MASTER

A framework for controlling lead-times in engineer-to-order manufacturing companies

Erpelinck, S.

Award date:
2008

technische universiteit eindhoven

Operations Management & Logistics

[redacted]

Master of Science Program
Operations Management & Logistics

Eindhoven, April 2008

A framework for controlling lead-times in Engineer-to-Order manufacturing companies

by
S. Erpelinck

Student identity number 0571333

in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Supervisors:
Dr.ir. H.P.G. van Ooijen, TU/e, OPAC
Dr.ir. N.P. Dellaert, TU/e, OPAC

TUE. Department Technology Management.
Series Master Theses Operations Management and Logistics

ARW 2008 OML

Subject headings: Engineer-to-Order, delivery, lead-time control, production control

Preface

In the current report the results of a master thesis project, are presented. The master thesis project can be seen as the final project in the master program Operations Management and Logistics at the Technische Universiteit Eindhoven, and is carried out within the sub-department Operations, Planning, Accounting and Control.

The master thesis project started with a preparation in which an area of research had to be identified. Since my interests are broad, and I had no clear preferences about the area I wanted to do my research in, the identification and selection of the research area were difficult for me. In April 2007 Mr. van Ooijen approached me with a request from Eaton Industries B.V. who were searching for a graduation student of the OPAC department. From the first appointment at Eaton Industries B.V., where I heard about the products they produced and the operational problems they faced, I became enthusiastic about a research project at Eaton Industries B.V. A literature study followed, from which I identified an area of research that was currently missing in literature, and which corresponded to the operational problems faced at Eaton Industries B.V. This made me even more enthusiastic to start with my research project.

In August 2007, I started at Eaton Industries B.V. with finishing my research paper and research design and approach. From this the master thesis project followed. The main problems that I faced during the project were the changes in management at Eaton Industries B.V., who were the initiators of the project. Despite of that, I have had a nice time at Eaton Industries B.V. and on the TU/e campus. Now, at the end of the project, I look back on a good time, in which I have learned a lot. Not only with regard to research skills that I obtained, but also the relationship of theory and practice, and the obstacles of bringing theory into practice.

During the research project I've had valuable inputs which helped me accomplish the research project and develop my skills. Therefore first I'd like to thank my first supervisor, Dr.ir. H.P.G. van Ooijen, for the valuable inputs during the meetings we had and the recommendations during the project that gave me insights to deal with problems I faced and write the report. I also thank my second supervisor, Dr.ir. N.P. Dellaert for his insights during the project that helped improve the project and write the report.

Further I'd like to thank the people at Eaton Industries B.V. for the inputs they have given me and the nice time I had working there, and my friends for the relaxing moments during my study. Finally I'd like to thank my parents and sister for advises they gave me during my study and the nice time at home during my study and my research project.

Summary

Introduction

From a literature study conducted prior to the project described in this report, it was seen that customization is an increasingly important factor in manufacturing companies. Besides customization, customers have become more demanding in terms of costs and quality. However, relatively little research is done on manufacturing companies that allow a high degree of customization such as Make-to-Order companies and Engineer-to-Order companies. Within these companies that allow a high degree of customization, besides price and quality, delivery performance is an important competitive factor.

Recent research that has been done within Engineer-to-Order companies mainly has focused on the quotation for orders and manufacturing (planning and control) within Engineer-to-Order companies. An overall framework that describes the activities that are typically carried out in an Engineer-to-Order company and shows the implications from various activities on other activities is missing however. Besides that, research in Engineer-to-Order companies mainly has focused on internal processes. External sources that interact during the total delivery lead-time and the implications the interaction of external sources has on internal processes, mainly is disregarded.

Based on the literature study, limitations that followed out of the literature study, and relevant research questions that were identified from the literature study, the following definition for a master thesis project is made:

Develop a framework that can be used to control the total delivery lead-time within an Engineer-to-Order manufacturing company.

Additional valid research questions that should be answered during the development of a framework to control the total delivery lead-time within an Engineer-to-Order manufacturing company are:

- What characteristic stages can be identified during the total delivery lead-time within an Engineer-to-Order manufacturing company?
- What typical stakeholders can be identified during the total delivery lead-time and its characteristic stages and how do these stakeholders interact?
- What typical main problems can be identified during the total delivery lead-time and its characteristic stages, which harm delivery performance?
- How can the delivery lead-time be managed in such a way that delivery performance can be controlled?

This report will elaborate on the research questions and aims to provide answers to the questions stated. The research and its results that are discussed in the report are based on scientific literature and data from an Engineer-to-Order company, Eaton Industries B.V.

Operational problems at Eaton Industries B.V.

Eaton Industries B.V. is an Engineer-to-Order manufacturing company specialized building large new customized cylinders and offering service and repair for all brands of hydraulic cylinders. The company currently employs 109 people in various functions and had total sales of almost € 20 million in 2007.

Although the company made a rapid growth during the past years, there are quite some operational problems at Eaton Industries B.V. First of all, the operating profit has been negative since 2003. This is mainly due to high material inventories, low efficiencies and outsourcing and subcontracting at premium costs. Besides that, problems are faced with regard to recruitment of experienced and skilled personal, long throughput times of customer orders and a low delivery reliability of customer orders.

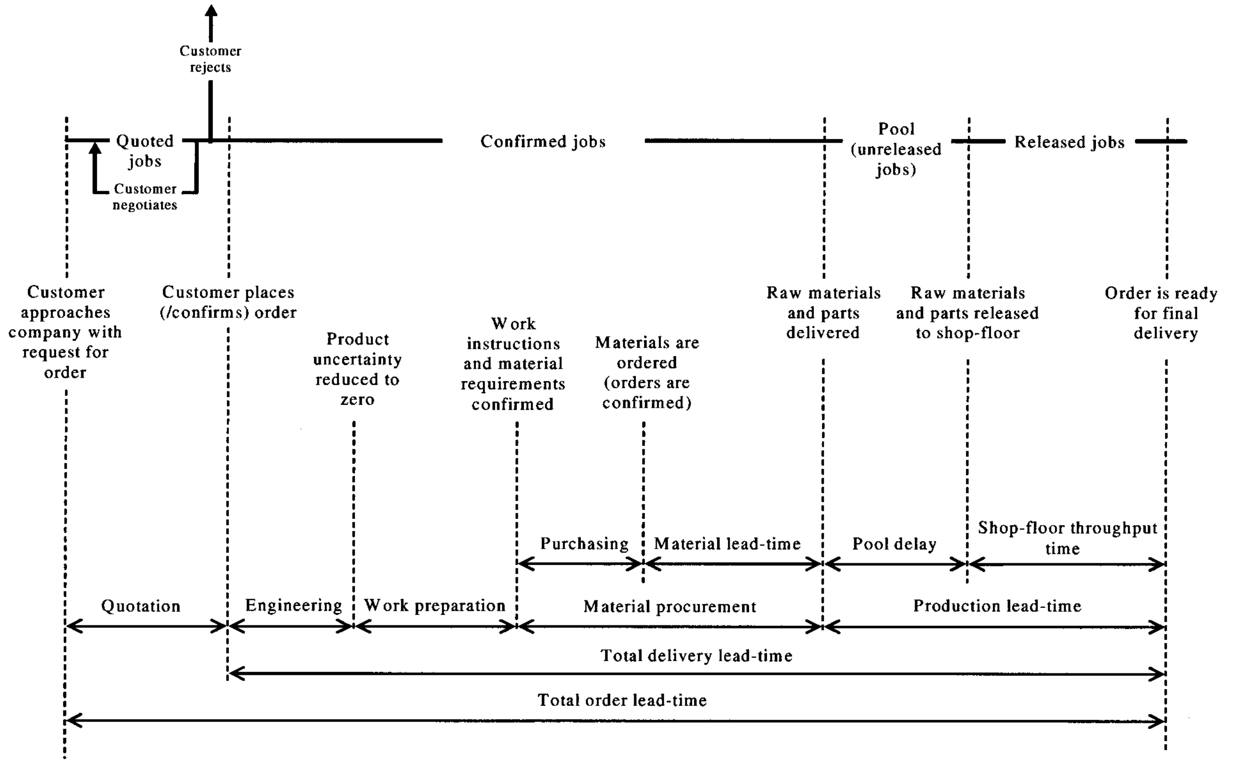
As stated in the introduction, delivery performance is an increasingly important factor within Engineer-to-Order companies, especially for gaining orders. A data analysis that was carried out at Eaton Industries B.V. using data of 55 new build cylinder projects which were delivered between September 2005 and September 2007 showed that only 6 projects were delivered on or before the promised scheduled due date. This supports the impressions at Eaton Industries B.V. that delivery reliability is quite low. The current report therefore will present suggestions with regard to lead-time control which can be used to improve future delivery reliability at Eaton Industries B.V.

A framework to control lead-times at ETO manufacturing companies

Based on requirements mentioned in the introduction, operational problems faced at Eaton Industries B.V. and requirements that came forward from an additional literature review, requirements are stated which should be captured by the framework that has to be developed. Following from these requirements it can be concluded that the framework should:

- Capture all activities typically conducted in an Engineer-to-Order manufacturing environment;
- Identify typical lead-time components and identify clear milestones that separate these lead-time components;
- Show for these various lead-time components and decisions made during the lead-time, the relation on the backlog of work;
- Describe and elaborate on activities that typically are carried out during the various lead-time components;
- Be used to identify stakeholders that typically interact during the lead-time and during the various activities;
- Provide a basis for activities that are required to control the total lead-time and its various components.

The framework that is developed, taken the requirements into account, is shown in the figure below. In the figure the characteristic lead-time components that can be identified are shown, and key moments that determine the start and end of these activities are represented. Further the state of the orders during time is shown, which can be used to control lead-times.



Based on insights from literature and activities carried out at Eaton Industries B.V., typical activities that are carried out during each of the phases that are identified in the framework are described in the report. Further the implications of activities and problems in each of the phases on lead-time control are described in the report.

Lead-time analysis at Eaton Industries B.V.

After the introduction and description of the framework, a more detailed study is done on the total delivery time and the various lead-time components identified in the framework. From this analysis it can be concluded that planned / estimated lead-times at Eaton Industries are often lower than the actual times spend for the various activities. With regard to production, the same conclusion could be stated with regard to production times at the various work centers. Besides that, it is concluded that a significant amount of production time is spend on outsourced processes.

Following on the data study with regard to lead-times at Eaton Industries B.V., problems that influence lead-time control and negatively influence delivery performance at Eaton industries B.V. are identified. The identification of problems at Eaton Industries B.V. is based on initial interviews that were conducted at the start of the project with representatives all over the organization, informal communication during the research project and experiences gained. Main sources of the problems that are identified with regard to delivery performance at Eaton Industries are mentioned below:

- Company commitment on quoting realistic due dates;
- Limitations of the information system (lack of valid information);
- Planning department and work preparation structure, capacity and knowledge;
- Limitations in the tools available at the planning department (these are not able to include backlog and capacity);
- Relative high workload, which results in capacity problems on departments such as the quality department and production;
- Inexperienced people at production (resulting in longer processing times and unnecessary rework);
- External factors:
  - Customers (waiting with accepting orders and designs and change specifications);
  - Suppliers (long and market dependent material lead-times and delivery reliability);
  - Subcontractors (market dependent outsourcing lead-times).

Based on the framework that identifies the various typical activities that are typically carried out at an Engineer-to-Order company and the characteristics and problems for lead-time control, suggestions can be given to control delivery performance and lead-times in an Engineer-to-Order company.

Controlling lead-times in ETO companies

To control lead-times in Engineer-to-Order manufacturing companies, first it is important that realistic internal lead-times are determined. Determining lead-times for new orders, the workload of these new orders, workload of previously confirmed orders and capacity are determinative for the lead-times that can be quoted for each required phase. Determining reliable delivery dates and lead-times for new orders, first the time that is required to turn customer requirements into a detailed design, production requirements and material requirements should be determined. Subsequently it should be determined when the required materials are available and thus production can start.

Especially the determination of lead-times that are required for production operations is complicated. A method is described that can be used to determine and subsequently control shop-floor throughput times. This method is based on a general workload control approach described by Kingsman (2000) and fit with the characteristics of companies such as Eaton Industries B.V.

The main advantages from a workload based method, is that relative constant throughput times at the various work centers are created. Besides that, a limited amount of orders are simultaneously on the shop-floor, which simplifies shop-floor control.

With regard to the control of internal lead-times it is important that various key decisions can be taken on a different required detail of information, since various key decisions should be taken on different moments during the total order lead-time. Three levels of control: Aggregate Planning, Operational Planning and Production Unit Control are suggested to make decisions with regard to order acceptance, job release to production and priority dispatching at each work center.

After discussing suggestions for controlling internal processes, suggestions are discussed to control the following external influences on internal processes:
- Customers who wait long with the confirmation of orders;
- Market dependent material lead-times;
- Market dependent outsourcing lead-times.

With regard to long customer waiting times to confirm orders, the most reliable option is to assign a validity of a specific (limited) time for each quotation and quote a delivery window based on both (optimistic and pessimistic) delivery dates. If the aim is to quote for a single reliable delivery date, the probability of acceptation should be determined for each quoted order and quoted workloads should be planned and multiplied with this determined probability.

With regard to market dependent varying material lead-times and outsourcing lead-times, first of all reliable and actual information of lead-times are essential and should be used in internal planning. Besides that, requirements for materials and outsourcing processes should come from a reliable internal planning. Since interaction between a reliable internal planning and reliable actual information coming from external sources is critical, a close interaction with material suppliers and subcontracting companies is very important. Therefore close relationships should be developed with suppliers and subcontractors which aim to develop mutual trust and facilitate a free flow of information. Since the reliability of both material suppliers and subcontractors is critical, performance measuring, assessment and feedback of their performance is essential. Besides that, internal flexibility can be created by reserving some spare capacity (limited utilization in production) and have some determined margins in delivery windows.

Conclusions, recommendations and limitations

It can be concluded that the framework discussed in this report contributes to literature, since it captures all activities typically carried out in an Engineer-to-Order manufacturing company, identifies typical lead-time components and identifies clear milestones that separate these lead-time components. From this, suggestions are given to determine realistic delivery dates and subsequently control internal processes and external influences on internal processes.

Suggestions for further research are first to check the observations at Eaton Industries B.V. with other settings, and check whether similar problems can be identified. Besides that, using the framework introduced in this report, the implications that decisions in the various phases have on quality and cost aspects would give valuable new insights.

With regard to Eaton Industries B.V. it can be concluded that there are quite some operational problems that lead to a low delivery performance. Recently, actions are taken such as the installation of a new information system, MFG-pro, and the installation of a new planning system, Preactor.

Further development of the current installed information system is suggested to enable a more valid measurement of performance indicators, and give valuable feed back from which lead-time performance can be controlled. Subsequently, the use of a workload based planning and scheduling method is recommended. A workload based planning will lead to a lower variation in throughput times of orders at various work stations and keep the overview for the production controller well visible. Further a hierarchy in planning is suggested, which enables decisions made on various levels on a varying required detail of information. Finally additional research is required at Eaton Industries B.V. with regard to organizational responsibilities and internal communication within the supply chain.

To successfully implement the recommendations made in this report at Eaton Industries B.V., it is suggested to add expertise with regard to the information system currently used at Eaton Industries B.V. to the organization. Further the addition of a supply chain manager, who is able to structure responsibilities and information flows between the various operational departments is recommended.

Limitations of the current research is that suggestions made in the report are mainly based on problems found at Eaton Industries B.V. As suggested above, further analysis of other Engineer-to-Order companies is required to get a better picture of the applicability of current suggestions on other Engineer-to-Order companies. With regard to Eaton Industries B.V. it should be mentioned that the current report has focused on new-build cylinder projects. Additional research is required with regard to repair & service projects, and the influence large repair & service projects have on the process of new built cylinders. Further it should be mentioned that this project mainly has focused on time, and the control of time. Time is, next to factors as quality and costs, only one of multiple factors that are crucial in an Engineer-to-Order company.

Table of contents

1. Introduction

In the current report, the results of a master thesis project are discussed. This master thesis project is the final project in the master program Operations Management and Logistics at the Technische Universiteit Eindhoven, and is carried out within the sub department Operations, Planning, Accounting and Control.

The master thesis project as discussed in this report follows on a research paper which discussed the results of a literature study that was carried out preparatory on the master thesis project. From the literature study it was seen that customization is an increasingly important factor in manufacturing companies. Besides customization, customers have become more demanding in terms of costs and quality. With regard to manufacturing companies, it could be seen that most of the research done is on manufacturing companies that allow a limited degree of customization, such as Make-to-Stock and Assemble-to-Order companies. Relatively little research is done on manufacturing companies that allow a high degree of customization such as Make-to-Order companies and Engineer-to-Order companies. Within these companies that allow a high degree of customization, besides price and quality, delivery performance is an important competitive factor. Delivery performance in Make-to-Order and especially Engineer-to-Order has had little attention in research however.

Recent research that has been done within Engineer-to-Order companies mainly has focused on the quotation for orders and manufacturing (planning and control) within Engineer-to-Order companies. Research within Engineer-to-Order companies that has gone into the quotation for orders has discussed aspects as cost estimation (e.g. Kingsman et al., 1996 and Kingsman and de Souza, 1997), problems and solutions within the customer enquiry stage (Kingsman et al., 1996) and the integration and coordination between production and marketing (Kingsman et al., 1993). Research on manufacturing within Engineer-to-Order companies has focused on aspects such as production control in Engineer-to-Order companies in general (Bertrand and Muntslag, 1993), workload control (Kingsman, 2000) and controlling manufacturing lead times (Kingsman et al., 1989).

An overall framework that describes the activities that are typically carried out in an Engineer-to-Order company and shows the implications from various activities on other activities is missing however. Besides that, research in Engineer-to-Order companies mainly has focused on internal processes. External sources that interact during the total delivery lead-time and the implications the interaction of external sources has on internal processes, mainly is disregarded.

Based on the literature study, limitations that followed out of the literature study, and relevant research questions that were identified from the literature study, the following definition for a master thesis project is made:

Develop a framework that can be used to control the total delivery lead-time within an Engineer-to-Order manufacturing company.

In order to work out this defined research definition, various research questions should be answered. Valid research questions that are identified, and should be answered during the development of a framework to control the total delivery lead-time within an Engineer-to-Order manufacturing company are:

- What characteristic stages can be identified during the total delivery lead-time within an Engineer-to-Order manufacturing company?
- What typical stakeholders can be identified during the total delivery lead-time and its characteristic stages and how do these stakeholders interact?

- What typical main problems can be identified during the total delivery lead-time and its characteristic stages, which harm delivery performance?
- How can the delivery lead-time be managed in such a way that delivery performance can be controlled?

This report will elaborate on the research questions and aims to provide answers to the questions stated. The research and its results that are discussed in the report are based on scientific literature and data from an Engineer-to-Order company, Eaton Industries B.V.

In the report, first Eaton Industries B.V. will be introduced in chapter 2 with regard to its internal organization, the markets the company serves, the product it produces and the way the product is produced. Subsequently in chapter 2, some operational problems that are faced within Eaton Industries B.V. and which led to the motivation to cooperate in the research are discussed. Chapter 3 will provide some backgrounds from literature that will help to have a better understanding for the discussion provided in this report. Subsequently chapter 3 discusses some backgrounds on the process that lead to the delivery lead-time framework that is developed. The framework that is developed and typical activities carried out are discussed in chapter 4. Using data gained at Eaton Industries B.V., chapter 5 subsequently gives an overview of problems that are faced at Eaton Industries B.V. which influence lead-time control. Based on findings described in literature and problems identified at Eaton Industries, chapter 6 gives suggestions on how to control lead-times within Engineer-to-Order companies, using the framework described in the report. Therefore in paragraph 6.1 a general method, based on Eaton Industries and literature, is described. Subsequently paragraph 6.2 describes how to deal with external influences on internal processes. Paragraph 6.3 finally gives some practical suggestions to deal with problems that are identified within Eaton Industries. The report will end with a conclusion and suggestions in chapter 7.

2. Company description, Eaton Industries B.V.

As stated previously in the introduction, the master thesis project is inspired by, and carried out at Eaton Industries B.V. Before elaborating on a framework for controlling lead-times in the Engineer-to-Order environment, the company Eaton Industries B.V. and its main problems will be introduced.

2.1. Organization and market

Eaton Industries B.V. was founded in 1980 as a small machinery plant under the name of Hydrowa. After integration in Sophus Berendsen in 1988 and integration in IMC in 1998, the company was acquired by the Eaton Corporation in 2000. Since the foundation in 1980, the company shifted from a small manufacturing company producing machinery parts, into a manufacturing company specialized in producing customer specified hydraulic cylinders. The original name of the company, Hydrowa, changed after acquiring by the Eaton Corporation into Eaton Hydrowa, and subsequently in September 2006 into the current company name, Eaton Industries B.V.

The Eaton Corporation, which acquired Eaton Industries B.V. in 2000, is a rapidly growing, global operating, industrial manufacturer with 2006 global sales of $12,4 billion (compared to $11,0 billion in 2005 and $9,7 billion in 2004). The Eaton Corporation has four main business segments which are responsible for the annual sales:

- Electrical (34 % of 2006 sales);
- Fluid Power (32 % of 2006 sales);
- Truck (20 % of 2006 sales);
- Automotive (14 % of 2006 sales).

Eaton Industries B.V. is part of the Fluid Power group which in 2006 thus was responsible for 32 % of annual sales from the entire Eaton Corporation. The Fluid power group is split up into four main divisions, each responsible for an amount of the total fluid power sales as shown below:

- Hydraulics (49 % of 2006 sales);
- Aerospace (37 % of 2006 sales);
- Fluid Connectors (10 % of 2006 sales);
- Filtration (4 % of 2006 sales).

Within the Fluid Power group, Eaton Industries B.V is part of the Hydraulics group. The main motivation for the Eaton Corporation to acquire Eaton Industries B.V. in 2000 and add to the Hydraulics group was to complement the Hydraulics group and be able to serve customers requiring large movements or heavy forces. Together with other companies which are part of the hydraulics group, the Fluid Power Hydraulics group is able to offer complete customized hydraulic turn key solutions.

Eaton Industries B.V., located in Eindhoven, currently employs 109 people, from which 105 are permanent employees in various functions (69 people are employed within the production environment and 40 people have an administrative job at the offices). An organizational structure of the situation at the end of 2007 is shown in appendix 1. The main competences of the company are to build large new customized cylinders and to offer service and repair for all brands of hydraulic cylinders. Customers of new cylinders, in 2007 responsible for 86,3 % of the annual sales (82% in 2006), mainly come from inter company sales (19 %) and three main markets: marine / offshore / dredging, civil and heavy machinery. The amount of which each of these markets contributes to the total annual sales differs from year to year. Offshore however is the largest market since years, and is expected to stay that for the next years.

Eaton Industries B.V. has made a rapid grow during the past years. This can be shown using some financial data, presented in table 1. From this data could be seen that total sales at Eaton Industries in 2007 (which includes both new-build cylinders as repair) has grown with 73,4% compared with 2006, to € 19.750.000,-. The total operating profit however, was negative during the last years, with a record negative operating profit of - € 1.187.000,- in 2007. Backgrounds on this negative operating profit will be elaborated further in paragraph 2.4.

Year	2004	2005	2006	2007
Total Sales	€ 8.658.000,-	€ 11.820.000,-	€ 11.365.000,-	€ 19.750.000,-
Operating Profit	- € 763.000,-	- € 391.000,-	- € 219.000,-	- € 1.187.000,-

Table 1: Financial data Eaton Industries B.V. (2004 – 2007)

2.2. Product

As stated in the previous paragraph, Eaton Industries B.V. is specialized in the production of (large) custom build cylinders. The design and dimensions of these cylinders have a wide variety, with bores varying between ∅ 25 mm till ∅ 1.200 mm, stroke lengths varying up-to 22.000 mm and working pressures up to 320 Bar. Before elaborating on the physical production process within Eaton Industries B.V., first the product, a typical hydraulic cylinder will be described in more detail.

The main parts within a typical hydraulic cylinder are:
- Piston [1];
- Piston rod [2];
- Barrel [3];
- Cylinder bottom [4];
- Cylinder head [5].

Further additional components as bolts, seals and sliding rings typically are used in a hydraulic cylinder. In figure 1, a hydraulic cylinder is schematically shown. Based on the description below and references made to parts shown in figure 1, a typical hydraulic cylinder is described.

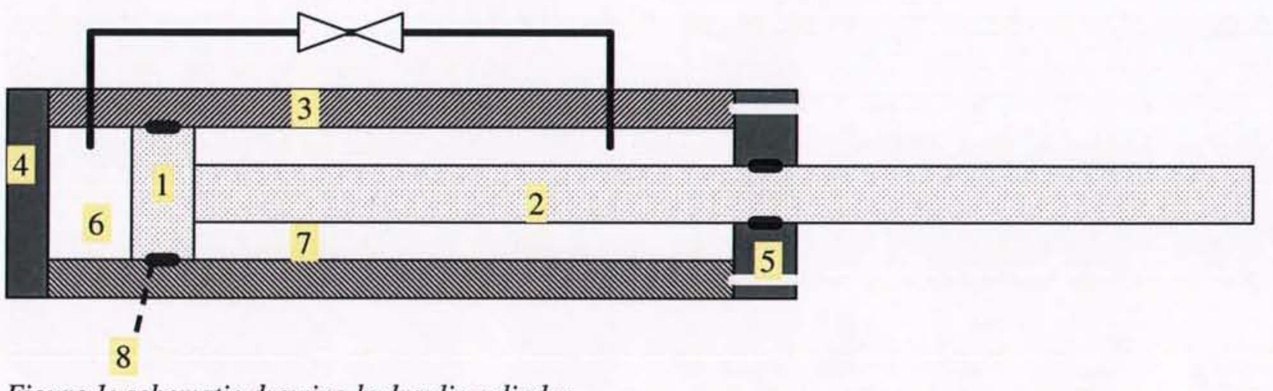


Figure 1: schematic drawing hydraulic cylinder

The chamber that is created between the barrel, the piston and the bottom of the cylinder is called the bottom chamber [6]. The chamber that is closed by the barrel, the piston and the cylinder head is called the piston rod chamber [7]. The piston and thus the piston rod are able to move through the barrel. This movement is achieved by pumping oil in one the chambers and releasing oil from the other chamber into a reservoir. As a result different pressures in the two chambers exist. Since the piston is free to move within the barrel, it will move in such a way that pressure in both chambers is balanced again.

Using this principle the piston rod can be used for pushing (piston rod moves out of the cylinder head) or pulling (piston rod moves into the cylinder). The surface of the piston determines, together with the maximum working pressure, the force that can be used for pushing. The difference in surface between the piston and the piston rod and the maximum working pressure typically determine the force that can be used for pulling.

As stated before, Eaton Industries B.V. is specialized in large custom build cylinders. Core competencies are cylinders with stroke lengths varying between 4 and 20 meters. The main applications of these cylinders are in marine / offshore / dredging, heavy industry and civil engineering, which are the markets of the main customers as stated in paragraph 2.1.

2.3. Production

In the current part of the report, the physical production process for creating hydraulic cylinders within Eaton Industries B.V. briefly will be described. During this production process, most of the parts used within the cylinder are produced internally at Eaton Industries B.V. from raw materials. Some (less critical) parts typically are purchased and subsequently assembled in sub-assemblies or the end product.

Since cylinders produced within Eaton Industries B.V. vary largely in design, dimensions and future applications, the production process for each cylinder may vary. However, the main production steps are largely the same. Main parts within a hydraulic cylinder that typically are produced internally at Eaton Industries B.V. are the cylinder barrel, the piston, the piston rod, the cylinder head and the cylinder bottom. Within the production process the barrel and the piston rod are the most critical parts, since these parts require most processing time and require processing on the most critical (capacity and cost) machines. Other internally machined parts as the cylinder head, cylinder bottom and piston are produced on less critical machines (more capacity and cheaper machines). Typically CNC turning and CNC milling machines are used to produce these less critical parts. Since the barrel and piston rod are the most critical parts during the production process, typical production steps for these parts are described below.

Cylinder barrel

The raw materials for cylinder barrels are steel tubes. For large cylinders the cylinder barrel may exist of multiple tubes. For a cylinder barrel consisting of multiple steel tubes, the first typical production step is to saw each of the steel tubes on the specified length. Subsequently both ends of each tube have to be turned after which they can be welded together. During the welding of the various tubes, flanges (made earlier on other workstations) also may be welded to the barrel, which later can be used to screw the bottom and head to the cylinder. After tubes are welded together and flanges are welded, the barrel may need heat treatment (glowing) with the purpose to relieve internal stresses (which result from the welding process).

Subsequently the outside barrel surface typically will be turned again to help future outlining and create matched edges which can be used for the subsequent production steps. These subsequent steps in the production process of a barrel are deep drilling and honing. The production steps deep drilling and honing are required for each cylinder. During the deep drilling process, the barrel is internally brought to the specified dimensions. The honing process has the aim to finish the internal geometry and surface in such a way that a smooth surface is created, in which the piston can move perfectly sealed without to much friction. After the honing process the barrel typically is turned again to simplify future assembly, after which milling is the next step. During the milling process for example holes in the barrel may be created on which future hoses and piping can be connected. When this production step is finished, normally the barrel is finished and ready for assembly.

Piston rod

The piston rod largely goes through the same production process as the barrel. Also the piston rod may consist of one or multiple tubes (or rods) which typically are sawed, turned, welded together, glowed and turned again. If necessary also milling might be required. The deep drilling and honing process is not required for the piston rod. However, the outside surface of the piston rod typically undergoes a surface treatment. The most common surface treatments are creating a Nickel layer or a Nickel / Chromium layer. Creating such a layer has the following advantages:

- An increased hardness of the piston rod;
- Controlled surface finishes;
- Increased corrosion resistance;
- A very low coefficient of friction;
- Thermal stability.

Besides creating a Nickel or Nickel / Chromium layer, another option is to treat surfaces with a coating and thus increase corrosion resistance, lower the coefficient of friction, control the finishes and increase thermal stability. When the surface treatment is finished, the piston rod is ready for assembly.

Assembly and testing

During the assembly process, the hydraulic cylinder is put together. The internal machined parts piston and piston rod are mostly screwed together (they also can be welded together during the production of the piston rod). Subsequently the piston and piston rod are assembled in the barrel and the cylinder bottom and cylinder head are attached. Standardized and bought parts such as bolts, sealing rings, packages and hoses typically are required during the assembly of the hydraulic cylinder. When the cylinder is assembled, the whole cylinder should be tested (which is typically done using external inspection instances). When the cylinder is tested and approved according to specification, the cylinder can be preserved and subsequently painted. After painting the cylinder is finished and can be packaged and shipped to the customer.

As stated earlier, the production process for cylinders may vary from the process described above. The sequence in which steps are conducted may be different. Barrels for example still might require welding (e.g. for bottoms) after deep drilling and honing is finished. Besides that, other steps may be required additional to the steps described above (such as the welding of eyes and support items on barrels). On the other hand sometimes some steps described above are not required. Besides that, during the production process the processing times required for the various steps may differ significantly between the various products. Possible and occasional physical material flows within Eaton Industries B.V. are shown in appendix 2. Within appendix 2, black lines are physical material flows of the critical parts, cylinder barrels and piston rods. Gray lines are material flows of less critical parts produced. Dashed lines stand for purchased parts.

At Eaton Industries B.V. machines on which processing is done are grouped based on their function. The main production groups that can be identified are CNC turning and milling (mainly used to produce cylinder bottoms, cylinder heads, flanges and pistons), conventional turning, welding, glowing, milling, assembly and testing. Besides that there are some capabilities that are required and described above, but are not in place at Eaton Industries B.V. The main capabilities that are often (almost for every cylinder) required but not in place internally at Eaton Industries B.V. are deep drilling and honing, surface treatment (such as Nickel Chromium treatment and coating) and painting. These activities therefore are outsourced. This means that for (almost) every cylinder that is produced external, processing is required. For cylinder barrels outside processing is needed for deep drilling and honing. For piston rods outside processing is required for surface treatment. The assembled and tested cylinder typically requires external painting and spraying.

2.4. Operational problems

As could be seen from the financial data presented in paragraph 2.1, Eaton Industries B.V. has made a rapid growth during the past years. However, operating profit has been negative since 2003. Reasons that are internally given for negative operating profits during the past years are high material inventories, low efficiencies, and outsourcing and subcontracting at premium costs. Other problems that are faced within the company are tightness of experienced and well trained personnel (which also influences quality issues such as required rework), long throughput times of customer orders and a low delivery reliability of customer orders.

In 2007, record annual sales of € 19.750.000,- were achieved, but in the same year also a record negative operating profit of - € 1.187.000,- was achieved. The main reasons that are internally given for the high negative operating profit of 2007 are:

- Prior year / quarter adjustments;
- Wrong margin assumptions;
- Labor shortage and efficiency;
- Subcontracting at premium costs;

So, besides the low financial efficiency, Eaton Industries B.V. management is aware that at Eaton Industries B.V. there are quite some internal operational problems. The current report will elaborate on delivery performance within Eaton Industries B.V. and comparable manufacturing companies. With regard to delivery performance at Eaton Industries B.V. it can be stated that lead-times for new built cylinders are high, and delivery reliability of these cylinders is low. The balanced scorecard reported an on time delivery of 76% in 2004 which dropped to 71% in 2006. In this measurement both repair & service projects and new-built cylinder projects are included. Repair & service projects typically have a relative short throughput time (compared with new built projects) and delivery reliability of the repair & service projects is assumed to be higher than the new built cylinder projects.

