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AN INTERDISCIPLINARY AND DESIGN ORIENTED APPROACH

Dennis R. Muntslag

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Design Oriented Approach

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To my wife, Sigrid

Managing Customer Order Driven Engineering

An Interdisciplinary and
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PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de Rector Magnificus, prof. dr. J.H. van Lint, voor een commissie aangewezen door het College van Dekanen in het openbaar te verdedigen op

woensdag 7 april 1993 om 16.00 uur

door

DENNIS RICHARD MUNTSLAG

geboren te 's-Gravenhage

Dit proefschrift is goedgekeurd door de promotoren:

prof. dr. J.A.M. Theeuwes

en

prof. dr. ir. J.C. Wortmann

PREFACE

This thesis addresses a specific subset of production situations, namely, the *engineer-to-order* plants which produce industrial equipment. This type of production plant is concerned with the engineering and production of complex industrial equipment to fill specific customer orders. These plants operate in a market which can be characterized as being extremely dynamic and erratic. Another characteristic of this market is the large degree of uncertainty which is due to unknown sales volumes and unknown product specifications for the future orders. The research described in this thesis deals with the control of a non-physical process, the *customer order driven engineering* which precedes the physical production of a product. Important decisions are made during this non-physical phase which have a significant effect upon the performance of the whole company. Up until now, very few or no publications have appeared on this subject. In view of current market developments, this can be seen as a serious omission. The substance of this thesis is an initial contribution to fill the gap in the literature in this area.

Acknowledgements

This research could not have been completed without the enthusiastic support of many individuals. In the first place, I wish to thank Professor Jacques Theeuwes and Professor Hans Wortmann who have been the key mentors for this research. They provided the necessary sponsorship to carry out this research on a part-time basis. Their enthusiastic support and the numerous issues which we discussed have had a great impact on the results. I also wish to thank my colleagues in the BM Section who provided a major stimulus for this research by providing a congenial working environment and the opportunities for exchanging ideas with other researchers.

In addition, I wish to thank the employees of Stork Bepak in Utrecht for their intensive, enthusiastic and constructive cooperation over the past years. Drs. Wilbert van Waes deserves a special thanks in this respect as the driving force behind the project. Furthermore, Bas Timmermans, Yolande van Alphen and Marcel 't Hart deserve special mention for their contributions with respect to specific parts of this research project in connection with their Masters Theses.

Last but not least, I wish to express my appreciation to my employer, Moret Ernst & Young Management Consultants (MEY MC) for the opportunity and the freedom which they afforded me during the past several years to carry out this research. It would be difficult to imagine a more stimulating work environment.

Dennis R. Muntslag

Best (The Netherlands), February 1993

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SUMMARY

This book deals with a specific subset of production situations, namely the typical situation for plants which produce *engineer-to-order* equipment. This type of production plant is concerned with the engineering and production of complex industrial equipment to fill specific customer orders. These plants operate in a market which can be characterized as being extremely dynamic and erratic. Another characteristic of this market is the large degree of uncertainty which is due to unknown sales volumes and unknown product specifications for the future orders. An important aspect is that a significant portion of the products produced by these plants must be engineered according to customer specifications. This engineering process which precedes the actual production of the product is referred to here as *customer order driven engineering*. It is apparent to the author that there has been little or no research and there have been very few or no publications concerning the design and control of customer order driven engineering processes within this type of production environment, in spite of the significant influence which these processes may have on the performance of the company as a whole. The design and control of the customer order driven engineering process should not be viewed in isolation from the control of the subsequent physical production processes. A number of problems which often arise in practical situations occur due to a lack of a clear control approach for customer order driven engineering within engineer-to-order production situations as follows:

- throughput times which vary widely and are difficult to control, leading to problems in meeting due dates in the subsequent physical production phase;
- resource capacity requirements which are difficult to determine in advance for a customer order, resulting in large discrepancies between the planned and actual costs for producing the finished product;
- a relatively large number of modifications to the product design after the product has been technically released for production, leading to unnecessary costs and wasted

internal throughput time;

- missing insights into the consequences of the various decision alternatives in terms of quality, timeliness and cost, thus leading to wrong decisions being made.

This book considers the way in which this type of customer order driven engineering process should be designed and controlled. Special attention is paid to integrating the quality factor with the timeliness and cost factors for controlling this type of process. This research provides a contribution to industrial engineering theory in the following areas:

- an initial attempt to fill the gap in the literature published on the subject of controlling customer order driven engineering in engineer-to-order production environments in the form of a design of the transformation process, a controlling system and a management information system for a selected case situation;
- exploring the possibilities for applying industrial engineering principles and concepts, which were originally designed to control physical production processes, to the non-physical production processes after incorporating some adaptations. In this case the non-physical production process refers to customer order driven engineering;
- integrating the factors of quality, timeliness and cost within a single controlling system and management information system;
- providing an extensive description of how design-oriented research can be carried out in the field of industrial engineering.

Following the introduction and problem description, the subjects of using a proper scientific approach, structuring the research and defining the scope of the analysis are discussed in some detail. Special attention is paid to the way in which the design-oriented (industrial engineering) research presented in this book is structured. A specific plant situation is analyzed in this book and used as the basis for designing the controlling system and management information system.

The major topic at the core of this book is the description of the actual organizational design. Subsequently, based upon a description and analysis of the selected case situation, the transformation process which lies at the heart of the customer order driven engineering, the controlling system and the management information system are all (re)designed for this case situation.

The customer order driven engineering process is designed here based upon development principles originally intended for use in the field of mechanical engineering. In connection with this, particular attention is paid to the way in which customer order driven engineering and customer order independent engineering are interrelated and the role which standard product descriptions play within this context. Attention is also paid to the relationship with the control aspects in connection with the design of this engineering

process. For (re)designing the controlling system for the customer order driven engineering activities in the selected case situation, a distinction is made with respect to:

- the composition and structure of the controlling system in terms of the levels of control and a recognition of the necessary control decisions;
- the definition of the various control functions and, in particular, the interrelationships between the factors of quality, timeliness and cost.

The management information system is (re)designed as the last step. The composition and structure of the data model is used as the basis for the design of the information system. The differences and the relationships between customer order dependent and customer order independent data elements play an important role here. Also covered is the relationship between computer-aided development systems (such as CAD systems) and the management information system described here. It is pointed out that product descriptions are stored and maintained in both types of systems.

The design of a control approach for customer order driven engineering in engineer-to-order production situations as described in this book can be seen as an initial contribution to the development of new concepts for the control of similar processes in comparable situations.

SAMENVATTING

Dit boek handelt over een specifieke subset van produktiesituaties, namelijk *engineer-to-order* bedrijven in de machinebouw. Dit zijn produktiebedrijven die complexe industriële machines ontwikkelen en produceren op klantorder. De marktsituatie waarin deze bedrijven opereren is sterk dynamisch van karakter. Daarnaast kenmerkt de markt zich door een grote mate van onzekerheid, omdat afzetvolume en precieze specificaties van de toekomstige omzet onbekend is. Een belangrijk aspect van deze bedrijven is dat het produkt voor een belangrijk deel moet worden ontwikkeld op specificatie van de klant. Dit produktontwikkelproces, dat voorafgaat aan de eigenlijke produktie van het produkt wordt *klantordergedreven produktontwikkeling* genoemd. Ondanks de invloed die klantordergedreven produktontwikkeling kan hebben op de prestatie van de onderneming is er, voor zover wij kunnen overzien, niet of nauwelijks onderzoek gedaan en zijn er niet of nauwelijks publikaties verschenen over de inrichting en besturing van deze processen, binnen dit type produktie-ondernemingen. De inrichting en besturing van het proces van klantordergedreven produktontwikkeling kan niet los gezien worden van de besturing van de daaropvolgende fysieke produktieprocessen. Het ontbreken van besturingsconcepten voor klantordergedreven produktontwikkeling binnen engineer-to-order produktie draagt belangrijk bij tot de volgende in de praktijk veelvuldig voorkomende problemen:

- sterk wisselende en moeilijk beheersbare doorlooptijden; hierdoor ontstaan vervolgens levertijdproblemen in de daaropvolgende fysieke produktie;
- moeilijk voorspelbaar capaciteitsbeslag van een klantorder, waardoor grote verschillen kunnen ontstaan tussen voor- en nagecalculeerde orderresultaten;
- relatief veel wijzigingen op het produktontwerp, nadat het produkt technisch is vrijgegeven aan produktie, waardoor onnodige kosten worden gemaakt en interne doorlooptijd wordt verloren;
- het ontbreken van inzicht in de technische, logistieke en economische consequenties van beslissingsalternatieven, waardoor verkeerde beslissingen worden genomen.

Dit boek gaat in op de wijze waarop dit soort klantordergedreven produktontwikkelprocessen zou moeten worden ingericht en bestuurd. Hierbij wordt bij de besturing van dit soort processen aandacht besteed aan de integratie van zowel het kwaliteitsaspect als het logistieke en het economische aspect. Met dit onderzoek wordt een bijdrage geleverd aan de bedrijfskundige theorie op de volgende punten:

- een eerste aanvulling van het hiaat in de literatuur over de besturing van klantordergedreven produktontwikkeling in engineer-to-order produktie, in de vorm van een ontwerp van het transformatieproces, een besturingssysteem en een bestuurlijk informatiesysteem voor een specifieke case-situatie;
- een verkenning van de mogelijkheid om bedrijfskundige besturingsprincipes en besturingsconcepten voor de fysieke produktie, met een aantal aanpassingen, toe te passen voor de niet-fysieke produktie; in dit geval voor klantordergedreven produktontwikkeling;
- een integratie van de aspecten kwaliteit, tijd en geld binnen één besturingssysteem en informatiesysteem;
- een uitgebreide beschrijving van een bedrijfskundig ontwerpgericht onderzoek.

Na een inleidende beschrijving van het probleemgebied, is uitgebreid ingegaan op de methodologische verantwoording, de opzet en de afbakening van het onderzoek. Hierbij is met name aandacht besteed aan de wijze waarop het in dit boek beschreven ontwerpgericht (bedrijfskundig) onderzoek is ingericht. Voor het ontwerp van het besturingssysteem en informatiesysteem is uitgegaan van een specifieke bedrijfssituatie, die in dit boek is geanalyseerd.

De kern van dit boek bestaat uit de beschrijving van het eigenlijke organisatie-ontwerp. Uitgaande van de case-beschrijving en -analyse is achtereenvolgens het transformatieproces van klantordergedreven produktontwikkeling, het besturingssysteem en het bestuurlijk informatiesysteem voor de genoemde case-situatie (her)ontworpen.

Het proces van klantordergedreven produktontwikkeling is ontworpen, uitgaande van ontwikkelprincipes uit de werktuigbouwkundige literatuur. Hierbij is met name aandacht besteed aan de wijze waarop klantordergedreven produktontwikkeling en klantorderonafhankelijke produktontwikkeling met elkaar samenhangen en de rol die produktstandaards daarbij spelen. Bij het ontwerp van dit produktontwikkelproces is ook aandacht besteed aan de samenhang met de besturing van dit proces. Bij het (her)ontwerp van het besturingssysteem voor klantordergedreven produktontwikkeling in de case-situatie is onderscheid gemaakt naar:

- de opbouw en de structuur van het besturingssysteem in de vorm van de niveaus van besturing en de identificatie van de benodigde besturingsbeslissingen;

- de uitwerking van de verschillende besturingsfuncties en in het bijzonder de samenhang tussen de aspecten kwaliteit, tijd en geld.

Als laatste stap is het bestuurlijk informatiesysteem (her)ontworpen. Bij het ontwerp van het informatiesysteem is met name ingegaan op de inhoud en de structuur van het gegevensmodel. Hierbij speelt het onderscheid en de relatie tussen klantordergebonden en klantorderonafhankelijke gegevens een belangrijke rol. Er is ook ingegaan op de relatie tussen bestaande computerondersteunde ontwikkelsystemen (bijvoorbeeld CAD-systemen) en het hier beschreven bestuurlijk informatiesysteem. In beide typen systemen vindt immers registratie plaats van produktbeschrijvingen.

Het in dit boek beschreven ontwerp voor de besturing van klantordergedreven produktontwikkeling in engineer-to-order produktiesituaties is een eerste aanzet tot de ontwikkeling van concepten voor de besturing van dergelijke processen in vergelijkbare situaties.

Chapter
1 INTRODUCTION AND PROBLEM DESCRIPTION

1.1 Introduction

Controlling production processes is still one of the major problem areas in manufacturing today. We refer to the control of production processes as being the production and delivery of products with an acceptable level of quality at an acceptable cost price within an agreed period of time, given a specific degree of uncertainty. A significant amount of research has been carried out with respect to this problem area, leading to the design of controlling systems and information systems for a variety of production situations. Two shortcomings become apparent when one studies these systems in detail, however. In the first place, it is apparent that the design of a vast majority of the controlling systems found in practice focus on only a single control aspect. As a result, the financial, production and quality control systems and their associated information systems have been developed independently of each other. In the second place, these controlling systems have been designed primarily to control the physical production processes within manufacturing plants. This means that the existence of certain non-physical processes within these plants has been ignored. Such non-physical processes can have a significant influence on the performance of the company as a whole. This is particularly evident for companies which engineer and produce made-to-order products based upon customer specifications.

This book focuses on a specific subset of this type of production situation, namely *engineer-to-order* production plants which produce industrial equipment. This type of production plant is concerned with the engineering and production of complex industrial equipment based upon customer orders. These plants operate in a market which can be characterized as being extremely dynamic. Another characteristic of this market is the large degree of uncertainty which is due to unknown sales volumes and unknown product specifications for the future orders. This study should be seen as an initial attempt to alleviate some of the above-mentioned shortcomings of the previous research in this area. The research results described here deal with the control of a non-physical process, the *customer order driven engineering* which precedes the physical production of the product. Important decisions are made during this non-physical phase which can influence the performance of the total company in a significant way. Special attention is focused here on an integral control of the quality, timeliness and cost factors since there is a lack of integration of these control factors within existing controlling systems.

In this first chapter, the problem area covered by this study is described and analyzed in more detail. Based upon this, a formal statement of the subject and problem underlying this study is then formulated. The area of research is described first in general terms in Section 1.2. Integrating the three control factors identified above is discussed in Section 1.3. This area of research is then analyzed in more detail in Section 1.4. The formal problem statement and research objectives of this study are presented in Section 1.5 to conclude this chapter.

1.2 Description of the area of research

Two specific topics were identified in connection with the description of the area of research in the previous section: engineer-to-order production and customer order driven engineering. A more detailed description of the area of research with respect to these two topics is covered in this section.

1.2.1 Engineer-to-order production

The topic of engineer-to-order production was introduced in the previous section. This type of production activity will now be described in more detail. The characteristics of a company's controlling system tend to be closely related to the characteristics of the type of production situation to be controlled (Wild 1977, Bertrand et al. 1990). From this point of view, a large number of classifications have been developed in order to make a distinction between the different types of production situations. Each type of situation requires a specific production control system. The classifications defined by Wild (1977), New (1977) and Sari (1981) are particularly relevant here. All three of these classifications are based upon the following common assumptions:

- the purpose of the classification is to make a distinction between the various types of production control situations;

- differences in the production control system can be explained in terms of the characteristics of the production situation in relation to the market situation;
- the distinction is based primarily on the nature of the customer orders and the role they play in the production process.

For the purpose here, we will make use of the classification developed by Sari (1981). In addition, we will limit the production situation possibilities to the production of complex configurations of industrial equipment. Sari makes a distinction between:

(1) *Make to stock*: producing finished goods from raw materials and semi-finished goods held in inventory, independent of the customer orders;
(2) *Assemble-to-order*: producing previously defined semi-finished goods from raw materials and components held in inventory and the subsequent assembly of these parts to produce finished goods after the receipt of a customer order;
(3) *Make-to-order*: purchasing, as necessary, and producing finished goods after receipt of the customer order;
(4) *Engineer-to-order*: engineering and producing custom-built products based upon a customer order.

The make-to-stock as well as the assemble-to-order production situations are radically different from the make-to-order and engineer-to-order production situations with respect to the importance of the customer order. The customer order is a major factor in the production system and the production control system in the last two situations since a large percentage of the production activities are customer order driven. In contrast to the make-to-order situation, the engineering activities become an integral part of the throughput time for completing a customer order in an engineer-to-order production situation. This is logical since the product in an engineer-to-order situation is developed more-or-less according to customer specifications. This means that non-physical transformation processes need to be controlled as well as the physical transformation processes. The control characteristics of a make-to-order situation and, even more so, of an engineer-to-order situation thus differ radically from the assemble-to-order and make-to-stock situations. We will now analyze the characteristics of engineer-to-order production situations in more detail. A large number of production plants can be characterized as being engineer-to-order shops. Nevertheless, the nature of these plants can vary widely with respect to:

- the complexity of the products produced;
- the degree of customization of the products produced;
- the design and complexity of the production processes;
- the characteristics of the markets and competitors.

For example, imagine the difference between a plant which produces custom-built cardboard displays and a plant which produces complex packaging equipment according to customer specifications. The present study focuses on a group of specific production situations which can be considered to be extremely complex from a control point of view. This group of production situations can be typified in a concise way based upon a description of:

- the characteristics of the product;
- the market and the competition;
- the production organization.

