvel, 2009). A frequently used method for causal prediction is a multivariate analysis technique. “Multivariate analysis refers to all statistical techniques that simultaneously analyze multiple measurements on individuals or objects under investigation” (Hair, 2006).

According to Hopp and Spearmann (2001) both qualitative as well as quantitative prediction methods have their advantages and disadvantages. Qualitative methods are based on personal judgments and are with a high possibility driven by subjective and political considerations. Therefore these models ignore or overreact to changes. On the other hand quantitative methods make use of some stochastic (based on probability) patterns which assume some stability. Therefore they are not able to predict future changes. Besides that, no model can incorporate all factors relevant for the phenomenon to be predicted. Many influential factors could not be included because of the lack of data. In order to cope with the disadvantages of both methods a combination of the two is preferable according to Silver (1998) and Hopp and Spearman (2001). Use a quantitative method to build a prediction model and judge if the outcome of the model is logical.

5.1.3 Relevant model

In this project the goal is to predict the impact of several factors on the resulting inventory performance. This would give the management insight in which decisions to take in order to improve ITR performance. Since the demand pattern of the company is non-stationary, a time series analysis is not applicable for this project. First of all the demand for product types observed in the past has no relation to the demand for these types occurring in the future in this company. Also the increasing trend in the demand pattern makes this parameter non-stationary.
Besides that resulting inventory performance is dependents on several other factors and not on the past observations of the inventory performance itself. The goal is to predict the performance of inventory as a function of several other factors and not as a function of time. Time would not be a relevant factor for this model. Therefore a causal model would be most applicable for this project.
Also a quantitative method would be preferable over a qualitative method for decision making. In the model developed by van den Heuvel (2009) showed, using a causal multiple regression model for the sale of action products in a supermarket that actions based on a quantitative model were better than actions based on a qualitative analysis.
Also a model developed by Wanke (2004) shows that a causal technique is helpful for logistic decision making such as the choice between make to order or make to stock. Wanke (2004) uses a regression technique to relate several influential factors to strategic logistic decisions. The conclusion was that no decision could be made on the basis of a single variable but on a relationship between several causal variables.
Also at the company several actions are taken to adjust inventory performance to desired levels. These actions are mostly based on personal judgments. Although these actions do not have the desired results yet a causal method would be helpful to take the right decisions to improve their inventory management performance. Besides the causal model qualitative analysis is still needed to judge if the relations found by the causal model are logically.

Following Hair (2006) there are several multivariate techniques available to build a causal model between predicted (dependent) variables and the predicting (independent) variables. The most suitable technique is based on the nature of the relationship and the variables. In this project the inventory performance is the variable to be predicted from several independent variables. All variables have metric values. Following the selection procedure by Hair (2006) a multiple regression analysis would be the appropriate technique for this particular situation. This criteria and selection procedure for the suitable technique is further explained in Appendix E1. According to Hair (2006) multiple regression analysis is general statistical technique used to analyze the relationship between a single dependent variable and several independent variables. The next paragraphs show the development of this model.

5.2 Variables

This paragraph introduces the variables used to build the regression model. Before data is usable for multivariate analysis it has to meet several restrictions, which are summarized in paragraph 5.2.1. After that the usable dependent and independent variables are described in the paragraphs 5.2.2 and 5.2.3.

5.2.1 Data assessment

The data available for the model building is limited. The variables used in the model are measured on a monthly basis. Several variables are available from January 2006 but other variables are available only since January 2007. The period of analysis for this project therefore is from January 2006 to February 2009. This makes 38 data points available. Besides that other variables only have 26 data points available. This makes the available dataset small. Due to this small dataset it is very important that the requirements for multivariate data analysis are not violated.

According to Hair (2006) four assumptions have to be met before data is usable in a regression model. These assumptions are: normality, homoscedasticity, linearity and the absence of correlated errors. These assumptions are briefly explained below here.

- **Normality:** This is the most important and fundamental assumption in multivariate data analysis. Especially when the available dataset is small (below 30 observations) this assumption is crucial. Violation of this assumption makes the resulting model statistically invalid. The test to determine the significance of the relation between the variables (t-test) is invalid if the variables are non-normal distributed. Therefore all variables dependent as well as independent should correspond to the normal distribution. The normal distribution and the test provided to asses normality are described in appendix E2
- **Homosedasticity:** this assumption refers to the fact that the variance of the dependent variable should be equally spread across the range of the independent variables. This means that the variance in the dependent variable should not be explained by only a small range of the values of the independent variables. Violation of this assumption is mostly caused by violating the normality assumption.
- **Linearity:** multivariate techniques are initially based on the correlations between the variables. Correlations represent the linear association between variables. Therefore non linear relationships will not be presented in the resulting models and would lead to an underestimation of the actual strength of the relationship. Besides that non-linear techniques are available as well but these are very difficult. The test to asses the linear relation between the variables is described in appendix E3.
- **Absence of correlated errors:** predictions in any of the techniques used are never perfect. The difference between the predicted and the explained observation is called an error. This assumption states that there should be no systematic patterns available in these errors. Violating this assumption means that another factor, which is not included in the analysis is affecting the results.

Besides the several tests to asses these requirements Hair (2006) also provides several remedies to meet these requirements when violated.

5.2.2 Dependent variable

The purpose of the model is to predict the inventory performance from the several available factors. The inventory performance is measured by the relation given in equation 3-1.
As already mentioned in the problem analysis the inventory levels are the main problem for the low performance. Also the inventory level is function of the COGS. It would be obvious that a part of the inventory increase is caused by the increase in sales. Higher sales allow higher inventory levels while performance stays the same. Besides that all other independent variables are related to the inventory level and not directly tot the inventory performance level Therefore for the regression modeling the relation could be simplified to the inventory level as dependent variable. Then the inventory level is predicted by the model and the predicted ITR level is obtained by dividing the COGS by this predicted inventory level.
Table 5.1 shows the normality test for the dependent variable inventory ITR. An explanation of this test is given in appendix E2 Table 5-1 shows that the P-value for the normality test is below 0.05 so the assumption that this variable comes from a normal distribution could be rejected with 95% of confidence.

	Shape directors tests					
	Skewness		Kurtosis		Test for normality	
	Statistic	P-Value	Statistic	P-Value	Statistic	P-Value
Inventory ITR	0.172	0.863	-5.344	0.000	0.879	0.000
Difference Inventory ITR	1.077	0.282	1.124	0.261	0.972	0.576

Table 5-1 Normality test for dependent variable

The remedies provided by Hair (2006) do not achieve normality. All possible transformations to the variable suggested by Hair do not achieve acceptable test values. Another possibility is to take the difference between the inventory level of the current month and the previous month as suggested by Chatfield (2004). This is given by the following formula

$$\Delta X_t = X_t - X_{t-1}$$

Equation 5-1 Differenced variable

The normality testy for this created variable is a stated in Table 5.1. Here all P-values are grater than 0.05. So this variable comes from a normal distribution with a 95% confidence. The dependent variable for the model therefore will be the difference in inventory level. With this predicted difference the resulting inventory is predicted by adding the difference to the known starting inventory level.

5.2.3 Explanatory variables

Here the available variables for building the regression model are presented. As stated before from several variables the data is available from January 2006. Another set of variables is only available since January 2007.
First of all the normality assumption for all variables should be assessed in order to determine whether they are usable to build the regression model. The normality tests for the variables are given in appendix E3. Also here is shown that almost none of the original variables meet the normality assumption. The remedy to take the differences between the observation in the month of measure and the observation of the month before also gives the desired results. The normality tests results for the differenced variables are also given in appendix E3. The differenced variables all meet the normality assumptions. Also the other assumptions are not violated with 95% confidence. The resulting variables are presented in Table 5.2

Variable	Available from	Variable description
ΔSKU	January 2006	Difference between the number of SKU in stock between the month of measure and the previous month
ΔQ	January 2006	Difference in the number of Quality rejections
ΔOTD_L	January 2006	Difference in On Time Delivery suppliers percentage of value late
ΔOTD_O	January 2006	Difference in On Time Delivery suppliers percentage of value on time
ΔOTD_E	January 2006	Difference in On Time Delivery suppliers percentage of value early
ΔOTD_M	January 2007	Difference in On Time Delivery Machining department
ΔOTD_A	January 2007	Difference in On Time Delivery Assembly department
ΔR	January 2007	Difference in the number of Reschedules
ΔSL_L	January 2006	Difference in the percentage of value delivered late based on requirement date (included slack time)
ΔSL_O	January 2006	Difference in the percentage of value delivered on time based on requirement date (included slack time)
ΔSL_E	January 2006	Difference in the percentage of value delivered early based on requirement date (included slack time)
$\Delta COGS_6$	January 2006	Difference in COGS calculated sum of COGS last 6 months times 2
$\Delta COGS_3$	January 2006	Difference in COGS calculated sum of COGS last 3 months times 4

Table 5-2 Independent variables for building the regression model

The variables presented in this table are the variables for which data is available. There are several other factors as stated in the analysis phase which have effect on the resulting inventory levels. Due to the qualitative nature of these variables no data could be found to support these factors. For example inventory increase due the informal behavior or the lack of standardized procedures in the organization could not be found in the data. Nothing is reported in databases of incidents caused by these factors.

For the OTD of materials by suppliers a distinction is made between the OTD variables and the SL (slack) variables. The OTD is based on Need by date and therefore the real OTD measure. The SL variable is based on the requirement date. Since there is an average slack time of three weeks between requirement and need by date this difference could have a considerable effect. For example late deliveries on Need by date would have no considerable effect on the company's operation as long as they are delivered before the requirement date. On the contrary this is even better for inventory performance.

For the COGS two variables are available for the model. Only one of the two can be added to the model at the same time. The index of the variable indicates how the COGS are calculated. There are two possibilities in this case as stated in Table 5-2. More about the COGS calculation is given in Chapter 6

5.3 Linear regression models

To use a regression model a relationship has to be assumed between the dependent variable and the independent variables (Montgomery, 2003). As these relationships are expected to be linear, a linear regression model can be used. The linearity test for the relations between the dependent variable and the independent variables is explained in Appendix E4. Also the results are presented in this appendix. The results show that most of the variables show a linear relation to the dependent variable. For the variables without a significant linear relation no non-linear relations could be identified. This means that a multiple linear regression can be used. Therefore relationship would have the form as stated in Equation 5-2 and is worked out in the sub-paragraphs below here.

$$Y = C + A_1X_1 + A_2X_2 + ... + A_NX_N$$

Equation 5-2 Linear regression model

With:
Y = dependent variable
C = constant or the intercept of the regression line
A_i = the weight of the independent variable X_i , i = 1…..N
X_i = the value of the independent variable, i = 1….N

5.3.1 Two model scenarios

In order to build the most appropriate regression model to predict the differences in inventory levels some important aspects have to be considered.
First of all there is the sample size of the data set. Only a small sample is available for fitting the model. This has a great impact on the number of independent variables allowed in the model. The minimum requirement obtained from Hair (2006) is a 5:1 ratio. This means that for one independent variable five observations are needed in order to ensure a statistical significant model and provide a general applicable model.
Secondly in this particular situation two scenarios are available due to the availability of data. A model could be fitted on the variables available from January 2006. From this point 37 observations are available (38 observations minus one observation in order to get the differencing variables). The second possibility is to fit the model on the data from January 2007. Here 25 observations are available (26 minus 1 to create the differencing variables). The advantage of the first one is that more observations are available and more variables could be taken in the model. The advantage of the second model is that more variables are available to include in the model. For both scenarios the best model will be fitted and compared to each other, as is explained below.

5.3.2 Performance of the models

For both scenarios the best regression models are fitted with a statistical software package called Statgraphics Centurion. This package has the possibility to select out of all entered variables the model which is performing the best. It also takes in consideration the maximum number of allowed variables due to the sample size. The performance of the models is judged on an adjusted R-squared measure. This measure indicates how much of the variance in the dependent variable is explained by the dependent variables entered in the model (Hair, 2006). The higher the R squared value the better the model explains the variance in the dependent variable.
A second performance measure to judge the best performing model is the Mean Squared Error (MSE). This measures the mean of the squared differences (errors) between the observed and the predicted values (Montgomery, 2003). The explanation and calculation for this measure is stated in appendix E4.
In the selection of the best performing of regression model the goal is to find the model which minimizes the MSE value.

Model	R square	Adjusted R square	MSE
2006	54.77	49.11	2.28E+12
2007	80.4	75.25	1.40E+12

Table 5-3 performance of the best models for the 2 scenarios

Table 5.3 shows the performance measures of the best models for the 2 scenario's. Both the models of 2006 and 2007 contain the variables ΔCOGS6, ΔSKU, ΔQ and ΔSLo. In the model fitted with the variables from January 2007 the variable ΔR is also indicated as significant. Looking at the performance measures it can be seen that the model of 2007 performs better than the model of 2006. The model from 2006 explains 49 percent of the variance while the model from 2007 explains over 75 percent of the variance in the dependent variable. Also the MSE for the model from 2007 is better than the model from 2006. As shown in Table 5-3 the MSE values for both models seems to be very large. This is due to the expression of the dependent variable. This is expressed in millions of Euros. Also the errors are expressed in millions. Squaring these differences result in the large values as presented in Table 5-3. Although the values are large the MSE for the model of 2007 is 40% better compared to the model of 2006. Concluding the model from 2007 is selected for further analysis.

5.3.3 Selected model

As stated above the model with data and variables from January 2007 is selected. The resulting model is presented in Table 5-4. The column estimates gives the coefficients for the included factors. Equation 5-3 gives the resulting formula for the selected model.

$$\text{Difference Stock ITR} = 130201 + 68860.1 * \Delta R + 6022.87 * \Delta SKU - 25491 * \Delta SL_O + 0.200595 * \Delta COGS_6 + 28921.7 * \Delta Q$$

Equation 5-3 Resulting linear regression model

		Standard	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
CONSTANT	130201.	249882.	0.521049	0.6084
ΔR	68860.1	17707.2	3.88882	0.0010
ΔSKU	6022.87	1881.87	3.20048	0.0047
ΔSLo	-25491.0	17509.4	-1.45585	0.0618
ΔCOGS6	0.200595	0.0712592	2.815	0.0111
ΔQ	28921.7	8170.06	3.53996	0.0022

Table 5-4 Regression results for the selected model

Also stated before is that the performance of the regression model is measured by the adjusted R squared measure and the MSE measure. The statistical significance of the models is assessed by the F-Ratio. This ratio tests whether the variance explained by the regression model is significant (Hair, 2006). More about this ratio and the calculation for this ratio is given in Appendix E4. Table 5-5 shows the resulting F-ratio for this model. The P-Value of 0.00 indicates that the fitted model is statistically significant at a 95% confident level.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	1.10723E14	5	2.21447E13	15.59	0.0000
Residual	2.69877E13	19	1.42041E12		
Total (Corr.)	1.37711E14	24			

Table 5-5 Analysis of variance for the selected model

In order to use the regression model for explanatory purposes the relative impact of the independent variables on the dependent variables has to be assessed. Because the measurement scales of the independent variables are not the same this relative impact could not be obtained directly from the resulting model. For example the COGS are measured in Euros and the SKU's in numbers. Also the variation in the variables is not the same. For example the difference in quality rejections has a standard deviation of 30 while the difference in SKU's has a standard deviation of 144. A solution to deal with this problem is to calculate the standardized variables. This makes all variables comparable in both scale and variability. Statgraphics has a function to calculate the standardized regression coefficients for assessing the relative impact of the variables included in the model. The standardized values are presented in Table 5-6.

Parameter	Estimate	Standardized
DF SKU	6022.87	0.363026
DF RESCHED	68860.1	0.428101
DF COGS 6 BACK	0.2006	0.305837
DF OP TIJD	-25491	-0.153028
DF KWALAF	28921.7	0.371454

Table 5-6 Standardized regression coefficients

The parameter with the highest coefficient has the largest relative impact on dependent variable. Here the reschedules have the largest impact on the differences in the inventory level.

Besides the statistical significance of the model the practical significance of the model has to be assessed. It has to be identified if the model behaves as expected. This assessment is based on the judgment of the researcher and therefore a qualitative method

The first factor is the difference in reschedules, is denoted as the strongest factor in the model according to the standardized coefficients. A higher number of reschedules induces an increase in inventory levels. The second factor is the difference in the number of SKU's. More SKU's in the inventory means higher inventory levels. The third factor, the difference in on time material availability on requirement date behaves also like expected. The negative sign means that increases in on time availability cause a decrease in inventory since the greatest contribution to the low on time availability comes from the early availability. An increase in COGS level indicates a higher inventory level. This is also as expected because a higher sales level allows higher inventory levels by the same inventory performance. The last factor included is the difference in the number of quality rejections. An increase in this number denotes an increase in inventory levels. This is like expected because rejected material creates extra rework which denotes a longer stay of material in the inventory.

Finally the factors not included in the mode are discussed. These are the on time delivery variables for the suppliers as well as for the machining and assembly department. For the supplier variables Figure 4-2 shows that the effect of early deliveries is mostly compensated by the effect of late deliveries. Also the added slack time between requirement and need by date causes that a decrease in OTD does not directly harm the company's process. The same holds for the OTD for the machining department. From figure 4-3 it can be seen that the decrease in performance is cause by an increase in late deliveries. Also here slack time is added to compensate these late deliveries. The last factor not included is the performance of the assembly department. A decrease in performance here harms the inventory position by reschedules. Problems in the assembly department cause reschedules. Especially these reschedules harm the inventory position because in this phase of the production process all material for a product is available. Due to this reschedules the materials stays longer in the inventory. Therefore the difference in assembly performance is indirectly covered by the difference in reschedules.

5.4 Model Validation

"After the best regression model has been selected the final step is to ensure that it represents the general population and is appropriate for the situations in which it is used" (Hair, 2006). First of all the model will be empirically validate. After that there will be verification in practice. This is done in order to asses the theoretical validation and tests this in the practical situation of this company. Since prior regression realization results or an existing theoretical model for the given relation between dependent and independent variables are not available only empirical validation approaches are applicable in this situation.