From this can be derived that the on-time delivery of new built cylinders will be lower than the percentage reported. Besides that, it is aware that the on time delivery percentage measured and reported does not reflect the actual on time delivery performance (which is thought to be lower).

The importance of delivering projects before or on the agreed due date is not fully understand by the company yet. It is stated that the order book at the beginning of 2008 is filled well for the upcoming time. As a result, on the short term the company thinks it is less relevant to increase competitiveness with regard to delivering on-time, since many orders were placed recently. Besides that, currently penalties for late deliveries are hardly requested by customers and if requested, the sales department usually can refuse them, without necessarily losing the order.

According to Eaton Industries B.V. the main reasons for the luxury market position of the company are a high overall market demand on large hydraulic cylinders and competitors that are dealing with similar problems with regard to delivery performance.

There should be the awareness however, that on the long term the market (and thus customer power) and competitor capabilities may change. Delivery performance can be seen as an important competitive factor for gaining orders. Especially when market demand is low, a high competitive advantage is crucial. Besides that, as stated above, due to changes in markets and market demand, customer power may change. When customers have the power to include penalties for late deliveries, low delivery reliability may cost a significant amount of money.

2.5. Delivery performance

The importance of delivery performance for Engineer-to-Order manufacturing companies is briefly discussed in the previous paragraph of this report. In paragraph 2.4 it is mentioned that the delivery speed and delivery reliability for new built cylinders at Eaton Industries B.V. are largely unknown. Some figures are given, but these are unreliable and very general. Therefore a data analysis is carried out on the delivery performance at Eaton Industries B.V to get more insight in the actual delivery performance.

In this analysis historical data from various sources at Eaton Industries B.V. is used. In the analysis, data from 55 new build cylinder projects which were carried out and delivered between September 2005 and September 2007 is included. Projects included contained 1 to 8 cylinders, with an average of 2 cylinders per project (standard deviation 1,8). A remark that should be made is that not all required data was available for all projects. As a result, data samples that are used to calculate various lead-times and performance indicators vary. There are more restrictions in the data (elaborated in paragraph 5.1.3), which limit the reliability of conclusions that can be drawn. Despite the restrictions in the data, the analysis gives a clear indication about the actual delivery performance at Eaton Industries from orders delivered between September 2005 and September 2007.

In order to determine the delivery reliability, 55 projects from the data sample could be used. From these 55 projects, 6 projects were delivered on or before the promised scheduled due date, which equals 10,91%. On average, projects were 15,88 weeks too late, with a standard deviation from 11,29 weeks. A data overview with regard to delivery reliability and lateness of projects during time is shown in figure 2.

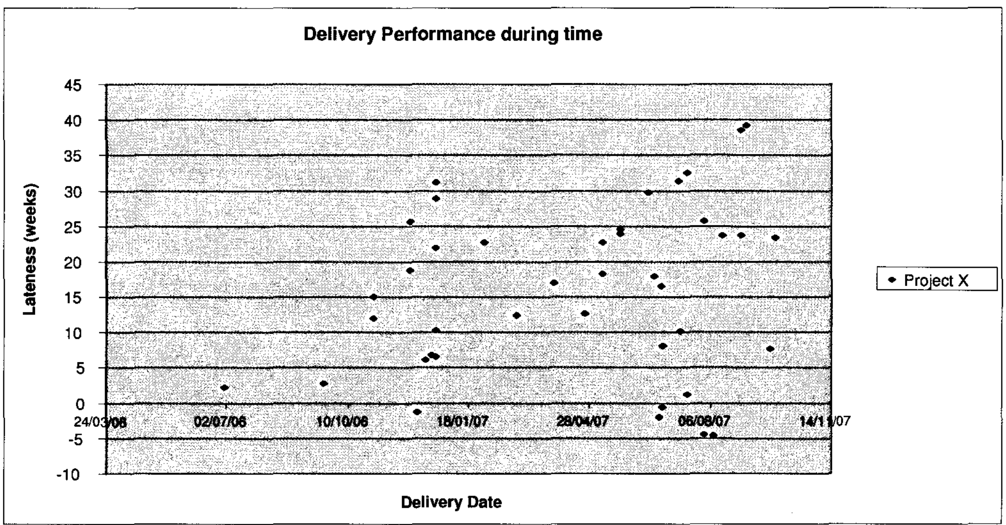


Figure 2: delivery performance Eaton Industries B.V. (55 projects analyzed).

The large variation in throughput times and relative long throughput times are characteristic for the Engineer-to-Order environment, as will be described further in this report. The delivery reliability at Eaton Industries is quite low however. The current report therefore will present suggestions with regard to lead-time control which can be used to improve future delivery reliability. The subsequent chapter first will give some literature backgrounds on a model that will be developed to control lead-times in an Engineer-to-Order company.

3. Literature backgrounds for the development of a framework

In the previous chapter the manufacturing company Eaton Industries B.V. has been introduced. Besides that, operational problems at Eaton Industries B.V. are discussed and a data analysis in which the delivery reliability at Eaton Industries B.V. is discussed is presented. Following on this, it is stated that in this report a framework will be developed, that can be used to control lead-times in an Engineer-to-Order company, and thus also may help to improve future delivery reliability at Eaton Industries B.V.

The current chapter will provide the backgrounds that are required to cover the scope of the framework that is developed and described in the current report. Therefore the chapter will start in paragraph 3.1 with a discussion on the classification of manufacturing companies. Manufacturing companies can be classified in many ways. As shown in paragraph 3.1, a well known classification is based on the way manufacturing companies meet their demand. Subsequently in paragraph 3.2, delivery performance in Engineer-to-Order companies is discussed briefly, after which literature on the development of a framework to control delivery performance in an Engineer-to-Order company is discussed in paragraph 3.3.

3.1. Classifying manufacturing companies

A well known classification that is described in literature regarding the way manufacturing firms meet their demand distinguishes between MTS and non-MTS (Amaro et al., 1999). The distinction between MTS companies and non-MTS companies is based on the receipt of the customer order relative to producing the end item.

MTS manufacturing firms typically have the end item already available in stock when the customer orders arrive and thus meet the total customer demand from stock (Kingsman et al., 1993). Production is planned and controlled to maintain end-item stocks at appropriate levels to meet a satisfactory customer service level.

Some characteristics of an MTS manufacturing environment that are described by Kingsman et al. (1993) and Persona et al. (2004) are:

- Standardized products;
- Product demand can be forecasted;
- Capacity can be planned (based on demand forecast);
- Product lead-times are unimportant to customer;
- Prices of products are fixed by the manufacturer.

In non-MTS manufacturing companies on the other hand, orders are received before the actual production of the end item is finished (Kingsman et al., 1993). As a result "some or all of the production takes place after the customer order has been received" (Kingsman et al., 1996). This enables the possibility to meet specific needs of individual customers. Within non-MTS manufacturing companies, a classification which distinguishes between three types of companies is discussed in literature: Assemble-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO), (e.g. Amaro et al, 1999, Bertrand and Muntslag, 1993 and Persona et al., 2004).

Wikner and Rudberg (2005) make a separation between production that is forecast-driven and production that is customer order-driven. The point that Wikner and Rudberg (2005) define as the point that separates forecast-driven production from customer order-driven production within a supply chain is the so called Customer Order Decoupling Point (CODP). In other words the COPD is "the point that indicates how deeply the customer order penetrates into the goods flow" (Wikner and Rudberg, 2005 p. 212).

Also the Customer Order Decoupling Point typology contains four typical cases, MTS, ATO, MTO and ETO. The four typical cases are sketched in figure 3, based on the so called P:D ratio. Both "P" and "D" are lengths of time, P-measures refer to the production lead-time and D-measures refer to the delivery lead-time (Wikner and Rudberg, 2005).

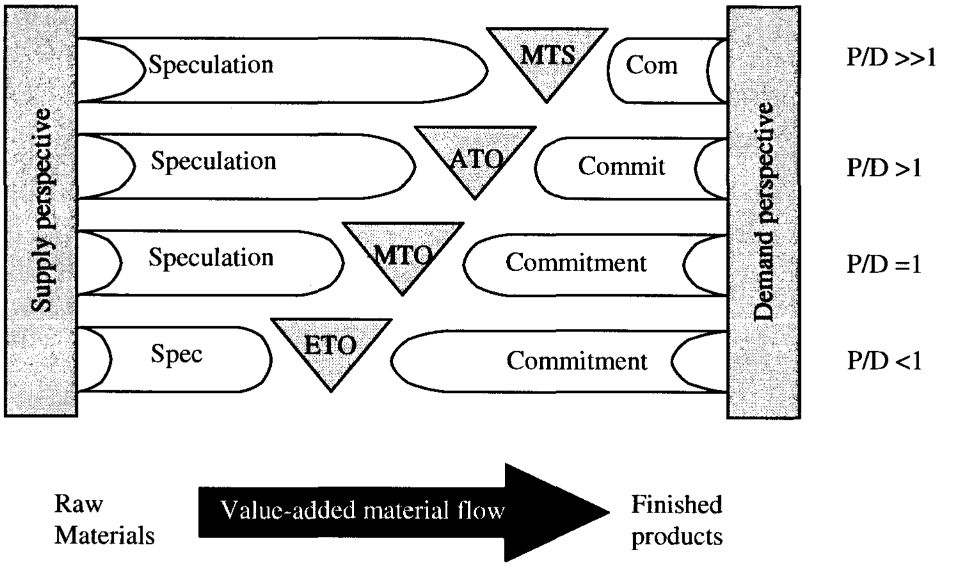


Figure 3: four typical production cases, based on the P:D ratio (Wikner and Rudberg, 2005 p. 213).

As opposed to ATO manufacturing, where products are assembled from standardized parts, and MTO manufacturing, where standardized designs may be modified, in ETO manufacturing, products are completely customized. The customer order penetrates through the supply chain to the product development stage. As a result, "products are manufactured to meet a specific customer's needs" (Amaro et al., 1999). For production, an ETO situation means that very little is known about what to manufacture and purchase until a customer order is received and engineered to customer specification.

3.2. Delivery performance in ETO companies

From the company description of Eaton Industries B.V. shown in chapter 2 and the classification of manufacturing companies discussed in the previous paragraph, it can be concluded that Eaton Industries B.V. can be classified as an Engineer-to-Order company.

Manufacturing firms can compete on numerous of strategic competencies. Some strategic competencies such as price / cost, quality, delivery speed, delivery reliability, customer service, flexibility, product design (features, functions and aesthetics) and product image are listed by Tersine and Hummingbird (1995, p. 8). It is impossible for an organization to excel in each of these competencies. Within each company one or a mix of some strategic competencies should be chosen to gain competitive advantage.

Within the Engineer-to-Order manufacturing companies, the main competitive strategic competencies are price, technical expertise, delivery time and reliability in meeting due dates. In a survey under 902 people working in the Make-to-Order industry (response rate 14,6 %) Wisner and Siferd (1995) identified on-time deliveries and total job costs as respectively second and third in importance, close behind finished-goods quality.

In the current report the focus will be delivery performance in Engineer-to-Order companies. Delivery performance typically can be seen as a taxonomy between delivery speed and delivery reliability. The constructs of delivery speed and delivery reliability will be defined and explained below.

3.2.1. Delivery speed

Delivery speed at a Make-to-Order firm can be defined as "the sum of the individual lead times for order entry and production of the order" (Handfield and Pannesi, 1992 p. 60). From a market perspective, delivery speed is the time that elapses between the receipt of a customer order and the moment of final delivery from that customer order. The delivery time, measured from the receipt of a customer order till the final delivery of a customer order is also called delivery lead-time (Bahu, 1999).

3.2.2. Delivery reliability

Delivery reliability can be defined as "the ability of the firm to deliver on or before the promised scheduled due date" (Handfield and Pannesi, 1992, p. 60). In literature the construct of delivery reliability is also known as on time delivery probability or delivery performance. Delivery reliability is only a valid construct for non-MTS firms. Only within these types of firms a delivery date is promised to the customer and thus can be met or not. In the MTS situation, measures for delivery performance are the customer service level and non-stock-out probability (Handfield and Pannesi, 1992). Issues as customer service level and non-stock-out probabilities in MTS companies are mainly discussed in the area of inventory theory.

The delivery reliability within an ETO manufacturer depends on numerous of factors, from promising a delivery time to a customer, to delay in final shipment to the customer. Delivery reliability and factors that influence delivery reliability will be described later in this report, especially in paragraph 5.2.

3.3. The development of an ETO lead-time framework

Before the start of the master thesis project, a literature study was carried out and a research design and approach was made. The research design and approach proposed to develop a framework which can be used to describe and subsequently control the total delivery lead-time in an Engineer-to-Order company. The framework that is created is mainly based on experiences and information gained from Eaton Industries B.V. and the following frameworks described in literature:

- Make-to-Order framework from Kingsman et al. (1989, p. 200);
- Engineer-to-Order framework from Bertrand et al. (1998, p. 270).

3.3.1. Frameworks described in literature

The framework presented by Kingsman et al. (1989, p. 200) identifies a hierarchy in lead times and backlogs which is valid for the Make-to-Order environment. The various lead-time components that are identified are components that are typically conducted in a Make-to-Order manufacturing company. Besides that, the framework shows for these various lead-time components and decisions made during the lead-time, the relation on the backlog of work. The backlog of work is, together with capacity, determinative for the lead-times.

However, as stated, the framework of Kingsman et al. (1989, p. 200) is valid for the Make-to-Order environment, but does not capture all activities conducted in the Engineer-to-Order environment. Some typical activities that are carried out in the Engineer-to-Order environment, engineering, work preparation and the purchasing process of materials, are not identified in the framework. Besides that, no clear "key moments" which separates various lead-time components from each other and clear definitions of the various lead-time components are given. Finally the framework as presented and typical activities carried out during the various lead-time components are not further described by Kingsman et al. (1989).

The framework that is presented by Bertrand et al. (1998, p. 270) is, in contrast to the framework presented by Kingsman et al. (1989, p. 200), applicable on the Engineer-to-Order environment. The framework does identify stages that are valid for the Engineer-to-Order environment and some hierarchy in lead-times is made.

However, in contrast to the framework presented by Kingsman et al. (1989, p. 200), the framework presented by Bertrand et al. (1998, p. 270) does not link the various lead-time components identified, to a control concept (of e.g. backlogs and work accepted). Besides that, also for the framework of Bertrand et al. (1998, p. 270) holds that no clear milestones are identified, various lead-time components are not defined, and typical activities carried out are not further elaborated.

Next to the frameworks described by Kingsman et al. (1989, p. 200) and Bertrand et al. (1998, p. 270), other frameworks that are described in literature are the frameworks described by Tersine and Hummingbird (1995, p. 12) and Persona et al. (2004, p. 637). These frameworks identify some activities that are typically carried out at an Engineer-to-Order manufacturing company. For these frameworks however, it also holds that no linkage is made to any control concept, activities or lead-time components are not defined and activities carried out are not further described.

3.3.2. The development process

The development of the framework as discussed in this report started with initial interviews among employees at Eaton Industries B.V., representing a variety of functions. Subsequently internal procedures and processes were checked and based on that, a clear picture of all activities typically carried out for a customer order was made. Subsequently findings were checked with literature, to be able to expand the findings and framework created, to other companies in other settings.

Following the approach described above, during the development of the framework, first the main steps that typically are carried out in an Engineer-to-Order company were identified. For each of the typical steps that were identified, subsequently typical activities that are carried out during each of the steps were analyzed. After the identification of main steps and activities, stakeholders that typically interact were identified.

With regard to stakeholders, many definitions for stakeholders are given in literature. The definition given by Karlsen (2002, p. 20) which is based on the PMBOK Guide (1996) captures the best the meaning of a stakeholder within a project environment. According to this definition a stakeholder can be defined as individuals, groups or organizations "who are actively involved in the project, or whose interests may be positively or negatively affected as a result of project execution or successful project completion" (Karlsen, 2002, p. 20).

Different ways of classifying stakeholders are discussed and used in literature. An example is the distinction between direct and indirect stakeholders, in which "indirect stakeholders are affected by organizational decisions and changes without being directly involved in the decision making process" (Ho, 2007, p. 256). Another classification distinguishes between primary and secondary stakeholders (Ho, 2007, p. 257). In this distinction, primary stakeholders are those who formally, officially or contractual have a relationship with the firm. Secondary stakeholders on the other hand are those who can affect or are affected by the firm.

A well known distinction between stakeholders is the distinction between internal and external stakeholders. Internal stakeholders are those who are employed at the Engineer-to-Order company. External stakeholders are stakeholders outside the firm and thus are not formally attached to the firm.

The distinction that can be made between internal and external stakeholders is the most important distinction within the framework that is described. Especially for control purposes, the distinction between internal and external stakeholders is important, as will be described further in this report.

Taken together requirements to improve lead-time control at Eaton Industries B.V. discussed in the previous chapter, and literature and deficiencies of current models discussed in the current chapter, it is decided to develop a framework that describes the total lead-time of an Engineer-to-Order manufacturing company.
This framework and its description should:

- Capture all activities typically conducted in an Engineer-to-Order manufacturing environment;
- Identify typical lead-time components and identify clear milestones that separate these lead-time components;
- Show for these various lead-time components and decisions made during the lead-time, the relation on the backlog of work;
- Describe and elaborate on activities that typically are carried out during the various lead-time components;
- Be used to identify stakeholders that typically interact during the lead-time and during the various activities;
- Provide a basis for activities that are required to control the total lead-time and its various components.

Taken the literature description and requirements discussed in the current paragraph into account, a framework is developed, which will be elaborated in the subsequent chapter.

4. ETO lead-time framework developed

After having discussed Eaton Industries B.V. and literature backgrounds on the development of a framework in previous chapters, this chapter will discuss the Engineer-to-Order lead-time framework that is created. As described in the previous chapter this framework should capture all activities typically carried out in an Engineer-to-Order manufacturing company, identify typical lead-time components and identify clear milestones that separate these lead-time components and show for each of these the relation on the backlog of work. Besides that, it should provide a basis for activities that are required to control the total lead-time and its various components.

Using the development process described in paragraph 3.3.2 and based on inputs from Eaton Industries B.V. and literature, a framework that fits the requirements that were stated previously is created. The framework that is created is shown below in figure 4 and on a larger scale in appendix 3. In these figures, the characteristic lead-time components that can be identified are shown, and key moments that determine the start and end of these activities are shown. Further the state of the orders during time is shown, which has implications for lead-time control (which will be elaborated later in this report). Each of the characteristic stages described in the framework are defined (mainly based on literature). Definitions of the characteristic stages are shown in appendix 4.

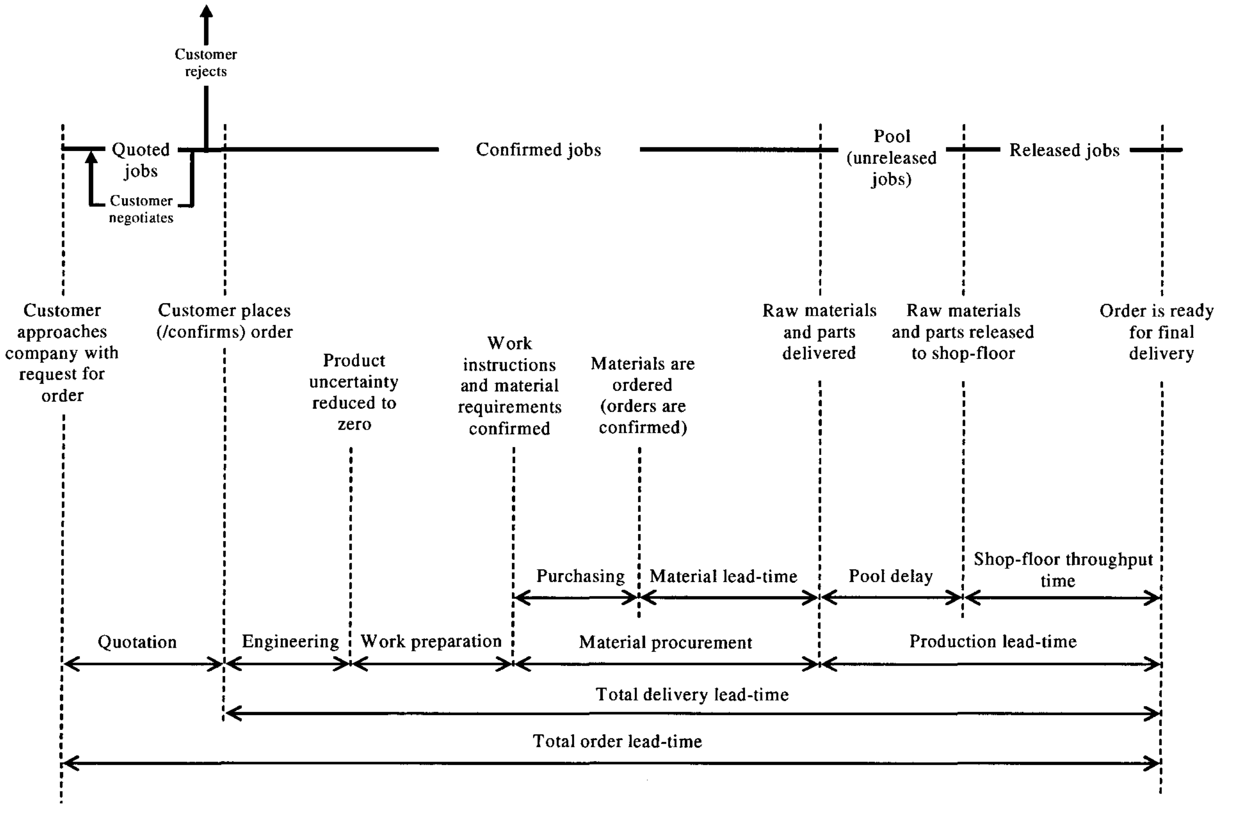


Figure 4: Engineer-to-Order lead-time framework

An overview of the main internal (both primary and supportive) and external stakeholders from an Engineer-to-Order company (based on literature and Eaton Industries B.V.) is shown in appendix 5. A brief description of each of the stakeholders is shown in appendix 6. In the discussion shown in appendix 6, a short description of each of the stakeholders, the primary tasks and responsibilities, and the main stakeholders that are involved during carrying out their function are discussed.

In the subsequent paragraphs of this chapter, activities that are typically carried out during the total order lead-time are described using the main phases identified in the framework. During the discussion, stakeholders (described in appendix 5 and appendix 6) that are involved in each of these stages are included and the way they interact is described.

4.1. Quotation for an order

The involvement in competitive bidding for orders is mentioned in literature as one of the two most important characteristics of an Engineer-to-Order company (Kingsman et al., 1996). When a customer requests a product within an Engineer-to-Order company usually at the same time, the same customer approaches multiple other companies with the same request. Based on the offers (bidding) from the various companies that are returned to the customer, the customer chooses typically one manufacturing company to place the order.

From the moment a customer places a request to make a bid for a specific order the first decision an Engineer-to-Order company has to make is whether to prepare a bid or not. The outcomes might be that:
- The company decides to prepare a bid;
- The company decides to refuse the request;
- The company seeks for further explanation on the request.

Preparing the bid, considerations that should be taken into account are: basic product specification and configuration, estimation of how the job will be made, what materials have to be used, an estimation of how much time is needed in subsequent phases, and an estimation of costs that have to be made during the process. Based on these considerations a bid can be made and presented to the customer. For the considerations that have to be made, typically other stakeholders within the company are involved. The marketing and sales department, usually responsible for the quotation, typically interacts with the engineering department who develops basic technical concepts, basic cost calculations (material costs and labor hours required) and may conduct a risk analysis. Besides communication with the engineering department, communication and interaction with the planning and scheduling department, who should give a reliable delivery date, typically is required during the quotation phase. Main deliverables that are presented in the customer bid are: technical specifications, price and order lead-time.

Based on the quotation presented by the company, the customer might decide to:
- Accept the quotation;
- Reject the quotation;
- Ask for further negotiations.

Since requests typically are placed at multiple companies, as a consequence each Engineer-to-Order company has to make many more quotations than the orders it actually receives (Kingsman et al., 1993). Within Eaton Industries B.V. in the period from October 2004 till October 2007, 243 quotes for orders were made. The hit rates in number of orders and in financial terms were:
- Hit rate in number of orders (number of orders received / number of orders quoted): 52,5%;
- Hit rate in financial terms (value of orders received / value of orders quoted): 34,77%.

Reasons for rejection of the quotations, as classified by Eaton Industries B.V., are shown below in figure 5.

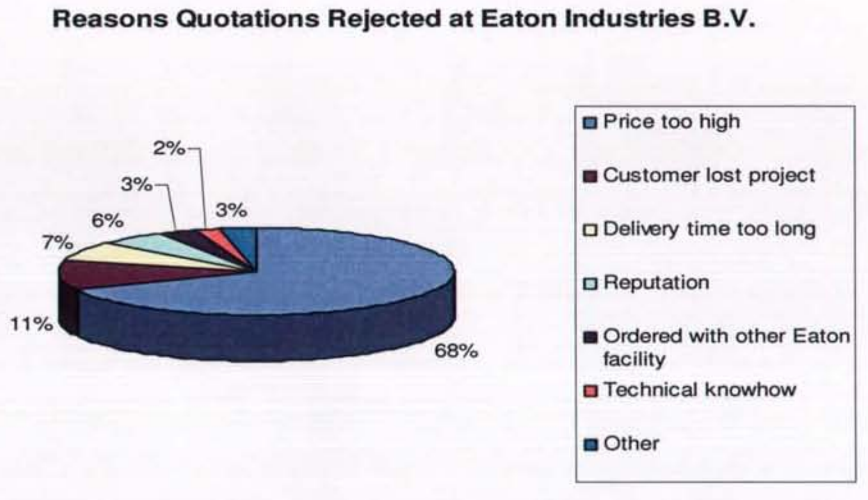


Figure 5: reasons for rejected quotations Eaton Industries B.V.

A typical problem that has to be faced during quotation is the determination of realistic lead-times and costs, which can be quoted to the customer. Since during the quotation stage there still is a lot of uncertainty with regard to project and product specifications, decisions should be made under uncertainty. Besides that, typically within the Engineer-to-Order environment projects often are unique and thus previous data and experience may not be valid.

Another typical problem that rises during quotation for an order with regard to lead-time control is whether quoted capacity should be reserved or not. Since only a limited amount of quotations become actual orders, eventually reserved capacity for an order may become available when the order is lost. When capacity is reserved for quoted orders, this reserved capacity should be taken into account when quoting for a new order. Since some of the reserved capacity becomes available later, unnecessary long lead-times are quoted (which might result in the loss of quoted orders). On the other hand, when capacity for quoted orders is not reserved, at the moment a customer confirms a quotation and places an order, capacity might be reserved for other orders that are placed between the quotation and confirmation and earlier quoted delivery dates may not be realistic anymore.

Taken these characteristics into account, during the quotation lead-time of an order, the following problems with regard to lead-time control can be identified:

- The amount of quoted orders that actual becomes future workload is uncertain;
- Reliable future delivery dates from quoted orders should be determined despite of high uncertainties with regard to required processes and workload of these quoted orders and required workload of earlier quoted orders;
- The duration of the quotation stage depends largely on the responsiveness of the customer who accepts the quotation or not, this cannot be completely internally controlled;
- When customers wait long with the acceptation of a quoted order, earlier determined and quoted delivery dates may not be valid any more.

The quotation lead-time of an order ends and when a customer, possibly after negotiation, accepts the quoted bid and places an order or decides to refuse the quoted bid. When the quoted bid is accepted and an order is placed, the order continues in the subsequent phase, the engineering lead-time.

4.2. Engineering

From the moment a customer places an order, the product can be further designed and specified. During the engineering stage, the main purpose is to turn the mainly functional specifications and basic technical specifications created in the quotation stage into detailed technical specifications. In literature many models and methods for design processes are presented. These vary from simple descriptive models such as the four stage model described by Cross (1994) which identifies the design phases exploration, generation, evaluation and communication, to more detailed and prescriptive models such as the model from Pahl and Beitz (described in Cross, 1994). A general prescriptive model of a design process is presented and discussed by Dym and Little (2000). In this model five stages, from client statement (need) till final design (fabrication specs and documentation) are identified: problem definition, conceptual design, preliminary design, detailed design and design communication. Especially the three design phases: conceptual design, preliminary design and detailed design are widely recognized and described in literature. Each of the phases is discussed briefly appendix 7 using Dym and Little (2000). In appendix 7 further the situation at Eaton Industries B.V. is elaborated in more detail.

The workload during the engineering stage is identified in the framework as confirmed jobs. The content of the workload is known and confirmed. However, there still is some uncertainty regarding the size of the workload of an order. With regard to engineering, a problem is that customers often keep changing specifications during the engineering stage. This leads to unplanned engineering work and may even lead to unplanned work in further stages of the project. Unplanned work of a specific project may have effect on other projects, since capacity is limited. Besides that, customers often wait significant times with the confirmation of designs, which result in a stagnation of project progress.

Another source of unplanned work during engineering are unplanned but required reviews of products that are faultily (not according to specifications) produced or assembled during production. For reviewing these faults, a choice that has to be made is whether to use general or specialized engineering capacity. When general production engineers can be used, this requires typically more time but does not interact the primary engineering process of new projects. Specific specialized engineers can be used on the other hand, which takes less time but does interact the engineering stage of other products (since these engineers typically are assigned to planned design tasks).

In general, the purpose of the design stage is to reduce the product uncertainty. At the end of the design stage, product uncertainty should be reduced to zero. Deliverables at the end of the design stage are technical drawings which specify dimensions and tolerances (from the end product, its sub-systems, and various parts), materials required and testing procedures. With regard to lead-time control, some problems that should be dealt with during the engineering lead-time are:

- Earlier determined specifications of an order may change during engineering due to more extensive feasibility studies and changing customer requirements, as a result the required processes and future workload of an order may change;
- Engineering may require more work than earlier planned, among other things due to optimistic estimating of required engineering work and changing customer requirements;
- Unexpected workload in the engineering department coming from other departments (such as production), that influences planning and processes of other orders at the engineering department;
- Dependency on customer approval, which may take a long time and cannot be completely internally controlled.

When an order is completely designed and thus product uncertainty is reduced to zero and documentation is completed, an order can continue with work preparation, which is elaborated in the subsequent paragraph.

4.3. Work preparation

During work preparation technical specifications determined in the engineering stage typically are worked out in working instructions and raw material and purchased parts requirements. For each order it has to be determined what raw materials (and purchased parts) to use, how to make the product, what machines to use and in what order, and what amounts of processing times are required on each machine (Kingsman et al. 1993). As stated earlier, materials required and dimensions and tolerances of parts are determined during the engineering stage by engineers.

Based on this, work preparation can determine the dimensions of raw materials and in what state raw materials should be delivered. This is the input for the SRM (purchase) department. Subsequently for each part, sub-system and the end product, the required operations and their sequence have to be determined. Subsequently processing times for operations and assembly can be determined (based on insights and historical experience from the production department and data).

Typically for the Engineer-to-Order environment, required production activities and especially estimated processing times may be hard to determine, since products and parts may be unique. Besides that, validity checks of estimations using feedback may take long times since the amount of time elapsed between work preparation and production may be large.

With regard to lead-time control, problems faced during work preparation that should be dealt with are:
- Required processes and processing times determined in this stage may differ from earlier, during quotation, determined processes and processing times and thus future workload of orders may change;
- Since products and parts usually are unique, it is hard to estimate reliable processing times.

When work preparation is finished, the raw materials that are required for each order and their dimensions and tolerances are determined and thus can be ordered in the subsequent phase, material procurement.

4.4. Material Procurement

When work preparation is finished and raw material requirements and part requirements are specified, materials and parts should be ordered. For the acquisition of materials many different terms are used in practice as well as in literature. Concepts such as procurement, purchasing, supply and logistics management are used interchangeable. In the framework that is created (shown in figure 4) all activities with regard to material acquisition fall under the concept of material procurement. As defined by van Weele (2001, p. 16) "procurement includes all activities required in order to get the materials or product from the supplier to its final destination".

In the framework material procurement lead-time is split up in the time required for purchasing the required materials (time elapsed until purchases are confirmed by suppliers) and the time for delivery of the purchased materials (time elapsed between a raw material purchase order is confirmed by a supplier till the final delivery of that material).

Both the purchasing lead-time and material lead-time will be elaborated in this paragraph.

4.4.1. Purchasing

Van Weele (2001) refers to Aljian (1984) to describe the main objectives during the purchasing process. Based on that description, the main responsibility during the purchasing lead-time is to "obtain the proper equipment, material, supplies and services of the right quality, in the right quantity at the right price and from the right source" van Weele (2001, p. 14). This statement is well known in literature and probably a little bit simplistic, however as also Baily et al. (2005) state, it is a good starting point for a discussion.

Different frameworks exist which describe typical activities that are carried out when ordering a product. In this report the framework by van Weele (2001) is used for discussing typical steps that are carried out when purchasing material or products.

The steps discussed by van Weele (2001) largely correspond with typical ordering steps presented by Baily et al. (2005) and Monczka et al. (2002). Below the main steps that are described by van Weele (2001) are summed:
- Determining on purchase order specifications;
- Supplier selection;
- The purchasing contract;
- Ordering.

Typical aspects that should be taken into account when carrying out the steps are discussed in more detail in appendix 7.

Characteristic for the Engineer-to-Order situation is that all activities, and thus also the purchasing of materials are related to a specific customer order. As a result, "the purchase and order of materials takes place on the basis of the specific customer order and the entire project is carried out for this one client" van Weele (2001, p. 214).