◆ *The characteristics of the product*

The type of production organization chosen here produces complicated and complex configurations of industrial equipment consisting of thousands of components. It is assumed that major investments have been made in developing products independently from the actual customer orders. Nevertheless, the customer is still in a position to be able to influence the choice and design of a significant portion of the product components and to influence the functionality of the product by providing specifications for customization.

◆ *The market and the competition*

The products chosen here are capital goods which represent major capital investments for industrial customers. The demand for these products depends to some extent on the economic climate. This means that sales may vary widely from one period to the next. Forecasting the demand, even at the product type level, is extremely difficult since the products are partially custom-built. There is a great deal of competition in terms of price as well as quality. This conclusion is supported by the fact that the number of order quotations is much larger than the number of customer orders actually placed.

◆ *The production organization*

Each customer order can be viewed as a project with a project network structure consisting of numerous activities to be performed. Examples of these activities are Engineering, Process Planning, Component Manufacturing and Assembly. Normally, more than one project is in production at any given point in time. The manufacturing of components is set up along functional lines using flexible manufacturing equipment in view of the general uncertainty regarding what product will be produced and the customized aspects of the product. In view of the size of projects, it is not possible to dedicate human resources to a specific project for a given period of time according to the generally accepted principles for a project organization. This means that a worker within the functional organization may be working on more than one project at the same time. The primary chain of production activities to be controlled can be split up into two major streams or stages of activities: a non-physical stage and a physical stage. The non-physical stage includes the quotation phase, the custom engineering of the product and the process planning activities. A number of activities to be performed within various independent production departments can be identified within each of these major stages. The major non-physical stage of activities can be split up into the following production departments:

- Engineering, where the customized parts of the product are engineered and drawings and bills-of-materials for the complete product are compiled;
- Process Planning, where the production instructions are prepared for each component and each product subassembly.

The physical stage which is part of the primary chain of production activities is comprised of:

- one or more production departments in which the various components are manufactured;
- one or more production departments in which the various components are combined into subassemblies and in which the final product assembly is completed.

Key activities in the assembly process requiring specialized knowledge are of strategic importance and are therefore not outsourced. The component manufacturing activities are planned based upon a certain capacity shortage in this type of plant. In this way a sufficient degree of utilization can be maintained for the internal manufacturing resource capacities even during the slack periods which are inherent in a situation in which there is a predominant uncertainty in the market demand with respect to product mix and volume. The need for sufficient flexibility with respect to production volumes is also important in this type of situation in order to be able to produce sufficient products when the market demand is at a high level. When there is a need for manufacturing more components, this flexibility is created by the external outsourcing of products and operations. When there is more assembly work to be performed, then the extra capacity is created by hiring additional (temporary) workers. The global flow of goods within an engineer-to-order production plant is diagrammed in Figure 1.1. An engineer-to-order production plant as characterized above is used as a model for the engineer-to-order production situations in the remainder of this book.

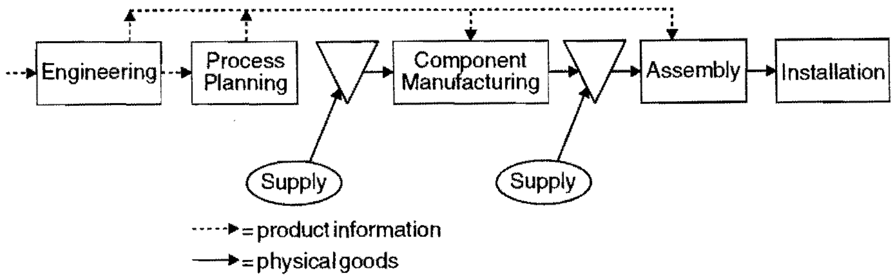


Figure 1.1. Global flow of goods for engineer-to-order production

1.2.2 Customer order driven engineering

In an engineer-to-order production situation, a number of business activities can be identified which precede the physical production activities for a customer order and should be included as an integral part of the total transformation process even though they are basically non-physical activities. These can be referred to as the *customer order driven engineering* activities. For the purpose of this study, such customer order driven engineering activities are defined here as being the non-physical activities associated with a customer order between the time of arrival of a request for quotation from a potential customer and the time of delivery of the product specifications in the form of drawings, bills-of-materials and the production instructions which are required for the physical production process. These non-physical activities generate the information which is required for the control and realization of the physical production activities. Examples of such non-physical activities include:

- specifying the customer's requirements;
- providing a customer quotation;
- the engineering activities related to a custom-built product.

Several complications which make control difficult become apparent in this case as compared to a customer order independent engineering situation:

- decisions must be taken in the face of a certain degree of product and process uncertainty since the product specifications and the required production processes are unknown until the customer order driven engineering activity has been carried out;
- there is less time available for making choices or taking decisions during the engineering phase since these are unique decisions and these engineering activities are

part of the order throughput time; a large percentage of the customer order driven engineering activities are, of course, associated with specific customer orders;
- the above-mentioned uncertainties generally result in numerous internal and external disturbances and changes.

A further explanation of the control issues surrounding customer order driven engineering is presented here based upon the following characteristics:

- product and process uncertainty;
- internal and external disturbances and changes;
- the iterative nature of this activity.

♦ *Product and process uncertainty*

One of the important characteristics of engineer-to-order production is the fact that products are produced which are custom-built and are therefore unique. The details of each product to be produced are not yet known when the order is accepted (product uncertainty). As a result, there is similarly no (detailed) knowledge of the capacity requirements (process uncertainty). This means that, especially at the start of the customer order driven engineering activity, assumptions are made and decisions are taken under conditions with a certain degree of product and process uncertainty. The information generating activities gradually provide additional data as processing progresses so that the product and process uncertainties can be reduced. It is then desirable to compare this data to the original assumptions and to review the decisions which were taken during an earlier phase of the engineering activities in order to determine:

a. the (technical, time-related and financial) consequences of any discrepancies between original assumptions and the resulting actual data for decisions which were made with respect to the current customer order;
b. the (technical, time-related and financial) consequences for the customer orders which are already being processed and for customer orders to be accepted in the future.

Any necessary corrective measures should be taken as soon as the above-mentioned consequences have been determined.

♦ *Changes and disturbances*

Various changes and disturbances can occur as the customer order driven engineering activities are being performed. A good example of an (external) change would be the recognition of new customer requirements with respect to the ordered product. These requirements are normally documented during the quotation phase in close collaboration with the customer. For various reasons, however, subsequent modifications and additions are specified in subsequent phases of the project (even after acceptance of the order) in many normal situations. Such changes and enhancements may have significant implications for the time-related and/or cost aspects of the current order as well as for other customer orders being produced and for future customer orders. The control over this part of the customer order chain is complicated since changes may occur throughout the whole customer order driven engineering phase, with consequences affecting the whole customer order chain. This means that an adequate control over the customer order driven engineering activities is of utmost importance since they may affect an important part of the total logistic and financial performance of the company. Two examples are presented here to clarify this point.

Example 1
A due date is agreed with the customer at the time of order acceptance. This due date is based to some extent upon an estimation of the total throughput time required for the engineering activities. Assume, for example, that the required throughput time for the engineering activities is initially estimated to be three weeks based upon 300 hours of engineering work, but that the actual amount of engineering work turns out to be 700 hours. An overrun of this magnitude could have a pronounced negative effect on the throughput time of the current customer order as well the other customer orders being processed. In addition, the cost variance between the initial budget and the actual cost price in this example will be equivalent to 400 hours. This is likely to have a significant impact on the profitability of the customer order as well as the company as a whole, assuming that these excess hours cannot be charged to the customer since a fixed price was agreed when the order was accepted. These hours could have been spent more profitably on other customer orders.

Example 2
At the time of order acceptance it is determined that 500 hours of milling work will be required based upon the technical order specification. This capacity requirement is subsequently used as the basis for determining the order due date. When the manufacturing specifications are worked out in the process planning phase, however, it is discovered that the required milling work will actually amount to 900 hours. This means that either the order due date will not be realized or that additional (internal and/or external) resource capacity will be needed in order to complete the order on schedule, resulting in a (strong) negative influence on the financial results.

♦ *Iterative nature*

The iterative nature of customer order driven engineering activities can be seen as an important characteristic which increases the complexity of the control problem. After the completion of a given task, it is generally possible and often necessary for a number of reasons to redo a previous task. This kind of loop in executing a given activity means that certain tasks are repeated and the previous results of a repeated task then need to be revised. A number of examples of this are described below.

Example 1
During the preparation of the product specification it becomes apparent that it will not be technically feasible to meet all of the customer's requirements. This means that an unplanned meeting with the customer will need to be arranged to discuss how the customer's product requirements could be re-specified.

Example 2
It is possible that a price calculation for a given product as specified by the customer turns out to be too high and, thus, unacceptable for the customer. This means that either the customer requirements or the product specifications will need to be modified to reduce the cost price of the product.

Example 3
The due date quoted by the plant based upon an estimation of the required amount of work may turn out to be unacceptable for the customer. The customer may then revise his specifications and requirements in order to reduce the production throughput time.

The three characteristics of a customer order driven engineering activity as described above for an engineer-to-order production situation are, of course, not independent of each other. The dominating product and process uncertainties can be seen as a main reason for internal and external changes. In addition, the iterative nature of customer order driven engineering activities is caused largely by the changes and disturbances which occur during this phase. A previously executed series of tasks may need to be completely or partially repeated whenever a change is introduced.

In spite of the influence that customer order driven engineering activities may have on company performance, it is apparent to the author that little or no research has been carried out and very few articles have been published with respect to the design and control of these processes within an engineer-to-order production environment as described here. The design and control of the customer order driven engineering process must be evaluated in conjunction with the control of the subsequent physical production processes. If no consistent control concept is used to manage the customer order driven engineering activities in an engineer-to-order production situation, this may be one of the important reasons why the following problems typically occur in practice:

- variable and inconsistent throughput times which are difficult to control, leading to problems in meeting due dates with respect to the subsequent physical production processes;
- difficulties in forecasting the resource capacity requirements for a customer order, leading to large discrepancies between the budgeted and actual costs of producing the order;
- an excessive number of changes to the product design after the technical specifications have been released for manufacturing, leading to unnecessary extra costs and delays in the throughput time;
- poor decisions are made due to a lack of information about the technical, time-related and financial consequences of various decision alternatives.

1.3 Integrating the control factors

It is necessary to determine which factors are to be included in the design of a control concept before the required control concept for customer order driven engineering can be developed. In this context, the term *control* is understood to mean "the planning, execution and operational management of goal-directed activities". This definition implies that control cannot be seen as an isolated activity, but must be seen, instead, as a means of achieving certain goals or objectives. Three objectives can be identified in terms of control factors when this definition is applied to the control of customer order driven engineering activities:

- *quality*: an accurate translation of the customer's requirements into a product specification;
- *timeliness*: realization of the product specification for a customer order within the agreed throughput time;
- *cost*: completion of the customer order driven engineering activity in such a way that the product can be produced within the established budgetary limitations.

This means that all three of the control factors mentioned above should be included in the design of a controlling system and an information system for customer order driven engineering activities. It is also important that all three of these factors are integrated within these systems as described hereunder. In the literature about organizational control and control concepts, the discussion is generally focused on only the quality aspects (see Garvin 1988) or only timeliness (see Bertrand et al. 1990) or only the cost aspects (see

Horngren and Foster 1991). When only one of these approaches is used, the direct relationship with the other two control factors is omitted. The interconnection between all three of these factors is needed, however, to ensure an effective control (of customer order driven engineering activities, in this case). Two arguments are presented in the following paragraphs to support this viewpoint.

In the first place, one or more of the above-mentioned control factors will be treated as secondary factors if all three factors are not taken together as the basis for control. For example, if quality is not included as a primary control factor, then the product quality will be considered only after the aspects of cost and timeliness have been satisfied. Since it is difficult to ascertain the quality of the (partial) products during the engineering phase, there will be a natural tendency to accept partial products as being completed as soon as the throughput time has elapsed or the budget is expended when the control of this process is concerned with only the time-related and cost aspects. This means that the partial products will be passed on to the next phase, regardless of the quality of these products since the control (and related responsibilities and authorizations) have only been concerned with the time-related and cost aspects. The various control functions in the organization will be concerned primarily with the factors for which they are personally held responsible and they will act accordingly. This type of situation typically results in product specifications of poor quality, leading to quality control problems during the subsequent physical production phase.

In the second place, another important interconnection exists between the three above-mentioned control factors which supports the conclusion that an integrated control approach is essential. The quality of the control of one control factor can have a strong influence on the quality of the control of the other factors. For example, if a problem is encountered in completing the technical specifications for a product (e.g., the quality is poor), then this could result in a longer throughput time for the engineering activities than originally planned (affecting the timeliness factor) and/or additional engineering capacity (affecting the cost factor). The trade-off with respect to the relative importance of two or more control factors must be evaluated in this case. Therefore, all of these factors should be integrated within a single controlling system.

In addition, the quality, timeliness and cost control factors for customer order driven engineering activities may not be isolated from the physical production activities. This is due to the strong relationship between the quality, timeliness and cost of the engineering activities and the quality, timeliness and cost of the subsequent physical production activities. A control concept should have an integral character. Therefore, the control approach for the customer order driven engineering activities should be designed in such a way that it is coordinated with the control of the physical production activities. In the remainder of this book, the term *control* will be used in reference to customer order driven engineering activities to mean the integrated control of the quality, timeliness and cost factors related to customer order driven engineering.

1.4 Further analysis of the area of research

The area of research was described in Section 1.2 in terms of dealing with the subjects of engineer-to-order production and customer order driven engineering. These subject areas are analyzed in more detail in this section.

1.4.1 Different degrees of engineer-to-order production

As mentioned previously in this chapter, this study focuses on the specific situation of engineer-to-order production plants which produce complex industrial equipment. Engineer-to-order production is unique due to the fact that customer order driven engineering is carried out. Nevertheless, different types of engineer-to-order plants can be identified, even when the scope of activities is limited to the production of complex industrial equipment. We have already seen that different types of production situations require different types of controlling systems (see Subsection 1.2.1). It is therefore logical that we make a distinction between the different types of customer order driven engineering processes for this same purpose. The classification developed by Wortmann (1989) for one-of-a-kind production situations can be used to define different types of engineer-to-order production situations (see Figure 1.2). Wortmann makes a distinction between *product*-oriented and *capability*-oriented plants in engineer-to-order production situations. This distinction is based upon the degree of *customer order independent* engineering. It is assumed that a product-oriented engineer-to-order plant has invested relatively heavily in engineering activities, specific resource capacity, standard procedures etc., independent of the customer orders. When such investments are made in advance, the products can then be produced quicker, cheaper and better than in a situation where such investments have not been made. As a result, however, the customer can only order products with more-or-less standard characteristics. On the other hand, there is the capability-oriented engineer-to-order plant which has invested in resource capacity which is more functional and universally applicable. Wortmann refers to these two types of engineer-to-order production plants as a *customization shop* and an *engineering company*. A customization shop has invested relatively heavily in engineering, independent of the specific customer orders. The customer is still able to change the product specifications to meet his own particular requirements, however. This means that a significant percentage of the engineering activities must be customer order driven. Relatively little investment in engineering is made independent of the customer orders in an engineering company. This type of company accepts orders for a wide range of products which can be engineered and produced using the available resource capacity. This means that these products are primarily custom-built.

The subject of this book is focused solely on the situation encountered in engineer-to-order plants which produce complex industrial equipment and can be characterized as being customization shops. In other words, this study deals with equipment manufacturers which engineer and produce custom-built machinery where a relatively heavy investment is made in engineering activities which are independent of specific customer orders.

	Engineer-to-order	Make-to-order
Product oriented	Customization shop	Fill-in-the-forms company
Capability oriented	Engineering company	Jobber

Figure 1.2. The classification of one-of-a-kind production situations (Wortmann 1989)

1.4.2 Different degrees of customer order independent engineering

The division into product-oriented and capability-oriented types of engineer-to-order plants is too general to be useful for a further classification of the customer order driven engineering activities. Various types of customer order driven engineering can be distinguished based upon a differentiation in the degree of independent engineering with respect to the specific customer orders. Based upon a further analysis of various engineer-to-order production situations, two aspects appear to be particularly important. These two aspects which, when taken together, can be used to determine the degree of customer order independent engineering are as follows:

- the Order-independent Specification Level (OSL);
- the degree to which the customer is allowed to specify a custom-built product.

A classification scheme to make a distinction between different types of customer order driven engineering can be defined, based upon these two aspects.

♦ *Order-independent Specification Level (OSL)*

The differentiation between two extreme forms of customer order independent engineering does not provide a sufficiently graduated scale for differentiating between the different types of customer order driven engineering activities. The degree of customer order independent engineering can, of course, vary from none to global functional specifications to the complete design of complex new industrial equipment. The degree to which the engineering activities are performed independently of the customer orders has a major impact on the quality management during the customer order driven engineering activities. When only the global specifications for a product family have been specified, the product uncertainty is much greater than in a situation in which the product has been fully specified, independently from the customer order. The degree of customer order independent engineering is expressed here in terms of the Order-independent Specification Level (OSL). The OSL represents the lowest level of product description which is still independent of any given customer order. There is, of course, an important relationship between the different OSL's and the engineering process. A certain OSL essentially tells us to what extent the engineering process has already been completed before a given customer order is accepted. A general understanding of the tasks involved in the engineering process is required in order to be able to understand the meaning of the OSL's defined below. The essential elements of the engineering process are described in more detail in Chapter 4. At this point it should be sufficient to provide a brief description of the successive steps in the engineering process and the accompanying product specification output which is based upon VDI 2221 (1986). This engineering process consists of seven engineering steps as diagrammed in Figure 1.3.