5.4.1 Empirical validation

For empirical validation 2 options are available according Hair (2006). The first one is to take a new sample from the general population and test the developed model. The second one is to split the current sample into two equal parts. Since to sample size in this case is too small for splitting (due to the requirements for minimal observations to variables) the most appropriate empirical validation approach is to test the regression model on a new sample drawn from the general population. In this case the general population is product line A1 for which the model is fitted. A sample of this population is product type P within the product line. In this situation the validation is used to test if the general model is transferable to a particular product line. Table 5-7 shows the results of the validation of the model on the P product type. Comparing the adjusted R square values of both models a slightly difference of 5% could be obtained. The MSE values for both models slightly differ. No specific guidelines are given for the deviation of the R square and MSE values in validation but in practice 5% gives no reasons to doubt (Hair, 2006) Since the differences are only small there is no reason to reject the generalizability and transferability of the model.

Model	R square	Adjusted R square	MSE
Product line A1	80.4	75.25	1.42E+12
Pump type P	76.45	70.26	1.32E+12

Table 5-7 Performance comparison for validation

5.4.2 Practical verification

The practical verification for the model consists of testing the performance of the model in practice. The model is used to calculate the estimated inventory levels with the predicted inventory differences. The calculation of this estimated inventory levels is presented in Equation 5-4.

$$\hat{I}_1 = I_0 + \Delta\hat{I}_1$$
$$\hat{I}_T = \hat{I}_{T-1} + \Delta\hat{I}_T$$

Equation 5-4 Predicted inventory calculation

The first predicted value differs from the others because the must be a starting which is real. For the other periods the predicted stock difference, which is given in equation 5-3 is added to the predicted level of the previous period

The estimated inventory levels are compared to the real observed inventory levels. The results are given in Figure 5-1. The underlying data for this model are presented in appendix E6.

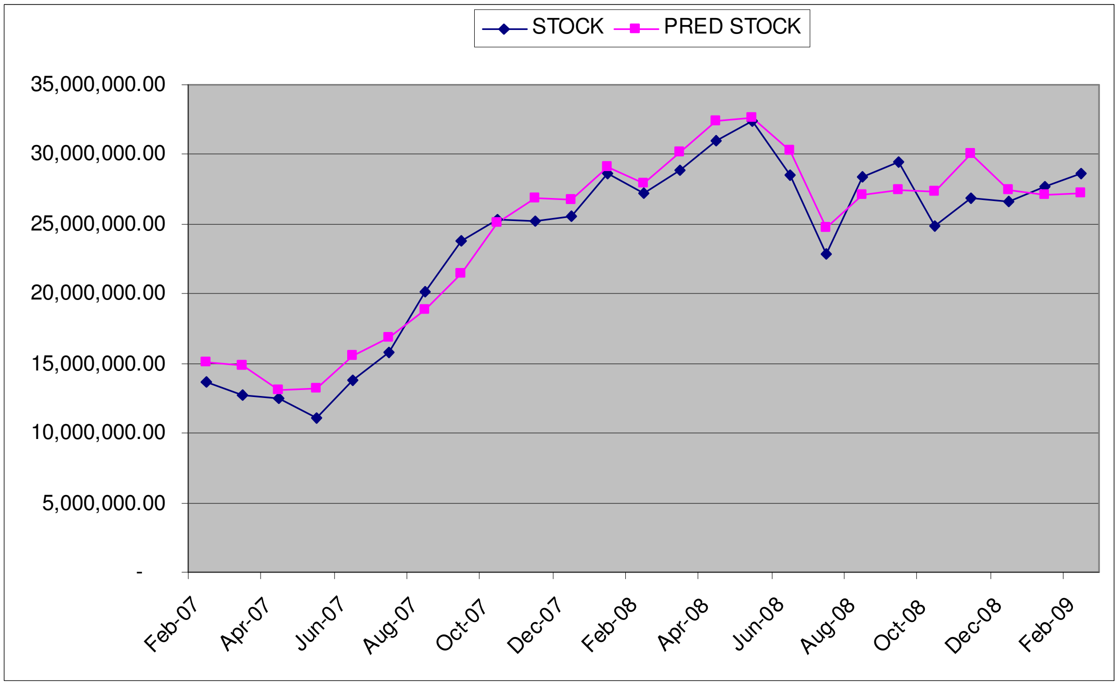

Figure 5-1 predicted versus observed inventory values

Te figure shows that the estimates follow the real values quite well. The performance is also assessed by the Mean Absolute Percentage Error (MAPE) measure. The calculation of this measure is given in appendix E4. The outcome of the MAPE is 7% this means on average the difference between the estimated and the observed inventory values would be 7%. Practically could be said that an average estimation accuracy of 93% is very high for a prediction model (Van den Heuvel, 2009).

5.5 Conclusion

The conclusion for this modeling chapter is that the developed model is good in representing the changes in inventory levels over the period of analysis. The main contribution of the model is that it gives the management of the company insight in which factors are important to the lowering inventory performance and help them to take the right corrective actions for adjusting performance to higher levels. In this chapter the third research question is answered. The developed model indicates the relative contribution of the most important factors to the resulting inventory performance. The next chapter will deal with the fourth research question. It provides possible solutions to the inventory performance problem.

6 Proposed organizational improvements

In the previous chapter a causal model was presented which shows the factors having the largest impact on the resulting inventory performance. This model has been built with the factors out of the organization which could be quantified. Several other qualitative factors as presented in Chapter four have also impact on the company's inventory position. It can only be said that these factors have impact but the relative impact of these factors could not be identified easily. This chapter provides some possible solutions to the organization for improving their inventory performance, taking into account the quantitative as well as the qualitative factors. The first paragraph deals with the way the ITR is calculated in the organization. After that a short look is taken to the inventory control within the organization. The last paragraph deals with the organizational factors having impact on inventory levels.

6.1 ITR Calculation

As stated before at this company the ITR is calculated based on the sum of the COGS of the last 12 months or based at 3 months (multiplied by four) according to company policy. The question here is whether this is the right way to calculate this rate for this particular situation. As seen in Chapter 3 different COGS calculations have a large impact on the resulting ITR levels. As an illustration Appendix E2 shows the resulting ITR for different COGS calculations.
Section 6.1.1 discussed appropriate way of COGS calculation and the usability of these methods at this company. In section 6.2.2 a COGS calculation method is proposed which is appropriate in this particular situation.

6.1.1 Appropriate way of COGS calculation

The most important aspect of the effectiveness of the ITR is that the inventory levels and the COGS correspond to each other (Britney, 1980). He also states in his article that especially in dynamic businesses constant inventory turn rates are hardly achievable. Therefore it is more desirable to set a target range, in which the ITR has to perform. If the sales pattern of a company is more stable turn rates could easily be calculated. If sales is constant over all months of a year annual COGS could be used. For less stationary sales patterns the following suggestions can be given for calculating annual COGS levels. These suggestions are derived from Chatfield (2004). If sales only contain a trend, COGS could be based on a moving average of the last 3 or 4 months (times four or three for annualizing). When only seasonal effects occur in sales COGS could be periodically based. For example if the sales pattern has a higher sales level in three months of a year COGS could be based on those three months (times four) for that period. If sales pattern contains both a trend and a seasonal effects or other fluctuations over time COGS calculation becomes more difficult. Several techniques are available to deal with these issues. A possible solution here is a time series analysis (Chatfield, 2004).
Looking at the particular situation in this company, due to the ETO situation the product mix of the company is very dynamic. The types and number of products in the production program this moment has no relation to production program of past or future periods. As Shown in Appendix D2 monthly sales levels are very fluctuating. There could be an increasing trend identified in the sales levels. Unfortunately this trend is not stable and fluctuates over time. Therefore time is not an appropriate factor in this case. Since all methods discussed here are based on time, they are not appropriate to use in this situation. This concludes that the COGS of the last three or twelve months are not representative for calculating annualized COGS levels. For this company another way of COGS calculation has to be found.

6.1.2 Proposed COGS calculation for this situation

A first remark to make here is that the ITR at this company is calculated by dividing all inventories by total COGS in a product line. This is not desirable because in the sales of product line A1 consist of two different streams. First there is the new equipment and the second stream consists of spare parts. Both streams have a different behavior. The new equipment stream is completely driven by real demand while the spare parts are mainly driven by forecasts and have a more stable sales pattern. It would be advisable to calculate different inventory turn rates for both streams in order to evaluate the performance of them separately. A crucial requirement for this is the possibility to allocate inventory to different streams.

Since the spare parts streams have a more stable sales pattern an ITR calculation based on the methods mentioned in the previous section might be appropriate. For the new equipment stream it is more difficult to find an unambiguous representation between COGS and inventory levels. First there is a look at the administration of the cost of goods within the company for financial reporting. For product line A1 a profile is used to assign the COGS over the lead time to a particular product type. The complete accounting profile is given in appendix E1. Figure 6-1 shows graphically the cumulative percentage of total COGS over the lead time of a product type.

Figure 6-2 shows the global average build up of the inventory level for a product type of product line A1. Relating Figure 6-1 to Figure 6-2 the most ideal way to relate inventory to COGS is for every product in the program at the moment, determine the inventory stage and calculate the corresponding COGS. For example take a product of type P5 which is one month before the delivery month in period T. According to Figure 6-1 the inventory level is then 95% of final inventory level. In order to calculate COGS corresponding to the inventory level in Period T 95% of the total COGS for that particular product must be taken. Now this value has to be annualized in order to obtain the COGS for ITR calculation. In this example the lead time for the P1 product is 9 months as shown in Figure 6-1. Therefore the product COGS value has to be divided by 9 and after that multiplied by 12. In order to obtain the periodically COGS level for period T this procedure is repeated for every product in the production program in that period.

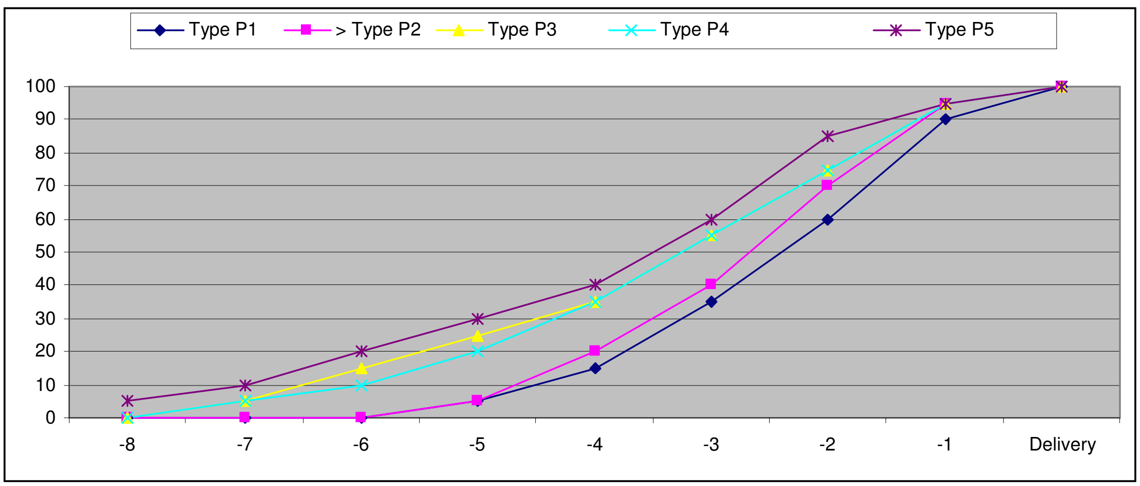

Figure 6-1 Accounting profile for COGS

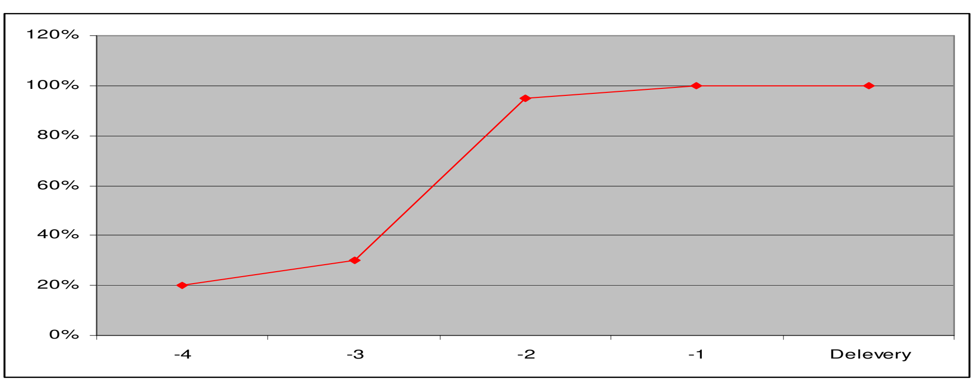

Figure 6-2 Inventory build up

If this method can be implemented in the administration system of the organization this would be appropriate otherwise it is a very time consuming way for the administration department.
Derived from this method a more simple way of calculation can be identified. A possible method is to look at the months in which inventory levels for a particular product type are high. This is for the delivery month and the 2 months before. Looking at the Corresponding periods of the COGS levels in Figure 6-1 is can be seen if the COGS of the last 6 months is taken on average 75% of COGS is included. Taking the COGS of the last 6 months (times two for annualizing) is a representative and easy way in this particular situation.

6.2 Inventory Control

This section briefly looks to the inventory control at the company. The first important aspect of current inventory control is that inventory is blind. This means that material is not dedicated to either spares or new equipment projects. The most important drawback from this way of controlling is the limited way of doing analysis on the inventory. If inventory is dedicated to spares and projects it is possible to calculate different ITR rates for both streams as suggested in the previous paragraph. Also the arrival of materials and the actual usage in the production could be analyzed if inventory is dedicated.
The second aspect is the classification of inventory. In the current way of working, material groups are based on their item function and not on logistic properties. Also a large part of the inventory consists of items (SKU) which are allocated to the rest category. All inventories are controlled by the demand generated in the company's ERP system. Looking to some logistic properties different control policies to different item groups or different item classifications would be appropriate. Three aspects to look at are mentioned below here.

Usage

The usage of several items is very different. Some items are used on a regularly basis while others are rarely used ore even are a unique item for single use. Also the variance of the usage differs much between items. An ABC classification suggested by Silver (1998) might be helpful to categorize items for several control policies for the spare parts stream. For the new equipment stream the ABC classification would not be suitable because there are many items within this stream which have a low usage but a high financial value. But when the demand and the time when it is needed in the new equipment stream are known a Just In Time (JIT)) strategy is very suitable. (Hopp & Spearmann, 2001). Material should only be there if it is needed. Here also a balance has to be found between ordering and inventory holding costs. Silver (1998) provides several heuristics to find this balance for items with a fluctuating demand. An example of such heuristic is the Silver-Meal method which helps to select the approximately best period and quantity to order.

Uncertainty

Uncertainty is the fundamental basis for having inventory. When zero uncertainty is obtained inventories could be eliminated. The greatest uncertainty this company faces is the OTD by its suppliers. Not only are the external suppliers unreliable. Also the internal suppliers such as the engineering and machining department are unreliable suppliers Due to this uncertainty slack time is added between the need by and requirement date in order to create a buffer to have materials on time available. This slack time is added for all items while not all items and suppliers have the same uncertainty levels. This is expressed in the high early values of the on time delivery measure presented in Chapter 4. In order to appropriate deal with this uncertainty, items should be classified based on this uncertainty. For items from reliable supplier's slack time could be reduced or even eliminated.

Project

Another separation in inventory could be made based on project articles and non project articles. Due to the ETO aspect each product is adjusted to customer needs. Therefore unique items are created which are only used in that specific product. Also many other expensive items are ordered for a specific product project. Dedicating inventory to specific projects makes it easier to control the need of particular materials. For example in the current way of working, all material is desired at the start assembly date. The assembly process takes on average 6 weeks and not all items are needed in the first weeks. If items are dedicated to specific projects the requirement dates for specific parts could be derived from the project planning and reflected in the system.

6.3 Organizational Changes

In this paragraph there is a look at the organizational aspects which have impact on the resulting inventory performance.

6.3.1 Organizational design

Bertrand (1998) mentions that ETO organizations are complex organizations. The material as well as the capacity complexity would be high. This demands a very flexible organization which could quickly anticipate on the market requirements which are uncertain because every customer has his own demands to the product. The customer order decoupling point lies at the engineering phase which means everything is adjusted to customer needs. Besides the flexibility another aspect of ETO is that demand for items is known on forehand which makes inventory control easy in one way. On the other hand it makes control difficult due to the material complexity which asks for always differing material requirements. Each new product is treated as a separate project in the production process. The question to ask here is whether a project organization would be better in this situation. According to Bertrand (1998) a pure project organization is not advisable in this situation. If resources are dedicated to a specific project they are not available for other projects. This decreases the flexibility of the organization. The desired organization would be a functional divided organization with flexible resources which could be quickly dedicated to projects. Within the functional departments the focus should be on projects. Besides that there is a department project management which is responsible for the monitoring and control of the entire product projects.

6.3.2 Organizational focus

As stated before in the diagnosis phase a lack of inventory focus and sub optimization are important contributors to the resulting inventory performance. Every department in the organization was behaving according to their own interests and performance measures. They have also the idea that what they are doing is the right way. Also the absence of the inventory focus by top management gave the idea to the organization that inventory performance is not very important. According to Chikan (2004) the role of inventories has to be changed from a passive role to an active role in the organization. In today's businesses inventories play an important strategic role in the organizations effectiveness and success. "Inventories are an integrated part of the value chain and serve as a strategic tool to achieve customer satisfaction and profit simultaneously" (Chikan, 2004). In order to become effective this idea first has to be supported and communicated by higher management. (Pritchard, 2002) If management does not give support and attention to it the organization will not see this as important. Pritchard also states in his article that the effectiveness of the inventory performance is determined by the participation of all involved departments together. Therefore it is crucial that everyone knows and is convinced which impact actions have on the resulting performance. Performance measures for individual departments must be in agreement with the overall inventory performance measure (here: the ITR). Also participation in reaching the desired performance is very important. All involved departments must be able to participate in improving the inventory performance and be convinced that what they are doing has a positive impact on the resulting performance. “Participation can have a cognitive function in that it promotes the exchange of task relevant information, a motivational function in that it increases the commitment to goals, and a social function that the presence of others creates group facilitation effects and persuasive communications by others” (Pritchard, 2002)

In addition to this an article by Alles (2002) describes a model of information and incentive effects of inventory in JIT production. This model is quite suitable here because due to the ETO situation demand and requirement dates are known. Therefore the JIT principle with limited or zero inventories is applicable to the organization. The ultimate goal is to have zero inventories. Therefore management must provide the idea that limited inventories is a good thing but process reliability and organizational effectiveness must not be harmed. The incentive of this idea is that all involved departments are forced to think in no routine and creative ways in order to influence performance positively

6.3.3 Knowledge & procedures

Also an important aspect obtained in the analysis phase is the lack of well documented and unambiguous procedures to tackle particular situations. This is due to the fact that knowledge available in the organization how to handle in particular situations is often in the persons mind and not explicitly documented. Explicit knowledge on how to handle in particular situations is from great importance for the organization and therefore it is not desirable to have this knowledge only available in a persons “head” (Hislop 2005). This kind of knowledge has to be available for the organization and must not be lost if a person leaves the organization. Also it makes it possible for other employees to take over work and for new employees to find out how things work. Also sharing knowledge is important for the several departments to know why things are done the way they are done. An example of this phenomenon at this company is identified in the interviews. OP makes a requisition for a certain quantity to order of a particular item. The purchasing department then orders more items than required. The operations planning department does not know why this is done. Only the particular purchaser responsible for this item knows why more items are ordered. He knows from his own experience that there is a minimum order quantity at the supplier. Ordering les items is possible but the minimum quantity has to be paid for. This situation leads to misunderstanding and unnecessary communication. If this item specific information has been stored with the rest of the item information in the system this misunderstanding could be avoided.