With regard to Eaton Industries B.V. few suppliers are able to deliver raw materials which are required for critical large parts such as barrels and piston rods. Besides that, the average delivery times for these materials typically are very long (about 4 – 5 months) and vary over time. The suppliers that are selected to purchase these raw materials are intermediary suppliers, who purchase their materials (buy capacity) at large steel mills. According to the purchase department within Eaton Industries B.V., ordering directly at steel mills is not possible, since Eaton Industries B.V. requires relatively very low quantities.

Since material lead-times for critical parts are very long, at Eaton Industries B.V. raw materials are often already ordered when engineering knows what materials are required (but engineering may not be finished with detailing). When ordering critical materials the purchasing department at Eaton Industries B.V. sends requests to three suppliers of raw materials:
- ThyssenKrupp materials;
- Van Leeuwen Buizen;
- Baleco.

In this request, the material requirements, required certificates, etc. are specified. The requested delivery time for the raw materials is estimated by the purchase department and set at a half year before the promised delivery date to the customer (a half year since this is the estimated average production lead-time). From the offers that are received, one supplier is subsequently selected, mainly based on the price offered for the materials. Subsequently materials are ordered.

In general, when ordering materials at suppliers, the main problems that are faced during the purchase decision and with regard to lead-time control are:
- It should be determined what required material delivery dates should be requested to suppliers;
- Material delivery dates that can be achieved by the suppliers may differ from earlier assumed material delivery dates determined during the quotation stage, as a result planned future activities of orders may change, which subsequently may change planned activities of other orders.

4.4.2. Material Lead-time

From the moment the material is ordered, a company has to wait until the delivery of the material has taken place. The main concern during the material lead-time is whether ordered materials are delivered on or before their agreed delivery date. The achievement of on-time delivery is important with regard to production control and related aspects. As described by Baily et al. (2005, p. 161) "if goods and material arrive late or work is not completed at the right time, sales may be lost, production halted and as a result clauses may be invoked by dissatisfied customers". The main activities a company can undertake during the material lead-time to prevent for late deliveries is monitoring deliveries and checking requested delivery dates with suppliers.

As soon as material is delivered and received by the warehousing and material handling department, the delivered material has to be checked against agreed terms to ensure that they meet these terms. Therefore typically input from the quality and purchase department is required. Especially the confirmation of technical specification is critical. For critical complicated parts it can even be decided to check at the suppliers' site, before shipment, and thus limit the risk.

Finally with regard to purchasing and purchasing activities it should be mentioned that continuously measurement, registration and management is a crucial activity with regard to material procurement. The purchasing cycle does not end when materials are delivered according to specification and administrational activities are finished. As stated by Monczka et al. (2002, p. 34) "continuous measurement is necessary to identify improvement opportunities or supplier nonperformance".

So with regard to lead-time control, during the material lead-time the following main problems may influence the planned activities and workloads:

- Material lead-times may be longer than planned and agreed with the supplier (supplier delivery reliability) and, as a result, this may influence planned future production activities;
- Materials are possibly not delivered according to the right specifications which may result in unplanned required production activities to solve the problems, or longer waiting times for materials that do meet specifications.

From the moment materials are delivered according to the required specifications, production activities may start.

4.5. Production Lead-time

The production time is the time elapsed from the arrival of raw material and parts that were subcontracted out, till the delivery date (thus the pool delay plus the shop floor throughput time). Production is regarded as a transformation process that takes inputs and transforms them to outputs that are of a higher value than the inputs (Kingsman, 2000, p. 74). Pool delay, which is not about transforming inputs into outputs, in literature usually is included in the production lead time. Pool delay can be shortened by for example faster releasing materials to the job-floor. If the processed materials subsequently wait at the shop floor the time they would otherwise have spend in the pool delay, the effect of decreasing the pool delay is negligible. As described by Tatsiopoulos and Kingsman (1983, p. 353), "it is the total time which is of interest to the marketing function". Both pool delay and shop floor throughput time will be discussed in more detail.

4.5.1. Pool delay

It is a common practice to keep orders in the form of delivered materials in a job pool before releasing to the shop floor. The pool delay is the time orders wait from the time materials become physical available until they are actually released to the shop floor (Tatsiopoulos and Kingsman, 1983). For the planner / production controller, holding a large pool of unreleased jobs means that it gives the planner more choice with regard to the release of orders. Besides that, non-released orders have low value (raw material only) which leads to lower capital tied-up. On the other hand, holding large inventories at a pool and having lower inventories on the shop floor "allows less flexibility to the foreman for day-to-day capacity balancing decisions" (Tatsiopoulos and Kingsman, 1983, p. 353).

Jobs within the job pool can be given priority to other jobs by releasing them earlier from the pool to the shop floor (Kingsman et al., 1989). Only the first operation work centers that can be controlled by releasing from the pool however. Controlling throughput of other secondary work centers is more difficult to do. Typically within a job-shop environment for example "their input is the combined output from many previous work centers and varies with product mix, routing sequence and the operation processing times" (Kingsman et al., 1989, p. 202).

As can be seen in figure 4, during the pool delay the status of orders changes from confirmed jobs in previous phases to pooled but unreleased jobs. With regard to lead-time control the main problems and concerns during the pool delay are:

- When to release orders to the shop floor, and what implications the release decision of one order has on other orders with regard to production lead-times.
- Materials of projects that should be released to the shop floor to meet planned dead-lines are not according to specifications, and as a result the planned release decisions should be delayed.

4.5.2. Shop-floor throughput time

The total time elapsed between releasing an order onto the shop floor and its completion is identified by Kingsman et al. (1989, p. 199) as the shop floor throughput time. When a job is released on the job floor there are various types of production that can be used to transform material in an end product. The production function typically "consists of a network of work centers, each with a capability to do a particular transformation task (Kingsman, 2000, p. 74).

The inputs to the system from a directly physical viewpoint are raw materials, components and sub assemblies, which are transformed within the production function into outputs, the finished final goods. In literature numerous types of production and different typologies to classify these types of production are discussed. One typology to classify production is discussed by Bertrand et al. (1998) and distinguishes on two main factors that are determinative for the logistical characteristics of a production department:

- Complexity of the material structure (material complexity);
- Complexity of capacity and variety in production sequence (capacity complexity).

The typology described by Bertrand et al. (1998) is elaborated in appendix 7. In this appendix five typical production departments are identified, based on varying material complexity and capacity complexity. Subsequently typical production control characteristics of the Engineer-to-Order environment are discussed in appendix 7.

Earlier in this report the involvement in competitive bidding was mentioned as one of the two most important characteristics of an Engineer-to-Order company as mentioned by Kingsman et al. (1996). The second characteristic mentioned by Kingsman et al. (1996, p. 220) is that "each order typically requires different amounts of processing work on the work centers of the firm".

Since within an Engineer-to-Order company products are by definition customized and produced based on customer order, many different products are produced in the production department. As a result, for each new order, "the manufacturer has to determine what materials to use, what machines to use for production and in what order and what amounts of processing times are required on each machine" (Kingsman et al., 1993, p. 220).

Determining and executing this for many orders leads to a situation in which:

- Different products may require different materials and parts, which can only be purchased once the product specifications are known (Bertrand and Muntslag, 1993);
- Different products need different physical operations which lead to a different number and different sequence of work centers visited for each product (Kingsman et al., 1996);
- The amount of work for each physical operation may vary.

The shop floor throughput time within an Engineer-to-Order company typically requires some machining (in which parts are produced from raw materials), assembly (in which parts, both produced and purchased, are assembled into sub assemblies and an end product) and testing (of sub systems and the end product).

The typology described by Bertrand et al. (1998) and elaborated in appendix 7 shows that companies that have a moderate to high material complexity and a have relative high capacity complexity typically can be classified as project assembly or to some extent as serial manufacturing. Due to the variability of order sizes, different amounts of processing time required and different routings through production, typically 90% of the total time in production is spend waiting in front of or between work centers and only 10 % of total time in production is used for actual production (Kingsman, 2000). Besides that, the lead-times are often long, mainly due to a large amount of work in process (Handfield and Pannesi, 1992).

Production at Eaton Industries B.V. can be classified as production with a moderate material complexity and a high capacity complexity. According to the typology described by Bertrand et al. (1998) this type of production can be seen as a serial manufacturing.

Production in serial manufacturing is mainly done in production divisions with a layout in which machines and people are grouped based on the function they can carry out. Since routings within production have a strong variation and there thus is no fixed routing, a layout based on function gives the flexibility that is required for this type of production (Bertrand et al., 1998). A production environment characterized by functional oriented resources is known in literature as a job shop.

Meredith (1992) describes a job shop production environment. Characteristics from a job shop as described by Meredith (1992, p. 250) and Kingsman (2000, p. 77) are summed below:

- Staff and equipment are grouped according to function;
- There is a large variety of inputs;
- A considerable amount of transport of either staff, materials or recipients is often required;
- There are large variations in system flow times (the time it takes for a complete "job" to be processed);
- In general each output takes a different route through the organization, requires different operations, uses different inputs, and takes a different amount of time;
- It is possible that a job may need operations on a particular work centre more than once in the sequence;
- Outputs differ significantly in their form, structure, materials, or required processing.

With regard to Eaton industries B.V., typical activities that are carried out during the shop floor throughput time were described in paragraph 2.3. Earlier in this paragraph was mentioned that production at Eaton Industries B.V., which has a moderate material complexity and a high capacity complexity, can be seen as a serial manufacturing. Taken into account the characteristics of a serial manufacturing environment and the characteristics of the job shop environment, and comparing these with the characteristics at Eaton Industries B.V., it can be seen that the production within Eaton Industries B.V. fits many of these characteristics.

With regard to shop-floor lead-time control, the characteristics of the shop floor described in the current paragraph and seen at Eaton Industries B.V. make the shop floor rather complicated to control. This leads to complications with regard to prioritizing, planning and coordination at production. Some typical problems with regard to shop-floor control for a situation as described in the current paragraph are summed below:

- For processes which require multiple materials coming from various previous processes and suppliers, all materials should be available at the right place on the right time;
- Actual processing times may differ from planned processing times, which influence the process of the order which is delayed, but also may influence other orders which need processing;
- Unexpected production faults can influence the process of an order enormously since rework may be required, or even new materials may have to be ordered and processed again;
- Time required for outsourcing processes may differ from planned required outsourcing times.

As can be seen from the description provided in this chapter, a framework is introduced which identifies typical activities that are carried out at an Engineer-to-Order company. Besides that, the relation of orders in various phases identified in the framework with their status for lead-time control is shown in the framework. In this chapter typical activities that are carried out during each of the phases that are identified in the framework are described. Besides that, various stakeholders that interact during each of the phases are identified. Finally the implications of activities and problems in each of the phases on lead-time control are described during the chapter. Continuing on the description in this chapter, the subsequent chapter elaborates in more detail on the total delivery lead-time at Eaton Industries B.V. As could be seen in chapter 2, delivery reliability of orders at Eaton Industries B.V. is not very high. The subsequent chapter will analyze data from Eaton Industries B.V. with regard to the lead-time components identified and described in the current chapter in more detail. Besides that problems that influence lead-time control at Eaton Industries B.V. are mentioned in the subsequent chapter. How to control the model that is introduced and described in the current chapter, will be further elaborated in chapter 6.

5. Lead-time analysis at Eaton Industries B.V.

In chapter 2 was shown that delivery reliability at Eaton Industries B.V. was quite low. Continuing on that observation and the description of the framework in the previous chapter, this chapter will present a more detailed lead-time analysis from new built cylinder projects at Eaton Industries. Paragraph 5.1.1 will show a data analysis of the total deliver lead-time and its components. Based on this analysis a lead time structure as observed at Eaton Industries B.V. is discussed and compared with the framework discussed in the previous paragraph. Paragraph 5.1.2 will discuss the production lead-time in more detail, after which some restrictions and inaccuracies from the data analysis are discussed in paragraph 5.1.3. Paragraph 5.2 finally discusses some qualitative problems that were identified at Eaton Industries B.V. and that negatively influence delivery performance at Eaton industries B.V.

5.1. Data analysis lead-time performance Eaton Industries B.V.

5.1.1. Data analysis of total delivery lead-time

Within the total delivery lead-time of an Engineer-to-Order manufacturing company typically some characteristic stages can be identified, as described in chapter 4. Data for the various lead-time components identified in the framework discussed in chapter 4 is analyzed. The main results are shown in appendix 8 and a summary of the results is shown in table 2. A remark that should be made is that outliers in data are included in the summarized data shown in table 2. Another remark that should be made is that in the material lead-time component from the data analysis only critical materials (required for piston rods and barrels) are included, since these materials are (or at least should be) determinative for lead-times.

	Nr. of projects included in sample	Nr. of projects finished on or before the promised scheduled due date	Percent of projects finished on or before the promised scheduled due date	Nr. of proj with sufficient data to determine planned and actual lead-times	Average planned time (weeks)	Standard deviation planned time (weeks)	Average actual time (weeks)	Standard deviation actual time (weeks)	Difference actual – planned lead-time
Total delivery lead-time performance	55	6	11%	44	31,5	9,7	48,9	14,1	17,4
Engineering lead-time performance	54	31	57%	43	3,9	4,5	9,3	9,2	5,4
Work preparation lead-time performance	54	31	57%	50	2,3	4,1	3,2	3,9	0,9
Material delivery lead-time performance	45 (118*)	(54*)	46%	45 (118*)	12,5	10,5	16,7	13,4	4,2
Pool Delay	45 (113*)	--	--	--	--	--	8,7	9,5	--
Production lead-time performance	44	2	4,5%	44	16,6	3,1	27,8	9,0	11,2

Table 2: summary results data analysis

* Number of "critical" material orders (a project typically contains multiple orders for critical materials)

Besides the main results shown in table 2, from the data analysis it can be concluded that the sales department released work to the engineering department on average 1,3 weeks after the order was confirmed (standard deviation 3,2 weeks). Officially, the engineering process starts when the sales department finishes. Since lead-times for critical materials required by Eaton Industries B.V. are typically very large, critical materials are ordered as soon as the order is confirmed and engineering has sufficient knowledge (main dimensions and material requirements) to purchase critical materials. The data analysis has shown that critical materials were ordered on average 2,9 weeks after the order was confirmed by the customer (standard deviation 7,9 weeks).

Based on the results provided in this paragraph, a lead-time structure can be sketched, that represents the situation at Eaton Industries B.V. The lead-time structure that is created based on the data analysis is shown in figure 6 and on a larger scale in appendix 9. In figure 6, planned times for various activities are represented by dotted horizontal lines. Actual times for various activities are represented in figure 6 by continuing lines.

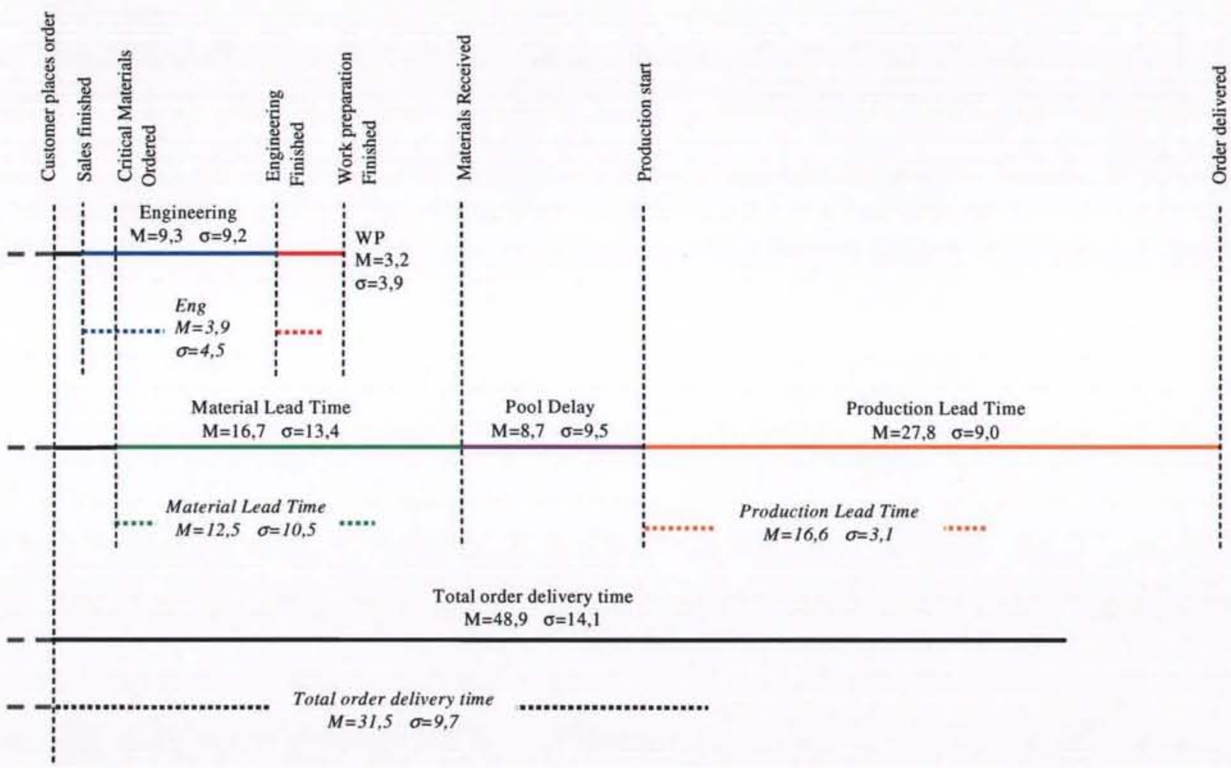


Figure 6: lead time structure Eaton Industries B.V.

From the lead-time structure shown in figure 6 it can be seen that the actual lead-times for various activities structurally are larger than the planned lead-times. Comparing the structure shown in figure 6 with the lead-time framework discussed in chapter 4 and shown in figure 4, it can be concluded that there is some difference. The main difference is that not all activities turn out to be sequential (as shown in figure 4), but some activities might be performed concurrent to other processes. Critical materials for example are ordered during the engineering lead-time, and the material lead-time of critical materials thus is concurrent to the engineering lead-time and work preparation lead-time. An explanation for this is given previously in this paragraph, since lead-times for critical materials at Eaton Industries B.V. are very large and therefore are ordered as soon as sufficient knowledge is available.

The lead time structure at Eaton Industries B.V. as shown in figure 6 might imply that the activities Engineering and Work Preparation become less critical for overall project lead-time performance, since delay in these activities doesn't automatically affect the total delivery lead-time. For control purpose, the differences in lead-time structure between the model described in chapter 4 and the situation shown at Eaton Industries B.V. (figure 6), have no large implications. Orders which are waiting for materials and orders at Engineering and Work preparation are in the same state with regard to lead-time control (confirmed orders), as shown in figure 4. This will be elaborated in chapter 6.

5.1.2. Data analysis of production lead-time

In the previous paragraph an analysis of the total delivery lead-time and its various components, conducted at Eaton Industries B.V. is shown. From this analysis it can be seen that the production lead-time requires a significant amount of time. Besides that, actual production lead-times turn out to be much larger than planned production times. Therefore the production lead-time was analyzed in more detail. The results of this analysis are shown in table 3 and discussed in more detail in the current paragraph.

	No of projects	No of parts	Planned setup time (hours)		Actual setup time (hours)		Planned procc time (hours)		Actual procc time (hours)	
			Average	SD	Average	SD	Average	SD	Average	SD
Turning B1	13	22	1,00	0,00	1,58	0,76	5,38	0,82	6,60	3,46
Welding B	23	47	0,55	0,36	1,37	1,30	3,38	3,51	6,83	9,24
SAW B	19	37	1,09	0,26	1,47	0,70	6,89	3,30	7,04	4,00
Turning B2	9	14	1,00	0,00	1,57	0,78	3,81	0,83	3,72	1,72
Ass B	11	32	X	X	X	X	2,64	1,04	3,26	1,44
Turning B3	14	27	1,27	0,42	4,12	3,34	7,68	0,84	8,29	4,61
Milling B	22	48	4,06	1,51	3,64	2,07	5,69	2,93	7,74	10,71
Total procc B			8,97		13,75		35,47		43,48	
Turning PR1	5	10	2,40	2,80	4,10	3,01	11,30	10,38	17,09	9,01
Welding PR	8	19	0,54	0,09	1,92	0,53	1,97	1,37	3,65	3,47
SAW PR	8	18	1,00	0,00	1,44	0,98	13,13	2,58	11,16	4,44
Ass PR	8	13	X	X	X	X	1,19	0,50	2,47	0,67
Turning PR2	4	6	6,50	2,60	7,38	1,08	28,00	4,00	22,61	3,78
Milling PR	10	14	3,75	0,43	2,35	1,28	1,60	0,12	2,39	0,99
Total procc PR			14,19		17,19		57,19		59,37	
Assembly 1	23	67	X	X	X	X	26,38	6,88	27,81	16,81
Assembly 2	19	45	X	X	X	X	2,24	0,94	5,78	5,47
Assembly tot	22	56	X	X	X	X	27,89	6,68	35,86	16,10

Table 3: processing times found by analyzing shop-floor data

In October 2007 a new ERP information system was installed at Eaton Industries B.V. As opposed to the previous system, the new system has the capability to record and present detailed production data. Therefore data which is registered using the new system was used for analyzing production data (as opposed to the analysis of the total delivery lead-time, which carried out using the "old information system"). Since the system was installed recently, relative few data (collected over a short time period, from the beginning of October 2007 till the end of December 2007) was used for analysis. Using labor hour registrations, processing times for various projects at various work centers could be analyzed.

Critical parts (barrels (B), piston rods (PR) and assembled cylinders with a minimum length of 1 m) from 51 projects, which were at different stages within production during the analyzed period, were included in the analysis. From these 51 projects, none of the projects could be followed from production start till finish. The physical length of the parts that were included varied between 1,16 m till 12,64 m (average 6,81 m). The results of the data analysis are shown in table 3. For typical production steps the average and standard deviation of the planned setup time, actual setup time, planned processing time and actual processing time is shown. Besides that, the number of projects included and parts included (projects may contain multiple cylinders) for determining processing times from typical production steps are shown.

In addition to the analysis of processing times, a brief analysis from outsourcing times is made. Shipment dates from the outsourcing processes are not recorded specifically at Eaton Industries B.V. From the data available an impression of outsourcing times could be given however (sometimes quality inspections before and after outsourcing were registered etc.). For outsourcing processes a standard time is scheduled which is shown in table 4, and can be compared with the actual average time.

		No of projects	No of parts	Standard time (weeks)	Average time (weeks)	Stand dev time (weeks)
DDH		**12**	**18**	**5.68 (924 hrs)**	**5,60**	**1,00**
Surface treatment	CHR 2400<L<5000	*5*	*5*	*2.50 (420 hrs)*	*2,50*	*0,60*
Surface treatment	CHR L>5000	*7*	*14*	*2.50 (420 hrs)*	*4,20*	*1,60*
Surface treatment	NI/CHR	*6*	*10*	*3.00 (504 hrs)*	*4,00*	*2,00*
Surface treatment	Overall average	**18**	**29**		**3,70**	**1,40**
Painting		**13**	**29**	**1.50 (252 hrs)**	**1,30**	**0,40**

Table 4: outsourcing lead-times found analyzing shop-floor data

From the analysis of production data presented in the current paragraph it can be concluded that planned / estimated production times are often lower than the actual times spend for production. Besides that, it can be seen that a significant amount of production time is spend on outsourced processes. The time that is estimated for the outsourcing of deep drilling and honing, surface treatment of small parts and painting was close to the actual time spend during the analyzed period. The time actual required for the outsource process of surface treatment for large piston rods was high (4,2 weeks) compared with the estimated time (2,5 weeks).

5.1.3. Restrictions data analysis

As stated previously in paragraph 5.1.1, there are quite some restrictions and inaccuracies in the data that is used. In the current paragraph, a brief description of the main restrictions and inaccuracies of the data used in the analysis is given. These restrictions especially hold for the analysis of the total delivery lead-time discussed in paragraph 5.1.1. For the analysis of the production lead-time discussed in paragraph 5.2.2, more reliable information was available. A weakness in this analysis is the relative small time period from which production data was collected. Besides that, some of the restrictions mentioned in this paragraph also hold for the analysis of the production lead-time.

With regard of restrictions, first of al, it has to be noticed that within the sample used in paragraph 5.1.1 not all data was available for all projects. As a result different lead-time components and performance indicators are calculated using different samples. There was quite some overlap in these samples, but still samples differ in size and content.

Another restriction with regard to the data used in paragraph 5.1.1 is that for several activities (e.g. engineering, work preparation and production), only release dates were given. When activities actual started was hard to find out, with the data that was available. As a result actual throughput times might differ from throughput times which were observed. Besides that, from the data available it is hard to gain insights in time which was actual spend on various activities (e.g. engineering, work preparation, purchasing).

From the data itself, it has to be noticed that it may be unreliable to some extent. During the research project, it was noticed that the actual situation sometimes was different from the situation as it was represented in the system. This holds for both analysis presented in the current chapter. An example is the delivery of materials. At Eaton Industries B.V. there often is some delay between the moment materials are physically delivered and deliveries are registered in the system. As a result, data regarding for example material delivery reliability by suppliers should be interpreted with care. Besides that, it should be questioned whether planned data in the system was actually planned before the start of an activity.

A restriction of the "old information system", Exact, which is used for the analysis in paragraph 5.1.1 is that changes in planning data could only be processed in the system by replacing previous planned data. This restriction was one of the main reasons Eaton Industries B.V. reported other delivery performance figures than those in this report, which are based on more reliable data sources such as customer confirmation documents.

Subsequently it has to be noted that during data analysis, no difference was made in size and complexity of various projects. A project typically contains the development and production of multiple (equal) cylinders. Besides that, of some projects similar projects were carried out before, and other are new and unique to the company. Finally the remark that some projects may be related to each other to some extent with regard to cylinder design and required delivery dates has to be made.

Taken these restrictions and inaccuracies together, it should be noted that no hard conclusions can be drawn from the data analysis discussed. However, the analysis gives a good impression from the situation at Eaton Industries B.V. with regard to delivery performance, lead-times and lead-time structure.

5.2. Qualitative problems delivery performance at Eaton Industries B.V.

Using a quantitative analysis, the previous paragraph showed that delivery reliability at Eaton Industries B.V. is quite low. Besides that, some problems that are faced at Eaton Industries B.V. were discussed previously in paragraph 2.4. In the current paragraph, problems that are faced at Eaton Industries B.V. with regard to delivery performance are stated in a qualitative way. The identification of problems at Eaton Industries B.V. is based on initial interviews that were conducted at the start of the project with representatives all over the organization, informal communication during the research project and experiences gained.

A concept of the problems that are stated below is discussed with people within the organization to check validity, and comments subsequently were taken into account. Based on the approach described above, the following problems with regard to delivery performance at various departments within the organization and in various phases of the delivery lead-time are identified:

Order quotation

- During the quotation for an order, the planning department is not able to give a realistic future delivery date (which is based on capacity and workload);
- Customers often wait long with order confirmation (earlier quoted delivery dates subsequently are not reviewed at the moment of order confirmation);
- Often unrealistic (short) delivery dates are quoted in order to improve the probability for gaining an order.

Engineering

- Customer keeps changing specifications which leads to increased times required for engineering (delivery date of a project remains often unchanged, despite changing customer requirements);
- The times planned and estimated for and by engineering are often underestimated (also engineering at India often takes longer than estimated, since these engineers have little experience with special designs, Eindhoven engineers subsequently need extra time for checking and updating of drawings created by Indian engineers);
- Customer confirmation of the final design created by engineering (drawing approval) may take a significant amount of time;
- Within production sometimes production faults are made, which subsequently require unexpected engineering capacity, since the actual product may differ from the earlier designed product (engineering should in that case check whether the product is still within allowable specifications, or whether specifications can be changed).

Purchasing / Material Deliveries

- Customers change specifications till late in the process, therefore sometimes the ordering of materials has to be delayed;
- Delivery times of critical parts are often very long (longer than estimated earlier during order quotation);
- Materials are often delivered later than promised by the supplier (supplier delivery reliability);
- Whether and when materials are actually delivered is bad communicated internally (e.g. from warehousing to production, planning and purchasing);
- Delivered materials sometimes are not according to specification (which results in long waiting times for new materials).

Production
- Not all materials are available on the planned production start date (due to late material deliveries, previous processes which are not finished yet and late certificate and quality checks on raw materials and previous processed parts);
- Searching times for materials (material identification) and time wasted due to the picking and setup of wrong materials;
- Production capacity (man and machine) is limited and workload high, which results in long production throughput times;
- Processing times that are determined are optimistic; actual processing times often take longer than planned processing times (this is supported by the quantitative analysis shown in paragraph 5.1.2);
- Long waiting times between arrival of raw materials or finished processes and required quality checks and magnetic research (done by external institutes) during the production process;
- Outsourcing activities often take longer than planned (outsourcing lead-times are largely dependent on the market demand at the subcontractor);
- Less critical materials and parts, required during the process (welding / assembly), often are not complete / available;
- Production faults occur during processing (rework is then required, and sometimes even new materials should be ordered and processed);
- Unexpected machine breakdowns and employee absenteeism;
- Long, sometimes unnecessary, waiting times between processes (and outsourcing), due to bad planning / communication.

Planning
- Delivery times of materials and outsourcing processes (which are market dependent) vary enormously (and thus are hard to estimate);
- When determining delivery times, accurate required production processing steps and times often still are unclear, which makes it hard to determine production lead times;
- Current workload which is accepted is mainly invisible for planning, which makes it hard to determine delivery dates (for orders that are released in production the future workload is largely clear, orders which are not released in production yet are mainly invisible for planning);
- The planning of orders is static, project planning is hardly adjusted during time;
- The impact of changing the planning for a specific order on other orders is hardly taken into account.

Next to the problems that are stated above, there are some problems which are in the culture of the company and therefore are hard to change. A problem that is often mentioned is a company culture which is often reactive (in stead of pro active). An example is that there is often waited to contact suppliers with regard to delivery status till materials are actually delivered too late. A proactive approach would inform the supplier some time before the planned delivery date, whether planned dates will be met by the supplier.

Another cultural issue which is mentioned often is that actions which are agreed are often without obligations and subsequently often get bogged down. It is often stated at Eaton Industries B.V. that there are enough procedures which describe what should be done, but there is little discipline to follow them up.

A final remark that has to be made is that in the past, there hardly has been done any calculation at the back end of projects or processes. As a result actual costs and times for projects and processes are hardly compared with planned and estimated costs and times. With regard to costs, in 2007 a start is made to compare costs that were actually made for a specific project with the costs and budget that were planned at the start of the project. With regard to processing times actually spend and planned, however, still no clear action is initiated.

Given the problems described in this paragraph, some main sources for the past limited delivery performance at Eaton Industries B.V. can be identified. The sources are not the cause of all problems that are faced, and some recent actions are taken which should improve future delivery performance. The identification of main sources which lead to the problems that are identified analyzing the past performance provides a starting point for a discussion on controlling lead-times however. The main sources for late delivery that are identified at Eaton Industries B.V. are:

- Company commitment on quoting realistic due dates;
- Limitations of the information system (lack of valid information);
- Planning department and work preparation structure, capacity and knowledge;
- Limitations in the tools available at the planning department (these are not able to include backlog and capacity);
- Relative high workload, which results in capacity problems on departments such as the quality department and production;
- Inexperienced people at production (resulting in longer processing times and unnecessary rework);
- External factors:
  - Customers (waiting with accepting orders and designs and change specifications);
  - Suppliers (long and market dependent material lead-times and delivery reliability);
  - Subcontractors (market dependent outsourcing lead-times).

Based on the framework that identifies the various typical activities that are typically carried out at an Engineer-to-Order company, the characteristics and problems for lead-time control which are discussed in chapter 4 and the problems that that are identified in this chapter, suggestions can be given to control delivery performance and lead-times in an Engineer-to-Order company. To achieve this, an organization should be organized and structured in such a way that the process and control of the required activities can be carried out in a reliable way. Current problems faced at Eaton Industries B.V. and the main sources for these problems, identified in this chapter, give insight in conditions that should be fulfilled in the organization to support a reliable delivery of orders. How to control the model introduced in chapter 4 and problems that may harm delivery performance identified in the current chapter will be elaborated in the subsequent chapter.

6. Controlling lead-times in ETO companies

In previous chapters of this report, a profile of typical Engineer-to-Order companies is sketched and especially the Engineer-to-Order manufacturing company Eaton Industries B.V. is discussed in detail. Following from the Engineer-to-Order lead-time framework that is described in chapter 4 and the lead-time analysis presented in chapter 5, the current chapter will present recommendations about how to control lead-times in Engineer-to-Order manufacturing companies. Therefore a method is developed, inspired by Kingsman (2000), which will be discussed in paragraph 6.1. Paragraph 6.2 will elaborate in more detail about how to deal with external influences on internal processes, which were identified in paragraph 5.2. Finally paragraph 6.3 presents, based on the problems faced within Eaton Industries B.V., some practical suggestions for Eaton Industries B.V.

6.1. Method for controlling internal processes

For a successful control of the internal processes and activities that are required to deliver a product against the agreed terms and delivery date, a prerequisite is that the total delivery lead-time determined during the quotation lead-time of an order is realistic. A realistic delivery date of an order should be based on the required activities for that order and workload of these activities, the workload from previous scheduled orders, and the capacity available at each of the departments that should perform the scheduled activities. Besides that, some safety margin could be used.