The first engineering step is the definition and analysis of the problem. This results in a statement of requirements which the product must satisfy. The second engineering step is to define the functions and sub-functions to be included in the product. A *sub-function* is defined here as being a function of a subsystem which contributes in some way to the realization of the ultimate function of the product (Pahl and Beitz 1988, Roozenburg and Eekels 1991). The ultimate function of a product can be decomposed into interrelated sub-functions which can be represented in a functional structure. The functional structure of a product can be seen as a model of the envisioned behavior of the physical product. The third engineering step is the development of solution principles. A single, technical

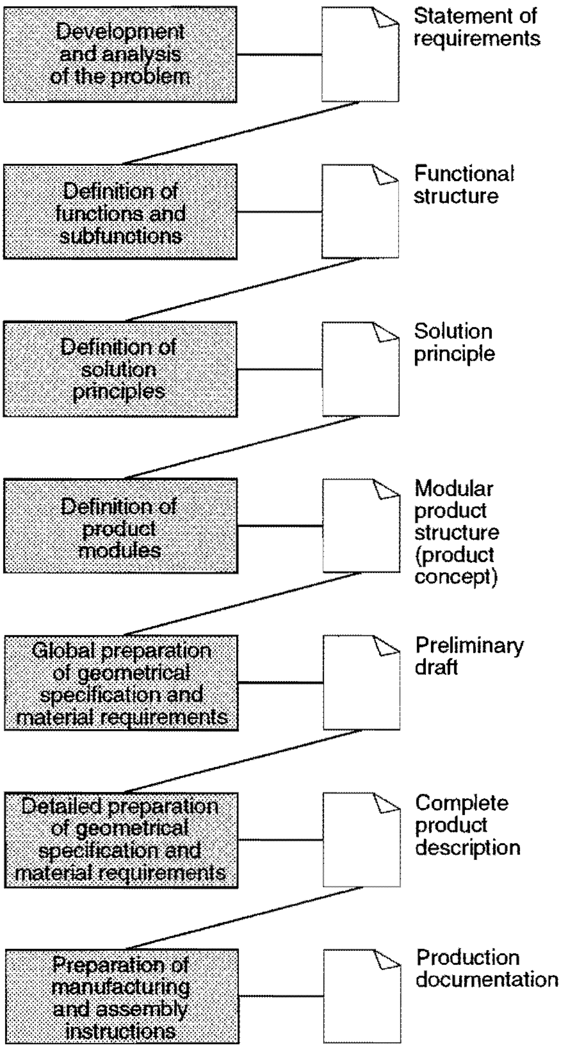


Figure 1.3. Steps in the engineering process (VDI 2221 1986)

solution principle is chosen in this step for the physical realization of each sub-function. A description of each chosen solution principle is then worked out, related to the functional structure of the product. The sub-functions and associated solution principles are assigned to feasible product modules which define the modular structure of the product in the fourth engineering step. Each *product module*, thus, becomes a collection of interconnected components of a product which represent one or more sub-functions and a specific application of the associated solution principles. The definition of product modules in this way leads to the modular structure of a product. This modular structure is referred to here as the *product concept*. The global geometrical aspects of the product and the material specifications are prepared for the most important modules in the fifth engineering step. This results in a so-called *preliminary draft* of the product in the form of sketches and supporting specifications. In the sixth engineering step, the detailed geometrical specifications and material requirements for all of the product components are determined and documented in the form of technical drawings and bills-of-materials. The technical documentation for the equipment is also prepared. The complete product description is finalized at the end of this step. The manufacturing and assembly instructions for all of the components and product subassemblies are prepared in the seventh (and last) engineering step. This final step is sometimes referred to as the process planning. This activity results in the completion of the production documentation required for producing the product.

Five OSL's can be identified in the customer order driven engineering phase based upon the general description of the engineering process presented above:

- OSL-1: engineering based upon a specific technology;
- OSL-2: engineering based upon pre-defined product families;
- OSL-3: engineering based upon pre-defined product sub-functions and solution principles;
- OSL-4: engineering based upon pre-defined product modules;
- OSL-5: engineering based upon pre-defined finished goods.

A short description of these five OSL's is presented here. An engineer-to-order plant which supports OSL-1 has chosen one or more specific technologies to be used as the basis for engineering all of the orders for various custom-built products. Using a specific "technology" is this sense means knowing and using one or more specific production techniques. An example of this approach is a company specialized in the application of hydraulic technology to various types of industrial products. An engineer-to-order plant which supports OSL-2 has defined a number of specific product families, independent of the customer orders. In this context, a product family refers to a wide range of similar finished goods with the same ultimate function. A company supporting OSL-2 has, thus, chosen one or more technologies in combination with a specific application area. An example of this approach is a company specializing in the production of a variety of bottling equipment. OSL-1 and OSL-2 are not directly related to the engineering process, but are associated more with the situations in which a company specializes in the use of specific technologies or a specific application area. In these companies, the actual engineering activities are fully driven by the customer order.

An engineer-to-order plant which supports OSL-3 has taken a major step in the direction of customer order independent engineering. At this level, the various product sub-functions are pre-defined with their associated solution principles within a specific product family, in addition to the ultimate, pre-defined function of the product. Examples of the sub-functions for a packaging machine could be: stack, reposition, fold and transport. The choice of solution principles is a separate engineering step, but is not defined as a separate OSL. When the sub-functions are defined independently from the customer orders (i.e., at OSL-3), this implies that standard solution principles have already been established for the technical realization of these sub-functions.

An engineer-to-order plant which supports OSL-4 has carried the pre-definition of products one step further by defining the various product family sub-functions in terms of *product modules*. A product module can be seen as a collection of components which cover one or more sub-functions. Product modules can be defined by a combination of bills-of-materials and technical drawings. When a modular product structure is used, then a complete custom-built product can be configured and constructed using the standard product modules. An engineer-to-order plant which supports OSL-5 has invested heavily in engineering activities which are independent of the customer orders. This level assumes that complete, basic equipment configurations have been engineered, regardless of any specific customer orders. Customization then takes place based upon the standard equipment configurations.

We can now compare the classification scheme proposed by Wortmann and the classification scheme described here for customer order driven engineering. Engineer-to-order plants which support OSL-1 and OSL-2 can be characterized as "engineering companies" in the terminology of Wortmann. Engineer-to-order plants supporting OSL-3 or higher levels can be characterized as "customization shops". This type of classification should, of course, not be interpreted in an absolute sense; a production plant which only supports OSL-3 (engineering based upon sub-functions and solution principles) may still use a number of pre-defined standard product modules, for example. The OSL characterization is only intended as a basis for establishing the primary engineering philosophy for a company. The OSL choice should therefore be made explicitly as a strategic decision in view of the impact that this choice may have upon the structural, control and information aspects of the customer order driven engineering activities. It should be obvious that a low OSL (e.g., OSL-1 or OSL-2) provides a relatively high degree of flexibility for marketing. However, a low OSL also leads to controlling systems only at a high level due to the product and process uncertainties. Part of the problem of controlling customer order driven engineering activities in practice can be found in the lack of a strategic OSL choice. The consequence of this is that each engineer and detail designer will then decide on his own product standards, generally contributing to uncontrollable projects.

♦ *Degree of customer specification freedom*

In addition to the OSL choice, the customer order driven engineering activities within engineer-to-order plants may differ with respect to the degree of freedom within which the customer is allowed to specify a custom-built product. The OSL only provides an indication of the extent to which engineering effort is invested in a product before the customer order is placed. The customer can still make various changes to the product design in view of the engineer-to-order character of the product. The degree of freedom for customer specifications can be used as an indication of the extent to which the customer is allowed to deviate from the standards incorporated in the pre-defined product descriptions which were developed independently of the customer order. The more freedom given to a customer at the chosen OSL to introduce changes or enhancements, the more complex the control problem will be. This is due to an increased technical risk. The likelihood that certain customer requirements may prove to be infeasible, or only feasible at a high cost or with a longer throughput time, increases as the degree of freedom for customer specifications is increased. The degree of freedom for customer specifications is expressed in functional terms (i.e., what the product should be able to do) since the customer requirements are also expressed in functional terms. Five levels of customer specification freedom can be identified and are ordered below according to an increasing technical risk:

- interfacing the product with the customer's current environment;
- choosing the sub-functions and making the associated internal configuration decisions;
- modifying the performance levels of the existing sub-functions;
- adding new, customized sub-functions;
- modifying the performance level of the ultimate function of the product.

The first level of customer specification freedom, which incorporates the least amount of technical risk, is concerned with the relationship of the equipment with the environment in which it must function. An industrial machine, for example, may need to be connected to an existing supply system or must be installed in a room with specific dimensions. This type of specification freedom generally is concerned with changes to the interfaces with the environment in which the product is to be used; as such, these product specifications have a lesser importance and a limited impact. The customer order independent engineering activities generally try to standardize and modularize these interfaces between the equipment and the environment as much as possible.

The second level of customer specification freedom is concerned with the choice and configuration of the sub-functions, the solution principles and the associated product modules. The customer generally selects a subset of the available sub-functions to be included in the final product. Technical problems may arise, however, when the selected subset of sub-functions is translated and configured into a modular product structure.

The third level of customer specification freedom is concerned with modifying the performance levels of the standard sub-functions. An example of this is when a standard bottle-shaping function is available which has been designed to process a batch of six bottles at a time at a rate of 25 batches per minute. If the customer then specifies that he requires a higher processing rate of 28 batches per minute, then it may be necessary to fully re-engineer this sub-function if the existing (alternative) solution principles do not provide an acceptable solution.

The fourth level of customer specification freedom deals with adding new, customized sub-functions as specified by the customer. This type of enhancement may have unknown technical implications for the existing sub-functions. An example of this would be the addition of a "bottle cleaning" sub-function to a standard bottling machine for a specific customer.

The fifth level of customer specification freedom concerns modifying the ultimate function of the product. The ultimate function of an industrial machine can also be defined in terms of the technical performance. An example of this is the number of bottles that a bottling machine can fill per minute. If, for example, the customer requires a higher level of performance than the standard available machine configuration is able to provide, then this may have far-reaching implications for the construction of the whole machine. The technical risk is extremely high in this type of situation.

Depending upon the chosen OSL, some of the customer specification freedom levels may be more important than others. As indicated previously, when only OSL-1 or OSL-2 is supported, the engineering activities are driven completely by customer orders since none of the product specifications are prepared independently in this case. The customer is provided with the opportunity to specify all of his product requirements, based upon the choice of a particular product family and/or technology. The customer specification freedom is, by definition, extremely large. When OSL-3, OSL-4 or OSL-5 is chosen, the specification freedom can be expressed in terms of one of the five levels described above. It is important to recognize that the advantages of a customer order independent engineering activity with a high OSL can be significantly reduced when a large specification freedom is allowed. For example, when OSL-4 is supported, the product is engineered to the product module level, independent of any customer order. If the customer is given the freedom to specify additional functionality which is significantly different than the existing product standards, then a major part of the engineering process will need to be carried out again. Therefore, an explicit choice should be made with regard to the allowable degree of freedom for customer specifications. The OSL choice as well as the choice of the degree of freedom for customer specifications should, of course, be based upon the company's marketing policies, position in the market and competitive situation.

1.5 Formulation of the research objectives

A description and analysis of customer order driven engineering activities in engineer-to-order plants has been presented in this chapter. It is apparent to the author that there have been very few or no publications concerning the control of customer order driven engineering activities within engineer-to-order plants. This is a significant omission in view of current developments in the market and the problems which have been identified in this chapter. During the past decade, the market has shifted from demanding a broad range of standard product variants to the specific product requirements of individual customers. An increasing number of companies will need to accommodate this shift in market demand by producing products according to the specifications of individual customers (engineer-to-order production). As a result, the control of customer order driven engineering activities will become increasingly more important. This conclusion leads us to the formulation of the following problem statement and research objective for this study.

Design a controlling system and an information system for customer order driven engineering activities in engineer-to-order production situations in which the timeliness, cost and quality objectives are evaluated and the production control, cost control and quality control information is provided in an integrated form to the decision-makers.

A number of aspects of this problem statement require additional clarification:

- the research is *design*-oriented. The resulting consequences for the research approach are explained further in Chapter 2;
- the objective of this study is not to design a theoretical control concept based upon complex decision rules. The intention of the study is to design a balanced combination of structure, control approach and information resources to support a customer order driven engineering process. In connection with this, an emphasis has been placed on the integration of the previously mentioned control factors, a clearly defined decision structure and the provision of integrated information to the relevant decision-makers.

Resulting from the problem statement formulated above, it is intended that this study will contribute to industrial engineering theory in the following ways:

- an initial attempt to fill the gap in the literature dealing with the control of customer order driven engineering activities in engineer-to-order production situations. The intended contribution is the design of a controlling system and an information system for a specific case situation (see Chapter 2). This first design will provide a basis for further research with respect to similar situations;
- an evaluation of the possibilities for applying and adapting control principles and concepts from the field of industrial engineering, which have been developed for physical production situations, to non-physical production situations. This evaluation will be limited to the specific situation of customer order driven engineering activities;
- integration of quality, timeliness and cost within a single controlling system and information system;
- contributing to the research methodology which deals with design-oriented research in the field of industrial engineering.

Chapter
2 RESEARCH APPROACH AND SCOPE

2.1 Introduction

The industrial engineering research described in this book is primarily design-oriented. The problem statement formulated in Chapter 1 has been developed for one specific case situation by redesigning the current organization. An explanation of the research approach used and the scope of this design-oriented research are provided in this chapter. The research method which has been followed is covered in Section 2.2. A model for redesigning organizations is described in Sections 2.3 and 2.4. Using this model, the approach and scope of this design-oriented research are described in Sections 2.5 through 2.7. A summary of the topics covered in this book are provided in Section 2.8 to conclude this chapter.

2.2 Description of the research method

Two types of (scientific) research approaches can be identified in the literature, namely, the *theory-developing* or analytic research approach and the *design-oriented* or applied research approach (Van der Zwaan 1990, Den Hertog and Van Assen 1988, Swanborn 1987). The differences between the design-oriented and theory-developing approaches are not to be found so much in the structure and the research method, but rather in the purpose of the research and the research techniques used (Swanborn 1987, Florusse and Wouters 1991). Theory-developing research focuses on describing, explaining and predicting systems and systems behavior. Design-oriented research focuses on the guidelines and procedures needed to influence and actually change systems and systems behavior (refer also to Figure 2.1).

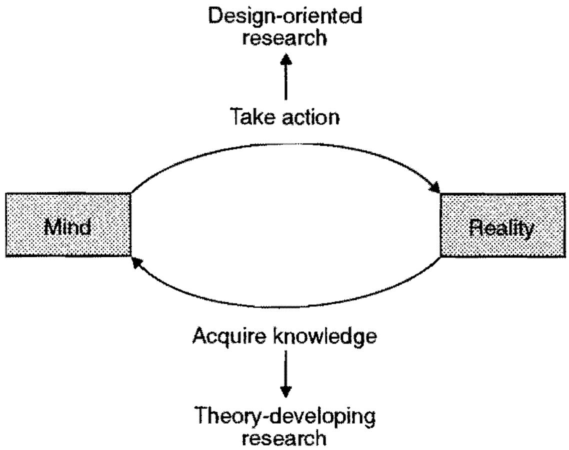


Figure 2.1. Distinction between theory-developing and design-oriented research

Industrial engineering research is often design-oriented when it deals with the (re)design of industrial engineering (sub)systems for the purpose of bringing about certain changes. Design-oriented (industrial engineering) research, according to Den Hertog and Van Assen (1988), concentrates on developing procedures which provide a basis for better designs. Designing industrial engineering (sub)systems involves goal-directed activities which are carried out in addition to the daily routine within an organization. For this reason system design, as a discipline according to Ackoff (1979, 1981), should be based upon empirical research carried out within the normal environment in which the systems are to be implemented. This refers to the diagnosis (the description of the type of system and the relevant problems), the design (the approach, decision-making and substance of the changes) and a prediction of the results (the evaluation). A similar structure has been used as the basis for the research here.