This knowledge sharing could be reached with a Knowledge repository (Davenport, De Long & Beers 1998). This is a database where al relevant information as procedures, documents and so on for effective operation is stored and could be retrieved easily by other users in the organization. Markus (2001) mentions that knowledge repositories are highly valuable when new employees enter the organization. In this way they easily find the relevant information for doing and learning on their job. Especially in times when there is not much time to intensively master new employees the details of their task this repository is helpful.

Most important implementation condition for this repository is that all processes are well documented and procedures are clear and unambiguous. So first of all clear process descriptions and procedures have to be developed. There has to be consensus in the organization how to handle in particular situations and this should be executed in a similar way each time.

To conclude in this chapter the answers to the fourth and fifth research questions are presented. First of all a possible appropriate way for representative ITR calculation out of a relation between the inventory and the COGS is given. After that several possible organizational changes to the organization for improving inventory performance are given. The most important improvement is the inventory awareness in the entire organization. Besides that the allocation of inventory, the control of items based on logistic properties and knowledge sharing are important improvements

Part 4: Conclusions

7 Conclusions and Recommendations

This final chapter concludes the research by summarizing the main results of the project. Paragraph 7.1 presents the main results of the project by answering the research questions. In paragraph 7.2 the main recommendations for better performance implementation are given. After that the following paragraph deals with some limitations for this research. Thereafter the next paragraph deals with the contribution of this particular project to the scientific literature. The last paragraph of this chapter gives some suggestions for further research.

7.1 Conclusions

In this paragraph the conclusions from this project are stated. The conclusions are presented as the answers to the research questions as formulated in Chapter one.

1. *What has happened in the period from May 2007 to July 2008 leading to the sudden drop in ITR levels and increases in inventory levels?*

Analysis showed that the period of ITR drop differs due to the way the COGS are calculated. Therefore the period of interest is not restricted to the period from May 2007 to July 2008.
In order to maintain ITR on desired levels the COGS and the inventory levels should be in relation to each other. Due to the ETO way of working demand for the coming periods is known. Therefore the COGS level for these periods could be determined. In order the maintain inventory performance the inventory level must be adapted to the COGS level. The main cause for the inventory performance problem is that the inventory levels are too high compared to the COGS levels.

2. *What are the factors contributing to the inventory management performance at this company?*

Out of the broad analysis a large list of factors, qualitative as well as quantitative are identified having impact on the resulting inventory performance. The most important factors are:

- The unreliable supplier performance due to a saturated suppliers market.
- The many reschedules in production partially caused by organizational sub-optimization behavior which caused much unnecessary inventory.
- The increasing number of stock keeping units in the inventory which have no specific holding function caused much higher inventory levels.
- The increased number of quality rejections.
- The lack of inventory focus of the organization and the material availability policy of the management
- The lack of clear procedures and explicit documented knowledge

3. *To what extend do the identified factors influence the performance of inventory management at the company?*

In order to determine the strength of the effect of several factors on the inventory levels a regression model has been built. The shows that the COGS, the reschedules, the number of SKU's, the quality rejects and the on time availability based on requirement date are the strongest contributors to the inventory performance. Around 75% of the variance in the difference in inventory levels is explained by the developed model. This indicates that the constructed causal model better explains what has happened than the current used judgmental methods of using factors in a single relation to inventory levels. These judgmental methods have not given the desired explanations so far. To conclude the regression model is used to predict the inventory levels over the period of analysis. For this period the model gives an error of 7% which means that on average inventory is predicted 93% confident.
For the qualitative factors no data support has been found in this project. Therefore the strength of these factors could not be identified.

4. *Which improvements could be made and to what extend do they contribute to the inventory position in this company in order to meet target performance*

The main improvements made to the organization are the focus on inventory by the entire organization. Each department must be aware of the impact of their actions to inventory levels. The trigger must be to take those actions to reduce inventory as much as possible without loosing customer satisfaction and profitability. This focus probably will lower the number of unnecessary SKU's in the inventory and prevents the early ordering of materials. Also the number of reschedules will reduce if every department is conscious of the impact of their actions.

Further procedures policies and knowledge should be made explicit and clear. Every one has to know how to handle in particular situations and procedures should be consistent and corresponding to each other. Another important point of attention is the supplier performance. Since supplier performance is unreliable much attention has to be paid to the selection of those suppliers. The problem has to be tackled by its roots. Adding slack time does not solve the problem it creates only a buffer to compensate the reliability.

The impact of the improvements to the quantified factors on the inventory level can be found in the constructed regression equation.

5. *What is the best calculation method for the Inventory Turn in this situation?*

As the literature suggests inventory levels and COGS levels should be related to each other in order to calculate an ITR which is representative for the performance. First of all the ITR is calculated for both the new product stream as well as the spares stream in the same way while both streams have different characteristics. Suggested is to calculate for both streams different rates. Crucial requirement here is that inventory could be allocated to the different streams. For the spares stream which is more stable a calculation over a certain period. For the new products stream a connection has to be made between the evolvement of inventory levels for a project and the administration of the corresponding COGS for the same project. The suggestion here is that calculating the COGS over the last 6 months times 2 (for annualizing) gives approximately the best relation.

7.2 Limitations

One of the main limitations for this project was the availability of quantitative data. Many factors are identified during the analysis phase but only for a small part historical usable quantitative information was available. Therefore it might be possible that factors which are very importance are not included in the modeling phase. For these factors only a qualitative judgment based on own experiences and information from others could be given.

For the factors which have historical relevant quantitative data only a small dataset was available. Only 38 or 26 data points for each factor are available. This gives some limitations to the modeling. First of all the normality assumption for small datasets is crucial to have a statistically relevant and usable mode. This made it necessary to explain the inventory levels indirectly by taking its differences. Another limitation of the small dataset available is the number of variables that could be included in the model. The last limitation mentioned here is that due to the small dataset the validation of the model was much more difficult. Normally an additional sample could be derived by having an additional sample or spitting the available sample. For this project an extra sub-sample must be derived from the existing sample in order to validate the model. This created much extra work.

7.3 Contribution to the literature

Besides the practical usefulness of a master thesis project one of the requirements is that it contributes to the scientific literature.

In this project two relevant contributions could be obtained. First of all there is the provided framework for the analysis and diagnosis of inventory performance problems provided by de Zomerdijk and De Vries (2003) and De Vries (2005, 2007). This thesis project shows that the framework presented by De Vries is applicable in a highly dynamic ETO organization like this company. It shows hat organizational factors have influences on the inventory performance. In an engineer to order situation a flexible organization is crucial to perform efficiently. In such an organization inventory is often a result of organizational effectiveness and traditional inventory control factors.

The second contribution is to the calculation of the ITR in situation with dynamic sales. Literature suggested that the COGS and inventory levels must be related to each other in order to calculate a representative ITR. Most ITR calculations are based on the evolvement of the sales pattern over time. This project provides a possible way of ITR calculation in a situation where the sales pattern is more dependent on the product mix than on the evolvement over time.

7.4 Recommendations for further research

This paragraph gives some suggestions for further research. First there are recommendations given for research at this company. After that some recommendations are given for further scientific research

7.4.1 Recommendations for further research at this company

Data availability
Recently, in this company more attention is given to inventory the last time. More and more analysis is conducted on inventory. For this research a limited number of data was available due to the lack of analysis possibilities so far. Due to the increased inventory focus the operations planning department is analyzing the inventory more intensively. With the available discoverer tool in the company's operating system more and more data reports are generated. Therefore the company must be able to use and adapt the constructed regression model. Then further research could be done when more data is available. Additional analysis could be conducted and additional variables could be added to the model in order to look if other variables are more important and the explanation power of the model increases. To conclude this it is recommended for this company to have a statistical software package like Statgraphics and trained employees to work with this package.

Future behavior and changing environments
Supplemented to the previous recommendation the future behavior of the inventory performance is interesting. Now the causal model is available and management has insight in which factors are important for improving inventory performance it is interesting to follow up the implementations of the decisions made by management. Also the changing environment (due to the economical situation) has influence on the inventory performance. It is interesting to follow up future behavior of the included factors and resulting inventory levels and compare them to the predicted relation. If deviations to the model occur further research could be conducted to identify what caused the deviation from the model. Possible the model could than be adjusted to the new situation.

Inventory allocation
Now inventory is blind in this company. No distinction is made between spare parts and different projects. If inventory is dedicated to spares or specific projects more additional research could be conducted. For example if allocation is available the time items are in stock before usage could be analyzed. Also forecast for spare parts and its realizations could be better analyzed. Further research has to find out what the possible cost and benefits are for the implementation of this allocation method

Item Classification
In the current organization items (SKU) are categorized based on functional characteristics. Due to the great variety of items in the production process a large part of the inventory consists of items in the rest category. Item classification based on logistic properties might be helpful for inventory control policies as suggested in Chapter six. Further research has to find out what the best item classification for this

company would look like and which policies or heuristics can be used for controlling the different categories.

Knowledge repository
This project suggested the implementation of a knowledge repository to structure knowledge and procedures. Further research has to find out how such a repository should look like and how it must be implemented. Also it is important to make a cost and benefit analysis for the implementation of a knowledge repository in this company.

7.4.2 Recommendations for further scientific research

Quantify organizational factors
As already stated in the articles by De Vries (2005, 2007) the impact of organizational factors on inventory performance is recognized by the developed framework. But the impact of these factors is still qualitative recognized. It would be a great step forward if these organizational factors could be made quantitative and taken into account in further analysis. The incentive of this project was to try to find quantitative data for these factors. Due to the limited available data this is not achieved. Further research is still needed to find this quantification. Possibly, intensive observations in an organization might be helpful for this quantification. For example unnecessary inventory levels caused by communication problems can be observed and reported over a period in order to find the extension to this factor

References

- Aken, J.E. van, Berends, J.J., & Bij, J.D. van der (2005), *Methodology for business solving,* Lecture syllabus 1PP50-MTO3, Eindhoven University of Technology
- Alles, M., Amershi, A., Datar, S., & Sarkar, R. (2000), Information and Incentive Effects of JIT Production, *Management Science,* Vol.46, No.12, pg. 1528-1544
- Ballou, R.H. (1999), *Business Logistics Management,* second edition, New Jersey, Prentice-Hall
- Bertrand, J.W.M., Wortmann, J.C., & Wijngaard J. (1998), *Productiebeheersin en material management,* second edition, Groningen, Wolters-Noordhoff
- Biggart, T.B., & Gargeya, V.B.(2002), Impact of JIT on Inventory to sales ratios, *Industrial management & data systems,* Vol. 102, No. 4, pg. 197-202
- Britney, R.R.(1980), Growth, Product Lines and Realistic inventory turns, *International journal of Physical Distribution and Logistics Management,* Vol. 10, No. 4, pg. 193-205
- Chatfield, C. (2004), *The analysis of time series, an introduction,* Boca Raton, Florida, Chapman & Hall/CRC
- Chikan A. (2004), The new role of inventories in business: Real world changes and research consequences, *International Journal of Production Economics,* Vol. 108, No. 1-2, pp. 54-62
- Chikan A. (2008), An empirical analysis of managerial approaches to the role of inventories. *International Journal of Production Economics*, (2008)
- Cooper, D.R. & Schindler, P.S.(2003), *Business Research Methods*, eight edition, New York, McGraw-Hill/Irwin
- Emans, B. (1990), *Interviewen, theorie techniek en training,* third edition, Groningen, Wolters Noordhoff
- Garrison, R.H., Noreen, E.W., & Seal, W. (2003), *Management accounting,* European edition, New York, McGraw-Hill Education
- Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E., & Tatham R.L.(2006), *Multivariate Data Analysis,* sixth edition, New Jersey, Prentice Hall
- Heuvel, F.P. (2009), *Action Prodcuts at Jan Linders Supermarkets,* Master thesis project
- Hislop, D. (2005). Knowledge Management in Organizations: A Critical Introduction. Oxford: Oxford University Press
- Hopp W.J., & Spearmann, M.L. (2001), *Factory Physics,* second edition, New York, McGraw-Hill/Irwin
- Kisperska-Moron, D. (2003), Responsibilities for inventory decisions in Polosh manufacturing companies, *International Journal of Production Economics,* Vol., pg. 129-139
- Kock, A.A.A. (2009), Manufacturing Critical-Path Time, *Pumpke 1 2009*, Vol. 21, No.1, pg. 21
- Markus, M.L.(2001), Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success, *Journal of Management Information Systems,* Vol.18, No.1, pg. 57-93
- Meridith, J.R. (2001), Hopes for the future of operations management, *Journal of Operations Mangement,* Vol.19, pg 397-402.
- Montgomery, D.C. & Runger, G.C. (2003), *Applied statistics for engineers*, third edition, New York, John Wiley & Sons Inc.
- Pritchard, R.D., Holling, H., Lammers, F., & Clark, B.D.(2002), *Improving Organizational Performance with the Productivity Measurement and Enhancement System: An International Collaboration,* New York, Nova Science Publishers, Inc.
- Rabinovich, E., Evers, Ph.T. (2002), Enterprise wide adoption patterns of inventory management practices and information systems. *Transportations Research Part E, Logistics and Transportation review,* pg. 389-404

- Ruffini, F.A.J., Boer, H., van Riemsdijk, M.J. (2000), Organizational design in operations management, *International Journal of Operations and Production Management,* Vol. 22, No. 7, pg. 860-879
- Silver, E.A., Pike, D.F., & Peterson, R. (1998), *Inventory Management and production planning and scheduling*, third edition, New York, John Wiley & Sons
- Strien, P.J. van (1997), Towards a methodology of psychological practice, *Theory and Psychology*, Vol.7, No.5,pg. 683-700
- Venner, M.H.W.C. (2009a), Issues *in inventory management*, Literature study performed as an introduction to this master thesis project.
- Venner, M.H.W.C. (2009b), *Researching Inventory performance* [redacted] *Project Proposal*, project proposal for this master thesis project
- Vries J. de, (2005), The complex relationship between inventory control and organizational setting: Theory and practice, *International Journal of Production Economics,* Vol. 93-94, pp. 273-284
- Vries J. de, (2007), Diagnosing inventory management systems: An empirical evaluation of a conceptual approach, *International Journal of Production Economics,* Vol 108, pp. 63-73
- Wanke, P.F., & Zinn W. (2004), Strategic logistics decision making, *International Journal of Physical Distribution and Logistics Management,* Vol. 34, No.5, pg. 466-478

[redacted]

- Zomerdijk L.G. and de Vries J.(2003), An organizational perspective on inventory control: Theory and a case study, *International Journal of Production Economics,* Vol. 81-82, pp 173-183

Appendices

Appendix A: The research process

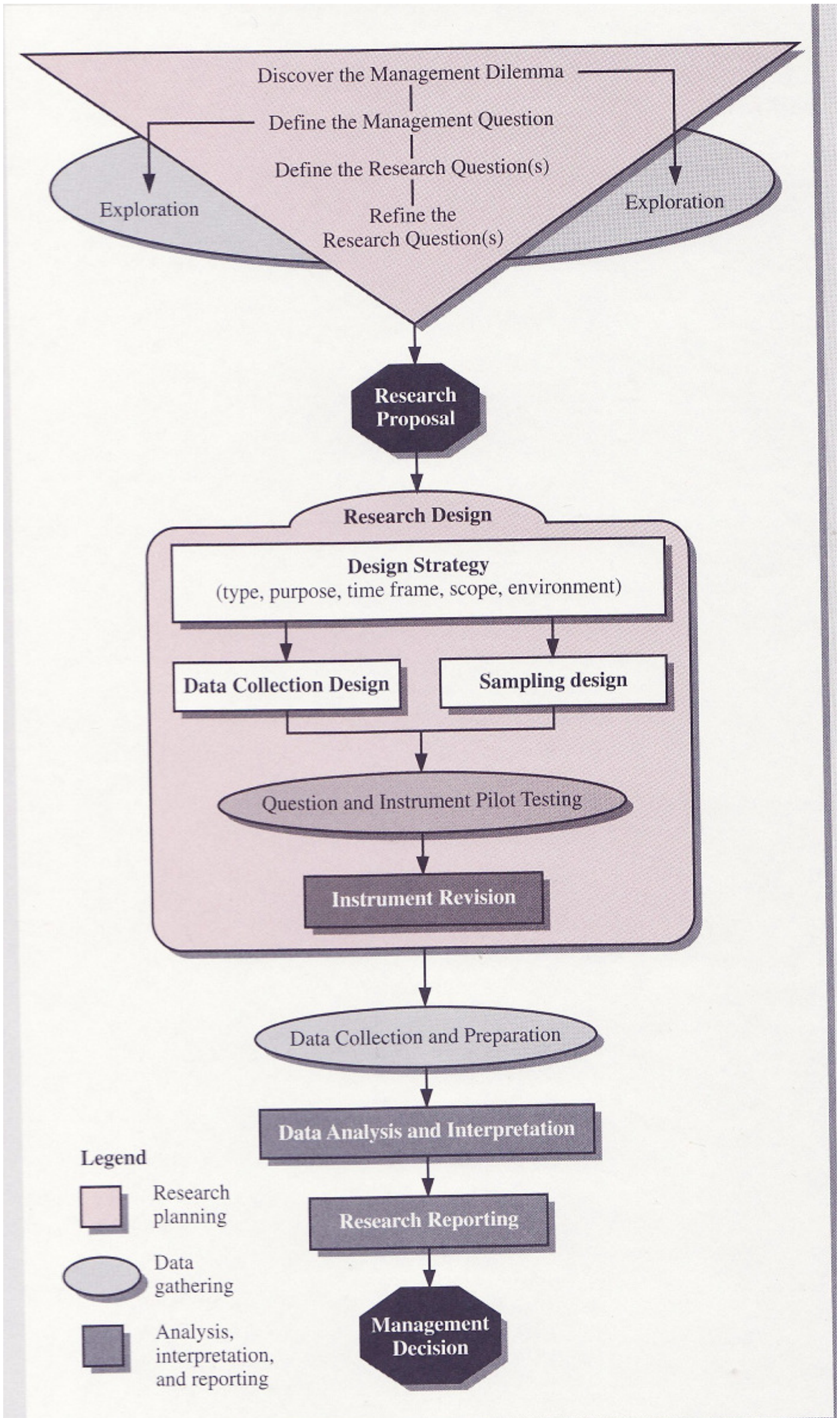

Figure A1 Research process for analysis (Cooper and Schindler, 2003)

Figure A1 shows the research process for the analysis phase of this project. The research projects starts with a Management dilemma and the exploration of the research area. This results in the development of the relevant research questions and ends up in a research proposal. This proposal is the starting point for the design of the analysis phase of the project. First of all the strategy for the analysis has to be determined. Out of the several available analysis techniques the most relevant ones suitable for the project has to be selected. Also the time frame, the scope en environment of the analysis has to be determined. After the strategic issues are determined the analysis could be designed for this particular situation. The relevant data for analysis is selected and the questions for the interviews are formulated. If all these issues are met and the resulting analysis model is tested with sufficient results the data collection and interpretation process can start. When sufficient data is collated for proper interpretation of the problem it is important to present to results in an appropriate way such that is readable and usable by management. The report must be to the point and understandable by the management such that they can take the right decisions.