Activities that typically should be carried out at an Engineer-to-Order manufacturing company are identified in the framework that is discussed in chapter 4. As discussed in chapter 4, activities that successively should be carried out for an order and decisions taken in each of the lead-time components, influence decisions that have to be taken in subsequent phases. For control purposes, four different states in which orders can be, are identified in the framework of chapter 4. These different states are quoted jobs, confirmed jobs, pooled (unreleased) jobs and released jobs. For control of total delivery lead-times these different states and the key moments that characterize and separate these states should be adjusted to each other. With regard to lead-time control, during the first phase, in which orders can be seen as quoted jobs, important decisions should be made with regard to required processing times and subsequently delivery dates should be set. The total delivery time of an order, which is the subject for control, is composed of three states in which an order can be confirmed jobs, pooled (unreleased) jobs and released jobs.

Confirmed jobs mainly require administrative activities such as engineering, work preparation and purchasing while released jobs mainly require physical production activities. The pooled jobs can be seen as a buffer between the confirmed jobs and the released jobs. The pool can neutralize the effects of confirmed jobs that are finished too late (with regard to engineering, material deliveries, etc.) and gives some flexibility to the production facility as discussed in paragraph 4.5.1.

So to control internal lead-times in an Engineer-to-Order manufacturing company, reliable and realistic lead-times and dates should be determined and subsequently it should be made sure that planned lead-times and dates correspond with actual dates and times.

6.1.1. Determining internal lead-times

Determining the time that is required to process confirmed jobs and thus to do the required engineering and work preparation activities and order the required materials should be done in close cooperation with the people involved in these phases. As stated earlier, the workload of new orders, workload of previously confirmed orders and capacity are determinative for the lead-times that can be quoted for each of the phases.

So for determining the time that is required for engineering, work preparation and material procurement, the capacity at these departments should be checked, and using the planning of accepted orders, it can be determined when a new order can be processed. Based on the characteristics of the order, the required workload for this order can be determined, and based on that, expected delivery dates from engineering and work preparation can be determined. The time that is required for material procurement, cannot be determined completely internal, since the material lead-time is dependent on external sources, the material suppliers. How to deal with these external material suppliers will be discussed in more detail in paragraph 6.2.2.

Determining required lead-times for production operations and controlling these shop floor lead-times is more complicated. In the current paragraph a method will be discussed that can be used to determine realistic dates for required production operations and control the shop floor lead-times within an Engineer-to-Order company. The method discussed in this paragraph can help to give some structure and guide to the planning of production processes and subsequently can be used to guide and direct other related work.

The method to control the shop floor presented in the current paragraph is inspired by (and extended from) Kingsman (2000). The main production planning and control principle used in that approach is workload control, which controls the queues in front of the shop floor and its workstations. In a review of multiple "classic" Production Planning and Control approaches such as Kanban, Manufacturing Resource Planning, Theory of Constraints, Workload Control and Constant Work In Process, Stevenson et al. (2005) identified Workload Control (WLC) as the most appropriate Production Planning and Control approach for Engineer-to-Order companies. However, as Stevenson et al. (2005, p. 888) state "although WLC is considered the most applicable approach, a generic WLC concept does not exist". Therefore the general WLC approach described by Kingsman (2000) is fit with the characteristics of companies such as Eaton Industries B.V. and a more specific approach is made. Before discussing the method, first the scope of the method and characteristics of companies that can use the method will be discussed.

To narrow the scope, a matrix presented by Stevenson et al. (2005, p. 886) can be used, which distinguishes between customization and shop configuration. Based on this matrix and taken into account characteristics of Eaton Industries B.V., the scope can be narrowed to Versatile Manufacturing Companies, using a General Job Shop Production environment.

Versatile Manufacturing Companies are manufacturing companies that deliver highly customized products. As opposed to Repeat Business Customers (which also delivery highly customized products), Versatile Manufacturing Companies can be characterized as manufacturing companies in which for each individual order is competed and "a high variety of products with variable demand are manufactured in small batches with little repetition" (Stevenson et al., 2005, p. 872).

With regard to the shop floor configuration, Stevenson et al. (2005) distinguishes between pure job shops and general flow shops. A general flow shop fits the shop floor configuration as it is at Eaton Industries B.V. A general flow shop is defined by Stevenson et al. (2005, p. 872) as a job shop with a "multi-directional routing, and a dominant flow direction".

Inspired by Eaton Industries B.V., additional characteristics for production processes, work centers within production and outsourcing processes, which should be reflected in the method, are formulated and summed on the next page.

In general the method should be able to include:

- Engineer-to-order Lead-time framework as described in current Master Thesis Report:
  - Quoted jobs (which include uncertainty of confirmation);
  - Confirmed jobs;
  - Pooled jobs (unreleased Jobs);
  - Released jobs.
- Market dependent material lead-times;
- Market dependent outsourcing lead-times;

With Regard to Production:

- All production starts at the same Work Center (WC 1), and finishes at the same Work Center (WC N);
  → Pool releases always first require processing on WC 1;
  → Final processing is always required on WC N;
- There is variety in routings of processes that are required for each part (however, there is one dominant flow direction);
- There is variety in processing times;
- One Work Center may be visited multiple times during the processing of one part;
- Outsourcing is required for each product (multiple outsourcing may be required for one part);
- Outsourcing times are market dependent and thus vary;
- The output of each work center may be the input to each other work center (and outsourcing).

For each work center:

- A given capacity for a certain time period (say day or week), which may change per period (using e.g. overtime);
- A maximum number of jobs (or workload) can wait in front of the workstation to be processed.

Outsourcing:

- Capacity (number of jobs that can be processed simultaneously) is unlimited;
- No waiting queue before outsourcing;
- Takes a number of time periods (which cannot be influenced internally), which may differ for each outsourced job.

Taken into account the characteristics described above, the situation could well be controlled using a discrete time method. In this method, the time horizon could be divided in equal time periods (days, weeks). In each of these periods, capacity at workstations can change. Time required for e.g. customer order acceptation, material delivery and outsourcing can be modeled by "assigning" them a specific number of time periods.

The Engineer-to-order lead-time framework as described earlier in chapter 4 of this report shows a hierarchy in lead-times and implications for production control in various stages. A representation of the method, which fits the characteristics and shows more specifically the pool of unreleased jobs and the states of released jobs within production, is shown in figure 7. The representation of the method shown in figure 7 describes the manufacturing environment, including the outsourcing process and N (in the example in figure 7, N = 3) work centers.

As described in the characteristics, pooled jobs are only released to WC_1 and finished jobs only leave through WC_N. Outputs from each work center (and outsourcing) can be directed to each other work center (where they join the queue).

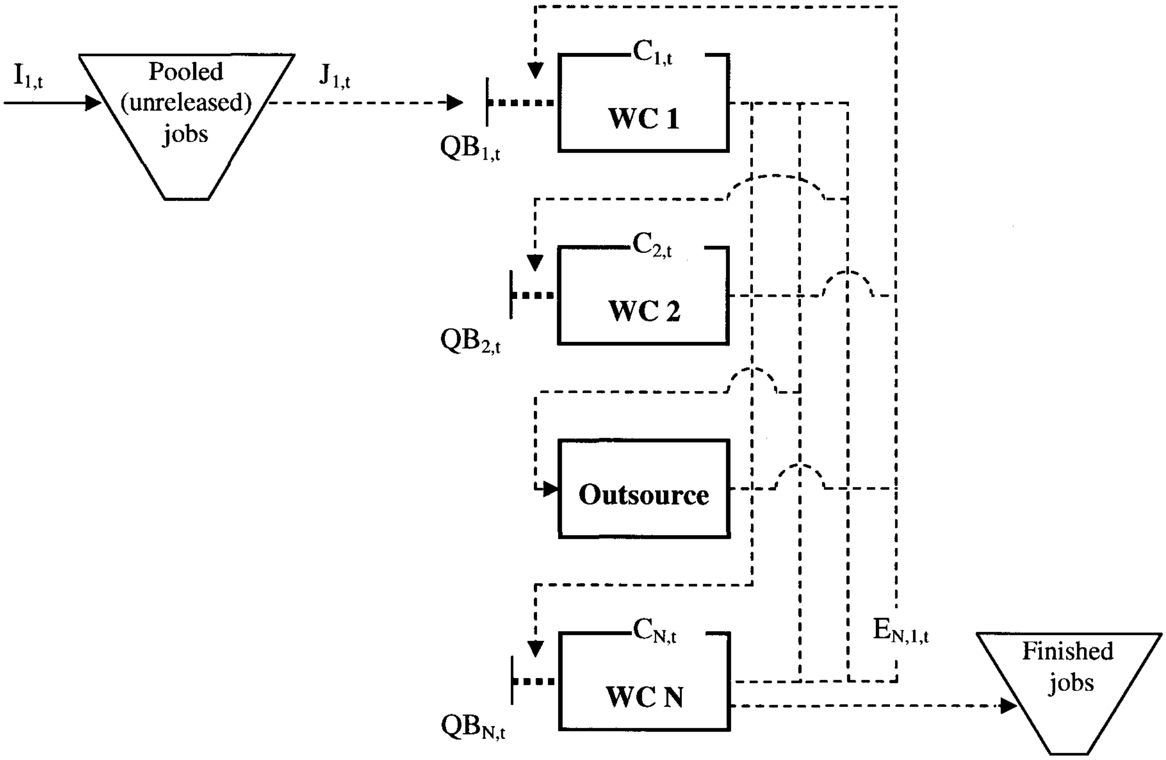


Figure 7: graphical representation method to control lead-times and capacity

An assumption that will be made is that an order that is processed at a work center in a certain period, will join the queue of the next work center in the sequence of that order at the beginning of the subsequent period. At the beginning of that subsequent period, jobs that were still queuing at the end of the previous period have priority above new arriving jobs. From the jobs that arrive in a certain period at a specific work center, earlier scheduled jobs have priority above new jobs.

Assuming that the routings of all scheduled orders are known, that the required workload of each scheduled order on each work center is known (and certain), and that capacities at work centers for each period are known, the workload at each work center during each period can be determined. When is determined what is processed in a specific period at each work center, the workload at the start of the subsequent period can be determined, since this is the workload at the beginning of the previous period, minus the workload that was processed during the previous period at that work center, and added with the workload coming from other work centers.

Taken into account the assumption that a job processed in period t at work center n, will join the queue of the next work center in the sequence of that job, at the start of the subsequent period t = t + 1, for the work centers, the proposed method (graphically represented in figure 7) physically means that:
the input workload each period t for WC_1 = Output t-1 from WC_2 directed to WC_1 + Output t-1 from outsourcing directed to WC_1 + Output t-1 from WC_N directed to WC_1 + Input released from the pool in period t.

In mathematical terms this can be described as:

$$V_{1,t} = \sum_{k=1}^{k} E_{k,1,t-1} + J_{1,t}$$

For each of the other work centers (WC_2 to WC_N) and the outsourcing process holds that:

$$V_{n,t} = \sum_{k=1}^{k} E_{k,n,t-1}$$

$V_{n,t}$ =	Physical input workload in period t at work center n;
$E_{k,n,t}$ =	Workload required for order k (processed in t at WC_k) at the subsequent process WC_n at period t+1;
$J_{1,t}$ =	Workload coming from the job pool in period t to WC_1 (released on the shop floor);
$QB_{n,t}$ =	Physical workload Queuing at the start of period t in front of Work center n;
$Z_{n,t}$ =	Actual work done in period t, by W_n.

For the physical queue in front of each work station each period, this means that:

Work station 1:

$$QB_{1,t+1} = QB_{1,t} + \sum_{k=1}^{k} E_{k,1,t} + J_{1,t} - Z_{1,t}$$

For the other workstations, WC_2 to WC_N, holds that:

$$QB_{n,t+1} = QB_{n,t} + \sum_{k=1}^{k} E_{k,n,t} - Z_{n,t}$$

When applying the workload control method, maximum limits for the queues (workload) at each workstation should be determined. Once the workload in a certain period at a work center exceeds the maximum allowable workload that is determined for that work center, the workload should be decreased. This can be done by either decreasing the input of the workload (rescheduling the order), or increasing the capacity at that work center.

Having a relative constant workload in front of each work center, that does not exceed the maximum determined workload, results in a relative low variation in throughput times for orders at each work station. Further, the number of work that is simultaneously on the shop floor is limited, which keeps the overview for the production controller clear. Besides that, control at each work center is made easier since the required work for each period is determined, and at each period required outputs are determined. The responsibility of how to achieve these outputs can be delegated to each of the work centers. The advantages for lead-time control will be further discussed in paragraph 6.1.2.

When determining the manufacturing lead-time that is required for a new order and determining the date that the new order can be delivered to the customer, the new order should be scheduled behind the earlier confirmed orders. Using the formulas and characteristics stated above, and taken into account the maximum workload levels that are set for each work center, a feasible solution should be found. Additional constraints that should be taken into account when scheduling a new order are stated by Kingsman (2000), and are mentioned in appendix 10. Taking these constraints into account, it is ensured that planned activities are achievable and realistic. Using the method described, the release moment from the new order on the shop floor and the required capacities of each work center for each period can be determined. Based on that, and given that the sequence and workload on each work center for the new order are known, the date that the new order arrives at each work center and leaves each work center can be determined.

A constraint that may be added to the constraints mentioned by Kingsman (2000) is that each period t, only jobs that physically wait (queue) in front of work station WC_n can actually be processed:

$$Z_{n,t} \leq QB_{n,t}$$

Another aspect that should be taken into account is that at the planned release date to the shop floor, all required preceding activities (such as engineering and work preparation) should be completed and materials should be available. If the planned lead-time till the arrival of materials is larger that the planned time till orders should be released on the shop-floor, the release at the shop floor should be scheduled later. This will be elaborated in more detail in paragraph 6.2.2.

An example is made (shown in appendix 11), to clarify the claims made in this paragraph with regard to relative constant workload in front of each work center and a low variation in throughput times at each workstation using a workload control approach. In this example, ten fictive orders that require processing on three work centers and require outsourcing for a number of periods, are scheduled using the workload control method. At t = 0, subsequently nine orders (order 11 – 19) are scheduled using the approach and constraints mentioned in this paragraph. For each fictive order the required routing and processing times are given. For each work center it is assumed that the capacity at each period is 40 hours, and the maximum workload that may queue at each work center during each period is 60 hours. As can be seen in appendix 11, based on this, for each order the required shop-floor throughput time and achievable customer delivery date are determined. Further in the report, in paragraph 6.3.1, the same example will be scheduled using the scheduling method currently used at Eaton Industries, and the main differences will be discussed.

A representation that shows the effects of the workload control method is shown in figure 8. Planning the 19 fictive orders using the method described and taken into account the constraints, results in a cumulative workload on WC 2 as shown in figure 8. As can be seen in the figure, the workload (difference between cumulative input and output in a certain period), never exceeds the maximum allowable 60 hours and is relative constant. As a result, the time that is required for each order on workstation 2 is relative constant (never exceeds 2 periods).

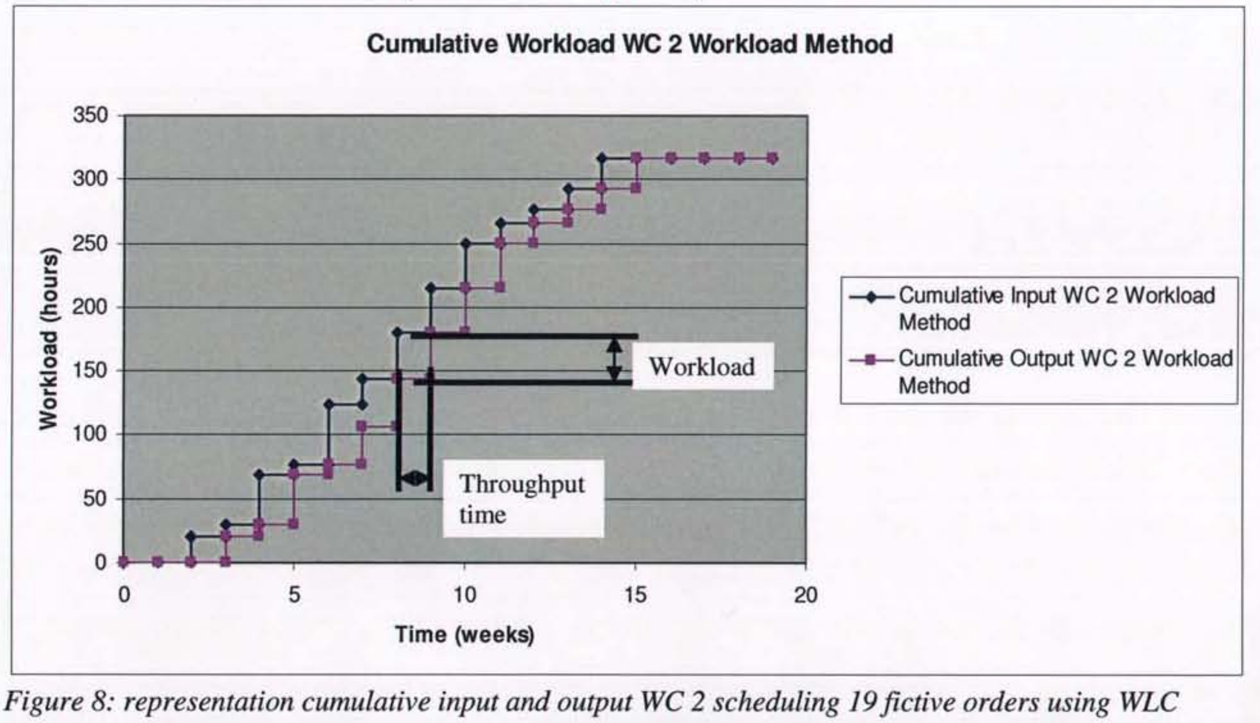


Figure 8: representation cumulative input and output WC 2 scheduling 19 fictive orders using WLC

So when determining reliable delivery dates and lead-times for new orders, first of all the time that is required to turn customer requirements into a detailed design, production requirements and material requirements should be determined. Subsequently it should be determined when the required materials are available and thus production can start. Using a workload method, subsequently shop-floor throughput times and delivery dates of products can be determined. How to control the total delivery time, and make sure that determined lead-times correspond with actual lead-times will be discussed in the subsequent paragraph.

6.1.2. Controlling internal lead-times

The previous paragraph showed how realistic delivery dates and lead-times for new orders can be determined. This paragraph will discuss how lead-times and internal factors can be controlled. Control problems were described previously in chapter 4. Some of these problems could not be internally controlled. How to control external influences on internal processes will be discussed in paragraph 6.2.

As described in chapter 4, using the framework shown in figure 4, during the lead-time of an order various important decisions have to be taken. Decisions that need to be taken have a variety in the required detail of the information. Kingsman (2000) has identified four typical key decisions that should be taken during the lead-time of an order at an Engineer-to-Order company, and which require a different detail of information:

- Order entry at enquiry stage (offer a quotation for an order or not);
- Order acceptance (accept customer order against agreed terms);
- Job release (releasing orders to the work floor);
- Priority dispatching (the order jobs are scheduled through each work center).

Since various decisions should be based on a variety in the required detail of information, it is important to have a hierarchy in levels of control. For production control, three levels of control are suggested by Bertrand and Muntslag (1993, p. 11 and p. 12):

- Goods Flow Control (GFC) "which is concerned with the overall coordination for a chain of production phases";
    - Aggregate Planning, "which deals with medium / long term coordination on activities primary based on aggregate data";
    - Operational Planning, which "involves timing of work orders and the periodic assignment of available resource capacity to individual products";
- Production Unit Control (PUC) "an organizational grouping of recourses which can perform independently and are capable of making reliable commitments".

The levels mentioned by Bertrand and Muntslag (1993) show a clear hierarchy. At the highest level, Aggregate Planning, the main decision is whether to quote for a specific order, and what delivery time to quote.

As discussed in paragraph 6.1.1, the date that a new order can be released to the shop floor can depend on internal factors and external factors. Internally, the time required for engineering, work preparation and processing of previous orders (that require the same processes as the new order) are determinative for the release date of the order. The internal date should be determined based on capacity and workload, using the method and constraints described in paragraph 6.1.1 of this report. On the other hand, the delivery time of materials that are required may be determinative for the release date of the order to the shop-floor, since the order cannot be released before material is available. The earliest release date to the shop floor is thus the latest of the date that all materials required are available or that capacity on the required work centers (determined by previous orders) is available.

On the highest level of control, an overview of the whole customer delivery lead-time should be held. Factors that disrupt the planned start dates of each of the planned main phases identified in chapter 4 should be noted and controlled at the highest level of control. So the highest level of control should not be restricted to high level control of production facilities, but should also control confirmed jobs which are not released yet. For each phase the input of work should be determined on the aggregate planning level, and to each of the phases it should be communicated what order should be ready at what time. Subsequently the main activities that should be done on the highest level of control is to make sure the main process evolves as planned, thus each of the required phases identified within the framework discussed in chapter 4 is finished in time for each order. At the highest level of control the state of each order should be known and if delay in one of the required phases occurs, the effects of these delays on other phases and other orders should be noticed, communicated and if possible corrected.

On the lower level of good flow control, the operational planning level, control decisions within each of the in chapter 4 identified phases should be taken. The main responsibility on this level is to control problems within each of the phases. Typical control problems in each of the phases are discussed in chapter 4. Priorities and sequences in which orders should be processed can be changed within every phase (engineering, work preparation, production, etc.) and the effects of unexpected workload and delays of orders on other orders can be controlled. Capacity decisions and assignment of resources finally can be determined at the operational planning level.

With regard to production on the operational planning level, there are two main controllable factors that could be used:

- The future input to the various work centers, which can be arranged by releasing work orders to the first work center (at the moment of release to work center 1, the sequence of an order, and thus input to other future work centers is known);
- The capacity of each of the work centers, which can be changed by e.g. working overtime (it can also be decided to subcontract work out).

Based on actual information and the actual status of pooled orders and orders released on the shop floor, the shop floor can be controlled in such a way that the constraints of the workload control method discussed in paragraph 6.1.1 remain satisfied. Subsequently deviations of the actual situation compared with the planned situation can be noticed, and decisions to limit the effect of these deviations (e.g. increase of capacity or change of priority of orders) can be taken.

On the lowest level of control, Production Unit Control level, priorities in jobs which are queued in front of work stations can be determined during each time period. Besides that, on this level, it is the responsibility to carry out what is determined and planned on higher levels. Within each period, the Production Unit Control should have the freedom to choose how to effectively achieve the required output. A low level of control and responsibilities to resources also can be given to resources in other phases, such as an engineer who has the freedom determine how to complete his work. The main constraint that should be taken into account on this level is that required outputs for each period, determined by higher level planning, are achieved each period by each resource.

So with regard to lead-time control, it can be concluded that it is important to have a hierarchical approach, which ensures decisions can be taken on various levels, which require a varying level of information. Thus where the high level decisions regarding quoted delivery time and start and finish dates of the main phases are mainly based on planned data, the actual release and capacity should be determined on the actual delivery of materials, actual workload required in production for previous orders and actual capacity of production facilities.

6.2. Controlling external influences on internal processes

The model introduced in the previous paragraph, contains some uncertainties, which cannot be completely controlled internally by an Engineer-to-Order firm. Three uncertainties stemming from external factors that came forward from the analysis within Eaton Industries B.V., and that caused problems for lead-time control, are:

- Customer often waits long with order confirmation (earlier quoted delivery dates subsequently are not reviewed at the moment of order confirmation);
- Material lead-times vary and the actual material lead-time may differ from the promised material lead-time;
- Outsourcing lead-times vary and the actual outsourcing lead-time may differ from the promised outsourcing lead-time.

The current paragraph gives suggestions about how to deal with these external influences within the planning and scheduling approach discussed prior in this chapter.

6.2.1. Capacity allocation during Quotation

In the method described in paragraph 6.1.1, projected future inputs of orders currently quoted and confirmed are identified, $I_{n,t}$. However, as stated earlier in the report, characteristic for a versatile Engineer-to-Order company is that typically only a part of the quoted orders will be confirmed and become real orders. The projected inputs to the shop floor are thus determined by the quoted orders that will be accepted and thus become actual orders and the orders that are already confirmed and are not released yet. Therefore it makes sense to split up the projected inputs at a specific period t, on a specific work center ($I_{n,t}$) into the projected inputs in a specific period from quoted orders on a specific work center ($Q_{n,t}$) and the projected inputs in a specific period from confirmed orders on a specific work center ($F_{n,t}$).

Since during quotation it is unknown what amount of the already quoted orders will be accepted, the most reliable option is to quote a delivery window. Assuming that all previous accepted (and quoted orders if accepted) must be processed on a work center, before processing a new order on that work center; the shortest lead-time can be quoted if none of the quoted orders become real orders. The delivery time quoted in that case can be determined by using the described model and stated constraints, and using projected inputs $I_{n,t} = F_{n,t}$.

The longest lead-time that should be quoted is a lead-time which has to be quoted if all of the quoted orders become real orders: $I_{n,t} = F_{n,t} + Q_{n,t}$.

A reliable delivery window that can be quoted is thus a delivery which uses both dates (optimistic and pessimistic) explained above. The larger the quoted workload ($Q_{n,t}$), the larger the delivery window will be. A simple solution to keep the quoted workload within certain limits, and thus keep the delivery window relative small, is to assign a validity of a specific (limited) time for each quotation.

If a delivery window is not desirable, and the aim is to quote a single reliable delivery date on each order, an option is to determine for each quoted order the probability of customer acceptation. The future workloads of these quoted orders on each work center n ($Q_{n,t}$) in this case can be multiplied with the probability of acceptation "P". The projected inputs that are used during quotation in that case become:

$$I_{n,t} = F_{n,t} + (Q_{n,t} \cdot P)$$

The probability that a quotation becomes an actual order should be estimated in this case. This can be done by using the characteristics of the order and the customer, earlier experiences (data) and impressions. However, estimating a reliable probability of customer acceptation may be a hard job. A tool that is suggested in literature to classify order requests on the probability of becoming actual orders is suggested by Kingsman and Mercer (1997).

With regard to the use of a probability of acceptation by the customer, it can be stated that if only a few orders are quoted, the estimated workload is probably different from the actual workload, since the actual acceptation is either 0 or 1. However, if many orders are quoted and the probabilities of acceptation are reliable, on the long term this will result in reliable projected inputs and thus quoted delivery dates.

6.2.2. Market dependent material lead-times

Material lead-times can have large consequences for the lead-times that are required for orders. As mentioned in the method described in paragraph 6.1.1, the delivery date of materials may be determinative for the release date of orders on the shop floor. Since planned release depends on the delivery of materials and available capacity in production, this planned release date should be based on these two factors. If material lead-times are market dependent, actual valid material lead-times should be used. If actual material lead-times are longer than the time that is required for having capacity to process an order on the shop floor, the planned production release date should be delayed till materials will be delivered. If, on the other hand, actual material lead-times are shorter than the time required for having capacity available for release, it makes sense to request for later deliveries of materials. By doing this, the pool delay of orders and inventories of raw materials can be controlled.

In the most optimal case, materials are available a specified (but limited) time before the planned release date on the shop floor. This way, a pool of unreleased jobs can be created, which enables some flexibility on the Operational Planning level.

For a reliable delivery of the entire order to the customer, two elements are critical with regard to delivery of materials. As described above, the requested delivery date of raw materials should be determined using (reliable) workload capacity planning in the production. Besides that, the reliability of the material supplier is essential.

Material deliveries in relationship with production planning are described in the JIT literature. According to Fawcett and Birou (1993, p. 18), the objective of JIT is "to obtain low-cost, high quality on time production". The JIT literature suggests to aim for a close interaction between buyers and suppliers. According to Golhar and Stamm (1993 p. 75) "the buyer and supplier work together to develop mutual trust and facilitate a free flow of information".

Besides selecting the right suppliers and building close relations with them, continuously tracking of suppliers and their performance can be seen as a crucial activity.

Suggestions for effective supplier management are mentioned by Kanan and Tan (2000). Kanan and Tan (2000 p. 11) state that "especially when there is great dependence on suppliers the need to effectively manage suppliers increases". According to Kanan and Tan (2000), three dimensions underlie supplier management:

- Effective supplier selection;
- Innovative supplier development strategies;
- Meaningful supplier performance assessment mechanisms.

6.2.3. Market dependent outsourcing lead-times

Manufacturing outsourcing is defined in literature as "the use of production facilities of other firms rather than using currently in-house or making new manufacturing capabilities" (Ehie, 2001 p. 31).

In the method described earlier in this chapter, outsourcing was seen as a process that has no waiting queue and delays an order with a specified time. Further, the number of orders that can be processed simultaneously is assumed to be unlimited. It is important to have actual outsourcing lead-times that correspond with the planned outsourcing lead-times. If actual outsourcing lead-times are larger than planned outsourcing lead-times, this influences the arrival of outsourced orders on subsequent work centers. Since in the method discussed in paragraph 6.1.1, for each period, the work that has to be done is planned in advance, a delay in outsourcing means that planned processing in a specific period may not be carried out and should be delayed to future periods. Since in these future periods, other orders were planned and capacity is limited, delay in outsourcing may have large consequences for planned production.

Because it is critical to have planned outsourcing times that correspond with actual outsourcing times, and outsourcing times can not be fully internally controlled, cooperation and communication with subcontracting companies is essential.

The outsourcing lead-time of an order, simply stated, is determined by the shipment date of the order to the subcontractor and the date the order is received back from the subcontractor. The date subcontracted parts are delivered to the subcontractor can internally be controlled by the manufacturing firm. The date that orders are received back from the subcontractor depends on the subcontractor, and is thus out of the control of a manufacturing company. As described in literature, the reliability of the subcontractor is critical for manufacturing outsourcing success.

The dimensions mentioned by Kanan and Tan (2000) with regard to supplier management that are discussed in paragraph 6.2.2, also hold for the management of subcontractors. Thus selection, development strategies and performance assessment mechanisms are important for managing effective subcontractor relationships.

So summarized, for a manufacturing company, it is essential to work with planned outsourcing lead-times that correspond with actual outsourcing lead-times. Therefore close cooperation with sub-contracting companies is required, to agree on planned shipments of future subcontracting. Although it is not possible to control the entire sub-contracting process internally at an ETO company, the ETO company is responsible for reliable shipment dates of products that has to be outsourced (become a reliable partner) and effective management of subcontractors. Besides that, flexibility can be included in the planning of orders, by reserving spare capacity on work stations, and having some buffer in the lead-times that are quoted for orders.

6.3. Practical suggestions for Eaton Industries B.V.

The current paragraph will give some more practical suggestions which are valid for Eaton Industries B.V. and are based on the main sources for the problems that are identified in paragraph 5.2. The theoretical model that is discussed in the previous two paragraphs has the ability to solve and control some significant problems that are faced at Eaton Industries B.V. However, not all problems that are faced at Eaton Industries B.V. can be solved using a more structured capacity based planning tool. Some problems that are mentioned in paragraph 5.2 such as a lack of company commitment and a lack of valid information are more practical and require practical and specific solutions. Besides that, to let the proposed approach that is suggested in paragraph 6.1 function well, some conditions should be "fulfilled".

6.3.1. Suggestions

The suggestions presented in the current paragraph include the most recent developments at Eaton Industries B.V. and thus provide a proposition on actions to continue from the current situation. Besides that it will be described how the proposed method and its underlying assumptions may be integrated with the current tools and actual situation at Eaton Industries B.V.

<u>Collection and feedback of useful and reliable data</u>
In each company the collection of useful and reliable data, and subsequent feedback of this data is critical. Especially for planning purposes, the use of reliable data is a prerequisite. Feedback of data gives insights in the quality of earlier estimations and can subsequently be used to improve future estimations. Besides that, reliable data gives management and employees valuable insights in their work and activities within the company, and subsequently may help to identify potential problems. Some data that was not available (or at least not reliable) during the project at Eaton Industries B.V. and that might give interesting insights with regard to lead-time performance is:

- Delivery performance Eaton Industries B.V. to its customers;
- Delivery performance material suppliers;
- Delivery performance subcontracting companies;
- Internal actual vs. planned processing times (estimated by e.g. work preparation).

Some information, such as delivery performance of material suppliers and subcontracting companies, is not collected at Eaton Industries B.V. Other information such as the delivery performance of Eaton Industries B.V. to its customers is available, but is unreliable and thus no clear conclusions can be drawn using this information.

Paragraph 5.1.3 discussed some inaccuracies in the current available data that restricted the data analysis carried out during the project. The inaccuracies described can give insights in potential improvements for future data collection at Eaton Industries B.V.

A final remark that has to be made with regard to data collection and feedback of data at Eaton Industries B.V. is the recent installation of a new ERP system, MFG-pro, in October 2007. This new system is used for the analysis of production data, and gives abilities to implement suggestions as made in the current report with regard to data collection. The system as it currently is installed has shortcomings and its potential is not fully used. Therefore a continuous future development of the current installed system is required.

<u>Integrating the proposed model in available systems and procedures:</u>
Since November 2007 a new planning system, Preactor, is installed at Eaton Industries B.V. Preactor is an Advanced Planning and Production Scheduling Software package. As stated on the Preactor website, "it has been installed over 2.000 companies in 64 countries around the world" (<u>www.preactor.com</u>). Companies that use Preactor vary enormous in size and market segments. Since these various companies require different capabilities from their planning system, various versions of Preactor exist. At Eaton Industries B.V. an advanced version of Preactor, Preactor 400 APS, is installed.

Preactor has the ability to use a finite capacity while scheduling production, an ability that was missing at Eaton Industries B.V. prior to the installation of Preactor. Besides that, a link between required materials can be made using Preactor, since it linkages different materials that are required, based on the BoM structure provided by an ERP system. This linkage to the ERP system also makes it possible to see the consequences of late material deliveries or delays in production.