Due to the reasons mentioned above, the approach chosen for carrying out *design-oriented industrial engineering* research described in this book includes research within an actual industrial situation as an important element. The organizational design approach described in this book is based upon one particular case situation. The use of a single case for design-oriented research is of scientific value only if it is clear that this concerns original research in addition to other aspects. This means that a solution must be found for a relevant industrial engineering problem which is then demonstrated to be workable in a specific case situation and/or based upon theoretical principles. An organization seen as a system cannot be treated as a physical entity (artifact) in the same way as the design of, for example, a physical product. An organization can be described in part as a physical entity, but is also something which cannot be totally influenced by the designer. This design cannot be evaluated solely and completely in a practical situation since (re)designing an organization must necessarily take place along with the daily activities within an organization. It is therefore impossible to control all of the relevant variables during the design and implementation phases in a practical situation. This could be compared to a situation in which a new garden is to be designed and planted. It is not possible to evaluate the quality of the design of a garden simply by judging how well the plants have grown. Various other variables, such as the weather, are also significant. Nevertheless, the design can still make allowance for some of the variables which cannot be controlled by the designer. In the case of a garden, for example, it could be assumed that an average amount of rain will fall in each period, however, there are limits to the allowance which can be made. A reasonable evaluation of the quality of the design of the garden can be made with respect to certain aspects based upon generally accepted principles. We can summarize by stating that the scientific value of an organizational design can be evaluated based upon the following aspects:

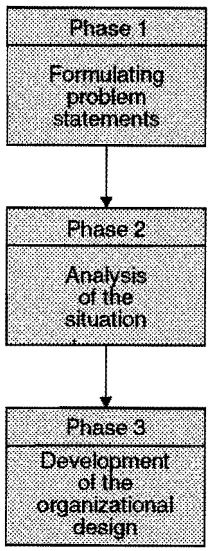


Figure 2.2. Research approach

- the originality of the design;
- the use of generally accepted theoretical principles and concepts;
- the extent to which the design should be able to resolve the identified problem (i.e., which line of reasoning was followed in the design process);
- the completeness and consistency.

The research presented here has been split up and carried out in three phases (see Figure 2.2). The first phase consists of identifying bottlenecks and formulating these in terms of problem statements. The selected case situation is analyzed in Phase Two. The results of this analysis together with current theories are then used to develop and evaluate an organizational design for the selected case situation in Phase Three. Special attention is focused on the evaluation aspects listed above.

2.3 Viewing an organization as a system

The subject involved in industrial engineering (re)design is generally (a part of) an organization. With respect to creating the design, the organization to be (re)designed is viewed as a system in this book. The terminology and definitions from systems theory are used here. According to In 't Veld (1981), a system can be defined as:

> *a set of distinguishable elements in the real world which is dependent upon the objectives formulated by the researcher. The elements in this set are interrelated and have (possible) relationships with other elements within the real world.*

The purpose of a system is to fulfil certain functions within its environment. In order to achieve this, internal processes must be executed within the system to transform the input into the output (see Figure 2.3). The output must have certain values or characteristics before the function can be considered to be properly executed. A system is referred to as being *controlled* when this condition is satisfied. *Steering* refers to the measures (i.e., steering signals) taken/issued within a system by a control unit based upon a given norm to ensure that the output satisfies the norm (In 't Veld 1981). Disturbances may occur, however, which have a negative effect on the transformation process and its associated output. A steered system is no longer controlled when disturbances occur. Nevertheless, it is desirable to achieve the established norms even when disturbances occur. Steering, by itself, is thus insufficient in real situations. It then becomes necessary to *regulate* the system. The function performed by a regulated system in its own environment is not affected by disturbances (within the limits of its regulating capabilities). *Controlling*, within the context of this book, should be interpreted to mean regulating and steering.

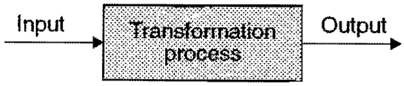


Figure 2.3. A system viewed as a transformation process

A controlled system can be included easily within a system of a higher order of which both the transformation unit (the controlled system) and the controlling unit are a part. In systems theory terms it is normal to describe this type of control situation in terms of (De Leeuw 1974):

- a *Controlled System (CS):* the system which is to be controlled;
- a *Controlling Unit (CU):* sometimes called a controlling system. This refers to human or non-human decision-makers, the decision-maker's organization and the decision rules;
- a *Management Information System (MIS):* the system which collects, processes, stores and disseminates the necessary information to support the Controlling Unit in making decisions and steering.

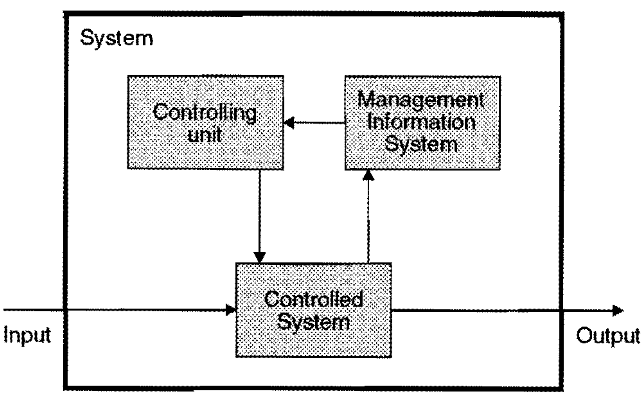


Figure 2.4. A control model for customer order driven engineering

A total system with its interrelated subsystems is illustrated in Figure 2.4. For the purpose of developing the organizational design, it will be assumed that the control model used for customer order driven engineering within engineer-to-order production situations will be similar to that represented in Figure 2.4. This means that the transformation process as well as the controlling system and the management information system will be included in the (re)design. Even though these subsystems are pictured separately here, this does not necessarily mean that these will be separate subsystems in reality. In view of the fact that the controlled system refers to an engineering process, this process can be partially carried out within information systems and with the support of information systems. These process-oriented information systems may include some of the same information as the management information systems.

2.4 (Re)designing organizations -- a model

2.4.1 A model for designing organizations

In an industrial engineering sense, designing realistic organizations generally means redesigning organizations which already exist in real-world situations (see also Section 2.2). This means that, in the remainder of this book, references to designing (parts of) organizations actually refer to *re*designing. A model for designing an organization is described in this sub-section. This model has been borrowed from Falster et al. (1991). The design of industrial engineering (sub)systems is concerned with goal-directed activities which are performed along with the normal daily activities within an organization (Den Hertog and Van Assen 1988). Goal-directed means that the organizational design will generally focus on achieving a pre-defined improvement in organizational performance. This is the *design objective*. The design of an organization as a system can be described as an activity which influences one or more of the system variables, the so-called *design variables (DV's)*, which have been selected in order to achieve a pre-defined improvement in system performance (i.e., the design objective). The improvement in system performance can be expressed in terms of so-called performance indicators. These performance indicators contribute to the realization of the organizational design objective by expressing the improvements in relation to the original situation. When the design objective is taken into consideration, it is not necessary to include all of the possible DV's. DV's which are not included and are therefore assumed to be given (i.e., cannot be changed), become basic assumptions upon which the design process is based. This essentially simple, theoretical model for designing an organization is presented in Figure 2.5.

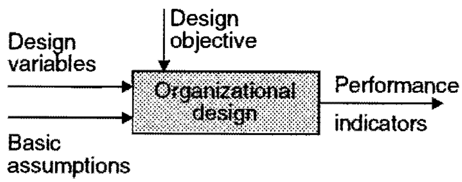


Figure 2.5. Basic theoretical model for designing an organization

Using this model to develop an organizational design therefore implies choosing and defining an appropriate set of DV's to achieve the design objective and to determine the related performance indicators. In any case, the following activities must be performed in order to determine the scope of the design:

- deciding on the design objective(s) and performance indicators;
- choosing the DV's to be included in the design.

2.4.2 Design objectives and performance indicators

Designing an organizational (sub)system is generally oriented toward achieving a pre-defined performance improvement with respect to that (sub)system. This is referred to as the ***design objective.*** After completion of the design of the organizational (sub)system, it must then be determined whether the design objective has been met in order to evaluate the quality of the design. Using the design model presented in the previous sub-section, this means that the design objective must be translated into a system performance measurement expressed in terms of the so-called performance indicators. The design objective for the research presented here will be derived from the objectives of customer order driven engineering seen as a subsystem within the total organizational system, since the design of customer order driven engineering is the primary concern. Customer order driven engineering is the non-physical transformation process which precedes the physical process and can be seen as a part of the total transformation process within an organization. An important question, however, is to what extent the objectives of customer order driven engineering can be isolated from the objectives of the organization as a whole. A number of important control decisions to be made during the engineering phase are related to a lesser degree to the local control of engineering, itself, and more to the integral control of the organization as a whole. Two examples of this are assigning a due date and providing a price quotation. These decisions can have a significant influence on the performance of the organization as a whole. The design of a controlling system for customer order driven engineering therefore cannot be seen in isolation from the controlling system for the total transformation process; it is an integral part of this total process. This means that parts of the integral control will be included in the design of the customer order driven engineering.

Based upon the control factors of quality, timeliness and cost mentioned in Section 1.3, the objectives of customer order driven engineering seen as a subsystem can be formulated as follows:

- a correct and complete transformation of the customer requirements into a product specification in a proper form and with sufficient quality that the product can be physically produced based upon this specification (the quality objective);
- the realization of these transformation activities within the agreed throughput time (the timeliness objective);
- incurring the lowest possible costs in the realization of the transformation activities (the cost objective).

As previously indicated in Sub-section 1.2.2, it is virtually impossible to realize all of the above-mentioned objectives in most practical situations due to the lack of an effective integrated control concept for customer order driven engineering. This leads directly to the purpose of the organizational design described in this book and also the area in which the original research value is to be found, namely:

> *the (re)design of customer order driven engineering as a system in which quality, timeliness and cost objectives are treated as an integrated whole. Information about quality, timeliness and cost is provided to the decision-maker in an integrated fashion in such a way that the engineering objectives can be realized.*

In view of the design objective with respect to the organizational system, the quality can be evaluated based upon the degree to which the system can satisfy the objectives after the organizational design has been developed. In terms of the design model, the performance indicators for the design can be derived directly from the objectives of customer order driven engineering.

2.4.3 A classification for the design variables

An extremely large number of design variables (DV's) can be identified in connection with designing an organization. Some examples are the organizational structure, the control structure and the design and realization of processes. A certain differentiation in the DV's can be made, however. In order to be able to make the decision of which factors will and will not be included as DV's within the scope of the design, two aspects can be evaluated and used as the basis for classifying each of the DV's:

- the control level in the organization;
- the point-of-view from which the organization is analyzed.

♦ *The control level in the organization*

Three control levels can be identified in an organization, depending upon the planning horizon and the impact (Anthony 1988), for the purpose of making a differentiation in the design variables, namely:

- *"Strategic planning"* (strategic level), defined as "the process of deciding on the goals of the organization and the strategies for attaining these goals." Choices are made at this level concerning markets and marketing strategies, product technology, etc.;
- *"Management control"* (structural level), defined as "the process to implement the organization's strategies." Choices are made at this level concerning products, production processes, capacity requirements, control structure, information resources, etc. In other words, this level concerns designing the organization as a system;
- *"Task control"* (operational level), defined as "the process of ensuring that specific tasks are carried out efficiently and effectively." Choices are made at this level concerning the amount of capacity, establishing norms, order patterns, etc.

The design variables can be defined at the three control levels of an organization as identified above. A structure can be imposed in this way for all of the various design variables which could theoretically be used. There are, of course, important dependency relationships between the levels. Design variables defined at a higher level determine the boundaries within which design variables at a lower level can be defined. There are, for example, more degrees of freedom for defining design variables at the strategic level than at the structural level. There are, thus, more degrees of freedom at each higher level.

♦ *The point-of-view from which the organization is analyzed*

There are various possible points-of-view from which an organization can be seen when deciding on the design variables for (re)designing an organization. Certain factors may or may not be important for inclusion in the design, depending upon the design objective. The following "views" are considered here, based upon the research published by Falster et al. (1991):

- the *"workflow view"*, which focuses on the processes to be carried out, the activities and the structure of the activity network;
- the *"resource view"*, which focuses on the required types of resource capacities in relation to the activities to be performed;
- the *"organizational/decisional view"*, which focuses mainly on the decision structure.

Similar to the differentiation of design variables based upon the control level, a differentiation can also be made based upon the three views described above. By combining these two criteria, nine different design domains can be identified for the classification of DV's. Several of these domains have been selected as being relevant for the present research; this selection will be described in Section 2.6.

2.5 Design approach

The control model (see Figure 2.4) as well as the PCI Model is used here to structure the organizational design approach. The control model tells us that it is possible to make a differentiation between the transformation process (Controlled System), the controlling system (Controlling Unit) and the management information system. The PCI Model tells us that there is a certain dependency between these three subsystems; this model has been described by Bemelmans (1986) and others. The three subsystems and their dependencies are diagrammed in Figure 2.6a. The reasoning behind these dependencies is that a controlling system (C) cannot be defined at random, since it is dependent upon the characteristics of the specific situation involving the primary transformation process (P) to be controlled. The required management information resources (I) are, in turn, dependent upon the characteristics of C and P. Therefore, the characteristics of P must be identified which more-or-less dictate which form of C (control) is required and then the characteristics of both P and C must be identified which determine which "I" approach should be followed, before a controlling and information system can be designed. This type of dependency implies that a fixed sequence should be followed in developing these three subsystems in designing the organization: first designing the transformation process (P), then the controlling system (C), and finally the information system (I).

The approach presented here, however, also suggests a dependency relationship in the other direction: from the controlling system (C) and the management information system (I) to the transformation process (P), as well as from the management information system (I) to the controlling system (C) (see Figure 2.6b). From the point of view of control, certain requirements can be imposed on the design of the transformation process. For the

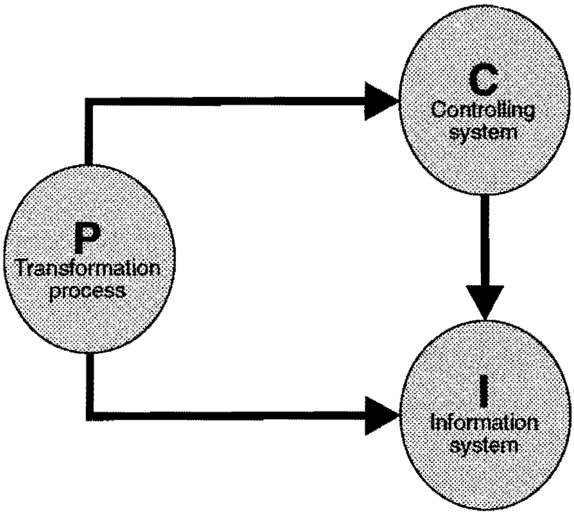


Figure 2.6a The PCI Model (I)

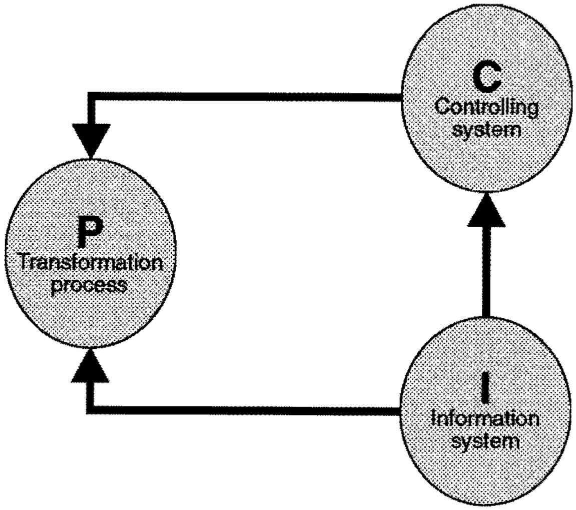


Figure 2.6b. The PCI Model (II)

purpose of quality assurance, for example, it may be desirable to make a distinction between certain sub-processes and/or components during the engineering phase. Particularly in the case of customer order driven engineering, this aspect is also relevant for the (management) information systems. Information systems, in general, cover a wider spectrum than only the management information systems. In broadest terms, we are talking about the use of information technology. Information technology can play an important role in supporting the execution of the transformation process in view of the fact that the result of engineering is actually an information product. This means that aspects of "I" (the support provided by information technology) may need to be included along with aspects of C when designing the transformation process (P). The use of information technology to support the transformation process can subsequently influence the design of the controlling system.

In view of these dependencies, the design approach in this book will be structured as follows. To start with, the transformation process P will be designed, taking the control (C) aspects into account. Then the controlling system (C) will be designed, based upon the design of the transformation process (P). Finally, the management information system (I) will be designed, based upon the designs developed for P and C. The influence of information technology on the design of P and C is discussed after an evaluation of the feasibility of information technology applications within the transformation process (P).

2.6 Limiting the scope of the design

2.6.1 Limiting the design variables

Only a subset of all of the possible design variables have been included in the organizational design described in this book. The design approach presented here is limited to a certain number of design domains, on the one hand, and limited to a certain number of design variables per domain, on the other hand. It is assumed that the other design domains and the so-called "unaffected" design variables are fixed for the purpose of this research. In developing the design, it is assumed that the unaffected design variables have already been fixed at appropriate values within the organization. The organizational design is only concerned with the structural level (management control) in the organization. This limitation in scope is the result of the objective of this design-oriented research as formulated in Sub-section 2.4.2. This objective concerns the choices to be made regarding the design of customer order driven engineering within an engineer-to-order production situation viewed as a system. These types of choices are dealt with at the structural level. This means that the DV's at the strategic level (strategic planning) and at the operational level (task control) are to be taken as given (fixed input) for the design when this approach is followed. The exclusion of DV's at the operational level can be justified as follows. The DV's at the operational level can be subdivided into:

- DV's directly related to making the actual control decisions. If these DV's were to be included, the intention would be to indicate how optimal decisions should be made. This would mean that the designer is assuming the role of decision-maker;

- DV's related to making decisions during and concerning the execution of the transformation process. If these DV's were to be included, the intention would be to indicate how the details of the actual transformation process should be carried out. This would mean that the designer is assuming the role of the operator.