Appendix B: Research Context

Appendix B1 Organization scheme

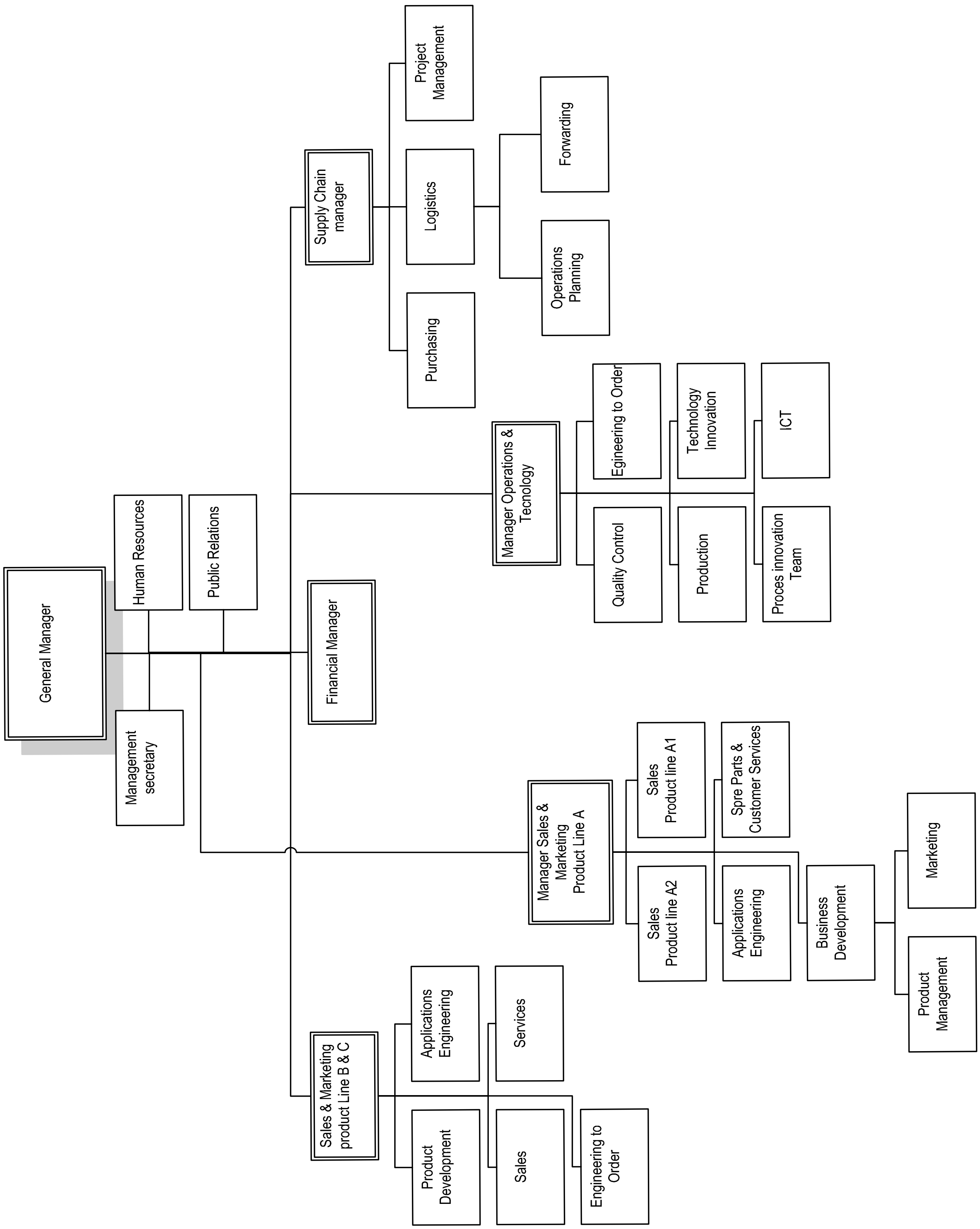

Figure B1 Organization Scheme

Figure B1 shows the organization scheme of the company. It shows that the organization is partly functional organized but has also a product oriented distinction. First of all there is the functional distinction between sales & marketing, finance, operations & technology and the supply chain departments. Besides that there are two separate departments for different product lines. Mainly the distinction between the product oriented departments is based on the sales and marketing function but also the engineering activities are place in this separate department.

Appendix B2 Project Plan

Figure B2 shows an example of a project plan for a particular product of product line A1.
It shows the time path from the "Kick off" of the product project to the assembly phase. This project consists of two identical products for the same customer. As an illustration of the long lead times for the projects at this company the figure show lead time of 52 weeks
1 week after the start of the engineering phase long lead items such as the valve unit and the drive unit are resealed for sub ordering while the engineering of these units still proceed. This is possible because in this way the items could already planned in the processes of the machining department or in the processes of external suppliers. The complete production details for these products then could be provided later on.
All items must be released by engineering 12 weeks before the start of assembly in order to get the materials available on time. Further the project plan shows the place in time of the several sub order and machining activities in the project.

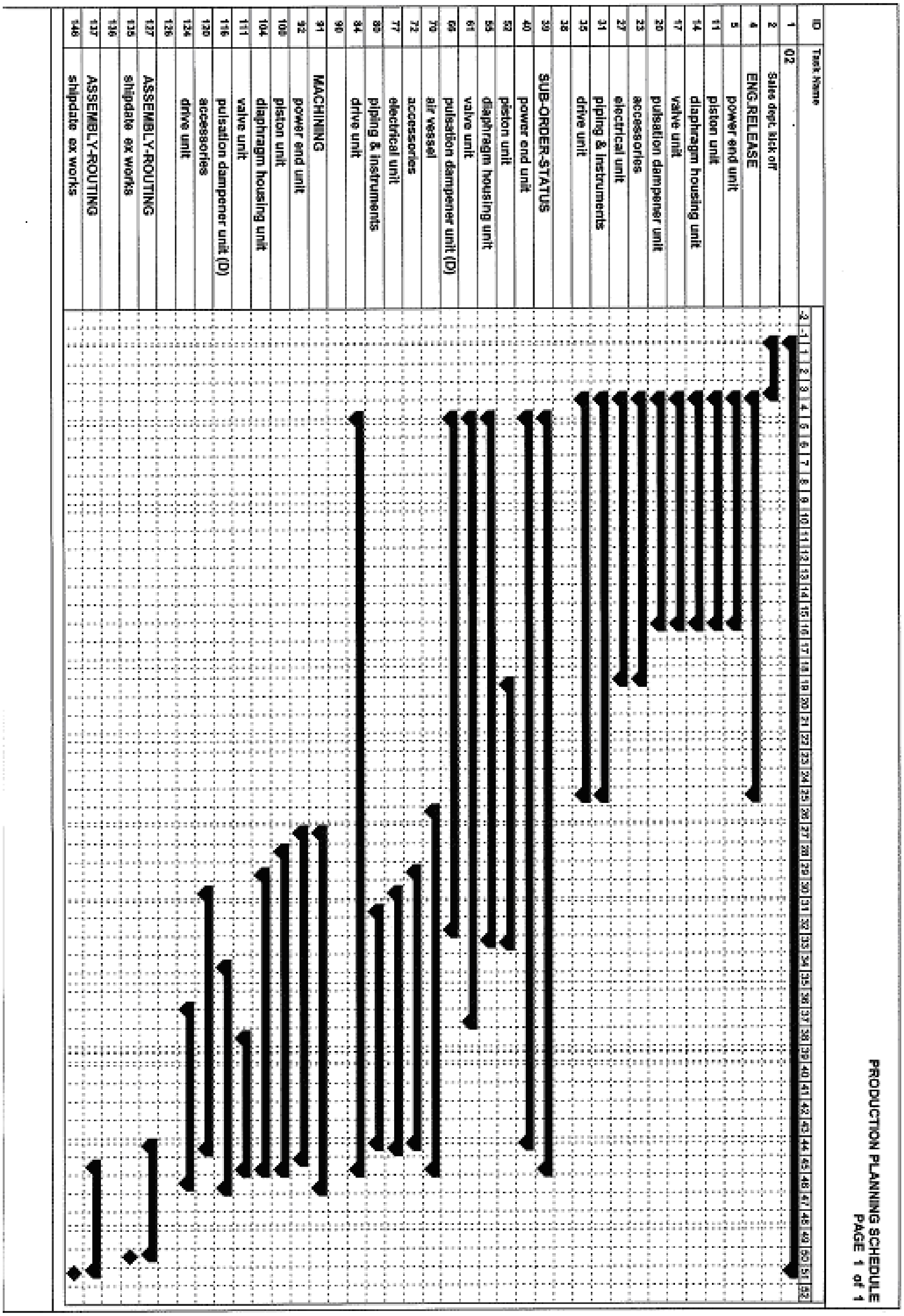

Figure B2 Project plan for a particular product

Appendix B3 Production steps

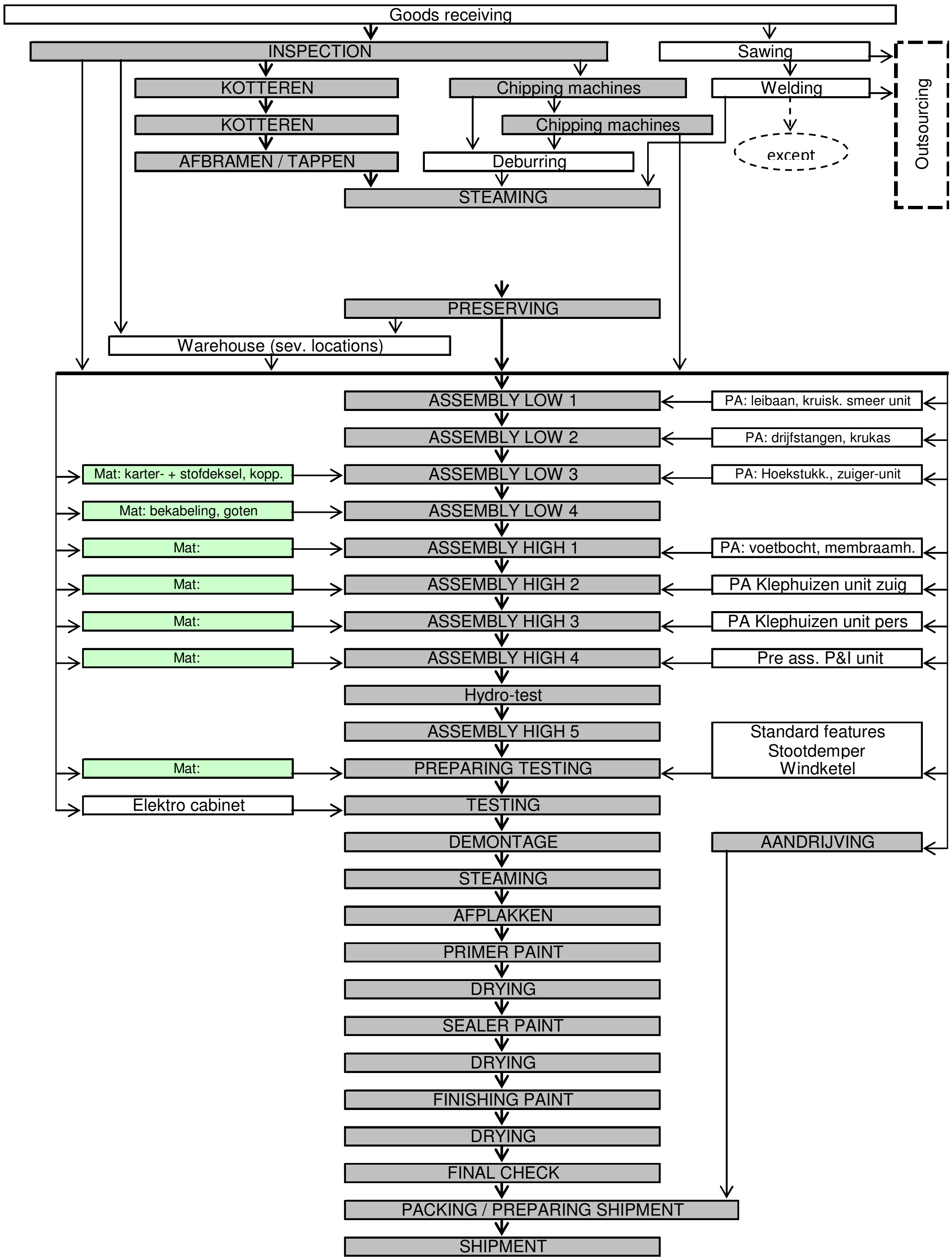

Figure B3 Production steps for a particular product

Figure B3 shows the machining and assembly steps in the production process of a particular product of product line A1 at the company. In the upper part for the figure the machining activities are illustrated. All processes starts with the receiving of goods. After inspection a distinction is made between complete products which are directly usable for the assembly and the raw materials for the machining processes. The assembly steps are presented by the boxes in the middle of the lower part of the figure. The boxes on the left and right side indicate which materials are added in that particular assembly stage. After the product has been assembled it is intensively tested. After the testing procedure the equipment is disassembled because it is too heavy for transportation in one piece. The last steps of the production process are the painting and packaging of the product. After that the product is ready for shipment.

Appendix C Inventory Analysis

Appendix C1 Stock, COGS and ITR product line A1

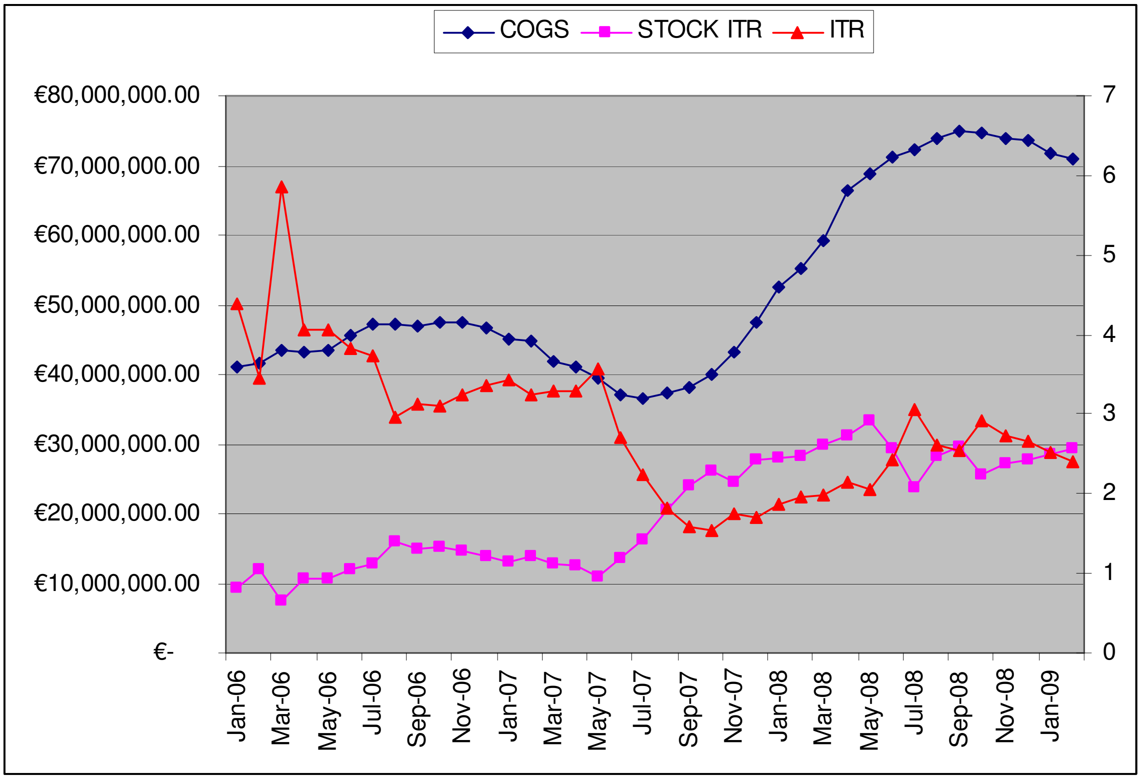

Figure C1 COGS, Stock and ITR for product line A1

Figure C1 shows the development of the COGS the inventory level and the resulting inventory performance measured by the ITR from January 2006 till February 2009. This figure is based on the COGS calculation of 12 months which is used at the company in that period. The inventory level increased from May 2007. Also the COGS level increased from that moment. Because the inventory increase is higher compared to the increase in COGS level, the inventory performance level, measured by the ITR drops.