Furthermore, reports can easily be made with regard to future machine utilization, estimated delivery dates of orders, required jobs that need to be processed on each machine on what time, etc.

At the current moment at Eaton Industries B.V. for each new order it can be defined in the system on which machine processing is required, and in what sequence. Subsequently the order is scheduled in the system. The system therefore requires information about when an order can start (which depends e.g. on availability of critical materials), and subsequently the order is planned on the first available date when capacity is available on the first required work center (since forward scheduling is used). From the time the first process is finished, the same procedure is repeated within the system for the second process, etc. Using this way of planning, at the current moment, orders are already scheduled in production till late in 2008.

This way of planning has major advantages above the previous way in which production was scheduled at Eaton Industries B.V. Using Preactor, implications of delays in processes, unexpected work and changes in delivery schedules from raw materials and outsourced processes can be easily seen. The program reschedules, using up-to-date information, and up-to-date expected finishing times of processes and orders can be extracted from the system. Besides that, the planning system has the ability to show for each work center what has to be carried out when, and in what order.

Although there are major advantages of the system as it is currently installed at Eaton Industries B.V., there are still some drawbacks on the way the system is currently used. First of all there is no clear hierarchy with regard to the control of planned orders. Currently all orders, from quoted orders to released orders, are planned on the same level in the production scheduling system. As a result many orders are scheduled at production on a long planning horizon. Based on that schedule, all control decisions, from delivery times that should be quoted till which product should actually be produced when on what work center are taken. As a result, hardly any freedom can be given to the production environment, and to the various work centers at production. Besides that, since all orders are scheduled on the same level, any delays or deviations in production influence all future orders in any state of the total order lead-time. Since there is no hierarchy in the system which enables control on various levels, one significant change, changes the entire schedule, and as a result expected delivery dates of multiple orders change.

Another drawback comes from the forward scheduling method, as it is used currently at Eaton Industries B.V. This scheduling method, in which are orders scheduled as soon as they can be processed on each work center required in the sequence, results in large variations in waiting times in front of work centers. Since an order is scheduled on each work center on the first date available, and the amount of work scheduled at the subsequent required workstations is hardly taken into account, large waiting times between various work centers can arise. As a result, some critical machines are currently scheduled with a very high workload (and high utilization over a long horizon). Besides that, there can be large variations in the workload at each work center.

Based on the discussion provided in paragraphs 6.1 and 6.2 some suggestions are stated below. First of all, there should be made some hierarchy within the current production scheduling, which allows planning on different horizons, as proposed in paragraph 6.1.2. As a result decisions on various levels could be made, and control decisions made on various levels have lower effects for the overall scheduling of delivery times. Subsequently, the use of a more workload controlled planning method should seriously be considered by Eaton Industries B.V. Since Preactor can be customized in many ways, it should be investigated whether workload can be scheduled using pre-determined allowable workloads that are scheduled at each work center. A planning method and philosophy using workload control, as proposed in paragraph 6.1 results in less variation in waiting times and a larger flexibility in scheduling, which is an advantage in an production environment as at Eaton Industries B.V.

In paragraph 6.1.1 is referred to appendix 11, where an example is scheduled using the in paragraph 6.1.1 suggested workload approach. The same example is used to schedule, using the production planning approach as currently used at Eaton Industries B.V. Two assumptions are made for both planning methods. First, when an order is processed on a work center in a specific period t, this order can only start the subsequent period t+1 with processing on the subsequent required work center (or outsourcing). Second, when in a specific period t on a work center is not enough capacity to complete the required operation of an order, the complete order is scheduled in first following period the work center has enough capacity to process the entire operation.

An example of an order which is scheduled using the "Eaton methodology" is shown in appendix 12. Subsequently in appendix 13 a comparison of both methods is shown with regard to delivery date determined, required shop floor throughput time and cumulative input and output on the various work centers. It is assumed that the orders 1 to 10 were already planned at t = 0, and 9 new orders arrive (orders 11 to 19). Orders 1 to 10 fill up the system, which is needed to compare both methods. The main results from the comparison with regard to differences in average shop-floor throughput time and average total delivery time are shown below in table 5.

	Eaton Method	Workload Control Method
Average shop-floor throughput time all orders (weeks)	6,79	6,42
Average shop-floor throughput time orders 1 - 10 (weeks)	6,10	6,50
Average shop-floor throughput time orders 11 - 19 (weeks)	7,56	6,33
Average total delivery time all orders (weeks)	11,47	11,26
Average total delivery time orders 1 - 10 (weeks)	8,50	8,60
Average total delivery time orders 11 - 19 (weeks)	14,78	14,22

Table 5, results comparison two production scheduling approaches

As could be seen in table 5, for orders 11 – 19 the workload method results in a shorter average shop-floor throughput time and an earlier delivery date. Besides that, as claimed, the workload method leads to a more balanced scheduling on the various work centers. As could be seen from the comparison of cumulative input and output of both methods shown in appendix 13, on work center 1 and work center 2 no large differences between both methods were observed. Comparing the cumulative input and output on work center 3 using both methods, however supports the claimed difference between both methods. The cumulative workloads at work center 3, that result from scheduling the example presented in appendix 11, using both methods are shown in figure 9.

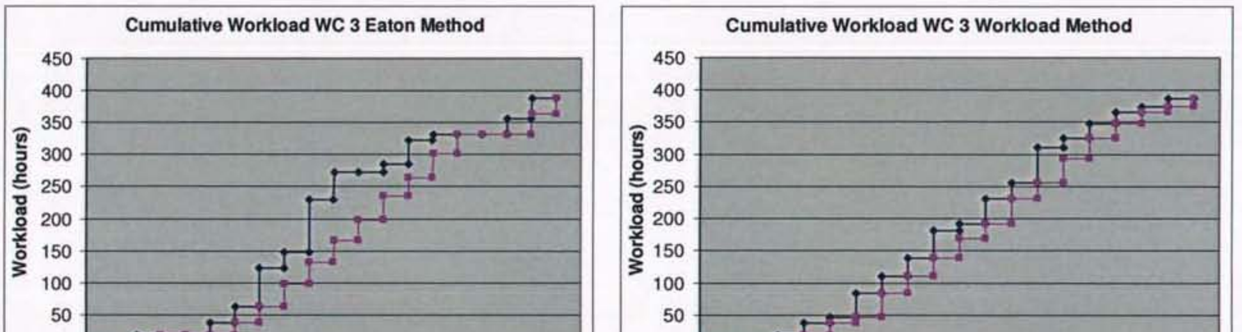


Figure 9: cumulative workload WC 3, "Eaton method" (left) and Workload Control Method (right)

As can be seen in figure 9, the workload method leads to a smoother input in production, which results in more constant lead-times at that work center. The Eaton method, shown in the left graphic of figure 9, has much more variety in the input in production. As a result, especially in week 10 and 11 the workload at WC 3 increases and the required lead-times increase since capacity is fixed.

The example that is scheduled and discussed in the current part is fictive, and thus does not represent the actual situation at Eaton Industries B.V. It shows however the difference between both methods and supports the claims made in this report. Similar results can be expected for other examples and real life situations.

Internal communication

A problem that was mentioned regularly within Eaton Industries B.V., and was identified as main source underlying the problems of late delivery was the lack of communication between various stakeholders. Suggestions for developing more pro-active relations with external stakeholders such as suppliers and subcontractors are mentioned in paragraph 6.2. With regard to internal communication (especially between planning, purchasing, production, the quality department and warehousing) a more pro-active attitude of the various stakeholders is needed. Especially improvements in communication with regard to the state of physical processes are required. Valid questions that all relevant stakeholders should be able to answer at any time and that are critical for the physical process are:

- Which materials are delivered (when) or will be delivered (when);
- Which outsourced parts are delivered (when) or will be delivered (when);
- Which processes are finished, and which processes (including outsourcing) can be started.

The new ERP system, MFGpro, may give opportunities to help improving a structured internal communication. Besides that, as stated above, pro-active attitude of the stakeholders involved is required, and further the organizational responsibilities should be clear to all stakeholders.

Organizational structure and responsibilities

As mentioned during the discussion of internal communication provided in the current paragraph, organizational responsibilities should be clear to al stakeholders. As experienced during the internship at Eaton Industries B.V. however, among stakeholders there are discrepancies in opinions with regard to organizational responsibilities. Besides that, some responsibilities seem not to be covered within the organizational structure. A practical example is identification of delivered raw materials and processed parts that can be outsourced to external companies. Another practical example is the (lack of) direction given to the warehouse and material handling department and its people. With regard to these examples it should be questioned who is responsible for communicating the delivery of materials, and what parts may be shipped to subcontractors.

Further identification of required tasks and processes, that are not captured within the organizational structure of Eaton Industries B.V. is important and should have future attention.

Identification and quality control of material and parts

A very practical problem, which often leads to significant problems within production is the (lack of) identification of raw materials and parts. Since raw materials and processed parts are regularly unmarked, or marked inconsistently, time is lost for searching and processing of wrong materials. This problem is known at Eaton Industries B.V. and some actions are taken recently to cope with this problem. Marking of raw materials and parts is still not carried out constituently however, and needs future attention.

Another problem that was mentioned often are relative long waiting times for quality and certificate checks on incoming materials and processed (and subcontracted) parts. The main reasons for this problem are a lack of communication, identification of materials and a high workload at the quality department. Lack of communication and identification of materials are already discussed in the current paragraph.
The high workload within the quality department seems to be a direct result of the recent rapid increase in production, relative to the capacity of the quality department. The current efficiency of the quality department requires further investigation. Following on this, it should be considered whether efficiency of the quality department can be increased or whether an increase in capacity of the quality department is required. Quality checks should not be a bottleneck within the production department.

Company commitment
As a final remark, the importance of company commitment on delivering orders within the agreed lead-time has to be emphasized. Recent changes in management have increased the awareness and importance of improvements that should be made in work processes and work as carried out at Eaton Industries B.V. Examples of recent actions that were taken as a result were the installation of a new ERP system, MFG pro and a new planning tool, Preactor. Another action was the initiative and assignment for a project as carried out and discussed in this report.

The current report has shown the importance of aiming for reliable deliveries of agreed orders. This start with company commitment on quoting realistic delivery dates, and continues with commitment on actions that are required to deliver the orders on the date that is promised to the customer.

Problems which harm internal processes are identified in this report. Subsequently actions are proposed and discussed that could be taken to deal with these problems. For future actions that have to be carried out to solve the problems that are described, there should be company commitment. A structured coordination of these actions and commitment to these actions in all levels of the organization is a prerequisite.

6.3.2. Implementation of suggestions

Following on the suggestions discussed in the previous paragraph with regard to improvements in delivery performance at Eaton industries B.V., this paragraph will give some suggestions to implement the improvements that are suggested. First of all, for a successful implementation of the suggested actions and improvements, the addition of expertise to the current organization should be considered.

In the previous paragraph was mentioned that the potential of the information system, MFG-pro, which is installed in October 2007 at Eaton Industries B.V, seems not fully used. A continuous development of this information system should be aimed, to fit the information system with the requirements of the users. Improvements in the information system to better use its potential, will not only positively influence delivery performance, but could have a positive influence on costs, quality aspects and customer goodwill, since decisions can be based on more and richer information, and more actual information can be presented.

In the current organization of Eaton Industries B.V., the expertise to continuously improve the information system and fit it to the requirements of the users seems not available. Therefore it is requested to either add expertise to the organization that may enable a development of the information system, or to train people in the current organization to enable a continuous development.

Somebody who is responsible to develop the information system at Eaton Industries B.V. should question what data currently is collected, how this data is currently collected, how the information is processed by the system and what outputs are currently generated. User requirements and comments should be taken into account to refine the system based on the user requirements and comments.

Some suggestions of measures that may give valuable insights with regard to delivery performance are given in the previous paragraph:

- Delivery performance Eaton Industries to its customers;
- Delivery performance material suppliers;
- Delivery performance subcontracting companies;
- Internal actual vs. planned processing times (estimated by e.g. work preparation).

So with regard to the new information system, it is suggested to add expertise to the organization to enable a continuous identification of requirements within the various departments and management, from which good and reliable performance measures can be developed, and which subsequently can be feedback.

Another suggestion to successfully implement proposed improvements is to add a supply chain manager to the current organization at Eaton Industries B.V. Currently at Eaton Industries B.V. various departments are mainly operating and administered autonomously. Each department has its responsibilities and operates to perform these responsibilities with high efficiency and satisfactory output. As came forward from the analysis at Eaton Industries and suggestions done in the previous chapter, problems with regard to lead-time control and possibilities for improvement mainly can be found in the interaction and transitions between the various processes. Therefore not only optimization within the various phases and processes is required, but especially optimization between various phases and processes is required. In the current organizational structure at Eaton Industries, the general manager stands above the various departments, but the general manager only has a limited focus on operational activities, since this function has responsibilities with regard to strategy, communicating with various stakeholders, etc.

A supply chain manager, who is able to completely focus on operational activities, should not only focus on improvements of processes within departments but especially guide improvements in processes and interactions between departments. The supply chain manager can be made responsible for the material handling and planning departments, and guide and organize these departments. Further the supply chain manager is able to control the supply chain on a high aggregate level of control, as suggested in paragraph 6.1.2. Besides that, a supply chain manager is well able to take the responsibilities with regard to some lean activities (which are required by the overall Eaton Organization) such as value stream mapping, and guide other improvement projects. These improvements projects can be with regard to lead-time control, but also with regard to control of costs and quality and improvement of efficiency.

What should be done to improve the overall supply chain is first to deliberate with the planning software provider and investigate to install and use a workload based planning approach at Eaton Industries B.V. Subsequently, the structure and division of responsibilities at the planning department should be examined, and arranged in such a way that a hierarchy in planning is possible, as suggested in paragraph 6.1.2. Further suppliers and subcontracting companies should be contacted, and the possibilities to develop closer tight relationships and improve supplier / subcontracting delivery performance should be examined. Periodic meetings between representatives from the various departments that typically are involved during the total delivery lead-time of a customer order should be scheduled to increase efficiency and identify what responsibilities currently are not captured well within the organization.

With regard to information that is required within various phases of the supply chain, internal communication at Eaton Industries (especially communication between the departments warehousing, planning, purchasing, production and quality) should be improved in such a way that at each moment, for each of the departments it is clear:

- Which materials are delivered (when) or will be delivered (when);

- Which outsourced parts are delivered (when) or will be delivered (when);
- Which processes (also within production) are finished, and which processes (including outsourcing) can be started.

Improvements in the information system (as suggested previously), assignment of responsibilities, regular meetings and procedures therefore should be considered.

Additional to the suggestions mentioned in this paragraph, with regard to various departments, some practical steps for implementation of the suggested improvements are stated below.

With regard to the sales department there should be determined (in cooperation with the planning department) a standardized validity period of quoted orders after which quoted orders expire and are not valid any more. Subsequently expired quotations may not be accepted without setting new, valid conditions. Further specifications should be frozen after the quotation phase for each order, and conditions under which a customer may change specifications should be determined. Finally regular formal meetings with a representative from the planning department (or supply chain manager) should be scheduled.

For the engineering department it is important to either assign a specialized production engineer (and subsequently ensure that the engineers of new projects can focus completely on these projects), or to schedule some capacity of engineers that they can spend on required engineering capacity due to production problems. Currently there already is a separation in responsibilities between the various engineers, but engineers working on new projects still are often disturbed with requests from production.

With regard to work preparation, the feed-back and insights in differences between planned workload vs. actual required workload should be improved. This can only be done if more valid and detailed information can be presented to work preparation in a well-ordered user friendliness way. The suggestion to improve the current ERP system is mentioned earlier. Determined workloads for new orders subsequently should be based on previous experiences and new insights.

At the purchasing department, it should be ensured that materials are only purchased using delivery dates that are given and approved by the planning department. Besides that, regular tracking of current material orders should be arranged by for example having a regular scheduled contact with the main suppliers, to inform about the status of these orders. On the longer term, a strategy to develop closer supplier relations should be developed.

With regard to production planning, a maximum allowable utilization at each work center (to cope with unexpected work and delays) should be set. Besides that a plan to create a hierarchy in planning, as recommended in this report, should be made. Following on this, production representatives should be trained about how to make independent but reliable decisions to enable control on the lowest level of the planning hierarchy. At production further the increase of in-house capabilities (e.g. deep drilling and honing) should be considered, to limit the required outsourcing of products and limit the risks caused by outsourcing with regard to lead-times and its control.

Finally the current capacity (and whether this capacity is sufficient) and efficiency within each of the following departments requires further investigation at Eaton Industries B.V.:

- Quality department;
- Planning department;
- Work preparation.

7. Conclusions, recommendations and limitations

7.1. Conclusions

In the current report a framework that can be used to control the total delivery lead-time within an Engineer-to-Order manufacturing company is discussed. The initiative for the development of this framework is based on deficiencies in literature, and inspired by problems within an Engineer-to-Order company, Eaton Industries B.V.

After an introduction, the report first has described the Engineer-to-Order company Eaton Industries B.V. with regard to the market, the product, production and some practical problems that are recently faced. After giving some literature backgrounds that help to have a better understanding of the framework and its development process, the framework is introduced. Each of the phases that typically can be identified during the lead-time of an order within an Engineer-to-Order company, are described based on activities carried out at Eaton Industries B.V. and literature. The inclusion of literature in this description contributes to an external validity of the findings to make them more applicable to other settings.

Subsequently, based on a discussion on delivery performance at Eaton Industries B.V. and a description of practical problems that influence the delivery performance found at Eaton Industries B.V., suggestions are given to control the total delivery lead-time of an Engineer-to-Order company. With regard to these instructions, first instructions are given to control internal processes on companies that can (as Eaton Industries B.V.) be characterized as Versatile Manufacturing Companies which use a General Job Shop Production environment. The suggestions that are related to controlling internal processes show a workload control based scheduling method, which is applied to the characteristics of Versatile Manufacturing Companies that use a General Job Shop in production. Following on the discussion of the workload control method, a hierarchy in control is discussed, since various key decisions should be taken at different moments during the total order lead-time, based on a different detail of information available. Three levels of control: Aggregate Planning, Operational Planning and Production Unit Control are suggested to make decisions with regard to order acceptance, job release to production and priority dispatching at each work center.

With regard to literature, it can be concluded that relatively little research is done on manufacturing companies that allow a high degree of customization such as Make-to-Order companies and Engineer-to-Order companies. Especially delivery performance in Engineer-to-Order companies, which is an important competitive factor, has had little attention in research. From the research that has been done within Engineer-to-Order companies, it can be stated that this research mainly has focused on some aspects such as the quotation for orders and manufacturing (planning and control) within Engineer-to-Order companies. An overall framework that describes what typically is done during the lead-time of an order within an Engineer-to-Order company, and how to control this lead-time is missing in literature.

The framework described in this report captures and describes all activities typically carried out in an Engineer-to-Order manufacturing company, identifies typical lead-time components and identifies clear milestones that separate these lead-time components and show for each of these the relation on the backlog of work. Besides that, it provides a basis for activities that are required to control the total lead-time and its various components. Suggestions are given to determine reliable delivery dates and to control the total delivery time.

With regard to Eaton Industries B.V. it can be concluded that there are quite some operational problems. First of all, the operating profit has been negative since 2003. This is mainly due to high material inventories, low efficiencies and outsourcing and subcontracting at premium costs. Besides that, problems are faced with regard to recruitment of experienced and skilled personal, long throughput times of customer orders and a low delivery reliability of customer orders.

Additional research on the backgrounds of the problems that are faced at Eaton Industries B.V. with regard to the long throughput times of orders and low delivery reliability of orders, identified some main factors underlying these problems. Internal factors as limited company commitment on quoting realistic due dates, limitations of the information system, limitations in the available planning tools, a relative high workload and limitations in structure, capacity and knowledge at the planning and work preparation departments were identified. Besides that, external factors such as customers who wait long with confirmation of orders and change specifications, long and marked dependent material lead-times and long and market dependent subcontracting lead-times were identified.

7.2. Recommendations

Future research in Engineer-to-Order companies is recommended. First of all, findings with regard to factors that harm delivery performance mentioned in this report are mainly based on observations at Eaton Industries B.V. It should be questioned whether in other Engineer-to-Order companies similar problems can be identified in the various phases during the lead-time of an order. Subsequently research should go into what other problems can be identified, that are not identified in this report. Further, using the framework introduced in this report, the implications that decisions in the various phases have on quality and cost issues would give valuable insights.

With regard to Eaton Industries B.V. it is suggested to implement a workload based method to schedule orders at production and, using this approach, determine delivery dates of new orders and subsequently control release and production of orders. Further it is recommended to enable a hierarchical control structure, which enables that various decisions could be based on a variety required detail of information.

Some additional practical suggestions for Eaton Industries B.V. are given in the report, which may help to overcome the main problems that are faced with regard to lead-time control. In these suggestions the importance of collection and feedback of useful and reliable data is discussed.

To successfully implement the recommendations made in this report, it is suggested to add expertise with regard to the information system currently used at Eaton Industries B.V. to the organization. Further the addition of a supply chain manager, who is able to structure responsibilities and information flows between the various operational departments is recommended. This supply chain manager is able to guide control on various levels with regard to time, cost and quality issues. Besides that, the supply chain manager can be made responsible to the material handling and planning departments.

7.3. Limitations

A remark that has to be made with regard to Eaton Industries B.V. is that the current report has focused on new-build cylinders. As stated earlier in this report, there is also a repair & service department at Eaton Industries B.V. For large repair & service projects, this department might use capacity of machines that are used for producing new-build cylinders. When these machines have a tight planning and high utilization, unplanned work coming from repair & service projects will influence the production process of new built cylinders. The repair & service department, the influence this department has on new built cylinders, and how to deal with this, requires further investigation at Eaton Industries B.V.

Another remark that has to be made is the fact that suggestions made in the report are mainly based on problems found at Eaton Industries B.V. Literature is used in this report to improve external validity and applicability to other comparable situations. However, further analysis of other Engineer-to-Order companies is required to get a better picture of the applicability of current suggestions on other Engineer-to-Order companies and gain insight in other potential problems, not identified at Eaton Industries B.V.

Finally, it should be mentioned that this report has focused on time and the control of time. However, time is one of multiple factors that are crucial in an Engineer-to-Order company. Other factors such as quality and costs require attention, and should be taken into account in decisions that have to be made. On the other hand, suggestions mentioned in this report are related to the control of time, but may have positive effects on other factors. The increased control in production that is suggested to control time for example may lead to a higher efficiency and lower stocks, which positively influences costs. Closer relationships with suppliers that are suggested to control supplier lead-times may, also have a positive influence on quality.

In general it should be stated that each of the decisions made should be seen in a larger perspective, and the influence on all relevant factors should be taken into account when making decisions.

8. References

Articles:

Amaro, G., Hendry, L. and Kingsman, B., 1999, *Competitive advantage customization and a new taxonomy for non make-to-stock companies*, International Journal of Operations & Production Management, Vol. 19, Iss. 4, p. 349 – 375;

Bahu, A.S., 1999, *Strategies for enhancing agility of make-to-order manufacturing systems*, International Journal of Agile Management Systems, Vol. 1, Iss. 1, p. 23 – 29;

Bertrand, J.W.M. and Muntslag, D.R., 1993, *Production control in engineer-to-order firms*, International Journal of Production Economics, Vol. 30,31, p. 3 – 22;

Ehie, I.C., 2001, *Determinants of Success in Manufacturing Outsourcing Decisions: A Survey Study*, Production And Inventory Management Journal, Vol. 42, Iss. 1, p. 31 – 39;

Fawcett, S.E. and Birou, L.M., 1993, *Just-In-Time Sourcing Techniques: Current State Of Adoption*, Production and Inventory Management Journal, Vol. 34, Iss. 1, p. 18 – 24;

Golhar, D.Y. and Stamm, C.L., 1993, *JIT Purchasing Practices in Manufacturing Firms*, Production and Inventory Management Journal, Vol. 34, Iss. 3, p. 75 – 79;

Handfield, R.B., and Pannesi, R.T., 1992, *An empirical Study of Delivery Speed and Reliability*, International Journal of Operations & Production Management, Vol 12, Iss. 2, p. 58-72;

Ho, C-H., 2007, *Identifying Stakeholders' Positions through Value Creation System*, The Business Review, Vol. 7, Iss. 1, p. 254 – 262;

Kannan, V.R. and Tan, K.C., 2002, *Supplier Selection and Assessment: Their Impact on Business Performance*, Journal of Supply Chain Management, Vol. 38, Iss. 4, p. 11 – 21;

Karlsen, J.T., 2002, *Project Stakeholder Management*, Engineering Management Journal, Vol. 13, Iss. 4, p. 19 – 24;

Kingsman, B.G., 2000, *Modeling input-output workload control for dynamic capacity planning in production planning systems,* International Journal of Production Economics, Vol. 68, Iss. 1, p. 73 – 93;

Kingsman, B.G., Hendry, L., Mercer, A., de Souza, A., 1996, *Responding to customer enquiries in make-to-order companies – Problems and Solutions*, International Journal of Production Economics, Vol. 46-47, p. 219 – 231;

Kingsman, B.G. and de Souza, A.A., 1997, *A knowledge-based decision support system for cost estimation and pricing decisions in versatile manufacturing companies*, International Journal of Production Economics, Vol. 53, Iss. 2, p. 119 – 139;

Kingsman, B.G. and Mercer, A., 1997, *Strike Rate Matrices for Integrating Marketing and Production During the Tendering Process in Make-to-Order Subcontractors*, International Transactions in Operational Research, Vol. 4, No. 1, p. 251 – 257;

Kingsman, B.G., Tatsiopoulos, I.P. and Hendry, L.C., 1989, *A structural methodology for managing manufacturing lead times in make-to-order companies,* European Journal of Operational Research, Vol. 40, Iss. 2, p. 196 – 209;

Kingsman, B.G., Worden, L., Hendry, L. Mercer, A. and Wilson, E., 1993, *Integrating marketing and production planning in make-to-order companies,* International Journal of Production Economics, Vol. 30,31, p. 53 – 66;

Marucheck, A. and McClelland, M., 1992, *Planning Capacity Utilization in an Assemble-to-Order Environment,* International Journal of Operations & Production Management, Vol. 12, Iss 9, p. 18-38;

Persona, A., Regattieri, A., and Romano, P., 2004, *An integrated reference model for production planning and control in SMEs,* Journal of Manufacturing Technology Management, Vol. 15, Iss. 7, p. 626 – 640;

Stevenson, M., Hendry, L.C. and Kingsman, B.G., 2005, *A Review of Production Planning and Control: the Applicability of Key Concepts to the Make-to-Order Industry,* International Journal of Production Research, Vol. 43, Iss. 5, p. 869 – 893;

Tatsiopoulos, I.P. and Kingsman, B.G., 1983, *Lead Time Management,* European Journal of Operational Research, Vol. 14, Iss. 4, p. 351 – 358;

Tersine, R.J. and Hummingbird, E.A., 1995, *Lead-time reduction: The search for competitive advantage,* International Journal of Operations & Production Management, Vol. 15, Iss. 2, p. 8 – 18;

Wikner, J. and Rudberg, M., 2005, *Introducing a customer order decoupling zone in logistics decision-making,* International Journal of Logistics: research and Applications, Vol. 8, Iss. 3, p. 211 – 224;

Wisner, J.D., and Siferd, S.P., 1995, *A survey of U.S. manufacturing practices in make-to-order machine shops,* Production and Inventory Management Journal, Vol. 36, Iss. 1, p. 1 – 7.

Text books:

Baily, P., Farmer, D., Jessop, D., Jones, D., 2005, *Purchasing Principles and Management,* Ninth Edition, Pearson Education Limited, Harlow, England, ISBN: 0273 64689 3;

Bertrand, J.W.M., Wortman, J.C. and Wijngaard, J., 1998, *Productie-beheersing en material management,* Houten, Educatieve Partners Nederland, Netherlands, ISBN: 90-11-04399-5;

Cross, M., 1994, *Engineering Design Methods,* Second Edition, John Wiley & Sons Ltd, Chichester, England, ISBN: 0 471 94228 6;

Dym, C.L. and Little, P., 2000, *Engineering Design: A Project-Based Introduction,* First Edition, John Wiley & Sons, Inc., Chichester, England, ISBN: 0-471-28296-0;

Ertas, A., Jones, J.C., 1996, *The Engineering Design Process,* Second Edition, John Willey & Sons, Inc., Chichester, England, ISBN: 0-471-13699-9;

Lester, A., 2005, *Project Planning and Control,* Fourth Edition, Elsevier Butterworth Heineman, Oxford, England, ISBN: 0-7506-5843-6;

Meredith, J.R., 1992, *The Management Of Operations: A Conceptual Emphasis*, Fourth Edition, John Wiley & Sons, Inc., Chichester, England, ISBN: 0-471-50909-4;

Monczka, R.M., Trent, R.J. and Handfield, R.B., 2002, *Purchasing and Supply Chain Management*, Second Edition, South-Western, Mason, United States, ISBN: 0-324-02315-4;

Weele, A.J., 2001, *Purchasing and Supply Chain Management: Analysis, Planning and Practice*, Third Edition, Thomas Learning, London, England, ISBN: 1-86152-978-3.

Internet sources:

www.eaton.com

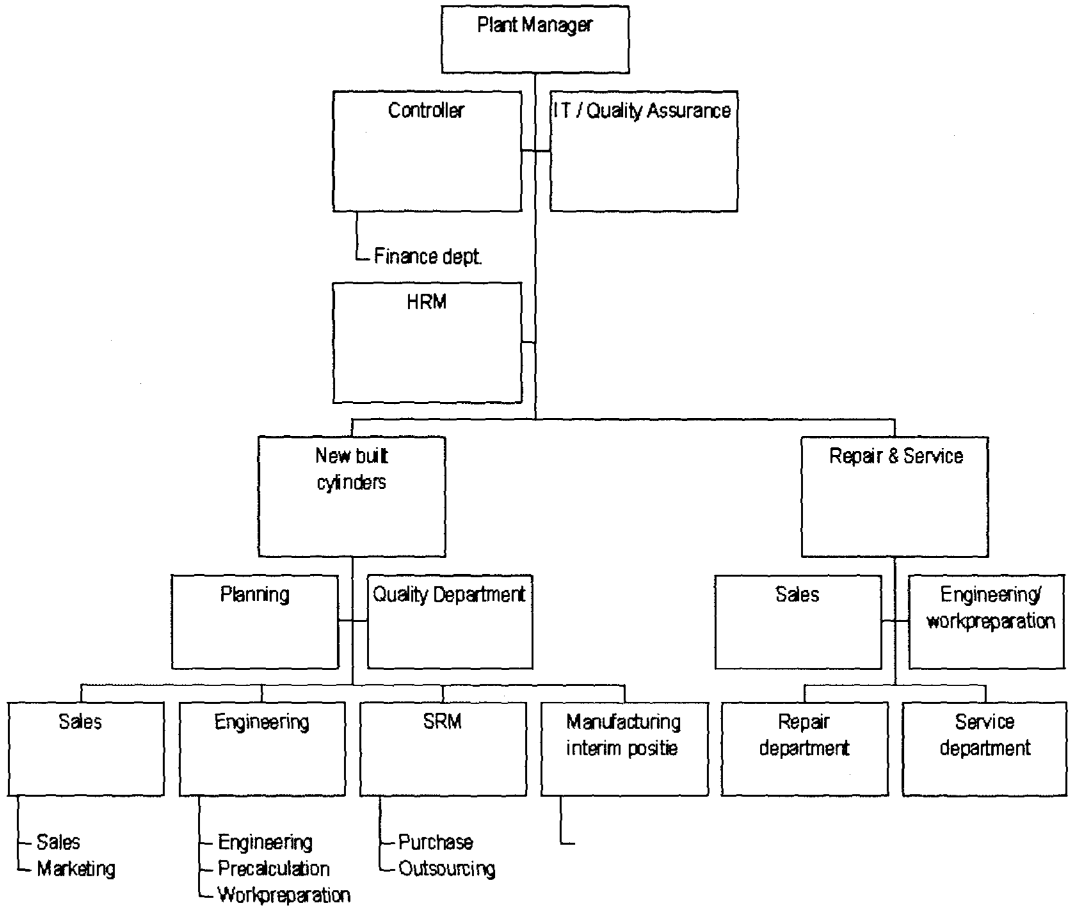
www.hydrowa.com

www.preactor.com

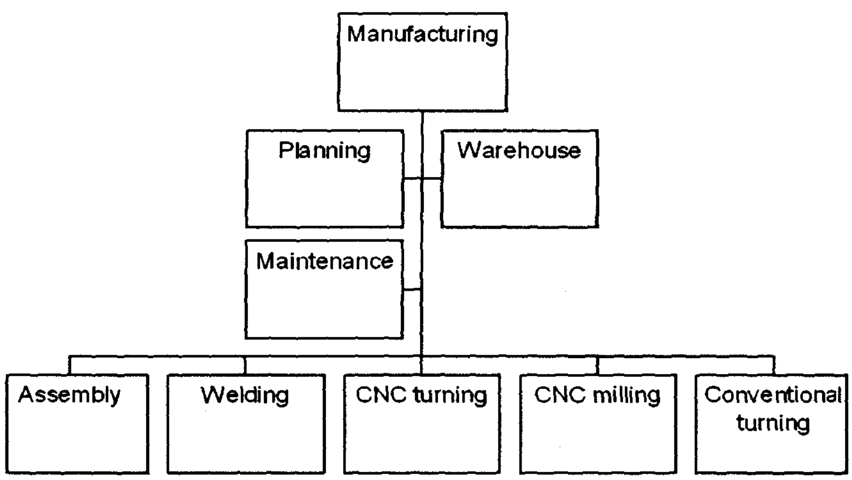
Appendixes

Appendix 1: Organizational charts Eaton Industries B.V.