In view of the nature of the DV's at the operational level, it is sensible to exclude these from the design in this research. This means that only three of the nine types of DV's identified in Sub-section 2.4.3 for designing an organization will need to be included here: the workflow view, the resource view and the organizational/decisional view at the structural level.

2.6.2 *Basic strategic assumptions*

By excluding some of the possible DV's at the strategic level within the organizational design, this means that certain strategic choices are assumed to have been made in advance with respect to the organizational design. In designing the customer order driven engineering, a certain strategic context is assumed. The organization's goals and the strategic choices which need to be made to realize these goals have, thus, already been determined. The basic strategic assumptions for the organization chosen as the subject of this research is described under the following headings:

- the product;
- the production organization;
- market and competition;
- engineering capabilities.

♦ *The product*

A particular policy with respect to the use of technology, the product assortment and marketing have been chosen and formulated. A decision has been made to produce complicated and complex configurations of industrial equipment consisting of several thousand components. Major investments have been made in engineering activities, independent of specific customer orders. Product family specifications have been prepared at the sub-function level. A large number of product modules have also been defined. This means that a choice has been made to support the OSL-4 order-independent specification level. The customer does not have complete order specification freedom (see Chapter 1). Customer-specific requirements are honored, provided that this does not lead to an increase in the total equipment performance level. New and customized sub-functions are only accepted when they can be seen as a logical extension of the existing functionality and when they introduce a relatively insignificant technical risk. Important issues in this type of situation are standardization and the re-use of information. The company offers products belonging to several product families in different phases of the product life cycle.

♦ *The production organization*

An "engineer-to-order" type of production organization (Sari 1981) has been chosen for this research. This means that a portion of the engineering activities is customized to the extent that a unique customized product is still based upon certain standards. Customer-specific adaptations are found in a large portion of the components. This leads to a multi-project environment within a functional organization. This means that a variety of different projects are active at the same time. In view of the limited scope of these projects, we can assume that it is not possible to dedicate specific personnel to a single project for a certain length of time in accordance with the normal principles of a project organization. The personnel within the functional organization may therefore be involved with several activities for more than one project at any given point in time. The expertise in the area of product assembly is of strategic importance. For this reason, this activity is never outsourced. A conscious decision has been made to invest in less than the required amount of capacity for the manufacture of components so that a sufficient utilization percentage can be realized even in slack production periods. The additional capacity which is required in peak periods is then found by outsourcing products as well as certain production operations.

♦ *Market and competition*

The company produces products for an expanding market sector. The production organization must deal with a market which demands high quality and an attractive price/quality ratio. The competition is fierce with respect to quality, price and delivery lead time.

♦ *Engineering capabilities*

Within the total engineering capacity, a distinction is made between the so-called thinkers (the developers of new concepts) and doers (the designers of the actual product). The thinkers (called "product engineers") are responsible for defining the concept for a product which the doers (called "detail designers") must work out into detailed technical alternatives. The resource capacity for developing new concepts as well as for detailing the actual products is in short supply and also of strategic importance to the company. It is, therefore, of utmost importance that these resources are utilized efficiently. In view of the scarcity of this category of personnel, it is not feasible, in the short term, to expand the capacity for developing new concepts, in particular. Much of the available resource capacity in this area is used in connection with preparing sales quotations. The customized product is not fully specified when the quotation is prepared since the chance of winning the contract is relatively small. This means that there are technical risks (and associated time and financial risks), generally for the company, itself, which can be completely eliminated only after order acceptance when the detail designers have completed all of the specifications.

The basic strategic assumptions described above provide a context within which customer order driven engineering must be carried out as an organizational subsystem within this type of organization.

2.6.3 The interrelationships between quality, timeliness and cost in the design

As previously mentioned, attention should be focused primarily on an integrated control of the quality, timeliness and cost factors in designing a customer order driven engineering process. The interrelationships and the trade-offs between these three control factors are important for the system design as well as for control purposes. In addition, the balance of the quality, timeliness and cost factors in the design may be different with respect to each of the aspects of P, C and I. Choices can also be made within each of these three design dimensions concerning the degree to which the interrelationships and trade-offs between quality, timeliness and cost factors are relevant for the design, itself. The exact role of these control factors and the definition of these factors in connection with the design are discussed below.

♦ *The balance between quality, timeliness and cost factors in designing P*

It goes without saying that quality is an important factor in the design of the engineering process (P). Process P should, of course, be designed in such a way that the customer requirements are transformed correctly and completely into a viable product. Satisfying the secondary requirements in connection with controlling the process is also included as part of the quality of the process design. The timeliness factor in the engineering process design means that the process must be designed in such a way as to ensure that the duration of the process is not unacceptably long. It is possible, for example, that a process is defined with a large number of sub-processes and iterations to ensure a high level of quality, but that the throughput time then becomes too long. The cost factor in the engineering process design concerns the efficiency of the process. The design costs can be evaluated in addition to the effectiveness of the process (i.e., quality and timeliness).

Special attention is paid to the quality factor with respect to the design of the engineering process (P) in this book. The realization of an acceptable throughput time for the process will be included as a secondary requirement since the timeliness factor plays an important role within the controlling system. Quantifying the balance between the quality, timeliness *and* cost factors in designing the process is difficult, however; this should be seen as a separate issue. For this reason, the cost aspect or, in other words, the efficiency of the way in which the process is *designed*, will not be covered in this book.

♦ *The balance between quality, timeliness and cost factors in designing C*

The quality factor with respect to designing the controlling system means that the control must be designed in such a way as to allow an integrated control of quality, timeliness and cost factors within the customer order driven engineering. The timeliness factor with respect to designing the controlling system means that the controlling system must be designed in such a way as to ensure that the duration of the control activities is not unacceptably long. Since time is involved in carrying out the control activities, there will always be some influence on the throughput time and the timely completion of the primary process. Therefore, attention must be paid to the time requirements and throughput time consequences of the control activities when the controlling system is designed. It is also worth noting that the management information system can play an important role in connection with the throughput times of the control activities since the throughput times can generally be shortened when these activities are supported to a greater extent by an information system. In this case the management information system (I) has a certain influence on the controlling system (C). The cost factor involved in the design of C concerns the efficiency of the controlling system and the total costs incurred in designing the controlling system.

Special attention is paid to the quality factor with respect to the design of the controlling system (C) in this book. The realization of an acceptable throughput time for the control activities will be included as a secondary requirement since the timeliness factor plays an important role within the controlling system. Similar to the situation of designing the primary process, it is difficult to quantify and balance the quality, timeliness and cost factors in designing the controlling system. For this reason, the cost aspect of *designing* a controlling system will not be covered in this book.

	Quality factor	Time factor	Cost factor
P	++	+	-
C	++	+	-
I	++	+	-

++ = included as main requirements
\+ = included as secondary requirements
\- = not included

Figure 2.7. Balancing quality, timeliness and cost in designing the PCI

♦ *The balance between quality, timeliness and cost factors in designing I*

A similar approach can be taken in designing the management information system (I) as in the case of the controlling system. The quality factor in connection with designing the management information system (I) means that the information system must be designed in such a way that it is able to collect, process, store and disseminate information about the primary process to support the decision-making and steering activities of the controlling system. The timeliness factor in connection with designing "I" concerns the throughput time of the control-related information processing and information dissemination activities. If this throughput time is too long, then it can have a negative effect on the control of the primary process. Similar to above, the cost factor in connection with designing "I" concerns the design costs for "I".

Special attention is paid to the quality factor with respect to the design of the management information system (I) in this book. Also in this case, the realization of acceptable throughput times for the information processing and information dissemination activities will be included as secondary requirements. Analyzing the cost aspect in this case poses the same problems as in the cases of P and C. For this reason, the cost aspect in this context will also not be covered in this book.

The balance between the quality, timeliness and cost factors in designing P, C and I, and the resulting definition of the scope of this research as described above, is illustrated in Figure 2.7. In summary, special attention is paid to the quality factor in designing P, C and I in this book; the timeliness factor is viewed as a secondary requirement. The cost factor is not included in the design. It could be concluded from the figure below that the cost factor in connection with control has been suppressed in this book. This is only true for the ***design*** of the system, however. Note that the cost factor is explicitly included (in relation to quality and timeliness) within the controlling system for the customer order driven engineering process. This aspect is included in Figure 2.7 within the ***quality of the design*** of the controlling system (C).

2.7 Topics covered in this book

The research approach as described in Section 2.2 has been used as the basis for presenting the topics in this book. The area of research and the problem statement for this research (Phase One) are described in Chapter 1. A further analysis of the case situation is developed (Phase Two) in Chapter 3. The organizational (re)design of the selected case situation is developed and evaluated (Phase Three) in Chapters 4 through 7. Chapter 4 covers the design of the transformation process (P), while the structure of the controlling system (C) is described in Chapter 5 and a more detailed discussion of the interrelationships between the quality, timeliness and cost factors within the designed controlling system is presented in Chapter 6. The design of the management information system is described in Chapter 7. In conclusion, an evaluation is presented in Chapter 8, covering the elements of the design which are universally applicable and the final conclusions and recommendations. Special attention is paid to the design implementation experiences in the selected case situation in Appendix A. The topics covered by this book are summarized below in Figure 2.8.

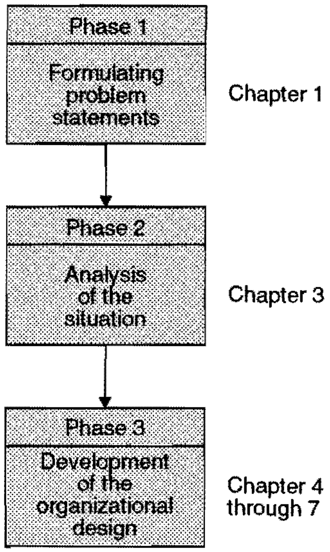


Figure 2.8. Topics covered in this book

Chapter
3 DESCRIPTION AND ANALYSIS OF THE SELECTED CASE

3.1 Introduction

As indicated in Chapter 2, the customer order driven engineering as found in a specific case situation will be redesigned in terms of a system. The transformation process, the controlling system and the management information system will be defined as an interrelated whole within this context (refer also to Figure 2.4). The company chosen for this case analysis will be described in this chapter along with a detailed analysis of the problems encountered in connection with customer order driven engineering. A brief description of the company characteristics is presented in Section 3.2, followed by a description of the internal organization in Section 3.3. The total transformation process, including the customer order driven engineering and the control of the transformation process, is then covered in Sections 3.4 and 3.5. Based upon this explanation of the selected case situation, a detailed analysis of the issues is presented in Sections 3.6, 3.7 and 3.8. The description and analysis of the selected case situation has been based partly on the work published by Timmermans (1991). Several conclusions are presented at the end of this chapter.

3.2 Company description and situation

Before the detailed characteristics of the organization and the transformation process are analyzed, a summary of the selected case situation is presented in this section in terms of several general characteristics, the range of products and the end-user market.

3.2.1 General characteristics

The selected case for the research presented in this book is a company which manufactures custom-built packaging equipment for industrial customers. This company specializes in the manufacture of packaging equipment for three application areas, namely:

- the (primary) packaging of liquids (not containing CO_2);
- the (secondary) packaging or boxing of a large range of prepackaged products;
- the (tertiary) packaging or loading of boxes onto pallets.

The company supplies single machines as well as complete production lines with multiple packaging machines to its customers. The organization has been set up primarily for supplying single units, however. The annual turnover is between 55 and 60 million guilders, of which more than 90% is derived from the sale of single units. The added value contributed by the company through its products averages approximately 45%. The delivery lead time for custom-built units varies from three to nine months, depending upon the extent of the product specifications provided by the customer. Approximately 240 persons are employed by the company, of which about half are directly involved in the production process (consisting of both the physical and non-physical production activities).

3.2.2 The range of products

The range of products is divided into three product families or product groups, namely: primary packaging equipment (bottling machines), secondary packaging equipment (packaging machines) and tertiary packaging equipment (palletizing machines). Each of these machines consists of a large number of components (i.e., several thousand). Bottling machines are the most highly-developed product group; they are almost solely based upon previously developed technical solutions. The customer driven engineering in connection with these units is relatively intensive and complex, however, and is primarily concerned with the filling mechanisms incorporated in these machines. More of the components in packaging machines and palletizing machines are typically customized, leading to a greater percentage of customer order driven engineering. Each product group has its own typical resource capacity requirement and needs specific engineering knowledge which is more-or-less dedicated to that product group. Manufacturing the components for bottling machines requires a relatively large number of mechanical operations, as opposed to the manufacturing of packaging machines and palletizing machines in which much more sheet metal machining is required. In addition, the standard policy is to purchase a significant portion of the components for products included in these last two product groups, rather than to manufacture them internally. The installation of bottling machines is relatively labor-intensive. In view of these typical resource capacity requirements as described here, it should be clear that the flexibility with respect to sharing resources between product groups is limited.

3.2.3 The end-user market

The company chosen as the selected case supplies equipment world-wide to manufacturers of fast moving consumer goods. These manufacturers are found primarily in the more developed countries and highly populated metropolitan areas. Equipment is supplied to companies in a variety of industrial sectors, particularly in the food and chemical industries. An especially strong market penetration has been built up in the areas of distilled beverages and dairy products. Even though sales are made worldwide, there are four countries (Netherlands, Belgium, United Kingdom and Germany) which are responsible for two-thirds of the sales revenues. The company has its own sales office in each of these four countries. Local agents are used in the other countries. The company is relatively small compared to its competitors; a number of other companies in this business have an annual turnover which is many times larger. Nevertheless, the company has an enviable reputation for manufacturing high-quality equipment. The competition is noticeable especially in the areas of packaging and palletizing equipment. This type of equipment can be marketed in a wide variety of industries. The threshold for breaking into a new market sector with this type of equipment is relatively low. The market for bottling machines is different, however. Manufacturers of bottling machines normally specialize in specific industrial sectors because the technological knowledge concerning the products to be packaged and the characteristics of these products play an important role. This means that the threshold for breaking into a new market with this type of product is relatively high. The average delivery lead time in the market varies from three to nine months, depending upon the size of the order and the degree of customization. The market is more sensitive to reliability than to the availability of extremely short delivery lead times.

3.3 The internal organization

The internal organization is divided into three functional divisions, namely: Sales, Engineering and Production. In addition, there are three staff departments: Finance, Organizational Development & Data Processing and Human Resources (see Figure 3.1). Each of the three functional divisions is described in more detail below.

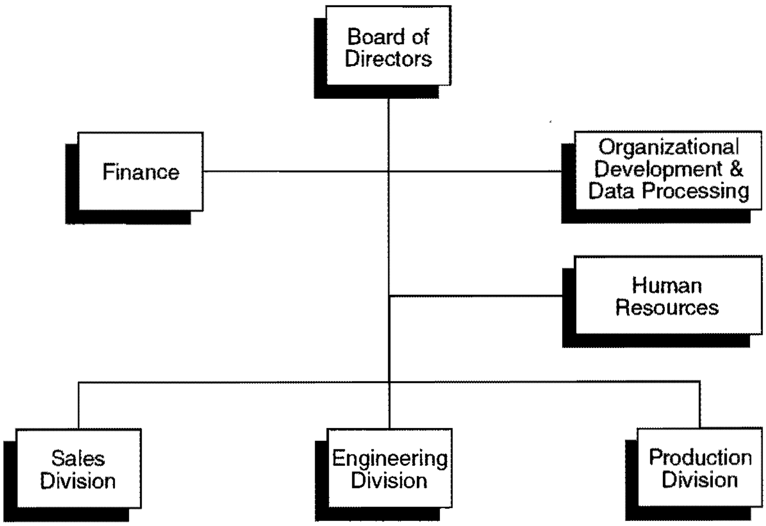


Figure 3.1. High-level organization structure of the company

♦ *The Sales Division*

The organizational structure within the Sales Division is relatively complicated. The total market area is segmented geographically into four Areas. Each Area is represented internally by one or more Area Coordinators (AC's). The sales channels consist of sales offices in the four primary sales countries and local agents in the other countries. In addition, there are a number of export managers who are responsible for specific language areas. The AC's are responsible for the contacts between the markets and the different sales channels, on the one hand, and the internal production organization, on the other hand. They take care of the communication and coordination (concerning quotations, customer orders, etc.) between customers, sales offices and agents, and the internal organization. The On-site Installation Department and Service Department are also part of the Sales Division. There is, thus, no segmentation by product group within the Sales Division; each Area and each sales channel is, in principle, responsible for selling products in all three of the product groups. A total of approximately 50 persons are employed in the Sales Division.