Appendix C2 Stock Structure product line A1

Figure C2 graphically shows the development of the stock based on the stock structure for the product line A1 from January 2006 till February 2009. It shows that the reserved stock has the largest contribution to the inventory increase from May 2007. The second largest contributor is the WIP level followed by the available stock. The obsolete and excessive stock only have a minor contribution the to the inventory levels. Therefore conclusion is that by far the largest part of inventory is covered by demand generated from orders or forecasts.

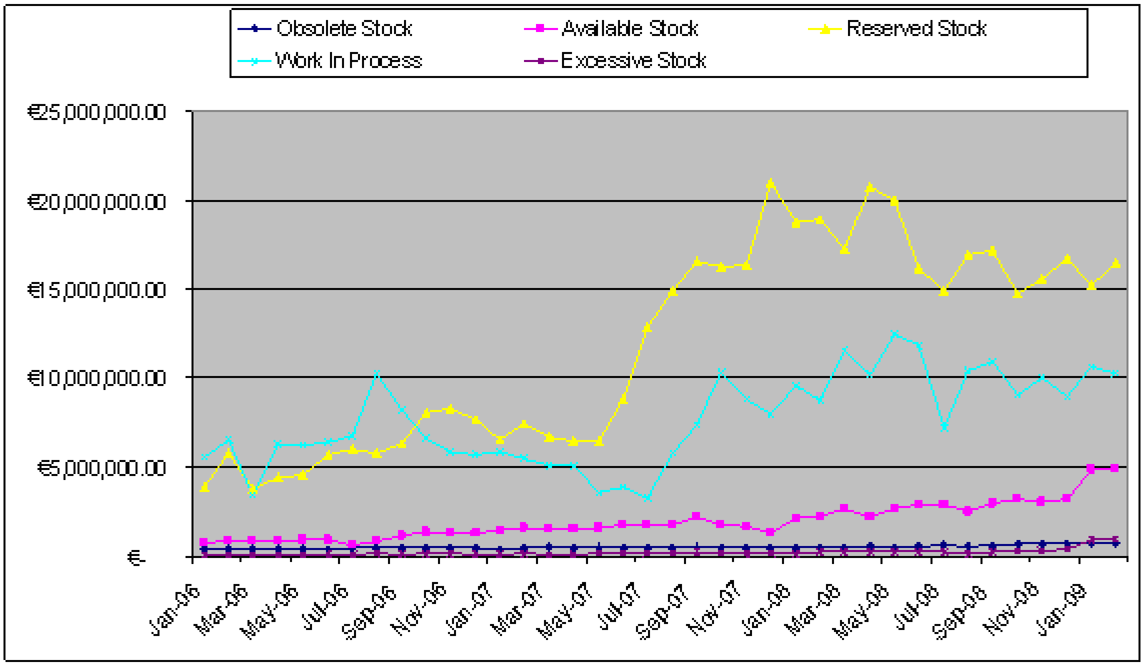

Figure C2 Stock Structure levels for product line A1

Appendix C3 Buy, Make and WIP product line A1

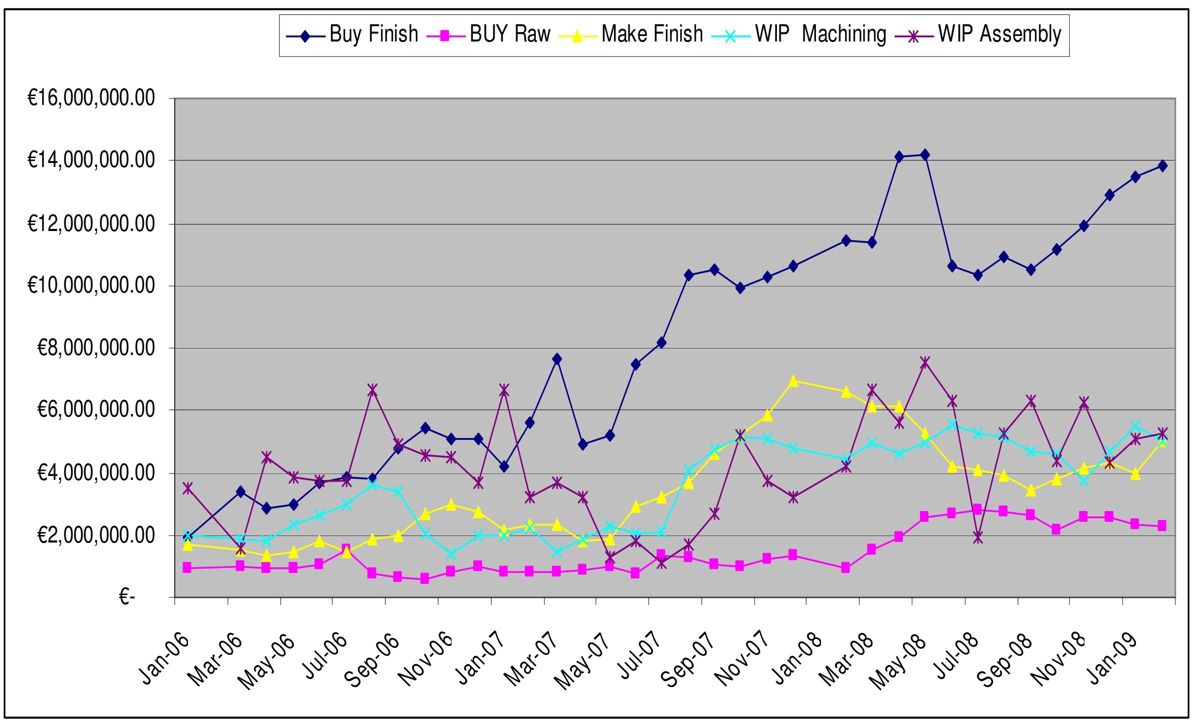

Figure C3 Warehouse Stock levels for product line A1

In Figure C3 the development of the stock levels based on the warehouse position is graphically presented. It shows that the buy finish inventory level counts for the largest part of the inventory increase from May 2007. Further a drop in the WIP assembly inventory level could be seen from the beginning of 2007. In that period a Kanban inventory control policy in introduced in the assembly department. Before this policy all material needed in the assembly are placed in the assembly area and count for the WIP level. After introduction Kanban material stays in the warehouse (buy finish and make finish) until it is really needed in the assembly process. The conclusion from this figure in that in general all warehouse inventory shows an increase from May 2007.

Appendix C4 Inventory Function

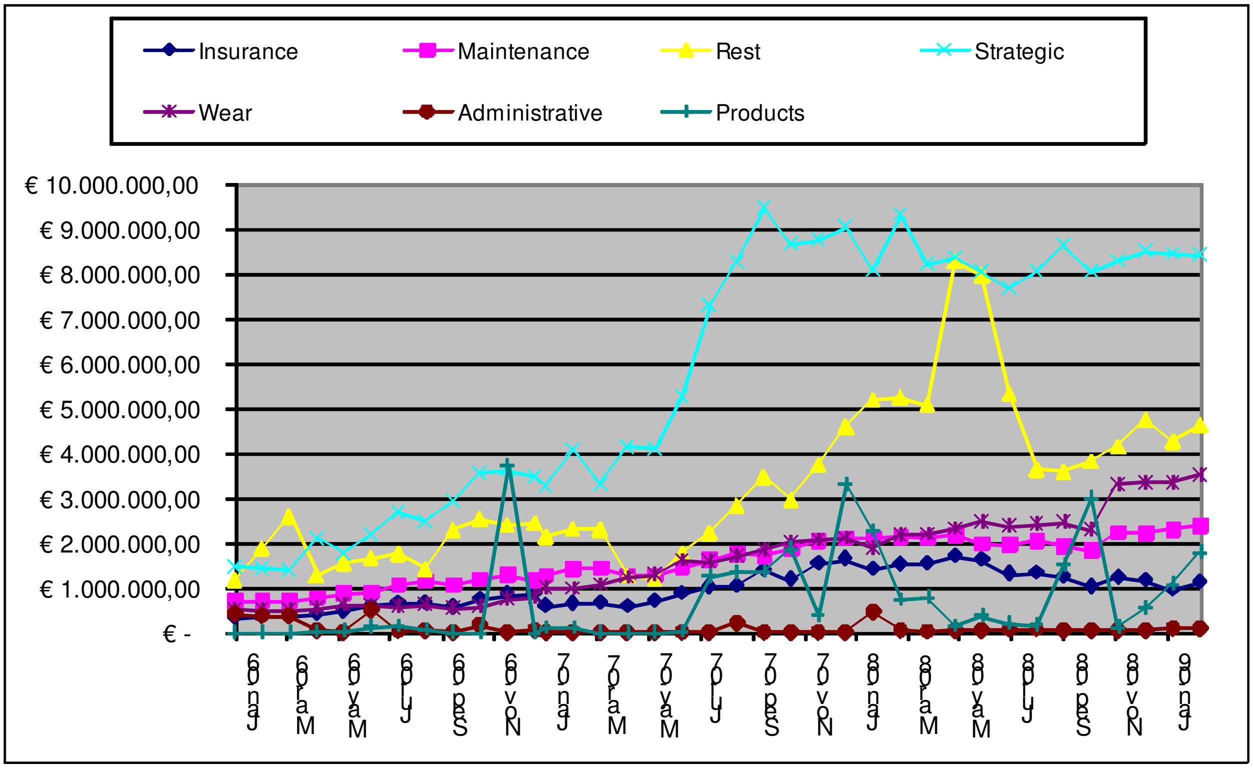

Figure C4 Functional stock levels for product line A1

Figure C4 shows the development of the inventory levels based of the function of the inventory. The first remark here to make is the fluctuating pattern of the products category. These fluctuations have a considerably effect on the total inventory levels and therefore on the inventory performance. Often these values occur in the inventory levels due to administrative reasons. Therefore the company decided to exclude this category from the inventory level for performance calculation. From the figure it could be seen that within the product line A1 the strategic inventory shows the largest increase over time. Remarkable is the large contribution of the rest category to the total inventory level. This category represents the second largest part of the inventory at this company while is have no defined inventory holding function. The other inventory function categories also show an increase over time.

Appendix C5 Inventory by item category

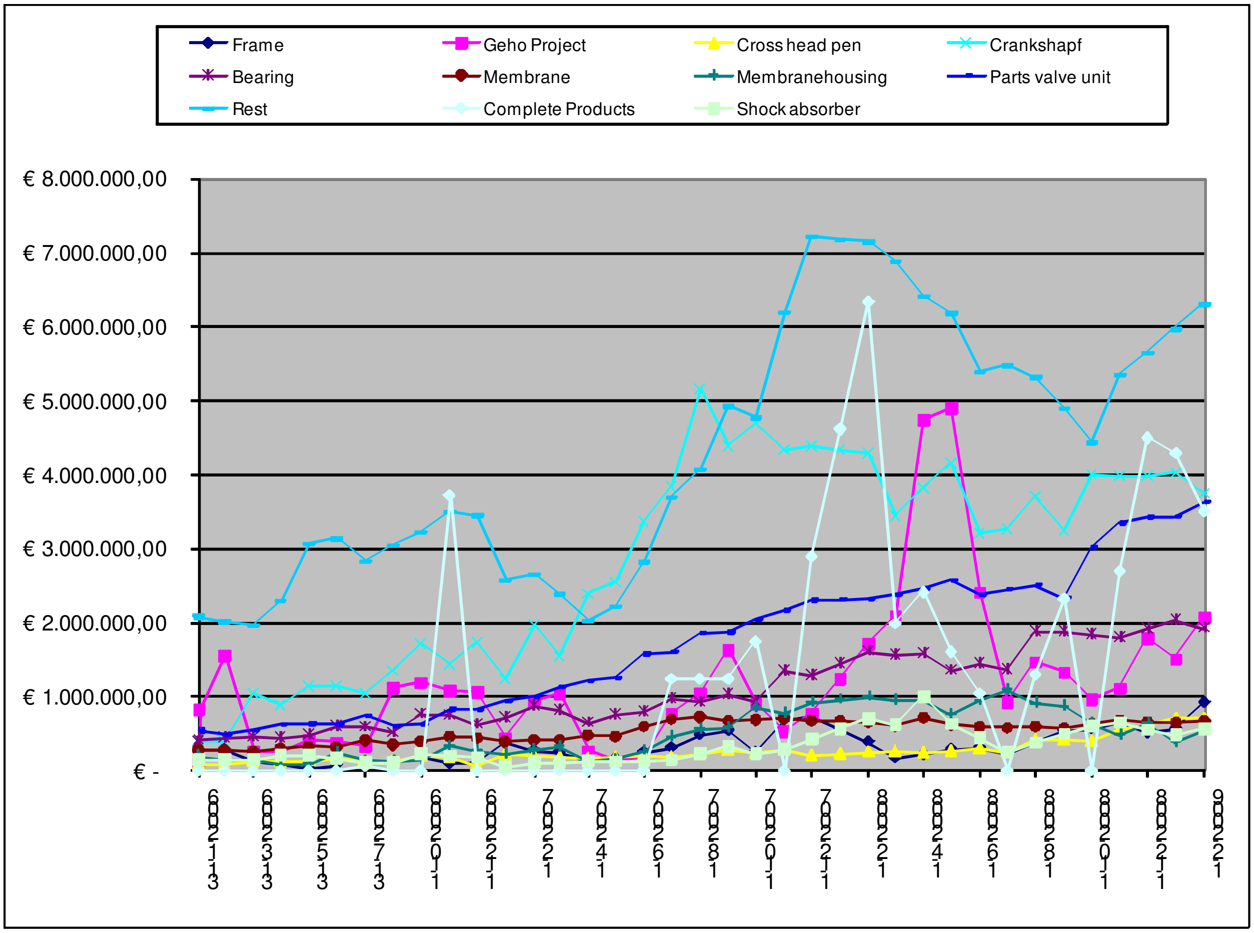

Figure C5 Item category levels for product line A1

In figure C5 the development from the inventory levels based in the identified item categories in this company is graphically presented. Also here the remark that the complete products category has a fluctuation pattern. Besides that also the project category has a fluctuating pattern with a large peak in the first half of 2008. This is due to a large project with 12 products for the same customer in that period. All the project specific parts for these products are ordered the same time. Here also remarkable is that the rest category has the largest contribution to the total inventory level. This means that the largest category in the inventory consist out of items which are not allocated to a specific category of attention. Normally it is expected that the rest category only consist of a minor part of inventory not needing specific or special attention.

Appendix D Factor analysis

Appendix D1 Interview Scheme

This appendix describes the interview setup for the qualitative analysis. This scheme is developed based on the interview theory provided by Emans (1990). The steps mentioned in this theory are provided below here.

Step 0 Goal of the interview

The goal of the in-depth interviews is to get insight in the organizational processes en to find out which factors in these processes are responsible for the deviating inventory performance. All departments which are involved in the company's production process and influence the inventory position are subject for these interviews. This in order to get a complete and unbiased overview of what has happened

Step 1 Definition of theoretical variables

Nr	Name	Collection A (respondent)	Collection B (Values)
1	Process	All respondents	Process description
2	Goals	All respondents	Available goals and performance indicators
3	Performance	All respondents	Vision on the performance of department and organization
4	Working together	All respondents	Communication and working together experiences
5	obstacles	All respondents	Possible obstacles for efficient working
6	Changes	All respondents	Changes in organization from May 2007 up till now
7	Reactions on changes	All respondents	How are changes handled
8	Reaction on Supplier reliability (internal as well as external suppliers)	Purchasing/ Operations Planning	How is reacted to reschedules and deviating delivery performance

Step 1 Theoretical variables

Step 2 and 3 From Theoretical to raw variables

	Step 2+3		**Step 5**		
Nr	**Raw variable**	**Value**	**Answer System**	**Answer Instruction**	**Document instruction**
1.1	General department working	Work description	Open question	Description of process	Key words
1.2	Contribution	Contribution to company process	Open question	Perception of contribution	Key words
2.1	Available performance measures	KPI	Open question	All KPI and importance	Key words
2.2	Performance	KPI performance	Open question	Perception of performance	Key words
2.3	Conflicts	Conflicting KPI	Open question	All possible perceptions	Key words

3.1	Departmental performance	Perception of department performance	Open question	Perception of the performance	Key words
3.2	Company performance	Perception of company performance	Open question	Perception of the contribution	Key words
4.1	Working together internal	Experiences within department	Open question	All possible experiences	Key words
4.2	Working together external	Experiences between departments	Open question	All possible experiences	Key words
4.3	Communication process	Experiences communication	Open question	All possible experiences	Key words
5.1	Obstacles	Experiences obstacles	Open question	All possible experiences	Key words
5.2	Obscurities	Perception of thing not clear for efficient working	Open question	All possible experiences	Key words
5.3	Frustrations	Perception of frustrations	Open question	All possible experiences	Key words
6.1	Changes	Indication of occurred changes in period	Open question	All experienced changes	Key words
6.2	Reaction on changes	Perception of how is reacted on changes	Open question	All possible experiences	Key words
7.1	Reaction on reschedules	Perception of reactions	Open question	All possible experiences	Key words
7.2	Impact of changes	Perception of the consciousness of the impact from changes	Open question	All possible perceptions and importance	Key words
8.1	Reaction on late deliveries	Reaction and experiences	Open question	All possible experiences	Key words
8.2	Reaction on early deliveries	Reaction and experiences	Open question	All possible experiences	Key words

Theoretical variables step 4 and 5

Step 4 from Goal to raw variables

	Step 4			**Step 5**		
NR	**Raw variable**	**Collection A**	**Collection B**	**Answer system**	**Answer instruction**	**Document instruction**
9.1	Interviewer	All interviews	Name interviewee	Closed question	None	Write down
9.2	Respondent	All interviews	Respondent number	Closed question	None	Write down
9.3	Date	All interviews	Date interview	Closed question	None	Write down
9.4	Time	All interviews	Interview duration	Closed question	None	Write down

Technical variables step 4 and 5

Step 5 from raw variables to answer and document systems

Is given in the tables by steps 3 and 4

Step 6 Instruction for asking questions

All raw variables are asked with questions to the respondents. It is important to get as much as possible information form the respondent. For the interview is from great importance to ask extra questions in order to get the desired information

Step 7 the sequence of questions

The subject of the interview would have the following sequence/

1. General overview of the activities of the department or person and the contribution to the company process
2. Goals of the department
3. Performance of the department
4. Occurred changes in department and organization
5. Reaction on occurred changes
6. Reaction on deviation of the standards operation process
7. Working together and communication processes
8. obstacles

The choice is made to handle the subjects working together, communication and obstacles at the end of the interview. These questions ask clearly to a personal perception of a person and would be therefore not entirely objective. Early asking these questions would harm the more objective questions in the first part of the interview

Step 8 Lay-out, introduction and closing

The introduction of the interview would clearly indicate the goals for the interview. It would introduce the student and the project he is working on in this company. Also the expectations and meaning for the interview is clearly explained. At the end of interview a short moment is taken to evaluate the interview with the interviewee. The interviewer gives a short summary of the answers obtained during the interview and asks the interviewee if this interpretation is right and no important facts are missing.