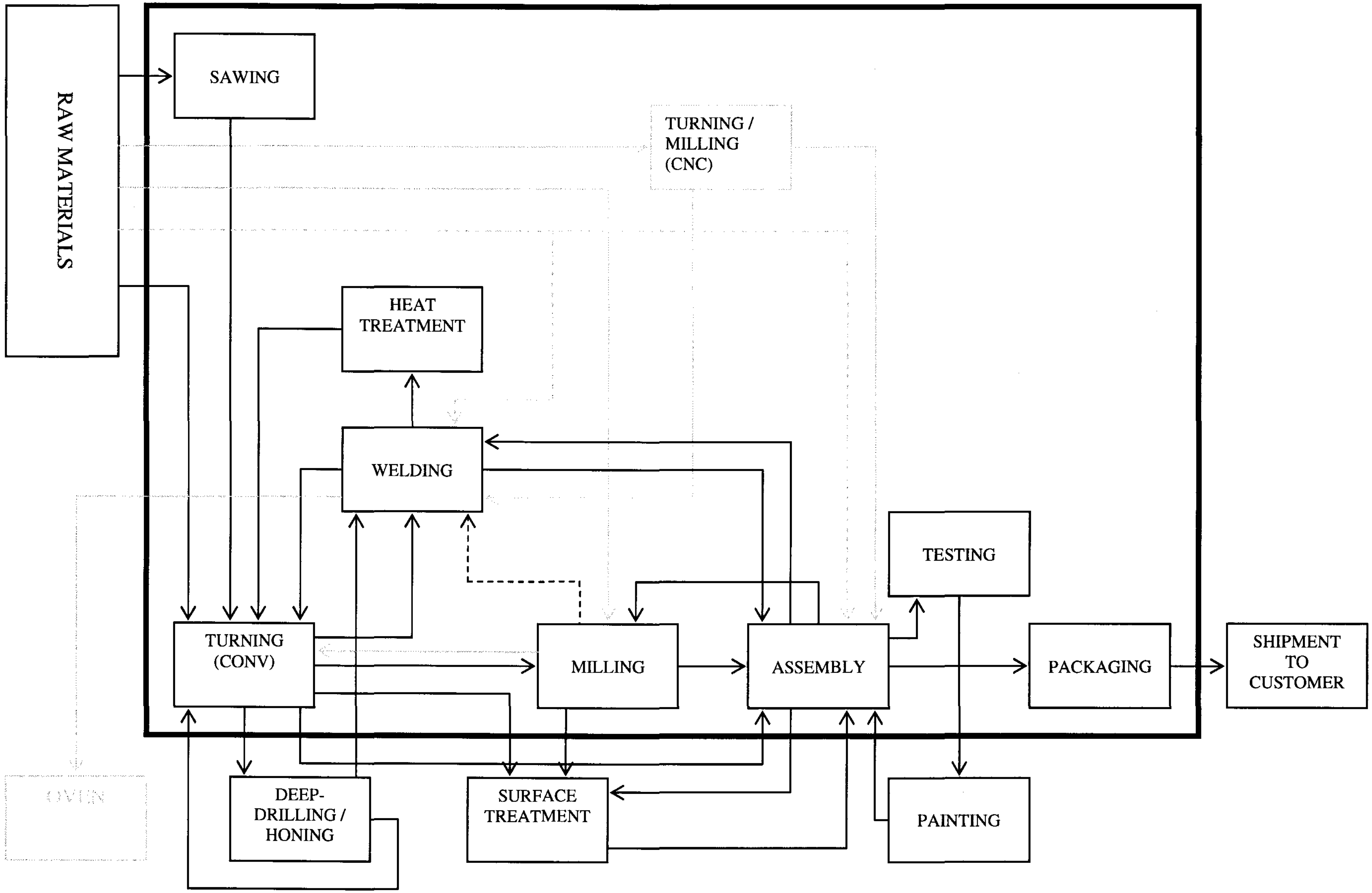
Organizational structure Eaton Industries B.V.



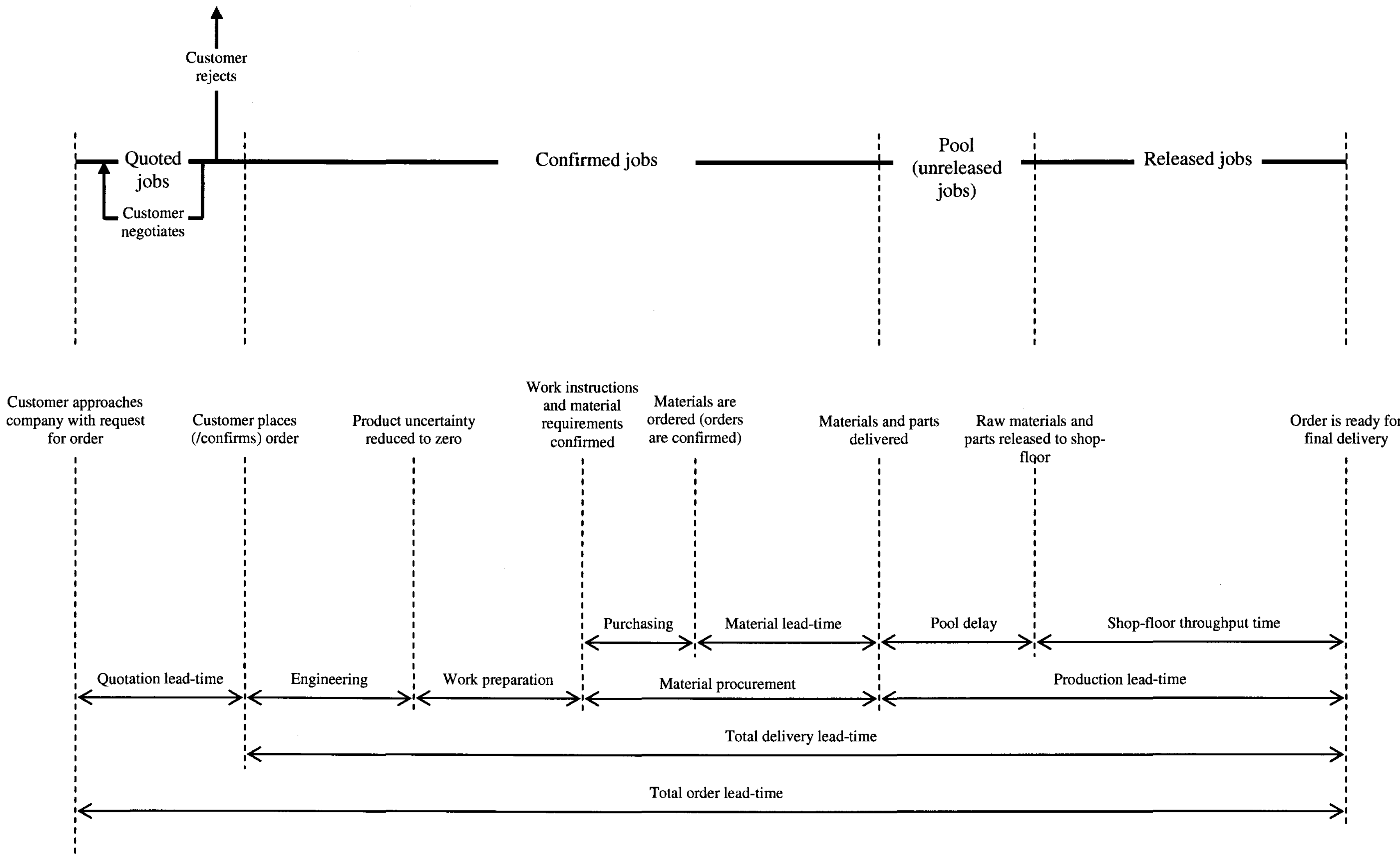
Organizational structure manufacturing organization Eaton Industries B.V.



Appendix 2: Physical material streams Eaton - Industries B.V.



Appendix 3: Engineer-to-Order lead-time framework



Appendix 4: Definitions Engineer-to-Order lead-time framework

Total order lead-time: the total time elapsed from the moment a customer first approaches a company with the request to quote for a specific order till the final delivery of that order (Bertrand et al., 1998).
= Quotation lead-time + engineering + work preparation + material procurement + production.

Total delivery lead-time: the total time elapsed from the moment a customer places (confirms) an order till the final delivery of that order (Bertrand et al., 1998 and Kingsman et al., 1989).
= Total order lead-time – Quotation lead-time;
= Engineering + work preparation + material procurement + production lead-time.

Quotation lead-time: time elapsed from the moment a customer first approaches a company with the request to quote for a specific order till the moment a customer places (confirms) that order;

Engineering lead-time: time expired from the moment a customer has placed (confirmed) an order till the moment the product is completely engineered, specified and documented (product uncertainty is reduced to zero).

Work preparation: the time expired for converting technical specifications into work-instructions and raw material requirements.

Material procurement: time expired from the moment that all raw material requirements for a specific order are specified and documented till the delivery of these materials.
= Time required for purchasing + material lead-time.

> *Purchasing:* time expired from the moment material requirements for a specific order are specified and documented till the moment suppliers are selected to purchase these (raw) materials and the purchase is confirmed by these suppliers.
>
> *Material lead-time:* time elapsed between a raw material purchase order is confirmed by a supplier till the final delivery of that material.

Production lead-time: the time elapsed between the arrival of raw material and parts sub-contracted out and the delivery date. (Definition of total manufacturing time as described by Kingsman et al. (1989, p. 199) is used):
= Pool delay + shop-floor throughput time;

> *Pool delay:* the time spend between arrival of raw material or parts sub-contracted out and the release of these raw materials and sub-contracted parts to the shop floor (based on Kingsman et al., 1989);
>
> *Shop-floor throughput time:* the total time elapsed between releasing an order onto the shop floor and its completion (Kingsman, 1989 p. 199).
>
> = "Sum of the operation times for all the work centres the order must pass through plus any time spent in the dispatching process" (Kingsman, 1989, p. 199).

Appendix 5 Overview of the main internal and external stakeholders from an Engineer-to-Order company

Based on Eaton - Industries B.V. and literature

Internal stakeholders:

Primary internal:
- Marketing and Sales;
- Engineering:
  - Pre-Engineering;
  - Detailed Engineering;
- Work preparation;
- SRM (Supplier Relationship Management);
  - Purchasing;
  - Outsourcing
- Manufacturing (/Operations / Production).

Supportive internal:
- Planning and Scheduling;
- HRM (Human Resource Management);
- Accounting and Finance;
- IT;
- Quality Assurance;
- Management;
- Warehouse and material handling;
- Maintenance;
- Customer service.

External stakeholders:
- Customer (is not always the end user);
- Supplier (raw materials and purchased parts);
- Sub contractors (At Eaton - Industries B.V. e.g.: deep drilling / honing ; surface treatment ; heat treatment ; painting);
- Eaton global organization and blanket division;
- Inspection instances.

Further external stakeholders, mentioned by Ho (2007, p. 256):
  - Government;
  - Community;
  - Shareholders;
  - Competitors.

Appendix 6: Tasks and responsibilities Engineer-to-Order Stakeholders

Based on Eaton - Industries B.V. and literature

Marketing and Sales

Setup and maintain a structured sales organization and customer relationship. The aim is to realize an optimal order intake and margin (financially and regarding to time).

The primary tasks and responsibilities are:
- Identification of opportunities and (technical) developments in the market;
- Introduce and recommend Eaton - Industries B.V. in target markets;
- To maintain a good relationship with customers;
- Close orders that satisfy stated conditions and margins.

Mainly communicates with the following stakeholders:
- Customers;
- Engineering;
- Planning.

Pre-Engineering

Design and formulation of technical concepts, including basic price calculations, which support the order quotations made to the customers.

The primary tasks and responsibilities are:
- Gain insights in customer requests and be abreast of customer demands, requirements and expectations;
- Analyze and evaluate the customer request;
- Development of basic technical concepts, and asses them based on costs (material costs and labor hours), risk analysis and report the results.

Mainly communicates with the following stakeholders:
- Marketing and Sales;
- Engineering (detailed);

Detailed Engineering

Work out offers that are approved by the customer, in detailed design, calculations and drawings.

Primary tasks and responsibilities are:
- Determination of detailed product design (layout / geometry, dimensions, tolerances and finishes) and required materials;
- Carrying out calculations with regard to product strength, performance (e.g. pushing and pulling forces) and tolerances;
- Determine how to test the designed product;
- Creation and documentation of technical drawings (including part drawings and composition drawings) and Bills of Materials;

Mainly communicates with the following stakeholders:
- Marketing and Sales;
- Engineering (pre);
- Customer;
- Work preparation;
- Production;
- Inspection instances;
- SRM (Purchasing).

Work preparation

Preparing production for a designed product in such a way that production can be carried out as efficient as possible

Primary tasks and responsibilities are:
- Check output from engineering on e.g. dimensions, material choices (with regard to machinability and weldability) and future assembly;
- Determine which operations are required in what sequence;
- Determine which machines can be used for which operations that are required;
- Determination of processing times that are required;
- Determination of specialized tools and capabilities that are required;

Mainly communicates with the following stakeholders:
- Engineering (detailed);
- SRM (Purchasing);
- SRM (Outsourcing);
- Production;

SRM (Purchasing)

Taking care for the on time, according to the specifications, delivery of required (raw) materials, parts and services against optimal conditions.

Primary tasks and responsibilities:
- Being informed of the (target) supply market and current characteristics of that market (e.g. prices, delivery possibilities and delivery reliability);
- Formulate purchase requests and approach suppliers;
- Receive, judge and select the best offer (negotiation on delivery terms and prices might be useful);
- Placing orders and documenting delivery terms, financial conditions, material specifications, etc.;
- Monitoring the material delivery time and communicating possible deviations.

Mainly communicates with the following stakeholders:
- Suppliers;
- Finance / Accounting;
- Work preparation;
- Engineering;
- Production;
- Warehouse and material handling.

SRM (Outsourcing)

Taking care for the on time, according to the specifications, delivery of outsourced parts and production work, against optimal conditions.

Primary tasks and responsibilities:

- Being informed of relevant sub contractors, their capabilities, and terms;
- Selecting the most capable sub contractor for each required outsource processing;
- Monitoring outsourced work and communicating status of outsourced work.

Mainly communicates with the following stakeholders:

- Work preparation;
- Production;
- Planning;
- Warehouse and material handling.

Manufacturing (/Operations / Production)

Responsible for planning, coordination and control of production processes, equipment and production personnel in such a way that use of resources, quality and customer satisfaction is maximized against minimal costs (high efficiency).

Primary tasks and responsibilities:

- Making sure production is carried out in such a way that a high quality product is produced, which meets the determined specifications;
- Achieving a high efficiency in the production environment with regard to use of resources such as people, machines and materials;
- During the achievement of the main tasks taking into account factors with regard to environment, safety and health.

Mainly communicates with the following stakeholders:

- Planning and scheduling;
- Engineering;
- SRM (Purchasing);
- SRM (Outsourcing);
- Warehouse and material handling;
- Maintenance;
- Work preparation;
- Customer (is not always the end user);
- Supplier (raw materials and purchased parts);
- Sub contractors;
- Inspection instances.

Planning and scheduling

Planning and scheduling resources (people, equipment and materials) in such a way that performance with regard to time, cost and efficiency is maximized.

Primary tasks and responsibilities:

- Translate delivery times, operations required and resources required into a planning and production schedule and communicate this with other stakeholders;
- Check progress during the whole process, adjust if necessary (priorities among orders should be determined), and communicate progress to other stakeholders;
- Aim for short and reliable delivery times, low costs and high quality, with an efficient use of resources.

Mainly communicates with the following stakeholders:

- Production;
- Marketing and Sales;
- Engineering;
- SRM (Purchasing);
- SRM (Outsourcing);
- Warehouse and material handling;
- Maintenance;
- Work preparation;
- Customer (is not always the end user);
- Supplier (raw materials and purchased parts);
- Sub contractors;
- Inspection instances.

Quality Assurance

Setup, carry out and maintain a quality system, which aims for an optimal product quality and a product with minimal deficiencies from the original specified product.

Primary tasks and responsibilities:

- Based on technical drawings, specifications, and regulations checking of incoming materials, produced parts and the end product;
- Checking and calibrating measurement equipment;
- Identifying which problems with regard to quality regularly occur, and subsequently suggest which improvements can be made with regard to production methods, equipment and material use;
- Report and archive findings.

Mainly communicates with the following stakeholders:
Within their work quality assurance mainly communicates with stakeholders that are involved in the production stage and if necessary the engineering department, who determined the specifications of the products.

So relevant stakeholders are:

- Production;
- Engineering;
- Warehouse and material handling;
- Maintenance;
- Sub contractors;
- Inspection instances.

However, as stated by Monczka et al. (2002, p. 86) "during the years the quality emphasis has shifted from detecting defects at the time of receipt or use to prevention early in the materials-souring process". So quality representatives are more and more involved in other stages during the customer order lead time, and thus give their input prior to the actual production starts.

HRM (Human Resource Management)

"Human resources (HR) is responsible for obtaining properly skilled labor and managers for the organization" (Meredith, 1992, p. 22).

Primary tasks and responsibilities:

- Know upcoming needs of both number of personnel and skill levels required in order to support and carry out the processes within the company;
- Responsible for upgrading internal firm skills through employee training and development;
- Organize and administrate organizational, personal and social concerns of employees which affect their work.

Mainly communicates with the following stakeholders:
Within their function HRM should communicate with all internal stakeholders. HRM normally is not involved in the primary processes and functions carried out by the organization however.

Warehouse and material handling

Responsible for the receipt, storage, release and internal transport of tools, parts and materials.

Primary tasks and responsibilities:

- Check whether the right tools, parts and materials are delivered in the right quantity;
- Storage materials at the right place such that they easily can be identified and picked;
- Keep information about inventory and goods in stock up-to-date;
- Release materials when demanded and make sure the right materials are transported to the right place.

Mainly communicates with the following stakeholders:

- Planning and scheduling;
- Production;
- SRM (Purchasing);
- SRM (Outsourcing);
- Work preparation;

Maintenance

Maintenance is concerned with the objective to keep equipment and tools within a state in which it can perform its desired function as specified, and if equipment does not perform as specified, to restore equipment such that it is able to perform as specified.

Primary tasks and responsibilities:

- Plan and carry out preventive maintenance (maintenance before systems fail and thus still operate as specified);
- Carry out corrective maintenance (maintenance when systems are failed and thus do not operate as specified);
- At Eaton - Industries B.V., the maintenance function is also responsible for safety and environment issues.

Mainly communicates with the following stakeholders:
- Planning and scheduling;
- Production;
- Warehouse and material handling;
- Inspection instances.

Accounting and Finance
Manages all accounting and financial aspects within the company.

Primary tasks and responsibilities:
- Performing accounting activities such as cost accounting, project accounting, payroll and capital spending;
- Managing working capital and cash flow
- Prepare profit plans and forecasts;
- Record and report operating result on a regularly basis.

Mainly communicates with:
Accounting and Finance is not involved in the primary process and functions carried out. The function is, as can be concluded from the discussion above, mainly concerned about operational results. It therefore may communicate with each stakeholder, internal as external.

ICT (Information and Communications Technology)
This function is relative new. However, the IT function within a company is becoming increasingly important, since the role of information is critical within an organization (Meredith, 1992). The function is mainly concerned with setting up, maintaining and improving computerized information systems.

Primary tasks and responsibilities:
- Administer computer, software and network systems within the company and thus enabling information transition (between stakeholders);
- Gain insights in internal wishes with regard to ICT hard and software systems, following market and ICT product developments, and based on these keeping the information system up to date.

Mainly communicates with:
Communicates with all internal stakeholders, and external suppliers of hard / software systems.

Customer (is not always the end user)
The customer is the person or party actually buying the product. The customer does not necessary have to be the end user.

The main factors on which a customer typically bases its purchase decision are:
- Price / cost;
- Product quality;
- Delivery performance (speed and reliability);
- Product design (features, functions and aestics);

Besides these factors, other factors such as flexibility, customer service and product image may affect the customers purchase decision.

An Engineer-to-Order company is characterized by its ability to customize. Meredith (1992 p. 53) defines customization as “offering a product or service exactly suited to the customer’s desires or needs”

Supplier (raw materials and purchased parts)
The supplier is the organization that provides the raw materials and parts.

Some characteristics of a good supplier are (Meredith, 1992, p. 724):
Deliveries are made on time, of the quality and in the quantity specified;
- Fairly priced;
- Able to react to unforeseen changes such as increase or decrease in demand, quality, specifications or delivery schedules;
- Continually improving products and services.

Besides that aspects as supplier's capabilities and past performance, management capability and commitment, technical ability and the ability to develop process and product technology have to be taken into account.

Sub Contractors
Baily et al. (2005, p. 334) refers to the Outsourcing Institute which defines outsourcing as "the strategic use of outside resources to perform activities traditionally handled by internal staff and resources".

There are many considerations that should taken into account before is decided to outsource. Some of the considerations that should be taken into account are listed by Baily et al. (2005, p. 335) and listed below:
- External supplier has better capability;
- External supplier has greater or more appropriate capacity;
- Freeing resources for other purposes;
- Reduction in operating costs;
- Infusion of cash by selling asset to provider;
- Reducing, or spreading, risk;
- Lack of internal resource;
- Desire to focus more tightly on core business;
- Economies of scale.

Outsourcing companies usually are specialized in performing a small range of operations.

EATON Management / Community
Besides the stakeholders mentioned and elaborated in the current appendix, within Eaton - Industries B.V., the Eaton global organization and the Eaton Fluid Power division, which is the blanket organization of Eaton - Industries B.V. can be seen as stakeholders. Eaton - Industries B.V. largely operates independently, however, the blanket organizations have their influences on the company. This works on two ways, on the one hand the global organization and blanket division have the ability and resources to support Eaton - Industries B.V. during conducting their work. Knowledge, connections, and use of brand names are examples of advantages gained by being within the Eaton organization. On the other hand, the overall Eaton organization and Eaton Fluid Power group puts constraints on Eaton - Industries B.V. These constraints should be taken into account when decisions have to be taken. This makes managing the organization more complex.

Appendix 7: Additional literature insights

Engineering

The starting point for each design process is the client's statement, identified by Dym and Little (2000) as the need for a design. The first widely recognized design phase, conceptual design, mainly looks for different concepts that can be used to achieve the clients need. The conceptual design is mainly focused on high level issues, such as finding suitable solutions and principles and combining them in concepts. The required output from the conceptual design stage could be one or several concepts, which can be analyzed and evaluated in the subsequent stage. This subsequent phase, preliminary design, thus mainly analyses and evaluates the concepts created in the previous phase. Alternatives have to be considered and choices have to be made. Doing this, some dimensions may have to be determined and basic calculations may be used. At the end of the preliminary design phase a final choice from the proposed concepts has to be made. During the final stage, detailed design, choices made before should be turned into detailed specified systems, sub-systems and parts. Drawings and, if required, detailed calculations should be made. This finally should lead to a final design, including fabrication specs and documentation.

During the design of a product numerous choices have to be made. Doing this, various factors should be taken into account, which influence the quality and value the product has to the ultimate user, the customer. Choices in favor for one factor may have contrary consequences on other factors. Factors that should be taken into account are e.g. (Ertas and Jones, 1996): reliability, maintainability, dependability, manufacturability, cost benefit and availability. Other functions such as SRM (availability and costs of materials), work preparation and production (manufacturability) might be involved during design for their specific knowledge.

During the design process multiple technical disciplines might be involved to design the sub-systems and adjust the various subsystems on each other. Examples of disciplines that might be involved are mechanical engineering, electrical engineering, software design and operational design.

Within Eaton - Industries B.V., mechanical engineering and design is the main discipline involved during detailed engineering. A complete cylinder typically is engineered and designed by one Engineer. At Eaton - Industries B.V., three full time engineers are employed. Besides that, there is an excising capacity at India of 4 engineers and one supervisor (supervising the four Indian engineers). These engineers work exclusively for Eaton - Industries B.V. Engineers at both Eindhoven and India have the capabilities to work out a complete cylinder.

The decision whether to outsource to India is mainly based on complexity and time constraints. Less complex cylinders with low time pressures typically are outsourced to India. The outcomes of the outsourced work always are checked in Eindhoven. Other activities during the design stage within Eaton - Industries B.V. are strength calculations (official strength calculations only are made by the "Eindhoven-engineers") and testing procedures.

As stated before, Dym and Little (2000) identified five stages that are typically conducted from client statement (need) till final design. Some of these design stages usually are carried out in the previous phase, during the order quotation. Typically for example a conceptual design is made during quotation, but it also may be decided to make a more detailed design during quotation. In the engineering stage, the design proposed (created by pre-engineering) in the quotation stage is taken as starting point and is, taking customer comments into account, worked out to final design (fabrication specs and documentation).

Purchasing

Determining on purchase order specifications

Material requirements specified during work preparation first should be turned into functional and technical purchase specifications. General examples of factors that might be included in purchase specifications described by van Weele (2001) are shown below:

- Quality specifications: how (with or without certificate) should materials be delivered and what technical norms and standards should the product have;
- Logistical specifications: quantities needed and delivery time to be respected;
- Target budget: indicating financial constraints;
- Maintenance specifications: how will the product be maintained and served by the supplier.

Supplier selection:

When purchasing requirements are specified, the next step is to select a supplier. Monczka et al. (2002) describe two methods for selecting a supplier: competitive bidding and negotiating. Competitive bidding involves a request for bids from suppliers. The objective is to select the most qualified bidder (Monczka et al., 2002). Negotiation usually leads to closer relation ships with selected suppliers and aims on reaching agreement in a cooperative mode Monczka et al. (2002).

The purchasing contract

After a supplier is selected typically a contract has to be made. Several important aspects that should be considered and included in the contract are (van Weele, 2001):

- Prices and terms of delivery;
- Terms of payment;
- Penalty clauses and warranty conditions.

Ordering

When a contract is agreed, the order can be placed. Sometimes the purchasing contract is the order. In other cases the order has to be placed, using the terms agreed in the previous phase within the purchasing process. Overall when placing the final order the following items should be considered and arranged during the purchasing process (van Weele, 2001 p. 67):

- An order number;
- A concise description of the product (material and dimensions);
- A unit price, the number of units required;
- The expected delivery time or date;
- Delivery address;
- Invoicing address.

Shop-floor throughput time

Material complexity is especially determined by the number of different materials needed to produce an order. Complex products which are made of many raw materials and assembled from many parts are classified as having a high material complexity. This complexity is strengthened when product structures partial correspond but also partial differ. This is largely related with a low repetition rate, since this increases uncertainty and integration from various operations is hard when repetition rate is low (Bertrand et al., 1998).

Capacity complexity is especially determined by different routings that products make through production and their variability in capacity requirement on the various workstations (Bertrand et al., 1998). A production environment in which different products make different routings through production and each product requires different varying capacity on the workstations has a high capacity complexity.

As stated before, based on these two factors Bertrand et al. (1998) made a typology to classify various typical production departments. The framework is shown below in figure 7.1.

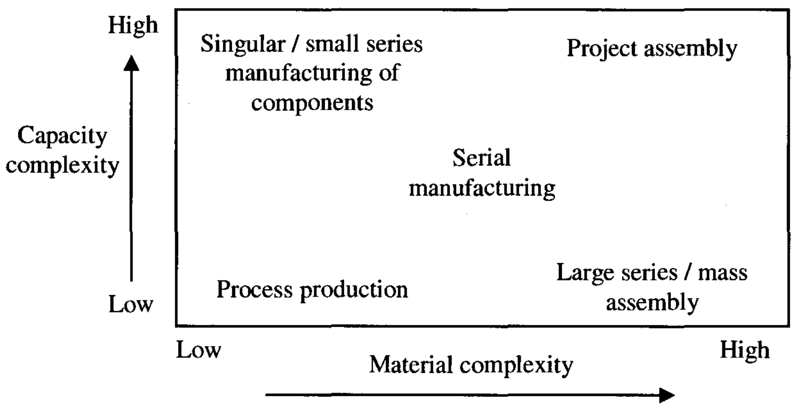


Figure 7.1: five typical production departments (Bertrand et al., 1998 p. 110)

Within Engineer-to-Order production environments, the typical production control characteristics have three aspects: dynamics, uncertainty and complexity (Bertrand and Muntslag, 1993). Dynamics of a production situation is determined by factors as the fluctuations in production orders, their content and their predictability. An Engineer-to-Order situation typically "has to cope with large variations in mix and sales volume, both in short and medium term" (Bertrand and Muntslag, 1993 p. 6). Coping with those fluctuations in ETO production requires a lot of flexibility since this type company deals with specific customer products and as a result little can be done in advance.

According to Bertrand and Muntslag (1993) uncertainty has great influence on the complexity of a production control situation. They identify three types of uncertainty: uncertainty of product specifications, mix and volume uncertainty of the future demand and uncertainty concerning the process. When uncertainty is high, production control should be able to anticipate on the uncertainty. This asks for a considerable flexibility, especially in the short term (Bertrand and Muntslag, 1993).

The third aspect, complexity, mentioned by Bertrand and Muntslag (1993) also has three main factors. The complexity of an ETO company is caused by the structure of the goods flow which contains not only a physical stage but also a non-physical stage (which contains steps as engineering and design and purchasing). This makes it hard to determine the progress of a specific order. Besides a complicated structure of goods flow, the multi-project character and usually complex assembly structure increases complexity. Specific materials typically have to be purchased for different orders and every order consists of a lot of activities.

Taken into account the production control characteristics described by Bertrand and Muntslag (1993), the operational characteristics described by Kingsman et al. (1993) and Kingsman et al. (1996) and other characteristics mentioned in literature as a high product variety, low volumes and long lead times of an ETO company (e.g. Persona et al., 2004 and Marucheck and McClelland, 1992), production in an ETO company can be classified as production with a relative high capacity complexity and moderate to high material complexity.

When both capacity and material complexity are high, the production environment is identified by Bertand et al. (1998) as a project. In literature projects are characterized as large scale operations which typically have a finite duration (Meredith, 1992). A definition of a project is given by Lester (2005, p. 1) who states that a project is "a unique set of coordinated activities, with definite starting and finishing points undertaken by an individual or organization to meet specific objectives within defined schedule, cost and performance parameters". Besides the high material and capacity complexity that was mentioned before, projects typically have a low repetition rate, which leads to a wide deployment of resources and typically (very) few orders are in progress simultaneously. The high material and capacity complexity and characteristics described above make the project production environment relative difficult to plan and control.