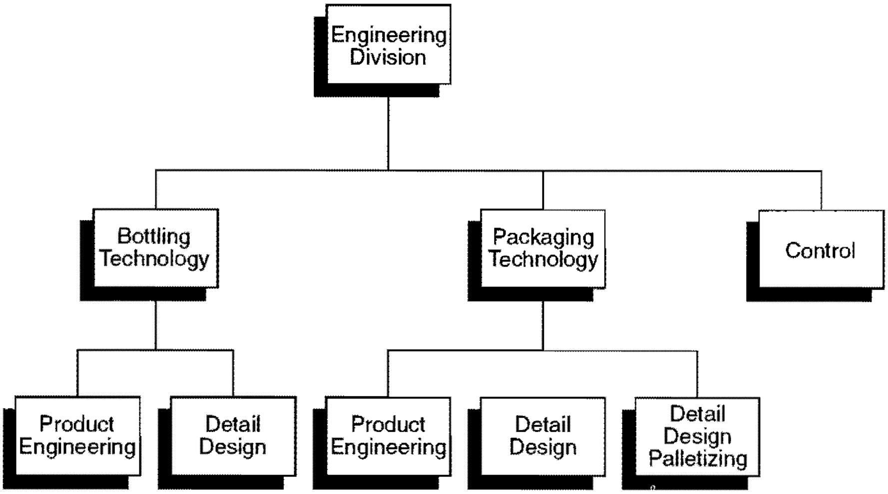


Figure 3.2. Organization structure of the Engineering Division

♦ *The Engineering Division*

Unlike the Sales Division, the Engineering Division is organized primarily along the lines of the product groups. A distinction is made between Bottling Technology and Packaging Technology within the Engineering Division. The Packaging Technology section includes specialists for both the Packaging and Palletizing product groups. Both the Bottling Technology and the Packaging Technology sections are split up functionally into a Product Engineering Department where the product concepts are initially developed, and a Detail Design Department in which the subsequent realization of the product design is worked out. A separate Detail Design Department exists within the Packaging Technology section for the Palletizing product group. The Engineering Division also has a separate Control Department for developing the machine control functions. Approximately 55 persons are employed within the Engineering Division (refer to Figure 3.2).

The activities associated with the customer order driven engineering fall primarily under the responsibility of the Engineering Division. Much of the analysis included in the remainder of this chapter is therefore related to the activities within this division.

♦ *The Production Division*

The Production Division consists of four departments which are directly involved with production activities and four other departments which are indirectly involved. The component manufacturing activity is split up into three production departments, namely: the Milling Shop, the Stamping Shop and a Universal Group. This last department is primarily responsible for manufacturing replacement parts in connection with equipment maintenance. In addition to component manufacturing, there is also an Assembly Section within the Production Division. The Assembly Section consists of a Pre-assembly Department and a Final Assembly Department. The four departments which are indirectly involved with the production activities are: Purchasing & Production Control, Process Planning & Technical Support, Quality Assurance and Technical Documentation & Administration. Approximately 120 persons are employed within the Production Division.

3.4 Description of the transformation process

The company described in this chapter can be characterized as a typical engineer-to-order plant. This means that the transformation process can be subdivided into a non-physical production process, the customer order driven engineering and a physical production process consisting of component manufacturing and product assembly. The way in which both of these sub-processes are carried out in the present situation, is described below.

3.4.1 Customer order driven engineering

At the highest level, the customer order driven engineering sub-process can be split up into three phases, namely: the sales lead phase, the quotation phase and the order phase.

Sales lead phase
The sales lead phase is initiated when an initial contact between a potential customer and one of the sales channels (agent, sales office or AC) takes place. It is assumed that the customer has a problem and is interested in finding out if the company can provide a solution. The salesman forms an opinion about the customer's requirements and determines to what extent a solution can be provided. A quotation with an initial price indication is provided if this is requested by the customer. If the customer requires a more detailed quotation and the salesman believes that there is a good chance of winning the order, then the customer's requirements are documented using a standard sales order checklist. This request for a detailed quotation is then passed on to the responsible AC who gives this to the Engineering Division. This initiates the formal quotation phase.

Quotation phase
The request for quotation is received by the Engineering Division and then evaluated and processed by a product engineer within the Product Engineering Department. The product specifications are only worked out in general terms at this stage in the form of a general technical description. This document is a summary of the customer requirements translated into product functions and provides the technical content for preparing a detailed quotation. After the price is established and a delivery date is determined, the quotation is then sent to the customer. The sales organization is then responsible for negotiating the contract details with the customer. The activities in the quotation phase may need to be repeated in some situations. The quotation is used in this way to inform the customer of the proposed solution. This is used as the basis for specifying any additional requirements and making subsequent adjustments to the product specifications. Negotiations with the customer can also result in changes to the price or the delivery lead time. One or more of the quotations to solve a customer's problem will ultimately lead to either a customer order or a breakdown in the negotiations. If the customer decides to place an order, then the order phase is initiated within the customer order driven engineering process.

Order phase
After the existence of a new customer order is made known within the organization, the Engineering Division works out the order specifications in more detail. The product engineer takes the product specifications, which have already been prepared in general terms, and fills in the details on technical order sheets. These technical order sheets are then passed on to the detail designers (in the Detail Design Department) who are specialized in the realization of the final product. These detail designers add the technical drawings, bills-of-materials and further details to the product specifications. The Detail Design Department also prepares the necessary plans for the Control Department so that the product control specifications can be worked out. The Detail Design Department then defines various *installation units* for simplifying the installation of each custom-built machine. Each installation unit can be seen as a group of components and sub-assemblies of the machine which are to be assembled simultaneously. A separate assembly order is drawn up for each installation unit. The specifications for each installation unit are then worked out separately, ensuring that the sequence of detailing is coordinated with the assembly sequence of the installation unit. As soon as the detailing activities for an installation unit have been completed, these are released to the Production Division.

The customer order driven engineering process is finished when all of the product specifications have been completed. Manufacturing instructions first need to be prepared, to the extent that these instructions are not already available, before the physical manufacturing of the customized components can be initiated. These instructions include the selection of operations, machines and tooling, as well as an indication of the operation times. These last activities are carried out within the Process Planning Department (of the Production Division).

3.4.2 The physical production process

The physical flow of goods consists of the physical production and purchasing activities. These activities can be initiated as soon as the previously mentioned non-physical activities have been (partially) completed. A significant portion of the components are purchased; even whole machine modules, often based upon customer specifications, are sometimes purchased as a part of a customer order. Purchase orders for components and sub-assemblies, as well as the arrangements for outsourcing of production capacity, are coordinated via the Purchasing & Production Control Department. The components and simple sub-assemblies which are neither purchased nor outsourced are produced internally within the three functionally-oriented manufacturing departments. The final customized product is assembled within the Assembly Section. The machine is extensively tested after the assembly phase using test materials (such as boxes, bottles, etc.) provided by the customer. After testing, the machine is partially disassembled and then shipped to the customer. The On-site Installation Department (of the Sales Division) is responsible for the final installation and start-up at the customer's plant.

3.5 Present method of controlling the transformation process

In view of the focus of the present study on customer order driven engineering, the present methods of controlling the physical part of the transformation process will be described here (in general terms) only when this is relevant for describing the control of the customer order driven engineering. Attention is paid to the production control (timeliness factor), in the first place. In the second place, controlling the quality and cost factors is described in further detail.

♦ *The present method of production control*

Three planning levels can be identified for production control within the company, namely: operational planning (independent of specific customer orders), first-cut planning and detailed planning (customer order dependent).

Operational planning
An operational plan is established once each year. This plan includes a forecast of the product quantities expected to be sold during the year for each product group. The medium-term resource requirements can then be calculated based upon this forecast. In this way, the operational plan represents an annual, coordinated effort (at a high level) to match the sales plans with the production activities. The forecasts included in the operational plan are also used as the basis for an annual determination of the standard hourly rates used in calculating the product cost prices (see further).

First-cut planning
Standard delivery lead times are used as the basis for customer quotations. The standard delivery lead time is determined based upon the number of hours estimated for detailed design and the finished product(s) to be supplied (i.e., a product group, a single machine or a complete production line). In view of the fact that the throughput time for the quotation phase can be fairly unpredictable, the future workload of the various resource capacity groups is taken into account only minimally. A first-cut plan in the form of a project network with aggregated activities is created for each customer order received. An estimate is made of the required resource capacity per group of aggregated activities based upon the general technical description. The earliest and latest start dates and completion dates are calculated per activity using the estimated resource capacity requirements. Standard project network structures have been defined for each product group. Internal due dates are calculated based upon the workloads within the Detail Design departments. Each customer order is added to the internal production schedule of the relevant Detail Design Department. The scheduled start date for the physical production is determined solely based upon the internal throughput time of the detailing activities in view of the limited flexibility and the limited diversity of skills found in connection with the detailing resource capacities. The due date is calculated by adding the standard throughput times for manufacturing and assembling the components to the scheduled completion date for the detailing activities. Capacity utilization profiles are then developed for each of the Detail Design departments, the Manufacturing departments and the Assembly departments based upon the project networks which have been established. Whenever a profile shows a planned over-utilization of the available resource capacity in one or more of the capacity groups, an effort is made to utilize the slack in the various project network structures in order to resolve the capacity shortage. If this does not provide a solution, then other measures such as overwork, outsourcing and reassignment of multi-skilled employees are taken to expand the available capacity. As a last resort, the scheduled due date for the order is postponed and the customer is notified of the anticipated delay in delivery.

Detailed planning
No detailed plans and priorities are used routinely within the Product Engineering and

Detail Design departments. The AC's approach specific individuals within the Product Engineering Department to arrange for the preparation of quotations. Priorities are, thus, set on an individual basis. The activities carried out by the Detail Design departments follow directly from the first-cut planning. A relatively simple human resource plan is also maintained to keep track of which persons are involved in which projects. A detailing order for a customer order may be split up into installation units within the Detail Design Department and allocated to various persons in this way. The priority is determined based upon the high-level plan made for the installation units within the assembly phase. After the detailed design and the process planning has been completed, the detailed planning is performed for the manufacturing of components and the assembly; the coordination and requisitioning of materials is also initiated at this point. An integrated, automated production control system is used for this purpose. A significant number of standard components are also made for stock, driven independently of the customer orders by the stock levels. A weekly summary of the order progress is prepared for each customer order. This summary provides a report of which departments have completed their tasks for each of the installation units.

♦ *The present method of providing quality assurance*

The present method of providing quality assurance for customer order driven engineering is incomplete and not performed systematically. There are no routine engineering reviews. Extra attention is paid to the development of the product specifications only on an ad hoc basis when major technical problems are encountered or when a customer order is accepted which includes major technical risks. No standards have been documented for structuring and preparing engineering documents and there are, similarly, no procedures for preparing drawings. This has resulted in a situation in which each employee involved in engineering activities follows his own set of norms.

♦ *The present method of financial control*

The present method of financial control over customer orders is concerned primarily with monitoring the actual project costs. This is done by preparing a project budget, keeping track of the actual project costs and then comparing the actual versus budgeted costs. The full cost price of the future product is calculated based upon the general technical description which was prepared during the quotation phase. This is calculated by the product engineer in most instances, but sometimes by a technical budgeting specialist. The full cost price is determined by estimating the material costs for each "product function" specified in the general technical description and adding to this the costs of using the specified resource capacities. These resource capacity costs are based on the estimated hours per type of directly involved resource capacity (detailed design, manufacturing and assembly) multiplied by a standard hourly rate. A limited number of indirect costs associated with the directly involved resource capacities are also covered by this hourly rate. A manufacturing cost price per product function is determined in this way. Standard surcharges are added to this (in terms of a percentage of the manufacturing cost price) for product engineering, warranties, marketing & sales and other overhead expenses to end up with the full cost price. The full cost price for the complete machine is obtained by finding the sum total of the full cost prices for all of the relevant product functions. The quotation price is calculated by the Sales Division and consists of the full cost price plus the desired profit margin.

The standard hourly rates for the various types of resource capacities and the above-mentioned surcharge percentages are established once each year based upon the forecasted sales and anticipated costs for each product group included in the operational plan. The total required hours per product group per type of resource capacity are determined based upon a "standard" machine which has been defined for each product group. A standard hourly rate for each type of resource capacity is calculated based upon the direct costs as well as the indirect costs per type of resource capacity. The above-mentioned surcharge percentages for other indirect cost categories are based upon the expected costs in each cost category expressed as a percentage of the total manufacturing costs.

If a quotation is accepted and becomes an actual order, then the project budget calculation which was made during the quotation phase is revised and finalized as a financial target for the organization. The actual hours per type of resource capacity and the actual costs of materials are subsequently accounted for per project. A comparison of the budgeted costs and actual costs can be made based upon this information for each customer order. This analysis is carried out after the product has been delivered to the customer and the customer order has been completely processed and closed.

3.6 Control characteristics of the transformation process

The typical control characteristics of the production plant depicted here (and of similar engineer-to-order equipment manufacturers) can be described in terms of erratic demand, uncertainty and complexity based upon the description presented above (see also Bertrand et al. 1992a).

♦ *Erratic demand*

A production situation can be called robust if it is able to anticipate and react to significant fluctuations with respect to, for example, sales volumes. Such fluctuations may be predictable but, nevertheless, difficult to deal with. The market demand for the products of the company described here can be characterized as being extremely erratic. Pronounced short-term as well as medium-term fluctuations in sales volumes are noticeable. This is characteristic of the market in which most engineer-to-order companies are active (see also Kingsman et al. 1989). Since this type of situation involves customer order driven production with competitive delivery lead times, it is not possible to compensate for the erratic demand by increasing and decreasing, for example, the capacity stock levels (see Wortmann and Wijngaard 1985). In addition to the erratic character of the total sales volume, the mix of the types of products which comprise the sales may also change radically. This may result in continual fluctuations in the utilization of specific types of resource capacities. A situation which is continually changing in this way requires a great deal of flexibility in the organization to be able to remain competitive.

♦ *Uncertainty*

According to Galbraith (1973), uncertainty can be defined as being the difference between the amount of information which is required to perform a certain task and the amount of information which is available within an organization. The required information is time-dependent. Uncertainty results when certain information is required now, but will only be made available at a later point in time. Using Galbraith's approach, three uncertainty factors can be identified in the production situation described here.

Product mix and volume uncertainty
The first uncertainty factor (macro uncertainty) concerns the unknown future demand with respect to product mix and sales volumes. It is extremely difficult to develop a reliable detailed forecast in view of the customized nature of the products and the different types of products (product families). An important additional element of uncertainty is the point in time at which a customer order is received. In view of the competitive market and the relatively low probability of quotations becoming orders, the company will always be in a situation in which the number of quotations issued exceeds the number of actual customer orders received. It is generally not known whether a potential customer will place an order based upon a quotation and, if an order is placed, when this will be done. This means that it is difficult to determine when to reserve production capacity.

Product specification uncertainty
The second uncertainty factor concerns the unknown aspects of the product specifications. Particularly during the customer order driven engineering phase, (parts of) the product specifications have not yet been finalized. This means that decisions dealing particularly

with resource capacity, delivery lead time and price must be made when there is still a certain degree of uncertainty. More specific and detailed information about the customized product is defined as the engineering process is carried out. For example, it is possible that equipment for which it was initially assumed that the performance specifications would fall within the established range of standards, turns out not to comply with these standards. This may lead to significant consequences for the total number of engineering hours, and thus for the cost and throughput time of the customer order. This means that the structure of the controlling system will need to take this factor into account. An important characteristic of the controlling system is that it is able to support the evaluation of previously made decisions and to anticipate new situations based upon additional, detailed information.

Process specification uncertainty
The third uncertainty factor concerns the unknown aspects of the process. It is extremely difficult to estimate the amount and types of resource capacities which will be required by a specific customer order since (parts of) the equipment remain undefined for a certain period of time. The type of resource capacity, in particular, is an uncertain factor in this respect. In practice, it is apparent that an exceptionally large variety of different types of operations is required for component manufacturing. This may result in a situation in which there are a sufficient number of hours available to meet requirements in terms of total hours, but that the available capacity per type of operation is completely wrong. The availability of a significant amount of external, short-term production flexibility is an important requirement in view of the likely mismatch between the resource capacity availability and requirements. The timely procurement of tooling can also become a problem when the production specifications for customized components, in particular, are defined at a relatively late point in time. This means that it should be possible to procure specific tooling without undue delay.

♦ *Complexity*

The company's production control can be characterized as being complex due to three factors in this situation.

Composition of the transformation process
The first complexity factor concerns the composition of the transformation process. The transformation process in this type of company consists of a non-physical phase in addition to a physical phase. The non-physical phase is the customer order driven engineering which also determines (a part of) the throughput time. However, because of the nature of the creative activities involved here, it is difficult to make a distinction between the processing steps and operations, analogous to the physical production phase.

This means that it is sometimes extremely difficult to determine the current status of the work-in-progress within, for example, the Product Engineering Department. In addition, some resource capacity needs to be reserved for the preparation of quotations within this department. This means that a constant trade-off is being made between allocating resource capacity to quotation preparation activities and order activities. This conflict between short-term objectives (the completion of customer orders) and long-term objectives (the acquisition of new orders) is characteristic of this situation. The physical part of the primary process is also relatively complex. The component manufacturing as well as the assembly activities involve a complex internal structure. Component manufacturing can be characterized as being a *job shop* situation in terms of the classification of production situations proposed by Bertrand (1989). This means that the coordination of resource capacities is, by definition, a complex problem with a large number of product routing possibilities and varying processing times. The assembly can be characterized as being a *project-oriented assembly* activity. The coordination of both the resource capacities and the required materials is a complex activity due to the "docking" character of the assembly activities and the diversity of components included in the product. Assembly activities are carried out at specific locations which have been specially-equipped for this purpose. These locations are more-or-less independent of the type of equipment being manufactured and lie at the heart of a complex scheduling problem due to the limited number of these specially-equipped locations. All of these aspects support the conclusion that controlling the various production departments is a complicated task.