The Basic Questions

Question 1

Question 1A: What is your function at the department?
Question 1B: for how long are you working in this function?
Question 1C: for how long are you working for the organization?

Question 2

Question 2A: What are the main tasks for the department?
Question 2B: What are your function and tasks in the department?
Question 2C: What is the contribution of the department tot the company process?
For Project Management

Question 2D: How are project plans generated
For Sales
Question 2D: How is the forecast or demand for new equipment generated?
Question 2E: How is the forecast or demand for spares generated?
For Operations planning:
Question 2D: How are sales orders generated to requisitions and production orders?
Question 2E: When and how is decided to process thing internal or external?
For Purchasing
Question 2D: How are Purchasing orders generated?

Question 3
Question 3A: What are the goals of the department?
Question 3C: Which Performance indicators are defined for this department?
Question 3D: are these indicators for the department only or for the entire organization?

Question 4
Question 4A: What is the performance of the department?
Question 4B: How is the performance in comparison to other departments?
Question 4B: What is the contribution of the department to the overall company performance?

Question 5
Question 5A: Are there important changes occurred in the period around May 2007 till now?
Question 5C: What was the reaction to these changes?
Question 5D: Has the performance of the department changes due to these changes?

Question 6
Question 6A: What is the reaction on changes occurred in the process. For example how is reacted to reschedules?

Question 7 (Especially for the interview with operations Planning and Purchasing)
Question 7A: What is the reaction to early deliveries?
Question 7B: What is the reaction to late deliveries?
Question 7C: What is the reaction to quality rejections?
Question 7D: What is the reaction to internal delivery performance?

Question 8
Question 8A: How is the cooperation within the department?
Question 8B: How is the cooperation between departments?
Question 8C: How is the communication in the organization?
Question 8D: Is all information needed available and on time?

Question 9
Question 9A: Are all tasks to be executed clear to you?
Question 9B: is it clear how to handle in particular situation?
Question 9B: Do you experience obstacles in the organization for efficient working?

Appendix D2 Sales development

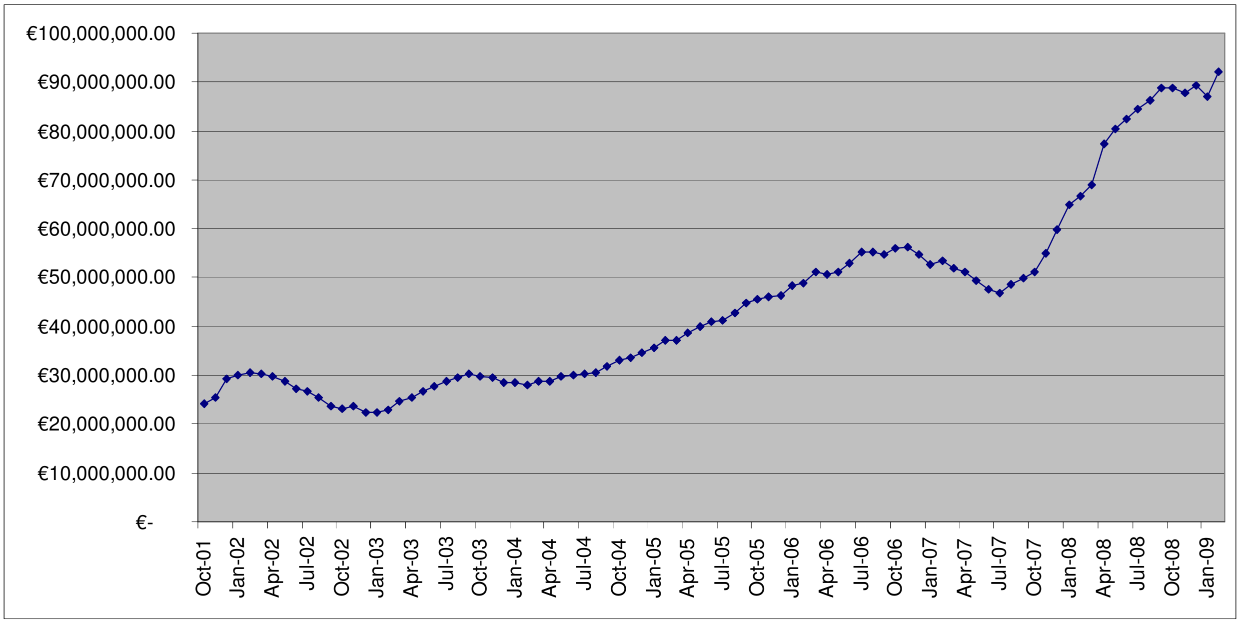

Figure D1 Sales development presented by annual COGS level

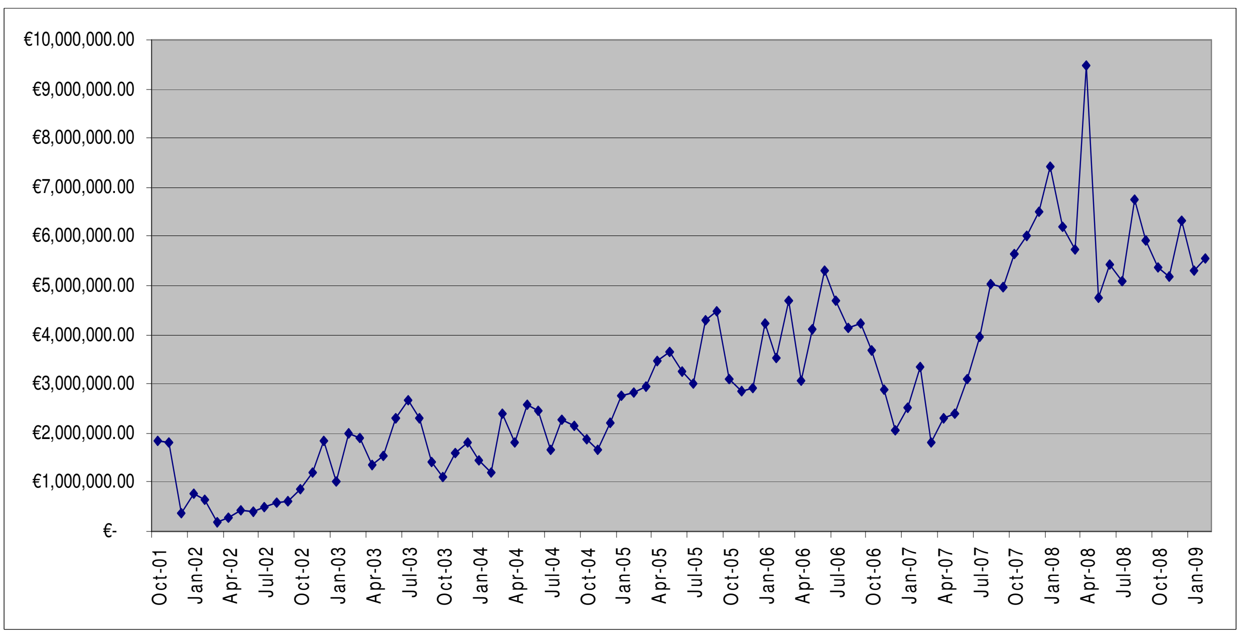

Figure D2 Sales development presented by monthly COGS level

Figures D1 and D2 shows the development of sales levels at the company based on the CODS from October 2001 till February 2009. Figure D1 shows the annual COGS as a sum of the monthly COGS of the last 12 months. Figure D2 shows the monthly COGS levels. It can be seen that the company faces increasing sales from the beginning of 2002 based on monthly COGS. In the second half of 2006 and the first months of 2007 sales shows a decrease. After this period sales again increase. This increase is significantly higher compared to the increasing sales in the periods before July 2006. For example, annualized sales increased from 20 to 65 million Euros in 4 years (January 2003 till January 2007). On average this is an increase of 11.25 million Euros a year. From May 2007 to May 2008 sales increases from 60 million to 90 million Euros. This means an increase of 30 million Euro in one year.

Appendix D3 Dates used in the order process

Figure D1 presents the used dates in the delivery process. As show the process consists of two paths leading to the assembly phase. The first one is the delivery of materials directly usable in the assembly. The second path shows the delivery of raw materials to the machining department and the delivery of the machining department to the assembly department. First of all the Promise date is the date which is arranged between the company and its customers for the delivery of products or spare parts. The need by date is the delivery date which is arranged between the company and the suppliers. The Requirement dates are the dates at which material really must be available because at this moment they are needed in the production process. In the machining department the schedule dates are the dates at which the material must be completed due to the production planning. Due uncertain deliveries by external suppliers (Raw as well ass complete materials) a slack time of three weeks is added to buffer for these uncertainties. Between the machining and the assembly department even a period of 1 month is added to buffer for unreliable deliveries

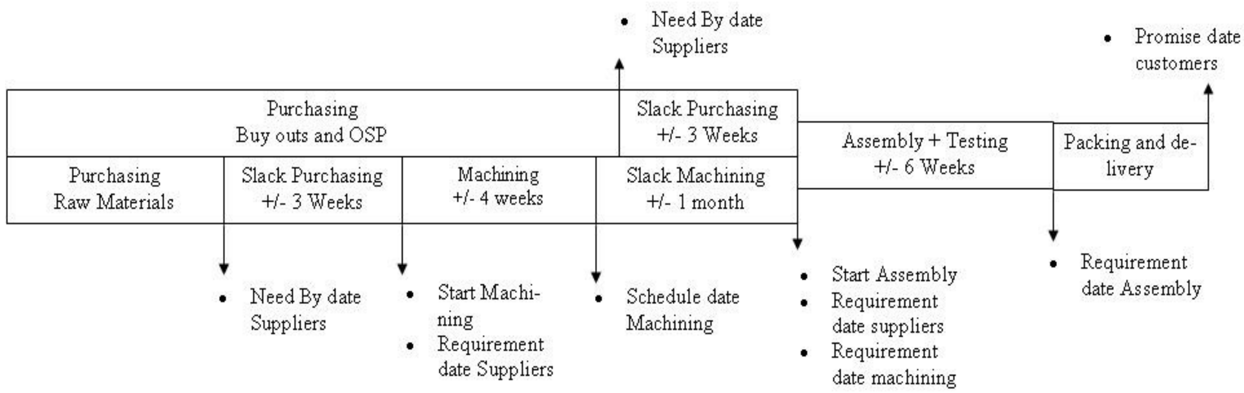

Figure D3 used dates in the order process

Appendix D4 supplier performance

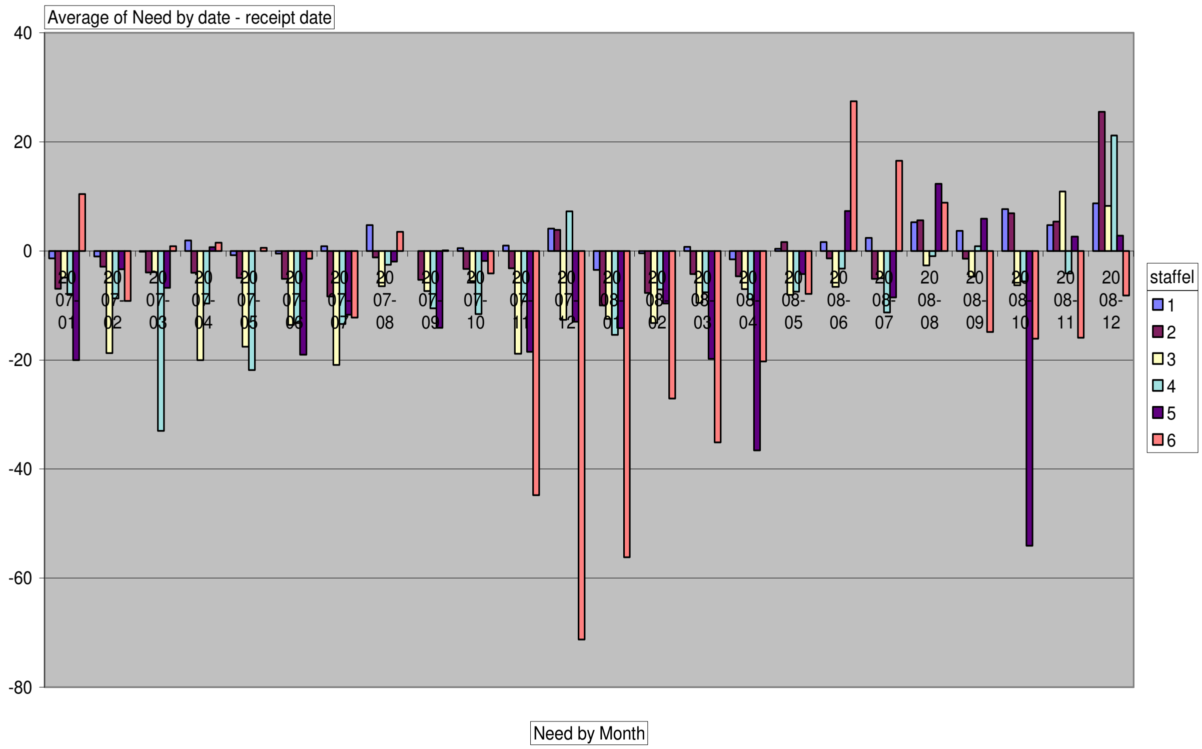

Figure D4 average between need by and receipt date based on item cost index

Figure D4 shows the average difference between the arranged delivery date (need by) between the company and its suppliers and the real delivery date of those suppliers. In this figure a distinction is made between the values of the items orders. The items are ordered on the Following indexation:

- category 1: items with cost price below 1000 Euros
- category 2: items with cost price between 1000 and 5000 Euros
- category 3: items with cost price between 5000 and 10000 Euros
- category 4: items with cost price between 10000 and 50000 Euros
- category 5: items with cost price between 50000 and 10000 Euros
- category 6: items with cost price over 100000 Euros

From the figure it can be seen that before especially items with high cost prices are delivered late in the period between November 2007 and May 2008. On average these values increased op to over 60 days late delivery in December 2007. Also the figure shows that before May 2008 on average almost all items categories are delivered late. After May 2008 this pattern changes to an on average slightly early delivery.

Figure D5 shows graphically the delivery performance based on the requirement dates. It shows that from May 2007 the late values increased with peaks of 40% late delivery. After May 2008 late values decreased to values around 5% at the end of 2008. Looking at the early deliveries based on requirement date is can be seen that till May 2008 these values fluctuate between 40 and 50 percent. After May 2008 these early deliveries increased up to 70% at the end of 2008.