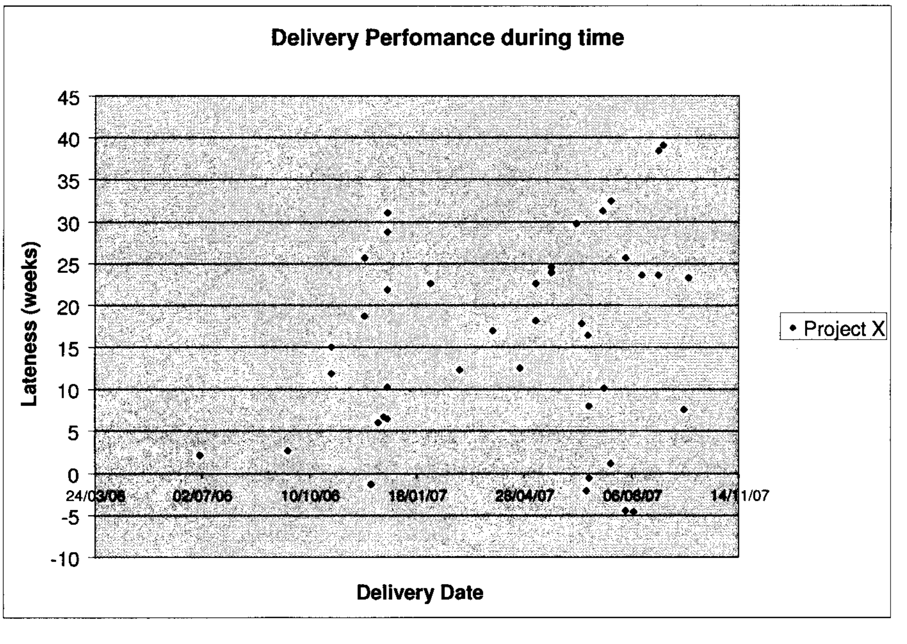
Appendix 8: Summary results data analysis

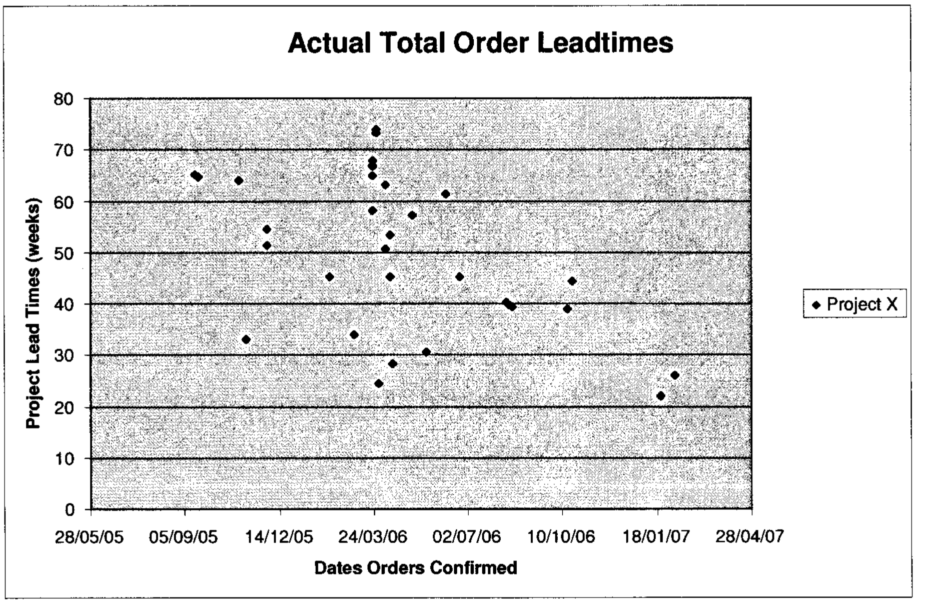
Total order delivery performance

(Lead-times measured in weeks)

Total number of projects	55
Total on time delivered	6
Delivery Performance	0.11
Average due date performance all projects	15.88
Stand dev due date perform all projects	11.29
Total on time delivered analysed:	
No of proj on time deliv	6
Average time delivered before due date	-2.93
Stand dev bef due date	1.66
Too late analysed	
No of proj too late deliv	49
Average exceeding due date	18.19

Nr. of projects analysed	44
Planned Total Delivery Time:	
Average planned tot delivery time	31.46
Stand dev planned tot delivery time	9.72
Actual Total Delivery Time:	
Average actual tot delivery time	48.90
Stand dev actual tot delivery time	14.07





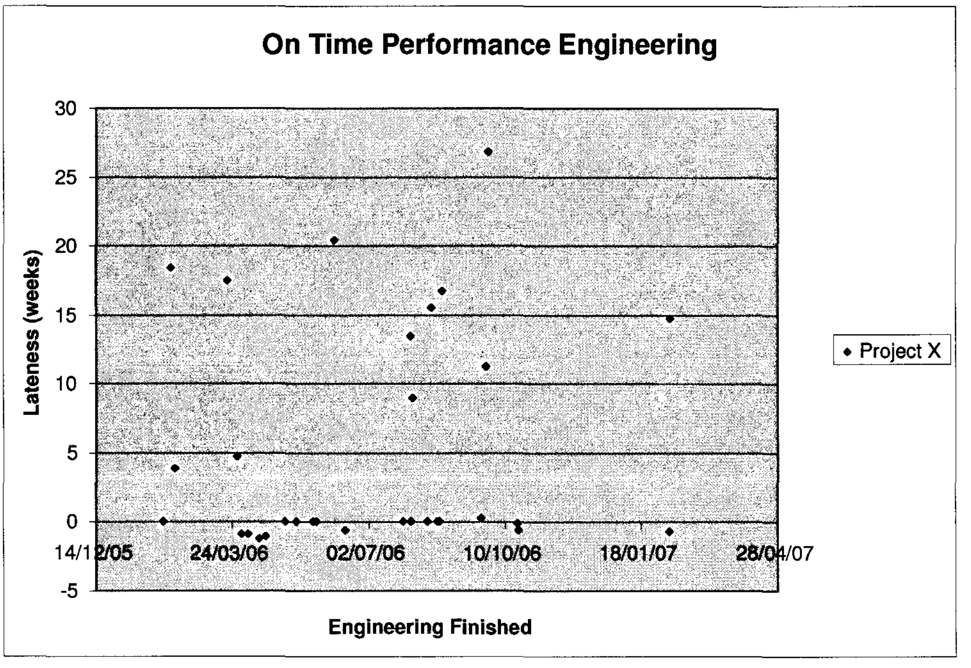
Engineering performance

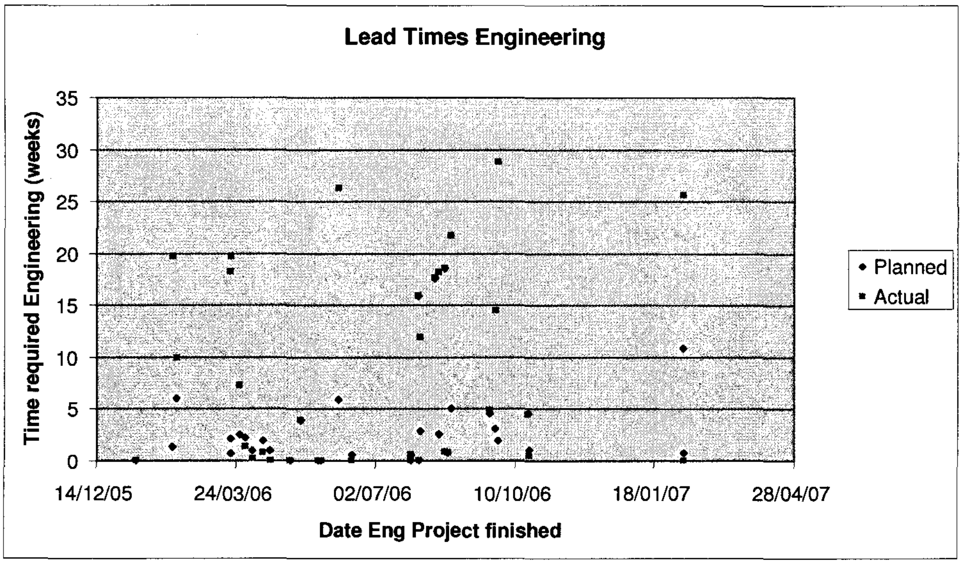
(Lead-times measured in weeks)

Total number of projects (with valid data)	54
Total on time delivered	31
Delivery Performance	0.57
Average due date performance all projects	5.08
Stand dev due date perform all projects	7.65
Total on time delivered analysed:	
No of proj on time deliv	31
Average time delivered before due date	-0.39
Stand dev time delivered bef due date	0.45
Too late analysed	
No of proj too late deliv	23
Average exceeding due date	12.46
Stand dev exceeding due date	6.51

Planned Total Lead Time:		
No of projects with valid data	43	
Average planned tot delivery time	3.85	Weeks
Stand dev planned tot delivery time	4.45	

Actual Total Lead Time:		
No of projects with valid data	43	
Average actual tot delivery time	9.30	Weeks
Stand dev actual tot delivery time	9.21	


On Time Performance Engineering
Lateness (weeks)
30
25
20
15
10
5
0
-5
14/12/05
24/03/06
02/07/06
10/10/06
18/01/07
28/04/07
Engineering Finished
Project X


Lead Times Engineering
Time required Engineering (weeks)
35
30
25
20
15
10
5
0
14/12/05
24/03/06
02/07/06
10/10/06
18/01/07
28/04/07
Date Eng Project finished
Planned
Actual

Work preparation

(Lead-times measured in weeks)

Total number of projects (with valid data)	54
Total on time delivered	31
Delivery Performance	0.57
Average due date performance all projects	4.04
Stand dev due date perform all projects	10.01

Total on time delivered analysed:	
No of proj on time deliv	31
Average time delivered before due date	-2.25
Stand dev time delivered bef due date	7.08

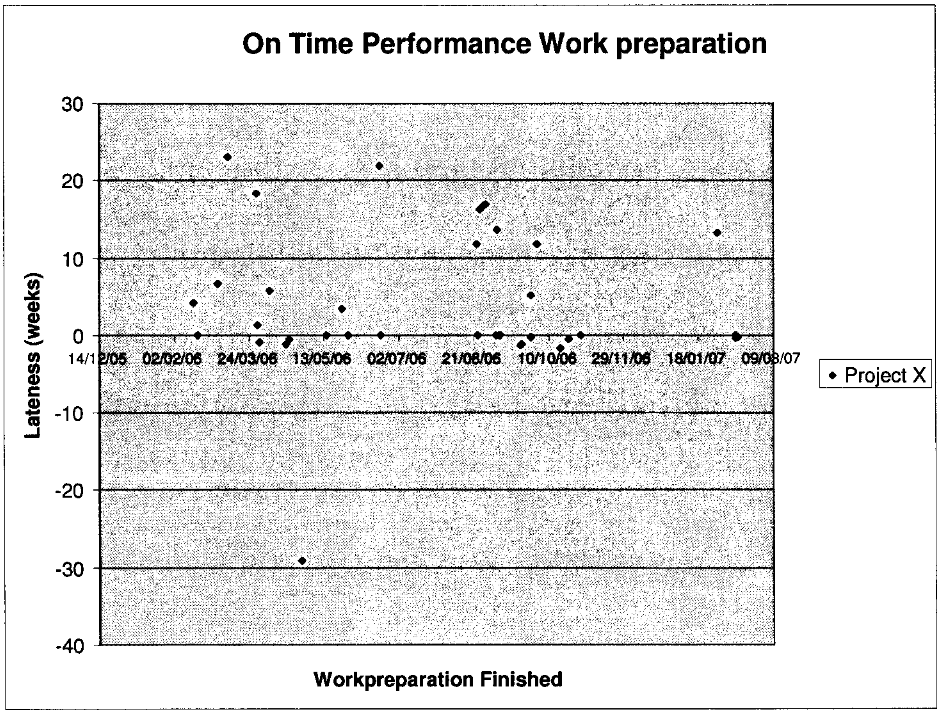
Too late analysed	
No of proj too late deliv	23
Average exceeding due date	12.53
Stand dev exceeding due date	6.52

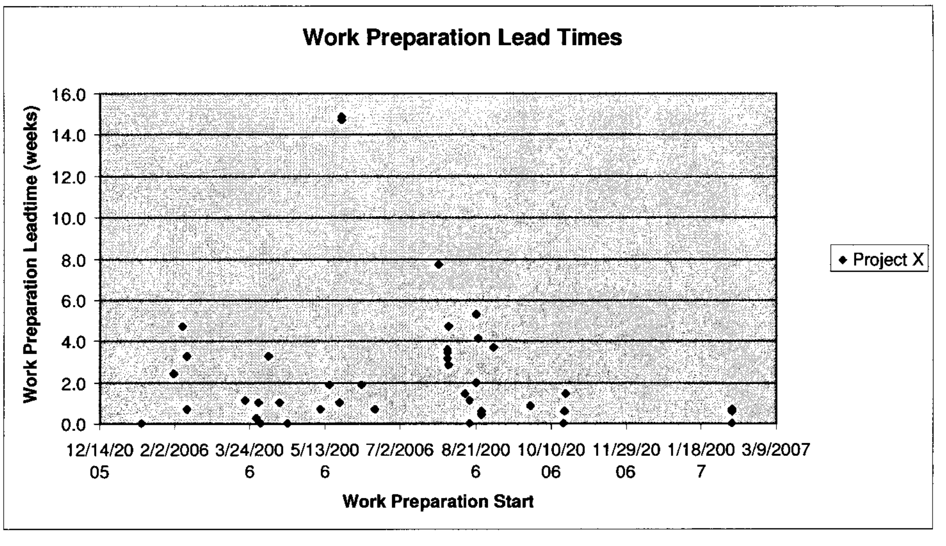
Planned Total Delivery Time (inculding outliers):		
No of projects with valid data	50	
Average planned tot delivery time	2.26	Weeks
Stand dev planned tot delivery time	4.13	Weeks

Actual Total Delivery Time (including outliers):		
No of projects with valid data	50	
Average actual tot delivery time	3.15	Weeks
Stand dev actual tot delivery time	3.87	Weeks

Planned Total Delivery Time (4 outliers removed):		
No of projects with valid data	46	
Average planned tot delivery time	1.17	Weeks
Stand dev planned tot delivery time	1.92	Weeks

Actual Total Delivery Time (4 outliers removed):		
No of projects with valid data	46	
Average planned tot delivery time	2.14	Weeks
Stand dev planned tot delivery time	1.87	Weeks


On Time Performance Work preparation
Lateness (weeks)
30
20
10
0
-10
-20
-30
-40
14/12/05
02/02/06
24/03/06
13/05/06
02/07/06
21/08/06
10/10/06
29/11/06
18/01/07
09/03/07
Project X
Workpreparation Finished


Work Preparation Lead Times
Work Preparation Leadtime (weeks)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
12/14/2005
2/2/2006
3/24/2006
5/13/2006
7/2/2006
8/21/2006
10/10/2006
11/29/2006
1/18/2007
3/9/2007
Project X
Work Preparation Start

Material delivery performance

(Lead-times measured in weeks)

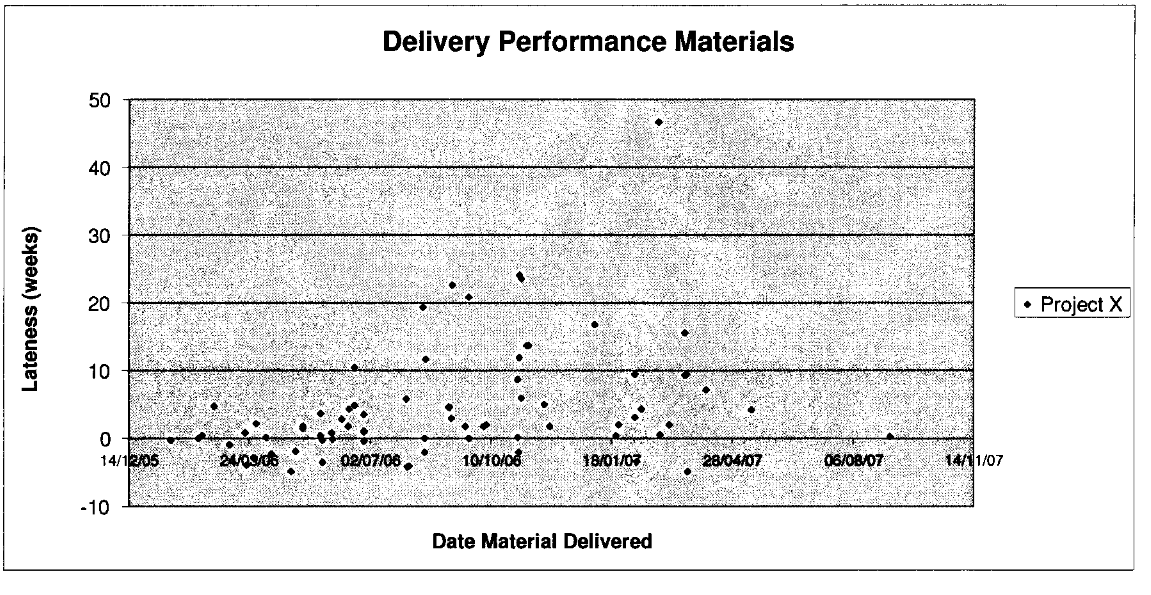
Total number of projects (with valid data)	45		
Total material orders included	118		
Average no of "materials" ordered per project	2.62		
Total on time delivered	54		
Delivery Performance	0.46		Data without 2 Outliers
Average due date performance all projects	4.18	Weeks too late	3.44
Stand dev due date perform all projects	8.36		6.29

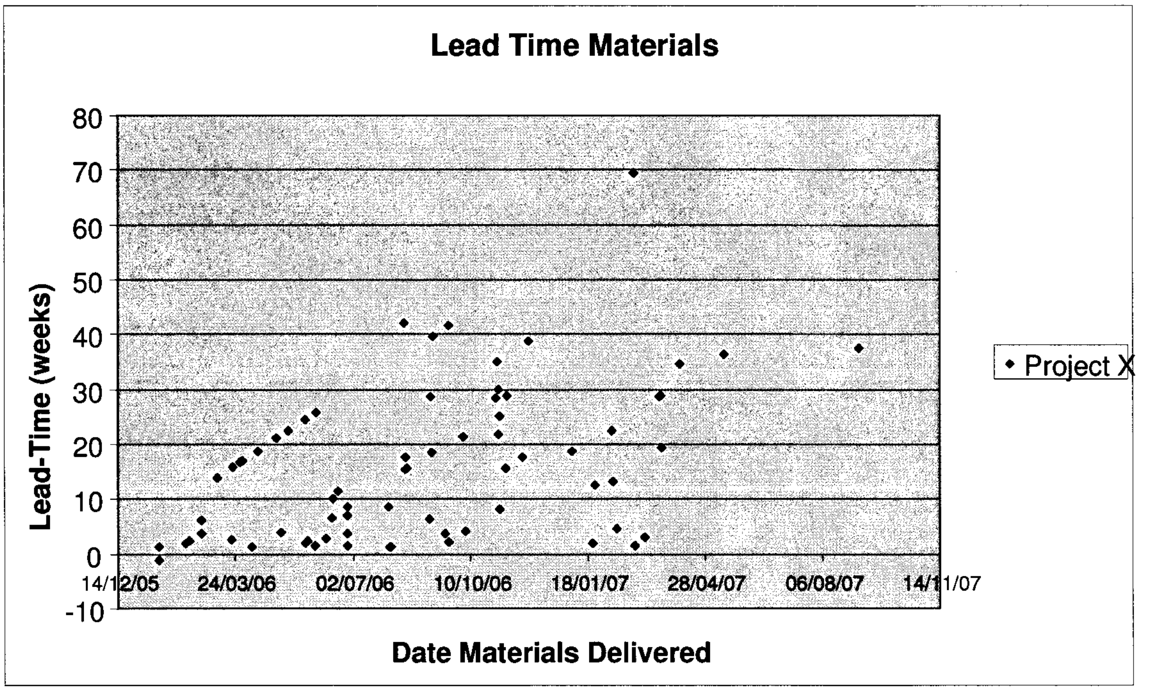
Total on time delivered analysed:			
No of proj on time deliv	54		54
Average time delivered before due date	-1.06		-1.06
Stand dev time delivered bef due date	1.78		1.78

Too late analysed			
No of proj too late deliv	64		62
Average exceeding due date	8.59		7.37
Stand dev exceeding due date	9.14		6.18

Planned (promissed) Total Delivery Time		
No of projects with valid data	118	
Average Promised Material delivery time	12.50	Weeks
Stand dev Promised Material delivery time	10.49	Weeks

Actual Total Delivery Time			Data without 2 Outliers
No of projects with valid data	118		116
Average actual tot delivery time	16.68	Weeks	15.77
Stand dev actual tot delivery time	13.47	Weeks	11.65





Sales Finished (/start engineering)

(Lead-times measured in weeks)

Number of Valid Data Items: 32

Sales (including outliers) - DAYS	
Average Time Sales Finished (after Order Confirmation) (days)	9.25
SD Time Sales Finished (after Order Confirmation) (days)	22.26

Sales (including outliers) - WEEKS	
Average Time Sales Finished (after Order Confirmation) (days)	1.32
SD Time Sales Finished (after Order Confirmation) (days)	3.18

Sales (without outliers) - DAYS	
Average Time Sales Finished (after Order Confirmation) (days)	3.67
SD Time Sales Finished (after Order Confirmation) (days)	5.47

Sales (without outliers) - WEEKS	
Average Time Sales Finished (after Order Confirmation) (days)	0.52
SD Time Sales Finished (after Order Confirmation) (days)	0.78

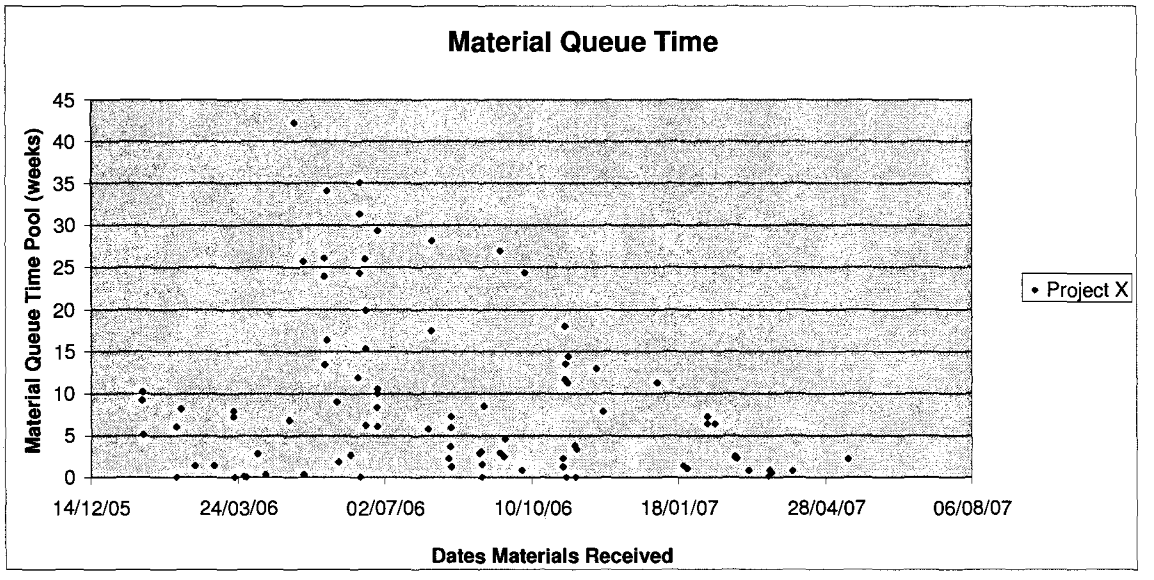
Materials ordered (relative to Customer Order Confirmation)

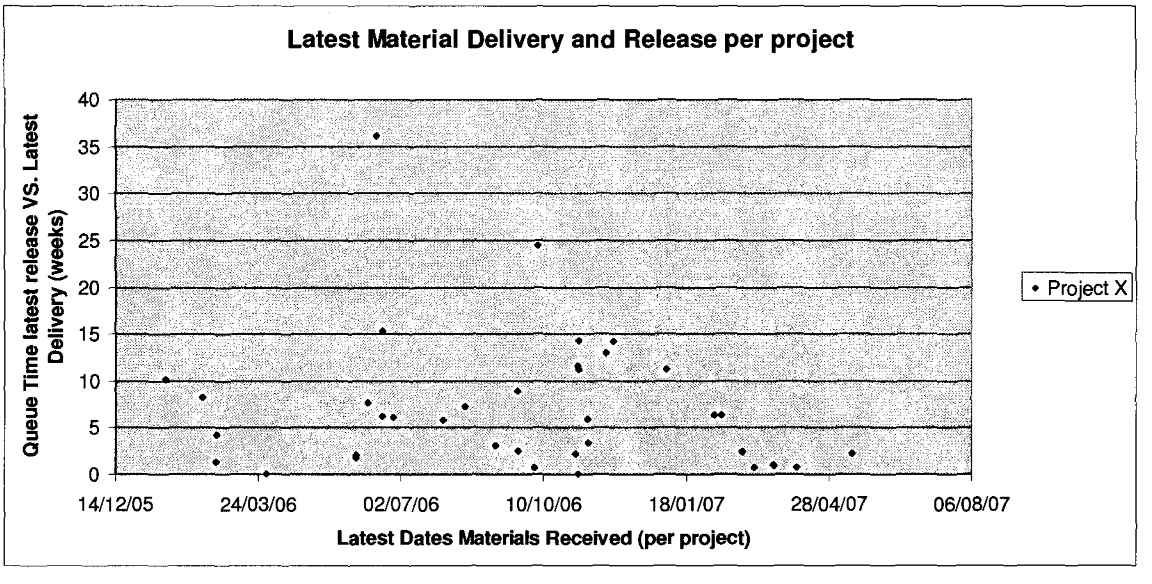
(Lead-times measured in weeks)

Number of Projects With Valid Data	42	
Number of Material Orders	109	
Average Time Material Ordered after Project Order Confirmation, All mat orders, including outliers and multiple orders per project	2.74	
SD Time Material Ordered after Project Order Confirmation, All mat orders, including outliers and multiple orders per project	8.54	
Average Time Material Ordered after Project Order Confirmation (including outliers)	2.92	Weeks
Stand Dev Time Material Ordered after Project Order Confirmation (including outliers)	7.91	
Average Time Material Ordered after Project Order Confirmation (2 outliers EXCLUDED)	3.03	Weeks
Stand Dev Time Material Ordered after Project Order Confirmation (2 outliers EXCLUDED)	4.58	

Pool delay

Projects included	45
Materials ordered	118
Material "vrijgave" dates available	113
Average Queue Time (all material items included) (weeks)	8.70
Standard Dev. Queue Time (all material items included) (weeks)	9.47
Average Queue Time (from last material receipt per project) (weeks)	6.73
Standard Dev. Queue Time (from last material receipt per project) (weeks)	6.88

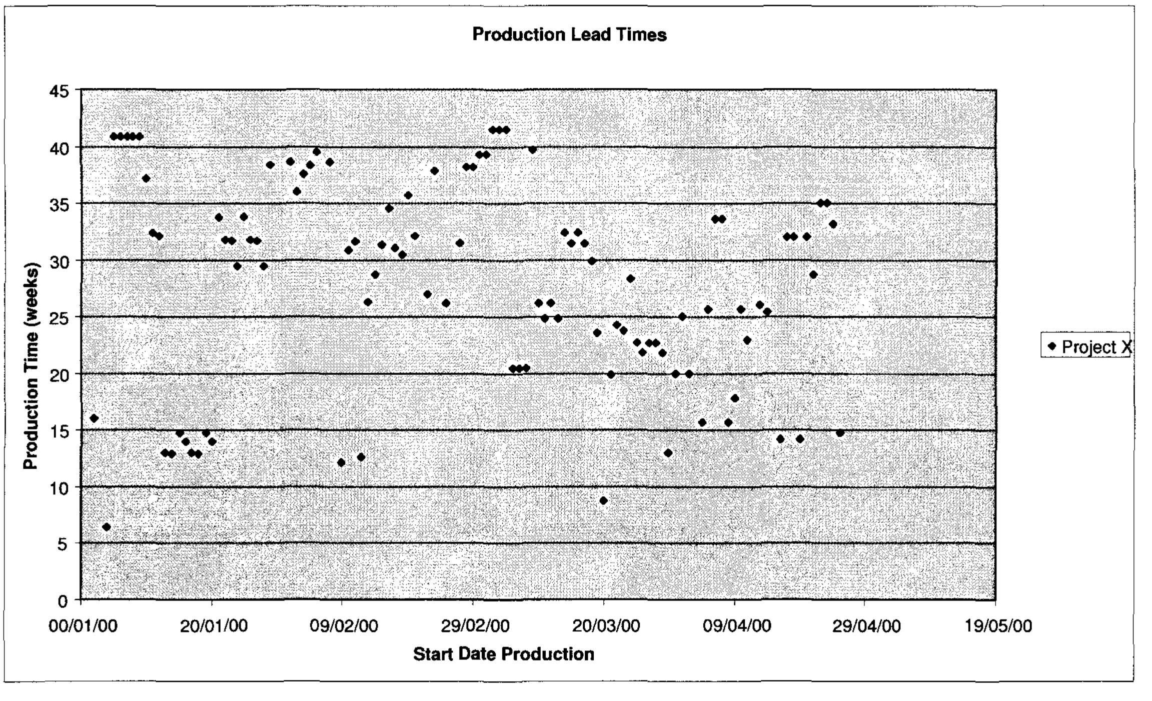

Material Queue Time
Material Queue Time Pool (weeks)
45
40
35
30
25
20
15
10
5
0
14/12/05
24/03/06
02/07/06
10/10/06
18/01/07
28/04/07
06/08/07
Dates Materials Received
Project X


Latest Material Delivery and Release per project
Queue Time latest release VS. Latest Delivery (weeks)
40
35
30
25
20
15
10
5
0
14/12/05
24/03/06
02/07/06
10/10/06
18/01/07
28/04/07
06/08/07
Latest Dates Materials Received (per project)
Project X

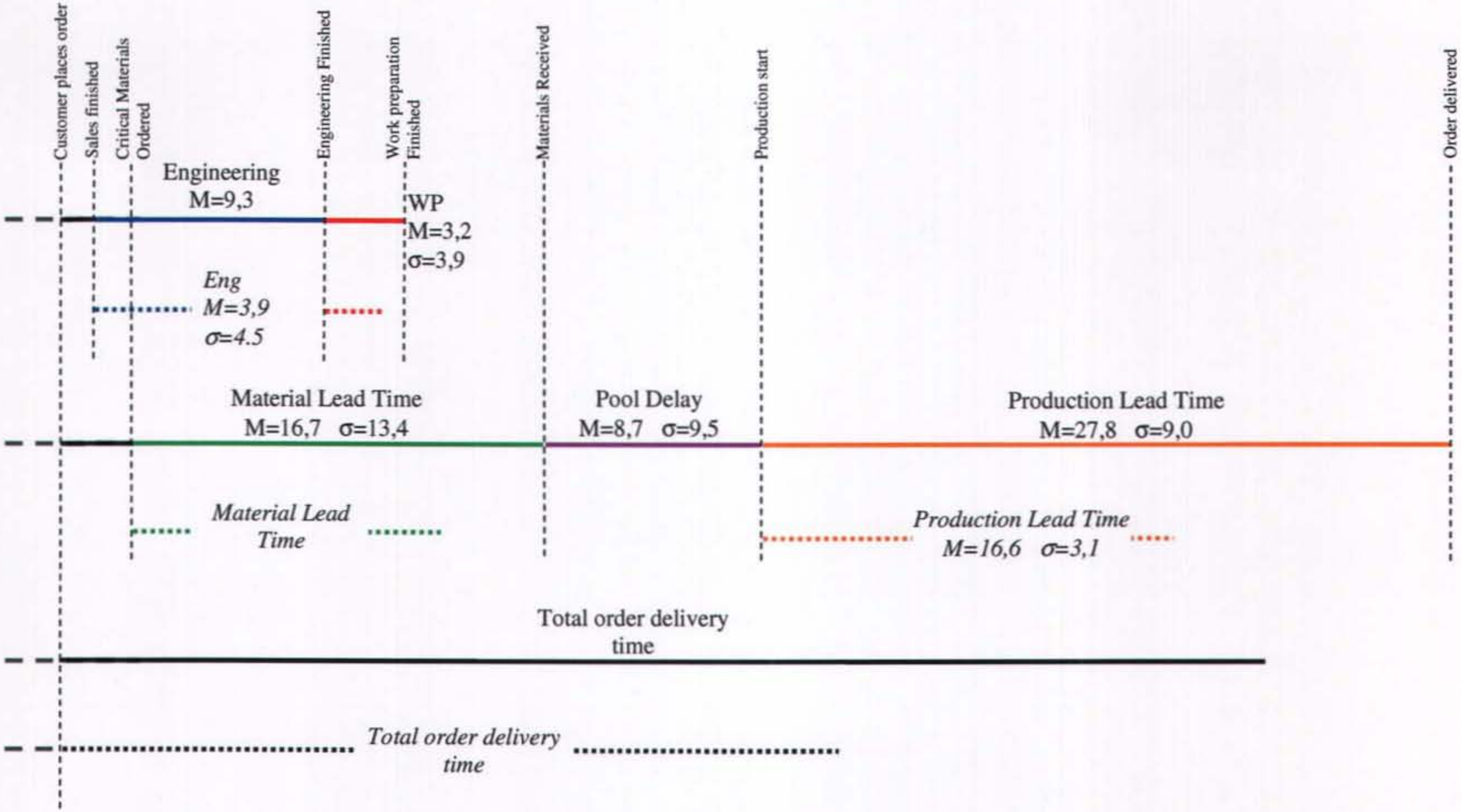
Production performance

(Lead-times measured in weeks)

Number of Projects analysed	44
Number of "parts" produced (with valid data)	104
Number of Projects deliverd on time	2
Delivery performance	0.045
Average production Lead-Time (all materials) (weeks)	27.76
Standard Dev Production Lead-Time (all materials)	9.03
Average Planned Production Time (projects) (weeks)	16.58
Standard Dev Planned Production Time (projects) (weeks)	3.08
Difference in averages planned / actual (more data)	11.18



Appendix 9: Lead-time structure Eaton Industries B.V.



Appendix 10: Constraints mentioned by Kingsman (2000)

Constraints mentioned by Kingsman (2000).

1:
The actual work that has to be done on WCn during the maximum delivery time offered = Workload that is initially released on WCn + all projected inputs during the maximum delivery time at WCn:

$$\sum_{T=1}^{T_T} Z_{n,t} = PB_{n,1} + \sum_{t=1}^{T_T} I_{n,t}$$

For n = 1 to N;

2:
The actual work done on WCn during each period t ≤ Available capacity WCn during each period t:

$$Z_{n,t} \le C_{n,t}$$

For t = 1 to TT , n = 1 to N;

3:
The total workload that has to be carried out on WCn ≤ Total capacity during the maximum delivery time offered:

$$TB_n \le \sum_{t=1}^{T_T} C_{n,t}$$

n = 1, 2, .., N;

4:
The initial advanced workload on WCn + The work carried out on WCn during the maximum delivery time offered = Output of work that is required from WCn during the maximum delivery time offered, to ensure planned jobs meet their delivery dates:

$$A_{n,1} + \sum_{t=1}^{T_T} Z_{n,t} = \sum_{t=1}^{T_T} W_{n,t}$$

For all n = 1 to N;

5:
The planned workload on WCn, after t periods = The current planned workload on WCn + Projected inputs of work to WCn over t periods - Actual work done over t periods, by WCn:

$$PB_{n,t+1} = PB_{n,1} + \sum_{k=1}^{t} I_{n,k} - \sum_{k=1}^{t} Z_{n,k} \ge 0$$

For t = 1 to TT – 1, n = 1 to N;

6:
The initial advanced work on WCn, after t periods = The current initial advanced work + The work that is carried out over t periods – The required work over t periods:

$$A_{n,t+1} = A_{n,1} + \sum_{k=1}^{t} Z_{n,k} - \sum_{k=1}^{t} W_{n,k} \geq 0$$

For t = 1 to TT – 1, n = 1 to N;

7:
Both initial Pooled and Released (planned) workload in period that requires processing on WC n future time periods + Projected inputs of work to WCn from previous stages over t periods ≤ Actual work done on WCn in t + the maximum lead time offered:

$$PB_{n,1} + \sum_{k=1}^{t} I_{n,k} \leq \sum_{k=1}^{t+T_P} Z_{n,k}$$

For t = 1 to TT – TP;

Appendix 11: Example Workload control production scheduling

Below the example is shown that is scheduled using the workload based method suggested in the report. From 19 orders the processes that subsequently have to be carried out on the various work centers, and the expected required time for each of these steps is shown below.