The multi-project character

The second complexity factor concerns the multi-project character of the company. Each customer order is comprised of a network of activities of which a portion has not yet been defined in detail. Nevertheless, the complexity is primarily due to the fact that a number of customer orders in various stages of completion are typically being processed simultaneously by the same transformation process at any given point in time. Delays which may occur as the result of some sort of uncertainty with respect to a given customer order can, thus, adversely effect the processing of other customer orders. It is a complex problem to optimally coordinate all of these activities.

The nature of the components of the product

The third complexity factor concerns the nature of the components of the product. In addition to a number of standard components, a specific machine consists of a (large) number of custom-built components which are, in principle, one-of-a-kind. The materials for the custom-built components of a customer order generally need to be purchased specially. In view of the long delivery lead times for some of these materials (e.g., specially moulded parts), it is often necessary to ask the Purchasing Department about the prices and delivery times of these materials before all of the detailed specifications of the machine have been defined. This may need to take place early in the order phase or even during the quotation phase.

3.7 The concepts of uncertainty and risk

Of all of the above-mentioned control characteristics, the aspect of uncertainty, in particular, significantly influences the controllability of customer order driven engineering. Uncertainty, defined as a situation with incomplete control information (see previous section), can lead to certain risks which can adversely affect the performance of customer order driven engineering and, therefore, the total organization. The concepts of uncertainty and risk are closely related and are often used interchangeably. Nevertheless, two separate concepts should be distinguished here. Since these terms play an important role in the design of the control of customer order driven engineering, a further explanation of how the concepts of risk and uncertainty are used in this book is provided below.

♦ *Risk*

The concept of uncertainty was defined in the previous section. The term *risk* is used in this book to refer to a situation in which various, mutually exclusive events may occur, each leading to a substantially different result in terms of quality/timeliness/cost. A distinction can be made between three types of order-dependent risk, which may have a certain dependency, when this definition of risk is translated to a customer order driven engineering situation.

- *Technical or quality risk*: the chance that (a part of) a product cannot be produced, technically, according to the initial estimates. This leads to a situation in which significantly more product engineering and detail design hours are required in the order phase than were originally estimated in the quotation phase. The assumption is that a technically acceptable solution can always be found. The technical risk generally leads to the other two types of risk.
- *Time risk*: the chance that the throughput time required for the engineering and production of the product is longer than was originally estimated in the quotation phase. As a result, the agreed delivery date for the customer order may not be achievable. The time risk may be caused by a technical risk, but it could also be caused by other factors.
- *Financial risk*: the chance that the cost of the engineering and production of the product will be more than originally estimated in the quotation phase. This may be

caused by a technical risk and/or time risk, but could also be caused by other factors.

Three types of uncertainty can be identified as indicated in the previous section. These types of uncertainty may include one or more of the above-mentioned risks. A further explanation of the relationship between the types of uncertainty and the types of risk is presented here.

♦ *Product uncertainty and risk*

The exact product specifications are not yet known in the quotation phase. A general product concept is developed and an estimate is provided of the number of hours which will be required to complete the detailed design of the product in the order phase. This uncertainty can lead to a technical risk if it becomes apparent during the order phase that the product concept is incomplete or incorrect, or that more hours are needed to complete the detailed design than originally anticipated. This means that additional product engineering and/or detailed design hours will be required to solve the unexpected technical problem. A technical risk may thus automatically lead to a financial risk (higher costs resulting from more hours than originally budgeted) and a time risk (the likelihood of a longer internal throughput time).

♦ *Process uncertainty and risk*

Due to the presence of product uncertainty, it is extremely difficult to estimate the amount and types of resource capacities which will be required to produce the product. The required types of resource capacity, in particular, are uncertain. In practice, a large variation is found with respect to the types and number of operations required. This may result in a situation in which there are a sufficient number of hours available to meet requirements in terms of total hours, but that the available capacity per type of operation is completely wrong. This process uncertainty may lead to a time risk if the execution of certain operations implies a longer delay. In addition, this may lead to a financial risk if more work needs to be outsourced and certain internal resource capacities are under-utilized to a greater degree than originally anticipated.

♦ *Uncertainty and risk with respect to product mix and volume*

A reliable detailed forecast of the sales demand is extremely difficult to produce in view of the customization aspect in this market. An important uncertainty factor in this respect is the point in time at which the customer order is received. In view of the competitive market and the relatively low probability of quotations becoming orders, the company will always be in a situation in which the number of quotations issued exceeds the number of actual customer orders received. It is generally not known whether a potential customer will place an order based upon a quotation and, if an order is placed, when this will be done. This means that it is difficult to determine when to reserve production capacity. The uncertainty with respect to product mix and volume can lead to a time risk when, for example, there is a higher sales volume than originally forecasted in a given period. This can lead to additional financial risk when penalty clauses are enforced or additional outsourcing is required.

In connection with the design of customer order driven engineering as a system, special attention must be paid to the prevailing uncertainties in order to reduce the risk as much as possible and to improve the controllability. Using the definitions proposed by Galbraith (1973), there are two ways of achieving this:

- *reduce the uncertainty*, and thereby reduce the risk. This can be achieved by expanding the amount of information which is available or by reducing the information requirements;
- *take measures to manage or deal with the uncertainty* and the associated risks. This can be achieved by, for example, incorporating slack.

These aspects and the choices which can be made in this connection are discussed further in Chapters 4 through 7 in connection with redesigning the system.

3.8 Further analysis of the problem issues

Based upon an extensive analysis of the selected case situation, a number of important problem areas have been identified in connection with the process of customer order driven engineering. These problem areas are described in more detail in this section. The problem issues are first summarized, below. This is followed by a detailed discussion of these issues.

3.8.1 Summary of the current problem issues

The current internal and external performance in the selected case is far from optimal. This is apparent with respect to:

- uncontrolled product quality, evidenced by the large number of engineering changes which take place after the engineering drawings have been released. In addition, an

extremely large number of quality problems are discovered during the internal product assembly phase and when the product is installed at the customer site;
- uncontrolled internal throughput times for the customer order driven engineering as well as for the physical production processes. This results in a situation in which over 60% of the customer orders are delivered too late;
- uncontrolled customer order costs, evidenced by the large discrepancies between the budgeted costs and actual costs as well as profit margins which are too low.

A significant number of the problems described here appear to be associated with the non-physical customer order driven engineering phase. In view of this, an in-depth analysis of the connection between the problems found in the customer order driven engineering and the problems concerning quality assurance, production control and cost control for the organization as a whole is used as the starting point for the redesign of this phase (see also Timmermans 1991). The results of this analysis are presented in the sub-sections below. In connection with this, a distinction has been made between the problem issues related to the engineering process (P), the control of the engineering process (C) and the provisions for management information (I).

3.8.2 Analysis of the engineering process

The most important problems concerning the current customer order driven engineering process are analyzed in this sub-section. This provides a basis for the new design for this process as presented in Chapter 4.

♦ *The structure of the customer order driven engineering process*

The most important problem concerning the current engineering process in the selected case is the absence of a proper structure for this engineering process. Several different aspects are involved. In the first place, a formal engineering approach is missing. The use of a formal approach implies, for example, that a product is developed following a certain method which takes the customer-specific requirements into account and translates the specified functions into a tangible form via a series of formal engineering steps (Pahl and Beitz 1988, Roozenburg and Eekels 1991). This type of formal, structured approach is not used within the current engineering process. The current engineering approach can be characterized as "engineering based upon previous products". Customized products are engineered based upon designs which have been used in the past and approximate (to some extent) the same functionality. Each product engineer and detail designer is free to contribute his own interpretation of how the product is to be developed, however. Formally approved and accessible product standards are missing. This problem is complicated by the fact that the documentation related to previous orders is poorly organized and poorly indexed. A formal description of the current engineering method also does not exist. This means that quality assurance is virtually impossible and that the training of new employees is hindered due to a lack of documented procedures.

In the second place, the various documents have not been defined formally which are produced, nevertheless, to describe the product in the various stages of engineering. Each product engineer and detail designer has his own way of documenting the product specifications. For example, there is no formal approach for developing engineering drawings and there are no naming conventions for identifying components. As a result, a multitude of problems may arise with respect to different interpretations of the product specifications. It is also apparent that the result of one of the important phases in the engineering process is not even documented. During the quotation phase, the general product specifications produced based upon the sales checklist are not recorded. Only a list of the so-called product functions is written down in the form of a general technical description. In reality, these are not the actual product functions but are rather references to previously developed technical solutions. The details of the proposed product concept are not documented, but remain in the product engineer's head in this way. This means that there is no opportunity for a meaningful review of the product concept, in spite of the fact that this forms the basis for determining the quotation price and the quoted delivery date.

In the third place, the coordination and communication between the various disciplines during the customer order driven engineering process is poor. This is true with respect to the transfer from Sales to the Product Engineering Department as well as the transfer from Product Engineering to the Detail Design Department. The coordination activities and the communications about customer orders involve substantive information only when (acute) problems arise. This lack of coordination and communications can be seen as a direct result of the absence of a formal engineering approach and formal engineering documentation. This means that each discipline tends to develop its own standards and documents for use within that particular department rather than for the effective communication of information to other disciplines. This inhibits the effective coordination of activities and communications between departments and leads to the creation of "functional walls". Order information is then merely "tossed over the next wall" following the completion of each step in the process.

♦ *The technical engineering split in terms of installation units*

Within the Detail Design Department, a custom-built machine is split into so-called *installation units*. Each installation unit represents a group of components and sub-assemblies belonging to a certain machine which are assembled together at the same time. A separate assembly order is also issued for each installation unit. Each installation unit is engineered individually, in the same sequence as the assembly sequence for the installation unit. As soon as the engineering for an installation unit has been completed, this documentation is released to the Production Division. A custom-built machine is split into installation units based upon the standard grouping of components which is pre-defined for the basic machine of this type. As such, the installation units can be seen as the highest level of the bill-of-materials. Each installation unit thus represents a separate set of drawings and bills-of-materials at a lower level. Each installation unit is modified as necessary to comply with the customized specifications. The current grouping in installation units has developed gradually over a long period of time, however, so that this now does not necessarily represent a partitioning of the product into modules which are logical from an engineering point-of-view. Some of the installation units have been defined as such because they are purchased from external suppliers or because they are assembled in a single operation. Nevertheless, there are a large number of interrelationships between the installation units. As a result, most of the installation units are not very modular and cannot be engineered independently, even though this is attempted in practice. The installation units associated with a given customer order are engineered and released more-or-less individually, often by different persons. In many instances this results in a situation in which installation units which have been released to the Production Division need to be recalled for modifications. This means that there may be a significant flow of (rush) orders for engineering changes for components which are already in production. This has a serious negative effect on the quality, financial result and timeliness of the customer orders.

♦ *Customer order driven and customer order independent engineering*

Within the Engineering Division, no sharp distinction has been made between customer order driven and customer order independent engineering. Customer order independent or innovative engineering is generally carried out based upon specific customer orders in the current situation. Whenever there is a requirement for a new function, a new product module or even a new product family, the current policy is to wait until a suitable customer order has been received which can then be used as the basis for the new development. The advantage of this approach is that the customer pays, at least partially, for developing the innovation in this way. This approach also has a number of major drawbacks, however:

- the technical risk is relatively high due to the innovative character of the development. This means that significant financial and time risks could also be present. This type of customer order can, in addition, always be characterized as being difficult to control;

- the basic nature of customer order independent engineering is different from customer order driven engineering. Since it is intended that the first type of engineering should lead to the establishment of future product standards, it is important that innovations in this respect are properly developed and tested with respect to the technological and financial (cost price) feasibility. Characteristic of this type of engineering is the attitude that "it can always be improved". This attitude is not appropriate in connection with customer order driven engineering where customized developments are generally one-of-a-kind and the motto should be "good is good enough". If customer order independent engineering is linked to actual customer orders, then there is a real danger that insufficient attention will be spent on the objectives which are independent of the customer order.

3.8.3 Analysis of the controlling system

The most important problems associated with the current controlling system for the customer order driven engineering process as analyzed in this section, provide a basis for the redesign of this controlling system in Chapters 5 and 6.

♦ *The formal controlling system*

A formal controlling system for customer order driven engineering is absent in the current situation. This is apparent with respect to a number of aspects. In the first place, formally defined control decisions and the responsible decision-makers have neither been defined nor identified. Control decisions in this sense should be found with respect to, for example: issuing quotations, setting prices, accepting orders and releasing work orders. Since these decisions have not been formalized, the related responsibilities and delegated authorities within the organization remain vague and ambiguous. In practice, this means that many of the control responsibilities are carried out, and priority decisions made, at a level which is (too) low in the organization by persons who would normally not be authorized to make such decisions. Given this ambiguity concerning responsibilities and authorities, no one feels responsible and it is difficult to hold anyone responsible for a specific order result.

In the second place, a formal review of the requests for quotation is not carried out. Since it is not possible to respond to all of the requests for quotation which are received during a given period of time, a method is needed for prioritizing and accepting such requests. This should be based upon criteria which are important to the company such as the product/market strategy. This prioritizing is not done in the current situation. Requests for quotation are accepted or rejected by various individuals within the sales organization and priorities are established based upon individual discussions with the product engineers. An explicit risk analysis concerning the requests for quotation is also absent. No analysis is made in advance of the existing uncertainties which imply certain risks. As a result, unpleasant surprises often occur in a later phase. This type of risk analysis could provide important input for the acceptance and establishment of priorities for processing the requests for quotation. Since no risk analysis is currently performed, no distinction is made between the requests for quotation which would fall into different risk categories.

In addition, there is no connection with the control of the physical production. The absence of a formal controlling system has a strong negative influence on the quality of the control of the physical production process in view of the importance of the customer order driven engineering for the physical production and the fact that this phase precedes the physical production activities. This is evidenced by, for example, the chronic internal tardiness of the engineering activities due to the absence of an internal control over the throughput times and resource capacity planning within the various engineering departments. This means that significant work backlogs exist even before the physical production activities are initiated.

♦ *Calculating a full cost price*

In the current situation, the quotation prices are determined in part by calculating a full cost price based upon average hourly rates with surcharges for allocating the indirect costs. A similar method based upon multiple surcharges (Horngren and Foster 1991) is often used in practice, even by larger companies which produce a wide range of different products (Howell et al. 1987). In view of the simplicity of this approach and the method used for allocating costs, however, there is little causal relationship between the indirect costs and the product at hand. In addition, the actual control effort and the actual use of indirect resources may vary radically between product groups as well as between orders in view of the diversity of products (particularly between product groups) in the selected case situation. Use of the current method of calculating cost prices and the "arbitrary" allocation of indirect costs means that certain product groups may be burdened with excessive costs while a fair share of these costs is not allocated to other product groups (see also Cooper and Kaplan 1987). The allocation of *direct* costs is, in fact, also imprecise due to:

- the lack of a formal engineering approach which implies that estimates of the material costs generally will be inaccurate;
- the lack of a risk analysis which implies that a reliable estimate of the required hours per type of direct resource capacity cannot be made.

A number of arguments can be brought forward to support the conclusion that the allocation of indirect costs to possible orders as currently done in the selected case situation does not provide any added value:

- in view of the radically different products and product groups in the selected case situation, it is virtually impossible to establish a causal relationship between a number of indirect cost categories and a potential customer order. Examples of these indirect cost categories include data processing costs, office space and the costs associated with customer order independent engineering. An arbitrary (detailed) allocation of these costs has no value with respect to predicting the actual costs of a customer order;
- the final price level in the selected case situation is dictated to a large extent by market conditions and is, thus, not determined by the company based upon the cost price. It is therefore not necessary to calculate an accurate and detailed full cost price for this purpose;
- The extent of the uncertainty in the selected case situation is such that there is very little knowledge of the product volume and mix regarding the future orders. If costs are allocated arbitrarily, then it is certainly not useful to do this at a detailed level in view of the uncertainties.

The calculation of a full cost price to be used as the basis for determining a quotation price does not appear to be worthwhile in the selected case situation in view of the fact that the price level of a potential order is dictated primarily by market conditions and that the allocation of indirect costs to potential orders cannot be done reliably.

♦ *The quality assurance system*

A structured approach to quality assurance is totally absent with respect to the customer order driven engineering (see also Section 3.5). Engineering reviews are held only on an ad hoc basis. In practice, this leads to a large number of quality problems during the physical production phase and a large number of engineering changes after the engineering drawings have been released.

In view of this situation, it should be clear that there is no evidence of an integrated control of the quality, timeliness and cost factors.