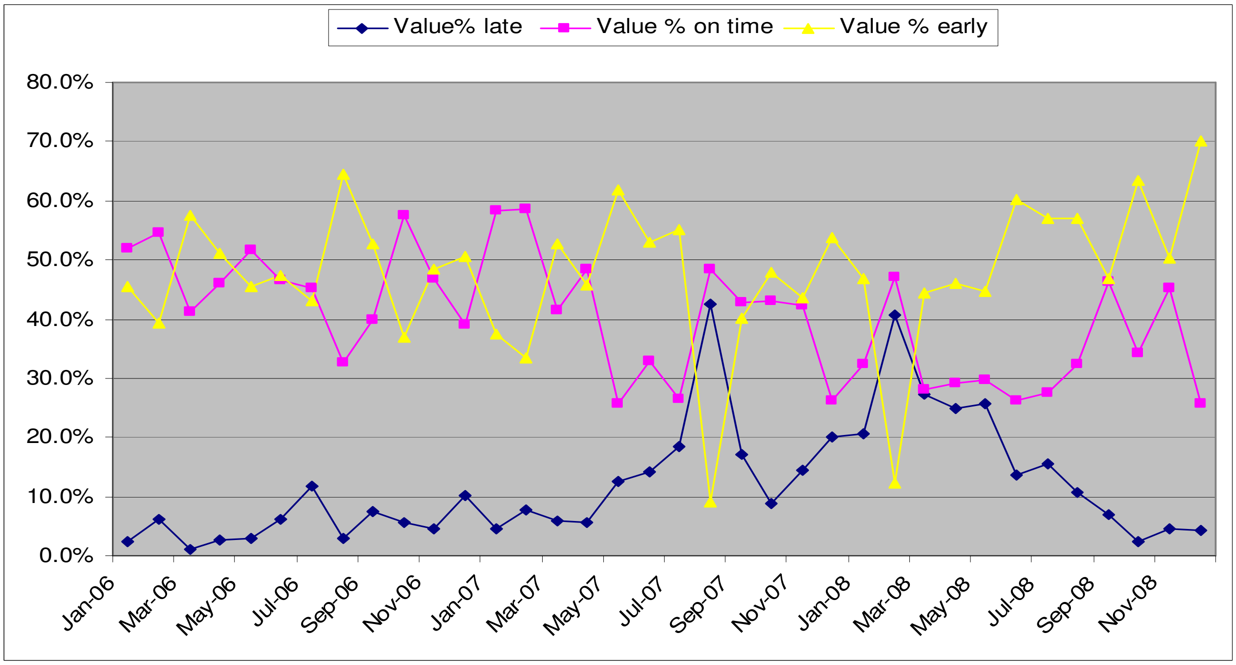

Figure D5 on time delivery based on requirement date

Appendix D5 causes for reschedules

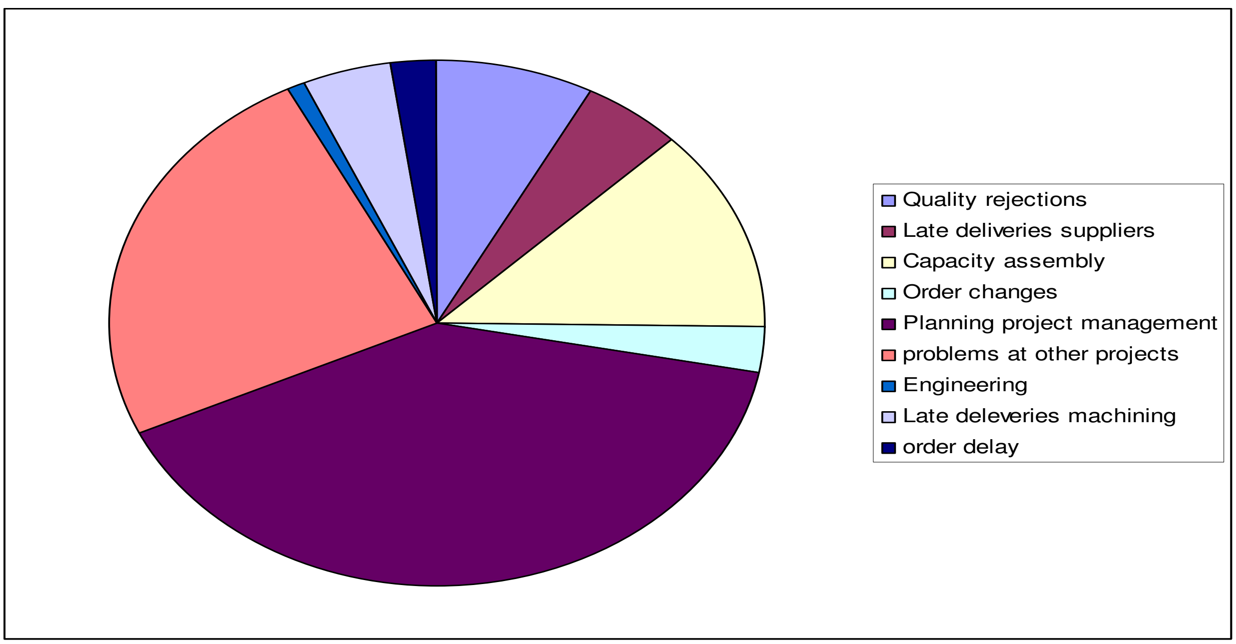

Figure D6 Causes for reschedules

In Figure D6 the caused for the reschedules are graphically presented. It can be seen that the largest part of the reschedules (40%) is caused b the Planning method of project management. after that 25% of the reschedules is cause by problems in other projects and 12% by capacity problems in the assembly department. The quality rejections count for 10% of the reschedules. The other categories only have a minor (less than 5%) contribution to the reschedules

Appendix E Prediction model

Appendix E1 Relevant model selection

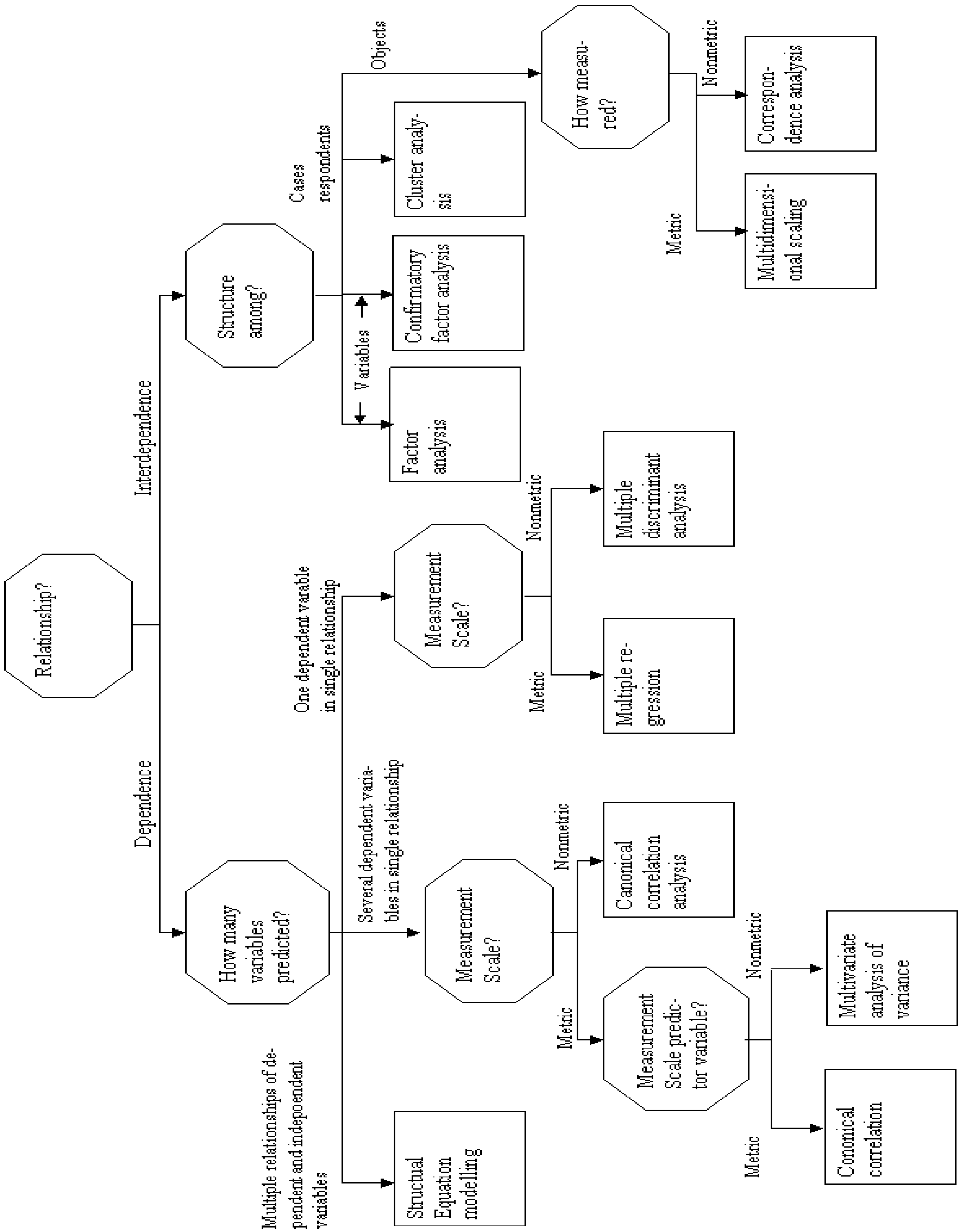

Figure E1 selection model for relevant multivariate technique

Figure E1 shows the selection procedure by Hair (2006) for the relevant multivariate data analysis technique. First of all the relationship between the variables must be assessed d. The question to ask here is if the relation consists of dependence of interdependence. When there is a dependence relationship there are one ore more dependent variables which are related to several independent variables. In an Interdependence relationship there is no distinction between independent and dependent variables. In the satiation of this project there is a dependence relationship. The goal is to explain the development of the inventory level (dependent variable) out of the development of several factors (independent variables). Here also the second question could be answered. There is one dependent variable in a single relationship with the several independent variables. The last question to ask now is the measurement scale of the variables. The distinction is made between metric and non metric variables. Metric means that a factor is measured with quantitative data, interval data or ratio data. Examples of metric data are a person's age or weight. Non metric data is also called qualitative data. They differ from metric data by indication the perception of a parameter, but not the relative amount. Examples of such data are the status of a particular parameter. For example a parameter could have the values low or high. In this project all identified variables have metric values. So the most suitable technique is multiple regression analysis according to the model of Hair (2006).

Appendix E2 Normal distribution and Tests for normality

In order to make a regression model statistically significant the normality assumption is crucial for the variables entered in the model. Without normality all statistical tests to the resulting model are invalid. Especially in small data sets like this project the normality assumption is crucial. This appendix explains the normal distribution and explains the three tests provided by Hair (2006) to assess the normality for the variables. Figure E1 shows the bell shaped normal distribution. The normal distribution assumes that the data within a variable is distributed around the mean of the variable as shown in the figure based on the standard deviation.

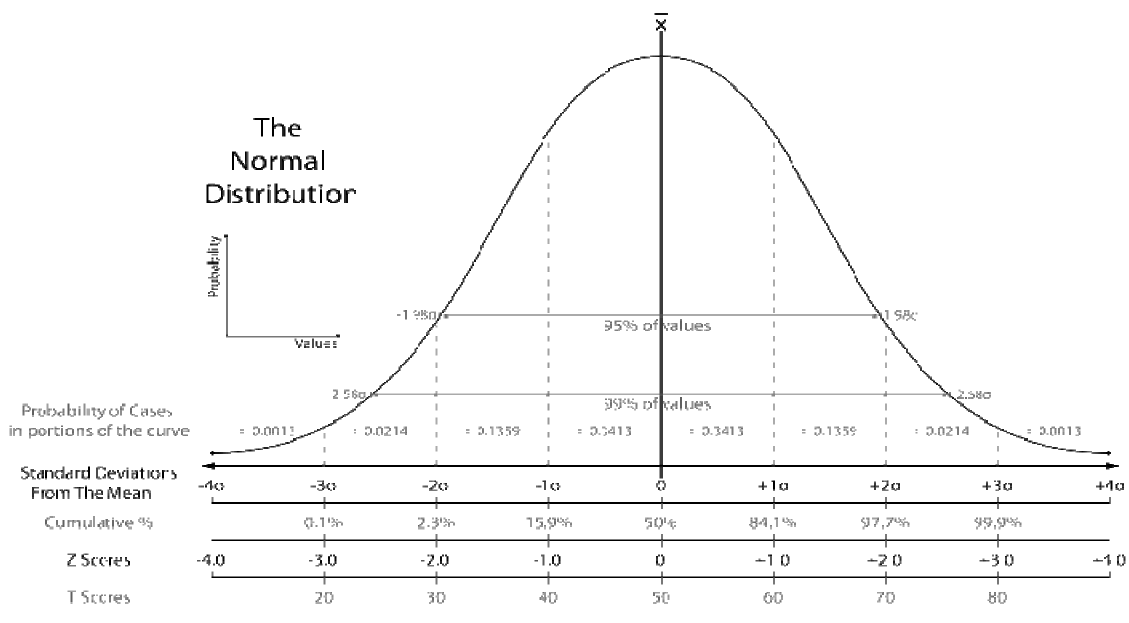

Figure E2 normal distribution shape

Hair (2006) provides three statistical tests to asses the normality of a variable. These test are explained here

Fist of all there are two tests that looks if the shape of the variable distribution corresponds to the normal distribution shape. The first measure is the Skewness. Here the symmetry of the distribution is tested. The variable should be equally distributed around the mean in order to be normal distributed. To statistically test the obtained skewness the z-score has to be obtained. The following formula gives the calculation of the z value for the skewness.

$$Z_{skewness} = \frac{Skewness}{\sqrt{\frac{6}{N}}}$$

Equation E1 z-value calculation for the Skewness

N = denoted as the number of observations within the variable. To become 95% confident that the variable belongs to the normal distribution according the skewness the z-value may not be higher than 1.96 or lower than -1.96.

The second shape measure is the kurtosis of the variable. This test looks if there are unusual peaks in the distribution of the variable. According to the shape of the normal distribution the peak of data should lie around the median of the data. Peaks at the beginning or at the end of the variable spectrum violate the normality assumption.

From the kurtosis values also the statistical z-score could be calculated

$$Z_{Kurtosis} = \frac{Kurtosis}{\sqrt{\frac{24}{N}}}$$

Equation E2 z-value calculation for the Kurtosis

Again N is the number of observations within the variable. Here for the z-score the same criteria as for the skewness measure are applicable.

The third statistical test which is executed in a statistical program as Statgraphics is the Shapirio-Wilks test. This test calculates the level of significance from the difference of the variable from the normal distribution. If the p-value of the test becomes below 0.05 it could be rejected that the variable comes from a normal distribution with 95% confidence.

Besides these statistical tests it is also important to graphically inspecting the normality of the variable. Especially in small data sets statistical test not always gives the right measures. A graphical inspection of the histogram of the variable therefore gives a valuable contribution to the decision of the normality of the data.

Appendix E3 Normality tests for the independent variables

Table E1 shows the normality test scores for the original variables. The values marked in red shows the test results deviating form normality by a 95% confidence level. This means that if the p-value of a test becomes below 0.05 the assumption that the variable comes from a normal distribution could be rejected with a confidence of 95%. In this case only 2 of the original variables meet the normality assumption.

	Shape directors tests						
	Skewness		Kurtosis		Test for normality		Normal distributed?
	Statistic	P-Value	Statistic	P-Value	Statistic	P-Value	95% confident
SKU	0.879	0.377	-2.21	0.026	0.902	0.003	No
Quality rejections	0.267	0.789	0.006	0.995	0.977	0.716	Yes
OTD Late	0.642	0.521	-1.876	0.061	0.922	0.045	No
OTD On time	1.283	0.199	2.213	0.027	0.951	0.143	No
OTD Early	1.642	0.084	1.039	0.299	0.925	0.017	No
OTD Machining	0.335	0.738	-212	0.034	0.937	0.125	No
OTD Assembly	0.246	0.805	-0.709	0.478	0.963	0.483	Yes
Reschedules	2.100	0.036	2.453	0.014	0.87	0.000	No
Slack Late	1.768	0.077	1.32	0.187	0.874	0.004	No
Slack On time	1.069	0.285	-0.747	0.455	0.88	0.005	No
Slack Early	1.771	0.077	1.191	0.056	0.894	0.015	No
COGS 6	0.793	0.428	-3.651	0.000	0.805	0.000	No
COGS 3	1.027	0.305	-1.888	0.059	0.849	0.001	No

Table E1 Normality test scores original variable

Figure E2 shows for the first variable of table E1 the graphical normality test.

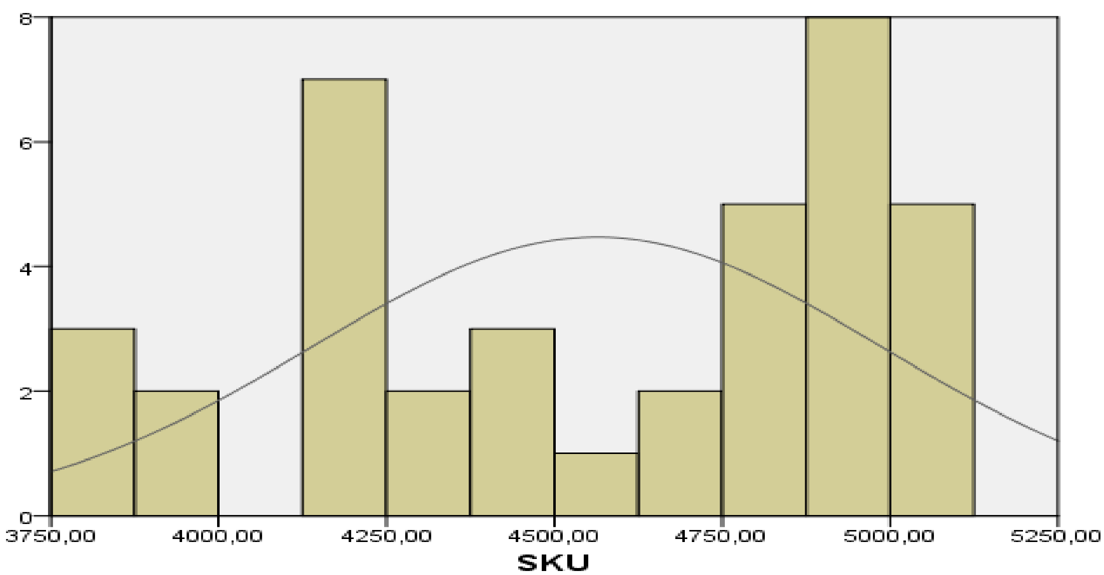

Figure E3 Normal distribution plot for SKU

Inspecting this figure shows that the variable does not come form a normal distribution. Especially the peaks at the end of the variable spectrum and the low values in the middle are violation the normality. This is also denoted by the kurtosis test in Table E1.
The transformations to the variables provided by Hair (2006) to achieve normality do not give the desired results. The difference remedy provided by Chatfield (2004) gives the results as shown in table E2. As shown here all differenced variables meet the normality assumption and are therefore usable to build the model. No test scores below the 0.05 level are obtained.