		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
1	procc steps	WC 1	WC 2	Outsource	WC 3		
	time pl	10	20	3	25		
2	procc steps	WC 1	Outsource	WC1	WC 2	WC 3	
	time pl	15	3	15	18	12	
3	procc steps	WC 1	WC 2	Outsource	WC 1	WC 2	WC 3
	time pl	20	10	3	15	16	15
4	procc steps	WC 1	WC 3	WC 2	Outsource	WC 3	
	time pl	14	17	8	4	14	
5	procc steps	WC 1	WC 2	Outsource	WC 3		
	time pl	14	16		22		
6	procc steps	WC 1	WC 2	Outsource	WC 2	WC 1	WC 3
	time pl	16	8	3	17	14	18
7	procc steps	WC 1	Outsource	WC 3	WC 2	WC 3	
	time pl	8	3	8	12	14	
8	procc steps	WC 1	WC 2	Outsource	WC 3		
	time pl	9	18	3	12		
9	procc steps	WC 1	WC 3	Outsource	WC 3		
	time pl	11	21	3	8		
10	procc steps	WC 1	WC 2	Outsource	WC 1	WC 3	
	time pl	13	14	3	18	12	
11	procc steps	WC 1	WC 2	Outsource	WC 3		
	time pl	10	20	3	25		
12	procc steps	WC 1	Outsource	WC1	WC 2	WC 3	
	time pl	15	3	15	18	12	
13	procc steps	WC 1	WC 2	WC 1	Outsource	WC 2	WC 3
	time pl	20	10	15	3	16	15
14	procc steps	WC 1	WC 3	WC 2	Outsource	WC 3	
	time pl	14	17	8	3	14	
15	procc steps	WC 1	WC 2	Outsource	WC 3		
	time pl	14	16	3	22		
16	procc steps	WC 1	WC 3	Outsource	WC 3		
	time pl	11	21	3	8		
17	procc steps	1	N	2	Outsource	WC 3	
	time pl	12	12	10	3	8	
18	procc steps	WC 1	WC 2	Outsource	WC 2	WC 1	WC 3
	time pl	16	20	3	17	14	18
19	procc steps	WC 1	Outsource	WC 2	WC 1	WC 2	WC 3
	time pl	12	3	15	13	10	17

An Excel model is made that represents the various workstations, workstation 1 to workstation 3 and represents the characteristics stated in the report. The model as it is made in Excel is shown below. The figure below represents the planned situation during the first 5 periods (weeks) at t = 0, after scheduling order 1 to 16. Similar models are used for workstation 2 and workstation 3. Using the model, the orders 1 to 19 were scheduled as described in the report. After the scheduling of each order, there was checked whether all stated constraints were satisfied ("true").

WC 1

Week	1	2	3	4	5	20	
Capacity (Cn,t)	40	40	40	40	40	40	
Cumulative capacity	40	80	120	160	200	800	
I n,t (during the period)	0	30	0	35	10	0	
QUEUING t-1	0	0	0	0	0	0	
J Jobpool,t	33	34	38	31	9	0	
J WC2,t	0	0	0	0	0	0	
J Outsourcing,t	0	0	0	0	15	0	
J WCN,t	0	0	0	0	0	0	
V WC1,t	33	34	38	31	24	0	
Physical Workload	33	34	38	31	24	0	
To be processed in t	33	34	38	31	24	0	
QUEUING CAPACITY = 20 = SPARE CAPACITY QB(n,t)	0	0	0	0	0	0	
Innit work advance (A n,t)	0	0	0	0	0	0	
Released workl req procc in future at start of the period (RBn,t)	48	64	86	108	86	0	
Pooled and released workload requiring procc in future (PBn,t)	192	159	155	117	121	0	
Total work in company requiring turning (TBn)	306	273	239	201	170	0	
Required output in period t (Wn,t)	33	34	38	31	24	0	306
Actual work done in period t (Zn,t)	33	34	38	31	24		
E WC2,t	20	10	30	8	36		
E outsourcing,t	Order 2 and 7			Order 12			
E WC3,t	0	17	21				
Orders Processed	1,2,7	3,4	5,9,10	6,12	2,8		
Orders Queueing							
Constraint 2: Z(n,t) =< C(n,t)	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 5a		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 5b		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 5		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 6a		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 6b		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 6		TRUE	TRUE	TRUE	TRUE	TRUE	
Constraint 7	TRUE	TRUE	TRUE	TRUE	TRUE		

ALL CONSTRAINTS SHOULD BE SATISFIED:

Constraint 1: TRUE	306	..=..	192	+	114
Constraint 2: TRUE FOR EACH PERIOD					
Constraint 3: TRUE	306	..?..	680		
Constraint 4: TRUE	0	..+..	306	..=..	306
Constraint 5 TRUE FOR EACH PERIOD					
Constraint 6: TRUE FOR EACH PERIOD					

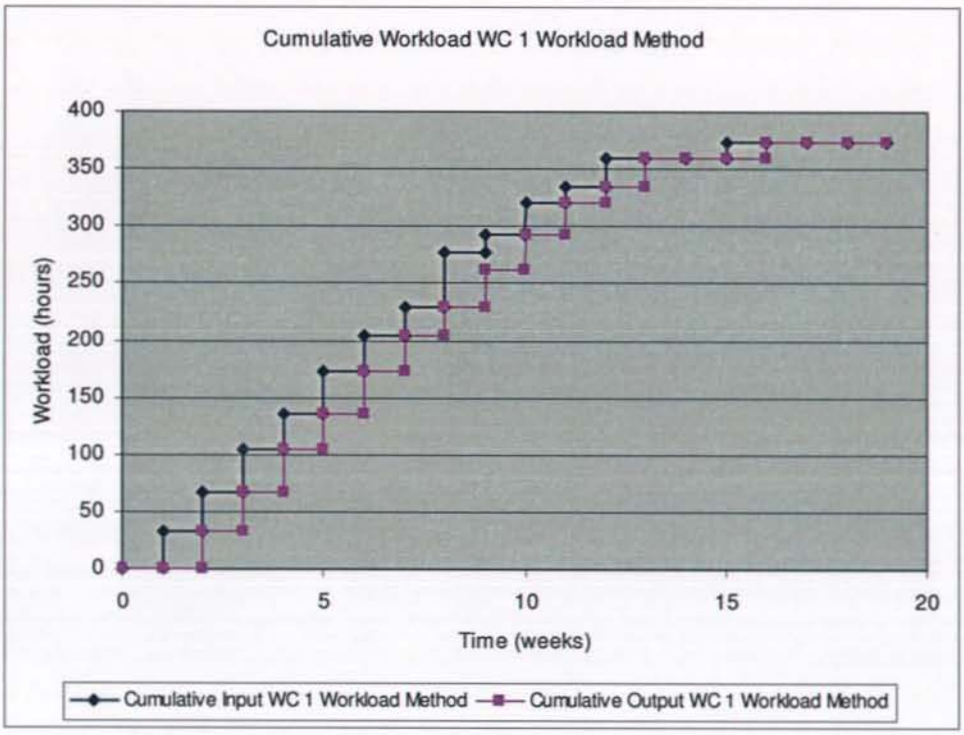
After scheduling the first 10 orders, and subsequently scheduling successively order 11 to 19, for each of the orders, the planned start (release) and end dates are determined, as shown in the table below. Based on the planned start and end dates the planned shop-floor throughput times are determined as shown in the table below.

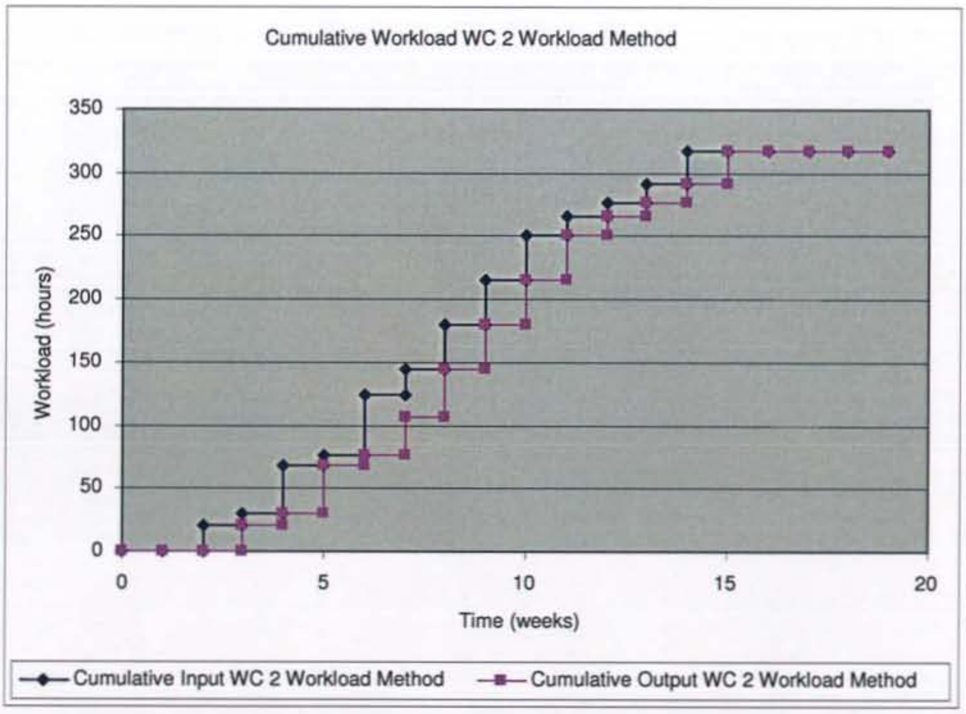
Workload Control Method Start and End Times

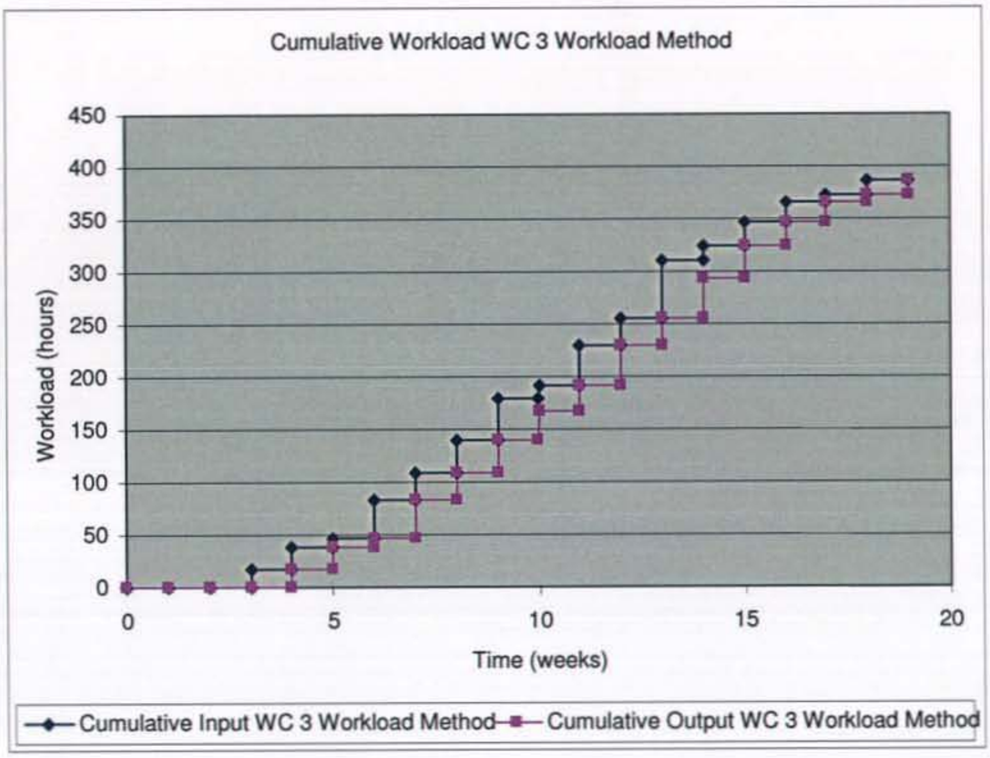
Order	Start Period	End Period	Man Lead-time
1	1	6	5
2	1	7	6
3	2	9	7
4	2	9	7
5	3	8	5
6	4	11	7
7	1	7	6
8	5	11	6
9	3	8	7
10	3	10	9
11	7	12	5
12	4	11	7
13	6	14	8
14	12	18	6
15	10	15	5
16	12	17	5
17	5	11	6
18	9	16	7
19	6	14	8

Average man leadtime all orders:		6,42
Average man leadtime orders 1 - 10		6,50
Average man leadtime orders 11 - 19		6,33
Average total delivery time all orders	11,26	
Average total delivery time orders 1 - 10	8,60	
Average total delivery time orders 11 - 19	14,22	

Subsequently based on the schedule that is made to process the orders, the cumulative inputs and outputs at each period are determined and represented in graphics.


Cumulative Workload WC 1 Workload Method
400
350
300
250
200
150
100
50
0
Workload (hours)
0
5
10
15
20
Time (weeks)
Cumulative Input WC 1 Workload Method
Cumulative Output WC 1 Workload Method

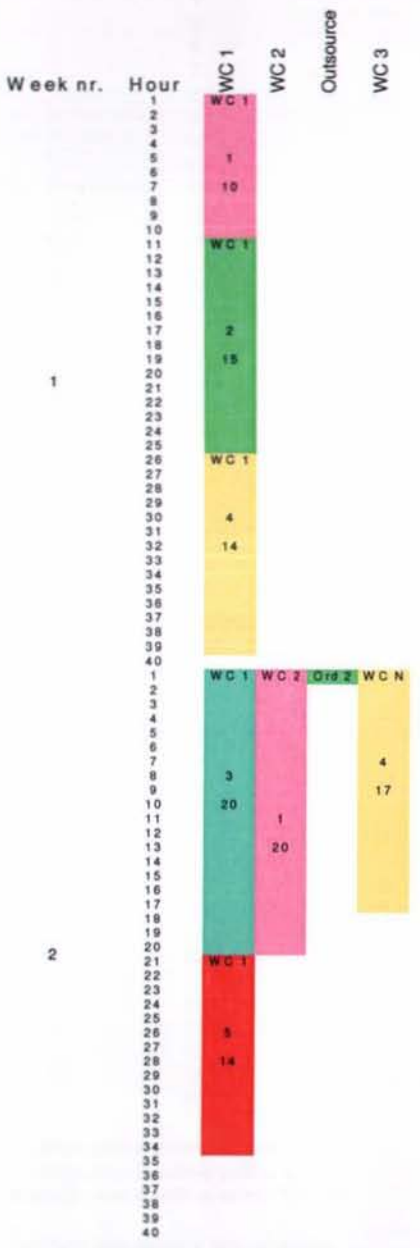

Cumulative Workload WC 2 Workload Method
350
300
250
200
150
100
50
0
Workload (hours)
0
5
10
15
20
Time (weeks)
Cumulative Input WC 2 Workload Method
Cumulative Output WC 2 Workload Method



Cumulative Workload WC 3 Workload Method
450
400
350
300
250
200
150
100
50
0
Workload (hours)
0
5
10
15
20
Time (weeks)
Cumulative Input WC 3 Workload Method
Cumulative Output WC 3 Workload Method

Appendix 12: Example forward scheduling as used at Eaton

Below an example is shown that represents the current way that orders are scheduled at Eaton Industries, and satisfies the constraints mentioned in the report. The figure below shows the first 2 periods that were scheduled, scheduling the 19 orders shown in appendix 10. In the example below, order 1, order 2 and order 4 should be processed in week 1. As can be seen in the example of appendix 10, order 10 requires the subsequent period 20 hours of processing on work center 2, etc.



Appendix 13: Comparison WLC production scheduling and forward scheduling as used at Eaton

Eaton Method Start and End times

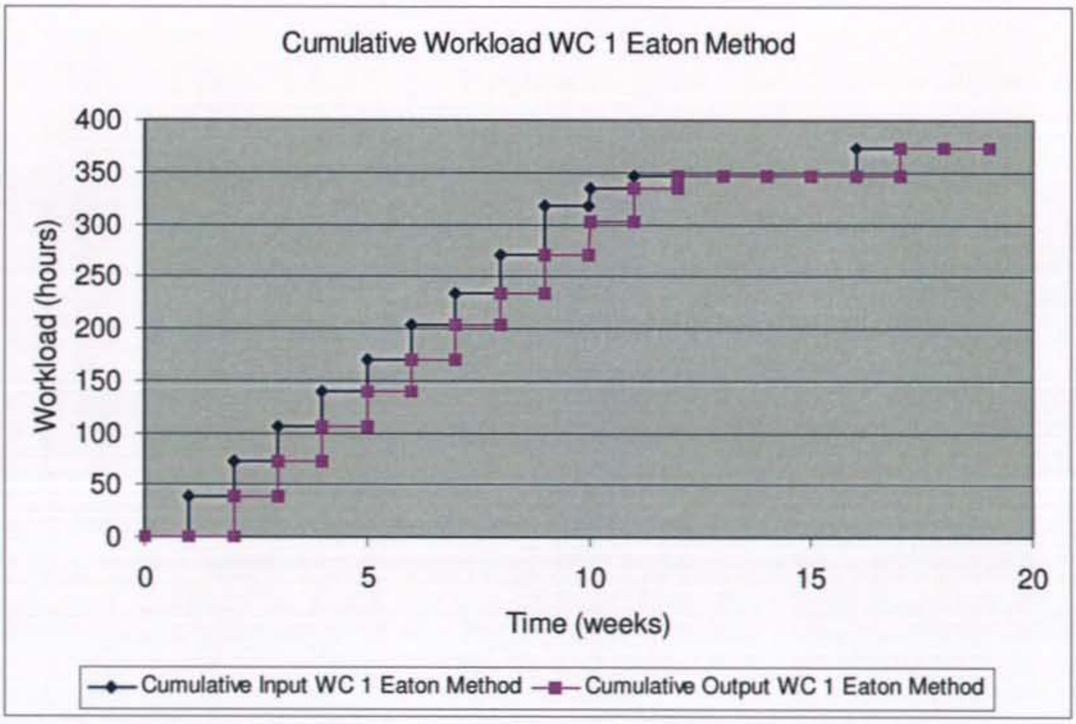
Order	Start Period	End Period	Man Lead-time
1	1	6	5
2	1	7	6
3	2	8	6
4	1	9	8
5	2	7	5
6	3	10	7
7	3	10	7
8	3	8	5
9	4	9	5
10	4	11	7
11	4	11	7
12	5	12	7
13	6	13	7
14	6	17	11
15	7	13	6
16	8	18	10
17	8	14	6
18	10	17	7
19	11	18	7

Average man leadtime all orders:		6,79
Average man leadtime orders 1 - 10		6,10
Average man leadtime orders 11 - 19		7,56
Average total delivery time all orders	11,47	
Average total delivery time orders 1 - 10	8,50	
Average total delivery time orders 11 - 19	14,78	

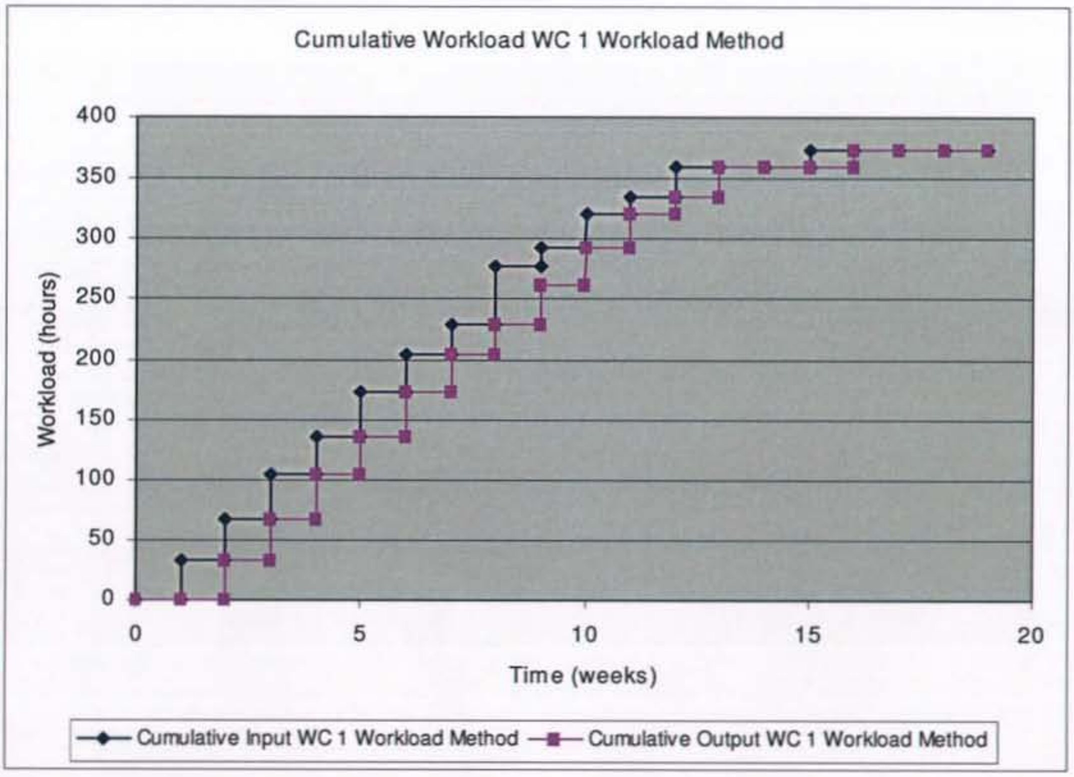
Workload Control Method Start and End Times

Order	Start Period	End Period	Man Lead-time
1	1	6	5
2	1	7	6
3	2	9	7
4	2	9	7
5	3	8	5
6	4	11	7
7	1	7	6
8	5	11	6
9	3	8	7
10	3	10	9
11	7	12	5
12	4	11	7
13	6	14	8
14	12	18	6
15	10	15	5
16	12	17	5
17	5	11	6
18	9	16	7
19	6	14	8

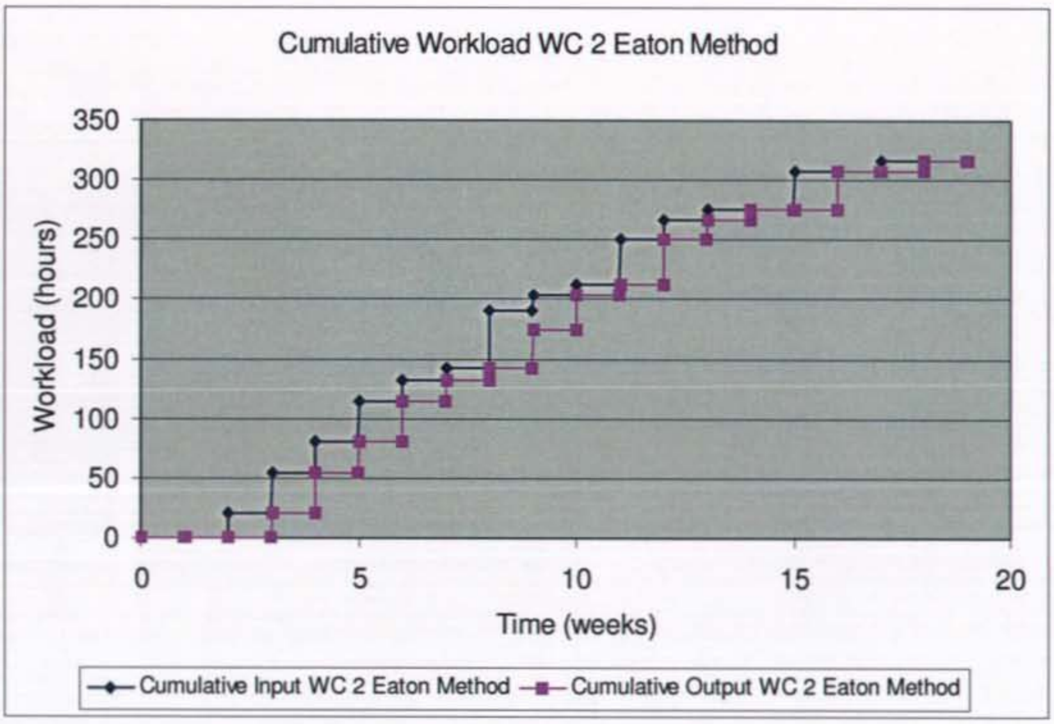
Average man leadtime all orders:		6,42
Average man leadtime orders 1 - 10		6,50
Average man leadtime orders 11 - 19		6,33
Average total delivery time all orders	11,26	
Average total delivery time orders 1 - 10	8,60	
Average total delivery time orders 11 - 19	14,22	



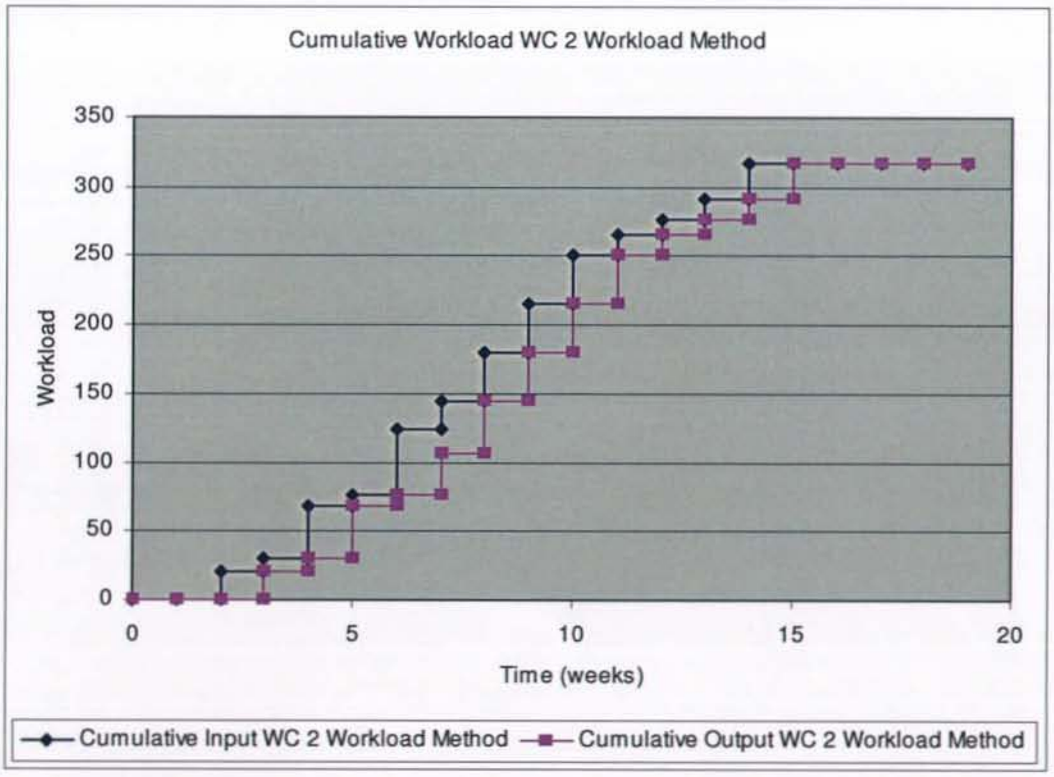
Cumulative Workload WC 1 Eaton Method
Workload (hours)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Time (weeks)
Cumulative Input WC 1 Eaton Method
Cumulative Output WC 1 Eaton Method



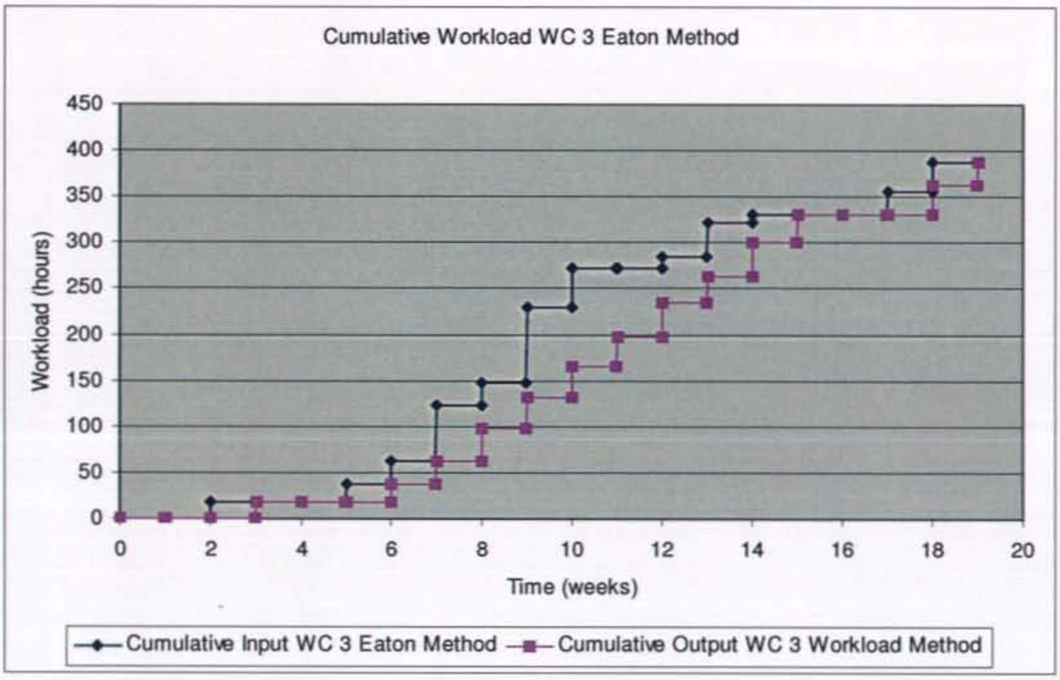
Cumulative Workload WC 1 Workload Method
Workload (hours)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Time (weeks)
Cumulative Input WC 1 Workload Method
Cumulative Output WC 1 Workload Method

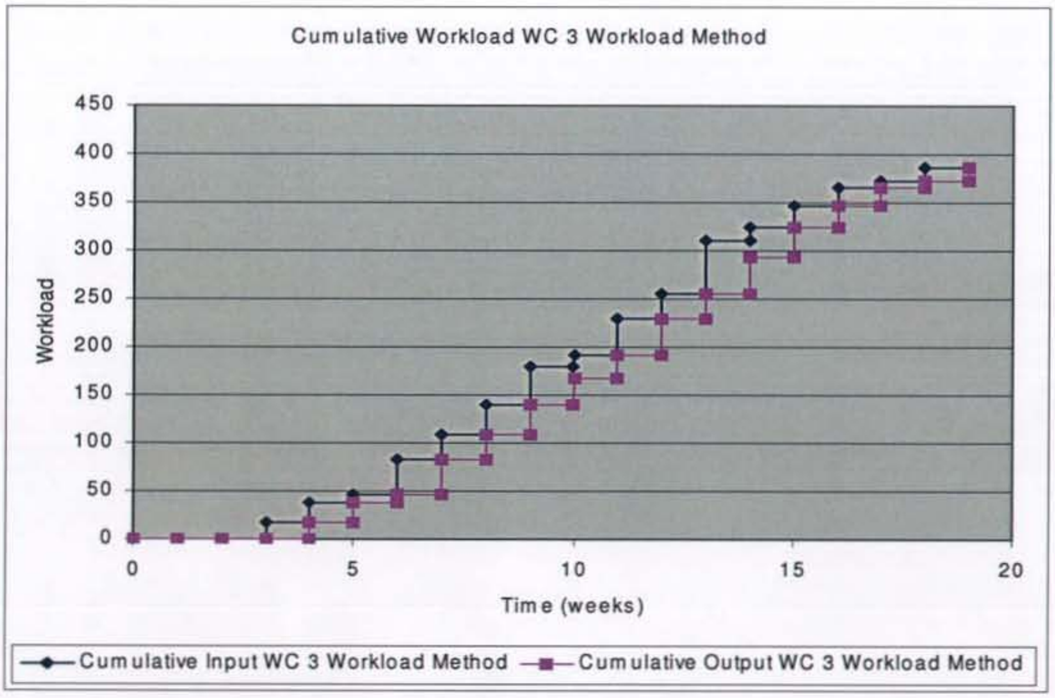


Cumulative Workload WC 2 Eaton Method
Workload (hours)
350
300
250
200
150
100
50
0
0
5
10
15
20
Time (weeks)
Cumulative Input WC 2 Eaton Method
Cumulative Output WC 2 Eaton Method



Cumulative Workload WC 2 Workload Method
Workload
350
300
250
200
150
100
50
0
0
5
10
15
20
Time (weeks)
Cumulative Input WC 2 Workload Method
Cumulative Output WC 2 Workload Method


Cumulative Workload WC 3 Eaton Method
Workload (hours)
Time (weeks)
Cumulative Input WC 3 Eaton Method
Cumulative Output WC 3 Workload Method


Cumulative Workload WC 3 Workload Method
Workload
Time (weeks)
Cumulative Input WC 3 Workload Method
Cumulative Output WC 3 Workload Method