	Shape directors tests						
	Skewness		Kurtosis		Test for normality		Normal distributed?
	Statistic	P-Value	Statistic	P-Value	Statistic	P-Value	95% confident
ΔSKU	0.929	0.353	1.461	0.144	0.966	0.387	yes
ΔQuality rejections	0.451	0.652	-0.672	0.501	0.979	0.779	Yes
ΔOTD Late	0.517	0.605	0.818	0.413	0.976	0.699	yes
ΔOTD On time	0.579	0.562	-1.558	0.119	0.957	0.202	yes
ΔOTD Early	0.391	0.696	0.225	0.822	0.982	0.866	yes
ΔOTD Machining	0.079	0.939	-1.202	0.229	0.965	0.537	yes
ΔOTD Assembly	0.044	0.965	-1.276	0.202	0.976	0.699	Yes
ΔReschedules	0.959	0.337	0.674	0.499	0.967	0.528	yes
ΔSlack Late	0.245	0.805	1.183	0.086	0.935	0.125	yes
ΔSlack On time	0.346	0.729	-0.479	0.632	0.961	0.437	yes
ΔSlack Early	0.587	0.391	1.374	0.169	0.942	0.169	yes
ΔCOGS 6	0.639	0.532	-1.029	0.304	0.931	0.086	yes
ΔCOGS 3	0.338	0.735	-0.756	0.449	0.939	0.139	yes

Table E2 Normality test scores Differenced variables

Figure E3 shows the graphical test to the differenced SKU variable to show that the statistical tests indeed gives the right result for the test variable. Inspecting this figure it could be seen that the distribution of the variable quite good follows the normal probability line. Only the peak is in the middle is a bit lager and at the end of the spectrum there is a small gap. So the statistical and graphical test does shows that the variables ΔSKu comes from a normal distribution. For all other variables the same could be obtained

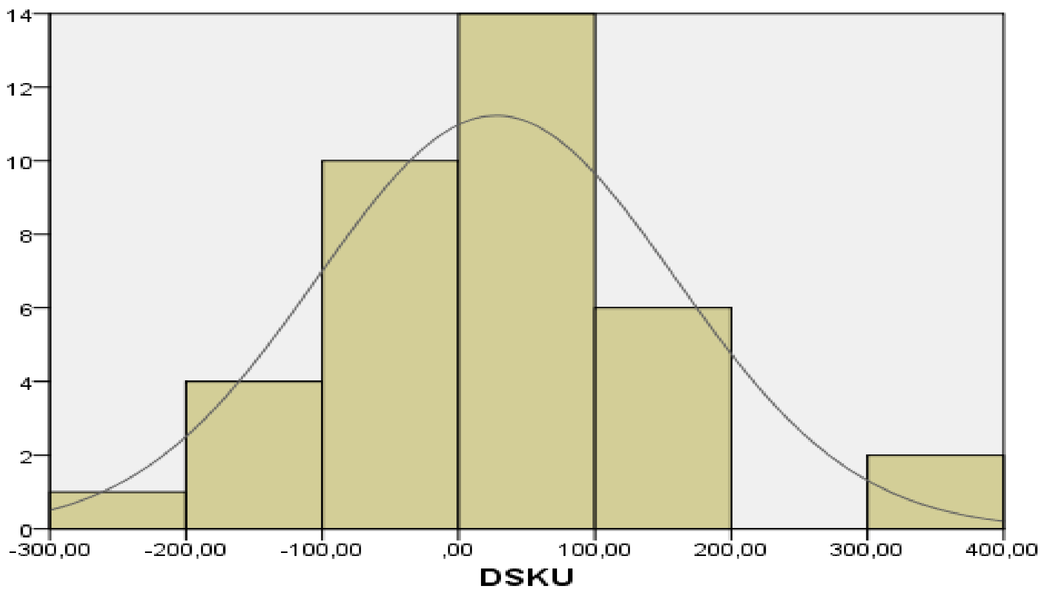

Figure E4 Normal distribution plot for differenced SKU

Appendix E4 Regression model linearity test

To use a regression model the assumption is that a relationship the independent variable and the dependent variables exists. When these relationships are expected to be linear, a linear regression model can be used. To test this assumption for each of the independent variables the relation with the dependent variable is examined. Therefore the assumption is that a simple linear relation exits between the independent variable x and the dependent variable Y:

$$Y = \beta_0 + \beta_1 x + \varepsilon$$

Equation E3 linear regression

Here ε is the random error with mean zero and (unknown) variance.
Suppose that n observations are done in the past, which resulted in combinations x and y: $(x_1, y_1), (x_{2,} y_2), \ldots.., (x_n, y_n)$. The coefficients β_0 and β_1 should be estimated in such a way that a straight line is created which has the best fit with the n observations done. In regression analysis, the best fit is determined by minimizing the sum of squared errors of the estimated line with the actual observations. To find out whether indeed a relationship exists between the dependent the independent variable x and dependent variable y, a t-test is conducted for the significance of the model. The hypotheses in this model are:

$$H_0 : \beta_1 = 0$$

$$H_1 : \beta_1 \neq 0$$

The null hypothesis is rejected with 95% confidence when the p-value of the statistical value obtained by the t-test is below 0.05. When the null hypothesis is rejected, it can be concluded that a linear relationship exists between the two variables. Extending this model with more independent variables, which also have a linear relation with the dependent variable, results in a multiple linear regression model.

The outcome of linearity tests for the independent variables with the dependent variable is given in Table E3. It shows that for most of the variables the linear relation exists. For the variables which have not a significant linear relation there it has to be identified if some none-linear relations occur.
A method to do this is the assessment of the residuals for the appearance of linear or non-linear relations. A linear relation in the residuals would indicate a relation between the variables which is not explained by a linear relation between the variables.
For the variable ΔOTD Assembly this residual plot is shown in Figure E4. The residual plot does not indicate any linear or non-linear relations between the variables. Also for the other variables no non-linear relation can be identified. Therefore a multiple linear regression model would be an appropriate one.

	t-test for linearity		Linear Relation?	None linear relations?
	Statistic	P-Value	95% confident	
ΔSKU	3.605	0.001	yes	No
ΔQuality rejections	1.988	0.046	Yes	No
ΔOTD Late	-0.206	0.837	No	No
ΔOTD On time	-3.906	0.001	yes	No
ΔOTD Early	0.058	0.954	No	No
ΔOTD Machining	2.117	0.045	yes	No
ΔOTD Assembly	-0.842	0.408	No	No
ΔReschedules	3.126	0.004	yes	No
ΔSlack Late	3.121	0.004	yes	No
ΔSlack On time	3.136	0.004	yes	No
ΔSlack Early	-0.882	0.384	No	No
ΔCOGS 6	3.102	0.004	yes	No
ΔCOGS 3	2.600	0.014	yes	No

Table E3 linearity tests for independent variables

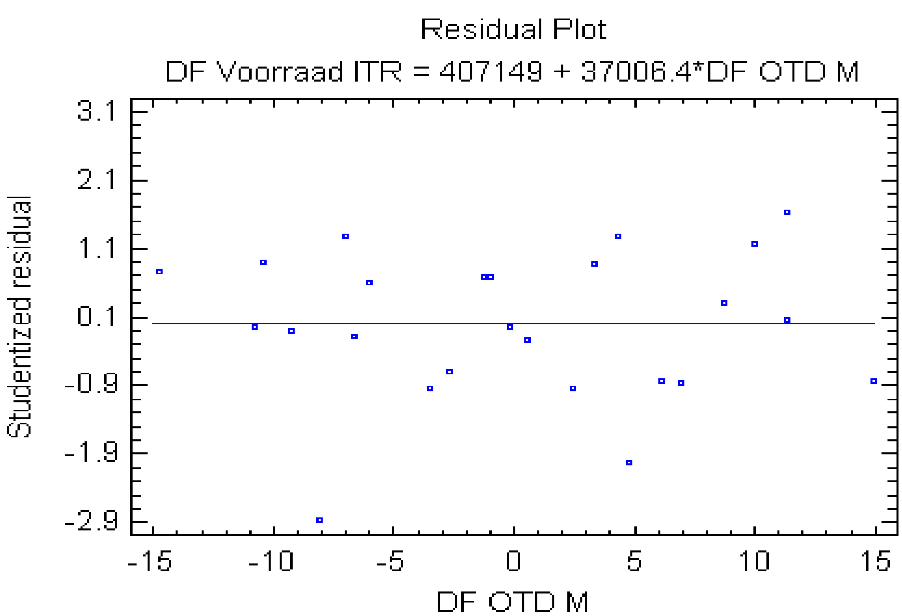

Figure E5 Residual plot for the relation between ΔStockITR and ΔOTD M

Appendix E5 Performance Measures

In this appendix the performance measures to evaluate the regression model are explained.
First of all there is the R-squared value. This measure is used as a global statistic to asses the fit of a multiple regression model (Montgomery and Runger, 2003). This value represents the part of the variability of the data that is explained by the model. A better value to measure this is the adjusted R square value. Here the number of variables entered in the model is considered in the calculation of the performance. Often, adding more variables in the model increase the explanation of variance in the data that has to be predicted.
A second measure for assessing the regression model is the Mean Squared Error (MSE). This measures the mean of the squared differences between observed and the predicted values.
In this project the MSE measures the differences between the observed and the predicted difference in inventory level. The MSE is calculated as follows.

$$MSE(\Delta InventoryITR)_{predicted} =$$
$$\frac{1}{(N-2)}\sum_{i-1}^{N}(\Delta InventoryITR_{i,observed} - \Delta InventoryITR_{i,predicted})^2$$

Equation E4 MSE calculation

The lower this measure the better the performance of the model.
The next measure is the F ratio to test the statistical significance of the regression model
The F-ratio is calculated out of the sum of squares of the regression model and its errors and the degrees of freedom of the regression model and its errors.
The calculation is al follows.

$$F - Ratio = \frac{\dfrac{\text{Sum of squares}_{\text{regression}}}{\text{Degrees of freedom}_{\text{regression}}}}{\dfrac{\text{Sum of squares}_{\text{residual}}}{\text{Degrees of freedom}_{\text{residual}}}}$$

Equation E5 F-ratio calculation

With:
Df regression = Number of variables entered in the model (including the constant) -1
Df residual = Sample size – number of entered variables (including the constant)

If the P-value for the F-Ratio is below 0.05 is can be concluded that the model is significant with a confidence of 95%.

The last measure which is assessed to determine the performance of the regression model is the Mean Absolute Percentage Error (MAPE) this measures the mean percentage of difference between the observed and the predicted value. In this project the resulting inventory levels are estimated by the predicted inventory differences. These estimated inventory levels are compared to the real observed inventory levels.
The calculation for the measure is the following

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left\|\frac{OBservedInventoryITR_i - EstimatedInventoryITR_i}{ObeservedInventoryITR_i}\right| * 100\%$$

Equation E6 MAPE calculation

Appendix E6 Practical model verification

$$\text{Difference Stock ITR} = 130201 + 68860.1 * \Delta R + 6022.87 * \Delta SKU - 25491 * \Delta SL_O + 0.200595 * \Delta COGS_6 + 28921.7 * \Delta Q$$

Equation E7 predicted difference in stock

	STOCK	PRED STOCK	DF STOCK	DF COGS	DF KWAL	DF OP TIJD	DF SKU	DF RESCHEDULE	ACT - PRED	Error %
Jan-07	15,654,411.22	15,654,411.22								
Feb-07	13,685,356.05	15,006,315.97	-648095.25	-1576000.00	-16	0.44	-81	9	1,320,959.92	10%
Mar-07	12,783,698.61	14,745,902.38	-260413.58	-4874000.00	-2	-17.14	-80	10	1,962,203.77	15%
Apr-07	12,510,826.13	12,949,130.83	-1796771.55	-2750000.00	-29	6.91	40	-9	438,304.71	4%
May-07	11,119,822.94	13,073,588.12	124457.29	-968000.00	17	-22.83	-8	-12	1,953,765.19	18%
Jun-07	13,740,223.63	15,460,157.66	2386569.53	-1926000.00	-13	7.27	382	13	1,719,934.02	13%
Jul-07	15,756,395.32	16,772,481.23	1312323.57	2892000.00	-26	-6.23	150	4	1,016,085.91	6%
Aug-07	20,185,692.74	18,769,914.02	1997432.79	3370000.00	60	21.81	134	-11	1,415,778.72	7%
Sep-07	23,755,484.97	21,330,103.96	2560189.94	6314000.00	11	-5.65	49	6	2,425,381.01	10%
Oct-07	25,350,109.62	24,964,549.42	3634445.46	6636000.00	31	0.37	91	11	385,560.20	2%
Nov-07	25,217,190.10	26,768,202.23	1803652.81	7228000.00	-21	-0.95	86	4	1,551,012.12	6%
Dec-07	25,516,596.19	26,663,446.80	-104755.43	6852000.00	-40	-16.09	-136	-1	1,146,850.61	4%
Jan-08	28,620,181.01	29,011,097.73	2347650.94	6912000.00	35	6.38	12	-1	390,916.72	1%
Feb-08	27,281,066.82	27,835,842.50	-1175255.24	2320000.00	-20	14.52	10	-13	554,775.68	2%
Mar-08	28,846,273.69	29,984,496.08	2148653.58	1582000.00	17	-18.79	-37	14	1,138,222.39	4%
Apr-08	30,934,438.33	32,245,801.28	2261305.20	900000.00	-8	0.97	114	22	1,311,362.95	4%
May-08	32,373,002.65	32,514,199.47	268398.19	-2484000.00	2	0.46	-119	19	141,196.82	0%
Jun-08	28,493,137.84	30,125,502.69	-2388696.78	-2200000.00	29	-3.48	-50	-39	1,632,364.85	6%
Jul-08	22,807,034.07	24,627,146.16	-5498356.53	-4668000.00	-78	1.28	-190	-19	1,820,112.09	8%
Aug-08	28,349,392.00	27,020,073.17	2392927.01	1094000.00	38	4.86	67	10	1,329,318.83	5%
Sep-08	29,511,008.81	27,353,675.07	333601.90	364000.00	34	13.94	81	-14	2,157,333.74	7%
Oct-08	24,819,289.34	27,259,027.65	-94647.42	-1396000.00	15	-12.05	-78	-3	2,439,738.31	10%
Nov-08	26,844,422.54	29,868,696.76	2609669.11	868000.00	-38	11.03	345	23	3,024,274.22	11%
Dec-08	26,687,857.30	27,300,625.35	-2568071.41	1834000.00	-21	-19.63	-242	-22	612,768.05	2%
Jan-09	27,668,489.23	26,921,974.12	-378651.24	464000.00	12	2.40	-89	-5	746,515.11	3%
Feb-09	28,582,063.47	27,138,432.60	216458.48	-2400000.00	1	-5.70	54	1	1,443,630.87	5%
								TOTAL	34,078,366.83	MAPE
								MAE	1,363,134.67	7%

Table E4 Predicted vs. actual stock values

Table E1 shows the Practical verification of the resulting model. The values for the difference stock level are calculated out of the differences in the independent variables of the model according to Equation E7. The starting point is January 2007, where the predicted stock level is equal to the real observed stock level. After that the predicted stock level is calculated by adding the calculated difference in stock to the predicted stock level of the previous month. The predicted stock levels are compared to the actual observed stock levels and the error is presented in the figure. After that the MAPE is calculated according to Equation E6. The table shows that on the selected period the model shows MAPE of 7%

Appendix F Organizational Improvements

Appendix F1 Profile for the COGS within product line A1

In Table F1 the COGS profile for the several products types in product line A1 are presented. It shows for example that a product of type P5 has a Lead Time of 9 months. In each of the months within this lead time a part of the COGS for this product is financially administered and used for performance reporting.

			Month								
Product type	Leadtime		Delivery	-1	-2	-3	-4	-5	-6	-7	-8
P1	6 months	% COGS	10%	30%	25%	20%	10%	5%			
		Cumm % COGS	100%	90%	60%	35%	15%	5%			
P2	6 months	% COGS	5%	25%	30%	20%	15%	5%			
		Cumm % COGS	100%	95%	70%	40%	20%	5%			
P3	8 months	% COGS	5%	20%	20%	20%	10%	10%	10%	5%	
		Cumm % COGS	100%	95%	75%	55%	35%	25%	15%	5%	
P4	8 months	% COGS	5%	20%	20%	20%	15%	10%	5%	5%	
		Cumm % COGS	100%	95%	75%	55%	35%	20%	10%	5%	
P5	9 months	% COGS	5%	10%	25%	20%	10%	10%	10%	5%	5%
		Cumm % COGS	100%	95%	85%	60%	40%	30%	20%	10%	5%

Table F1 COGS Profile for product line A1

Appendix F2 ITR Plots for different COGS calculations

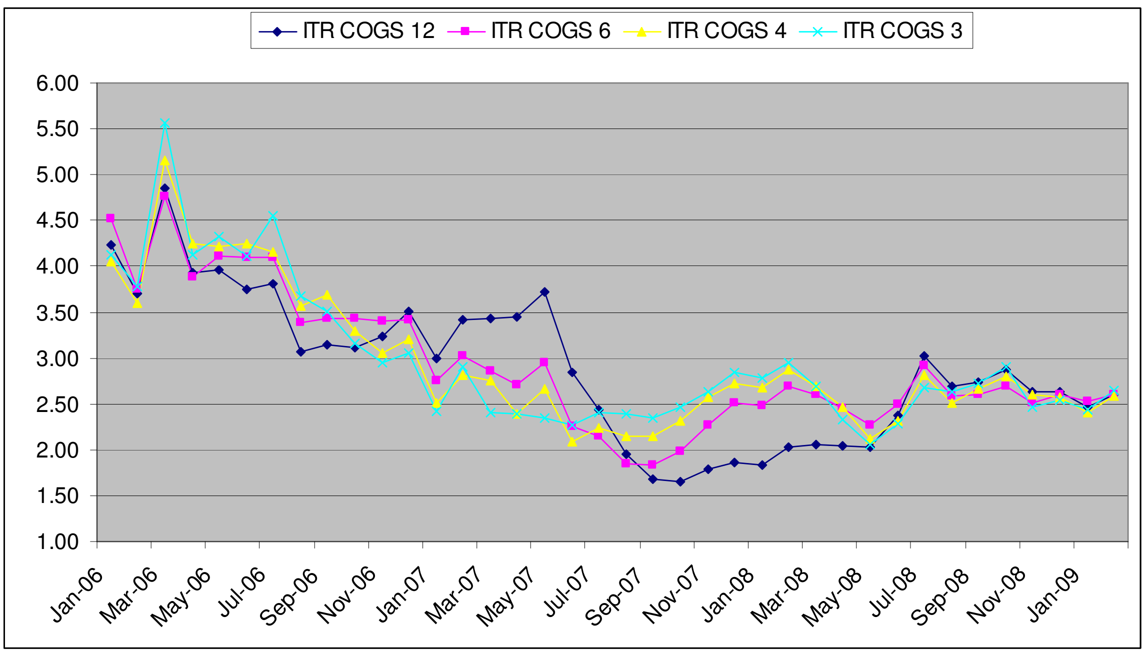

Figure F1 ITR level for different COGS calculations

Figure F1 presents the ITR for different used COGS calculations. ITR COGS 12 means that the annual COGS are based on the sum of the COGS of the last 12 months. And For ITR COGS 6 it means that the annual COGS is based on the sum of the COGS of the last 6 months (times two for annualizing). Looking at this figure is can be seen that From October 2006 till May 2008 the ITR COGS 12 has a significant different pattern compared to the other three patterns.