3.8.4 Analysis of the management information resources

It is not surprising to discover that there is little evidence of an integrated management information system in the selected case situation in view of the absence of a formal controlling system for customer order driven engineering. Several local information systems have been established, however, these systems are not integrated. The most important systems are:

- a quotation registration system in which each receipt of a request for quotation is logged and the issued quotations are registered;
- a (financial) project administration system in which project costs are entered for the purpose of keeping track of the project investments. This information is of limited use for the (cost) control of orders in view of the financial nature of the data, the delay in entering and processing the data in the system and the budgeting structure which is used (see previous discussion);
- a network planning system in which the project network structures for potential customer orders can be defined in order to generate resource capacity requirement profiles. This information is then used to determine final delivery due dates. This network planning system is completely separate from the management information system for the physical production process, however. The network planning system is also used to track the progress of aggregated activities (at a high level) based upon summary data provided by the various departments.

In the current situation, there is little systems support for the registration of data to monitor the status and progress of customer order driven engineering activities. Status information is collected on an ad hoc basis (primarily verbally) and generally consumes a significant amount of time.

3.9 Summary

In can be concluded from the analysis presented in the previous sections that the system structure for customer order driven engineering as described within the selected case is far from being optimal. In terms of the control model (see Chapter 2), this conclusion applies to the transformation process as well as to the controlling system and the management information system. In summary, it is clear that there is a primary focus on creativity and that insufficient attention is paid to structure and control in the selected case situation. The system of customer order driven engineering in the selected case situation is redesigned in Chapters 4 through 7, based upon the description and analysis presented in the present chapter. The design of the engineering process is described in Chapter 4. The controlling system is discussed in Chapters 5 and 6. Finally, the management information system is designed in Chapter 7.

Chapter
4 DESIGNING THE ENGINEERING PROCESS

4.1 Introduction

It should be apparent from the analysis presented in Chapter 3 that the design of the customer order driven engineering process is not optimal in the selected case situation. There is no proper definition of the different engineering sub-processes and engineering documents in addition to the lack of a formal engineering approach. This leads to a situation in which every employee is left to establish his own methods and standards, resulting in significant quality assurance problems and the associated production control and cost control problems during the lifetime of a project. The customer order driven engineering process is redesigned in this chapter. The basic objective here is to redesign the engineering process in such a way as to ensure that the new process will provide a good transformation of the customer's requirements into a product description which is feasible to produce (the quality factor).

Engineering principles have been borrowed from the mechanical engineering literature since the quality of this engineering process is of primary importance. The structure and the phases of the customer order driven engineering process have been derived in this way. Control requirements are also included in the design of the engineering process (see Section 2.5). This aspect completes the design of the customer order driven engineering process.

The terms *designing* and *engineering* are often used interchangeably in the literature. In a number of publications, however, a clear distinction is made between these two terms (see, for example, Roozenburg and Eekels 1991). Engineering covers a much broader area in this case. Product engineering and detailed design are seen as processes which are part of the total engineering activity. In view of the type of research (design-oriented research) described in this book, the term *design* will be used mainly to describe the research activities in order to prevent any confusion. The terms *engineering, product engineering* and *detailed design* will be used solely in conjunction with the transformation process which is the subject of this research. The term *product description* will be used to refer to the output of the different customer order driven engineering sub-processes.

Section 4.2 describes the design variables which are included and excluded from the design of the engineering process. The steps in the engineering process are then covered in Sections 4.3 and 4.4. The design requirements in connection with controlling the process are explained in Sections 4.5 through 4.7. The design of the engineering process is considered to be complete with the inclusion of these design requirements. Attention is focused on a number of organizational aspects in Section 4.8, the final section in this chapter.

4.2 Design variables used

Before the main points of the engineering process are discussed, the selection of design variables used in this research is explained in this section. Reference is also made to the scope of the design as presented in Section 2.6. In particular, the design variables which are most relevant from a workflow point-of-view have been chosen for the design of the customer order driven engineering process. Special attention has been paid to the processes and activities to be carried out, the structure of the processes and the products which result from these processes. Less attention is paid to the design variables which are most relevant from a resource point-of-view in the design of the customer order driven engineering process in this book. This means that very little is said about the human resource aspect, including issues such as:

- which skills or persons are required;
- the education and training requirements;
- motivating and compensating employees.

The design variables mentioned above, of course, play a role in designing the transformation process and, thus, influence the quality of the product description. Nevertheless, they have been excluded from this research. It is assumed that this aspect has been addressed sufficiently in the selected case in connection with the development of the organizational design. The important organizational aspects in connection with the communication and coordination between the disciplines associated with the customer order driven engineering process will be discussed, however.

Product → Form and characteristics → Functions → Satisfy a need

Figure 4.1a Relationship between product form and need

Satisfy a need → Functions → Form and characteristics → Product

Figure 4.1b The logical reasoning involved in product development

4.3 Engineering: the phases in the engineering process

Initially, a more detailed analysis will be made of the major points of the engineering process in order to be able to develop an optimal design for the customer order driven engineering process. This analysis is based primarily on the work of Roozenburg and Eekels (1991) and Pahl and Beitz (1988). A product is defined in this connection as a tangible system which is produced for the sake of its form and characteristics. A product's form and characteristics allow it to perform certain functions which satisfy a certain need. This logical relationship between the form of a product and the need which is satisfied by the product is illustrated in Figure 4.1a. A product is generally developed in the opposite direction, however. Based upon the needs to be satisfied, the functions which the product must perform are defined. The engineer is responsible for making the logical connection to decisions concerning the product form, based upon decisions about the functions which the product will need to fulfil (see Figure 4.1b). The form of a product can be defined in terms of the spacial (geometric) form as well as the physical/chemical form (material composition). The final development of a product therefore involves defining the spacial and physical/chemical form which the product should have in order to be able to perform the desired functions after it has been manufactured.

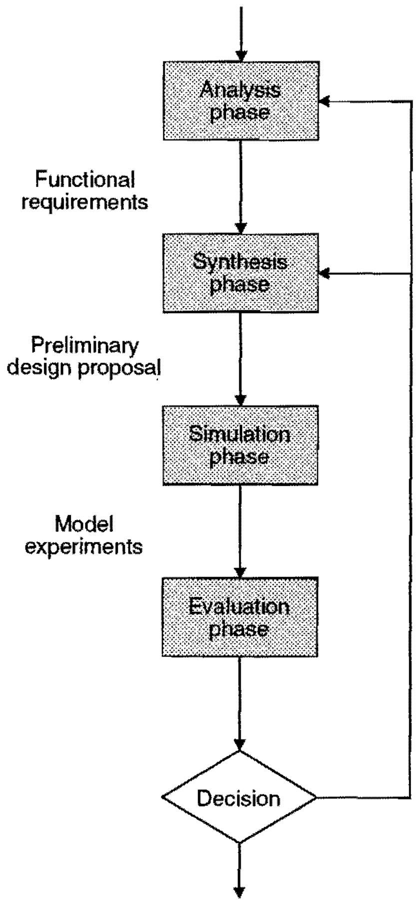


Figure 4.2 The basic development cycle (Roozenburg and Eekels 1991)

The core of the (mechanical engineering) product development problem is, therefore, the task of reasoning in reverse from function to form. The form of the product is the unknown entity. The question, however, is whether we are able to derive the spacial and the physical/chemical form from only the definition of the function to be fulfilled, the knowledge of the laws of nature and a logical reasoning process. The answer is "no", since many product solutions are theoretically possible. The reasoning from function to form (the development process) is not deductive (logically correct, in a formal sense; Roozenburg and Eekels 1991) but rather reductive (logically non-determinant, in a formal sense). Inductive logic can be seen as another example of reductive reasoning. The creative element of development is found in the reasoning from function to form. The central question is how the engineering process should be designed in order to ensure that this process produces valid conclusions and results. This assurance can be obtained by adding content and structure to the process of engineering reasoning from function to form.

♦ *The steps involved in the engineering process*

In developing a product, a line of reasoning is followed which starts with a purpose (the function) and ends with the means of achieving this purpose (the product description). Also in this engineering process, many different means can be found to achieve the intended purpose. Because of this, it is not always immediately clear which means will be the most efficient. As a result, product development basically becomes a trial-and-error process. This process consists of a sequence of empirical cycles (De Groot 1981) in which the knowledge about the problem situation and the product increases in a spiralling fashion. Roozenburg and Eekels (1991) have developed a model, the "basic development cycle", to represent this development cycle. This basic cycle model is illustrated in Figure 4.2.

Developing a product implies that the basic cycle must be completed at least once. The function which the product must serve is used as the starting point. The developer gains an impression of the criteria which the solution must satisfy in order to fulfil the desired function (= the functional requirements specification) during the *analysis* phase. A preliminary proposal is then generated in the *synthesis* phase. The synthesis activity is more difficult to define than the other steps in the cycle since the phenomenon of "human creativity" plays an important role. In addition, this is certainly the most crucial phase because it represents the point in the development cycle at which the product concept is described explicitly. In the *simulation* phase an opinion is formulated concerning the behavior and the characteristics of the product description through the use of logical reasoning and/or experiments with models. Simulations can lead to conditional predictions concerning the actual characteristics of the product. The value of the preliminary product description is then determined during the *evaluation* phase. A decision whether to develop the proposed design further or else to generate a better design proposal is then made based upon the value of the product description. The first preliminary product description usually will not be satisfactory. In this case, there are then two possibilities for the feedback of experience (see also Figure 4.2), namely:

- the developer returns to the synthesis step and generates a new preliminary product description, or
- the developer returns to the analysis step and re-evaluates the functional requirement

specifications along with the possible types of solutions.

This basic development cycle can be viewed as a prescriptive model which dictates each successive step. This basic cycle is so general and abstract, however, that it offers no practical solution for a conscious structuring of the engineering process in this form. Nevertheless, the basic cycle and the associated concept of a spiralling development can still be used to define a structure model or a phase model for the engineering process (Roozenburg and Eekels 1991).

♦ *The structure of the engineering process*

The engineering process is divided into phases of associated development activities in a structure model or a phase model for the engineering process. These activities each produce a product description at a certain stage of development. These successive product descriptions do not provide for alternative designs, but instead represent ongoing developments of the same product description which become increasingly detailed and concrete. There is a decision point following the completion of each phase; at this point the cumulative results are reviewed and evaluated before a decision is made whether to continue with the next phase. The basic development cycle is followed within each phase (see Figure 4.2) as the level of development becomes increasingly concrete. Phase models are based upon the concept that the product description being developed can be documented successively at three levels of abstraction, namely:

- in the form of a functional structure;
- as a structured set of solution principles;
- as a fully specified technical product description.

These three levels of abstraction for the product description being developed will be explained in more detail here using a concrete example borrowed from Pahl and Beitz 1988). Assume that we wish to develop a potato harvesting machine. The primary function of the machine in terms of a system can be defined as the transformation of flows of materials, energy and information (Pahl and Beitz 1988). The primary function essentially indicates which system behavior is desired within the given system environment. The primary function can be decomposed into a simple functional structure (Figure 4.4) when the primary function is described as a "black box" (Figure 4.3). A functional structure represents the behavior of a product in the form of a model of the sub-functions and the interrelationships between these sub-functions. A relationship between two sub-functions can have numerous meanings, such as a sequence relationship or a dependency relationship. The functional structure can then be developed further by providing more details for the various sub-functions.

Figure 4.3. The primary function of a potato harvesting machine (Pahl and Beitz 1988)

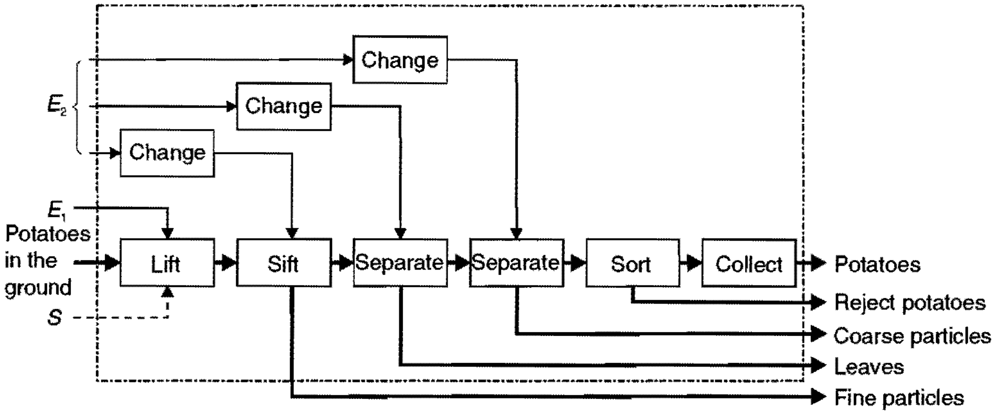


Figure 4.4. A simple functional structure (Pahl and Beitz 1988)

At a subsequent level, a review is carried out of known physical, chemical or biological effects which could be utilized to create the various sub-functions. A *solution principle* for a given sub-function is determined by deciding on the desired output in combination with decisions regarding the product form and materials. Several examples of sub-functions, their output and solution principles are presented in Figure 4.5. A *sub-function* in this context can be defined as a function of a subsystem which contributes to the realization of the total function of the system (= product). Exactly one solution principle is selected for the material composition of a sub-function. This aspect determines the level

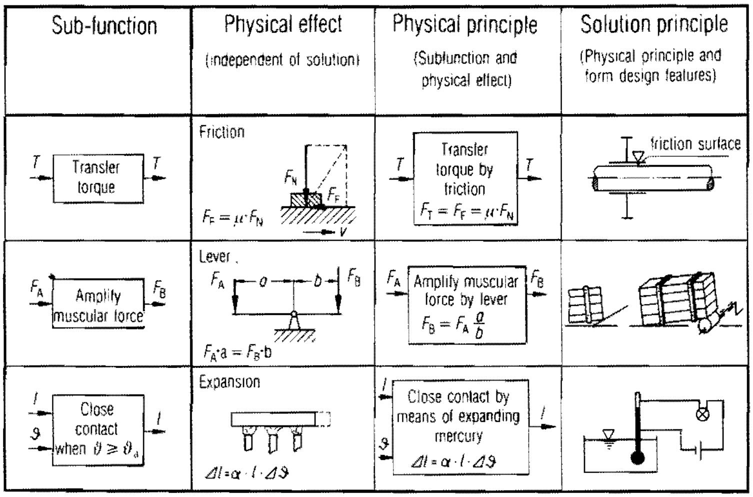


Figure 4.5. Examples of sub-functions and solution principles

of detail of the functional structure in terms of sub-functions. A number of alternative solution principles for the sub-functions of the potato harvesting machine are presented in Figure 4.6. A solution principle thus defines a part of the final product description (the geometry and materials). The choice of a solution principle in this case, in particular, concerns the logical reasoning from function to form in view of the fact that a transformation from abstract sub-functions to more concrete product form and material characteristics takes place. The selected solution principles are developed further, resulting in a detailed or *technical* product description at a subsequent level. The product description at this stage consists of completed technical drawings, bills-of-materials and production documents. Physical production activities can be initiated based upon these documents. The development of a detailed technical product description essentially means that more of the product characteristics are defined more precisely and that the solution principles are developed and integrated into a total detailed technical design. The process of developing a detailed technical product description is typically carried out in three steps due to the fact that many characteristics need to be taken into account. These three steps are:

- the development of a "product concept" (or modular structure); the solution principles are sufficiently detailed at this stage to allow other characteristics to be evaluated in addition to the technical and physical operation of the product. In connection with this,

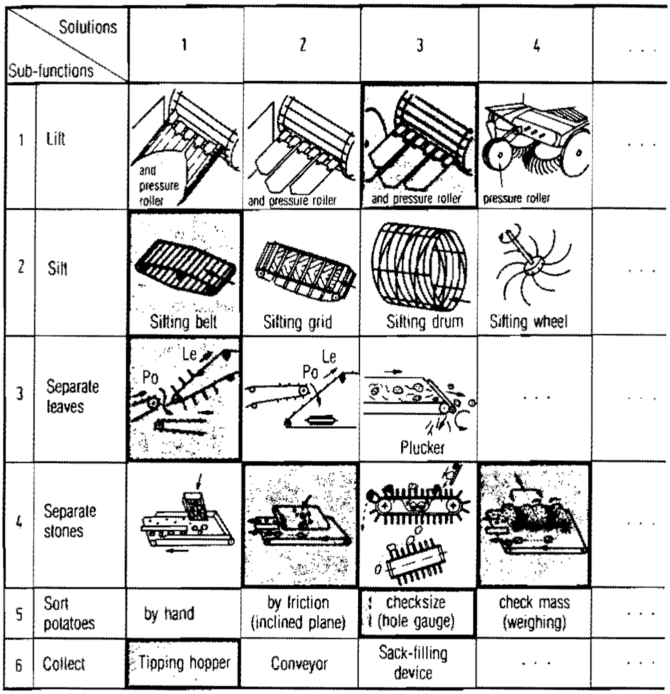


Figure 4.6. Sub-functions and solution principles for the potato harvesting machine

the parts and components need to be known to some extent, including the general form and the types of materials to be used in these components as well as the important interrelationships between the components;

- the development of a "preliminary draft"; the characteristic of a preliminary draft is that the primary sizing and the materials have been established for the most important product components;
- the detailed definition of the geometry and the materials for all of the product components, including the preparation of drawings and bills-of-materials.

An extremely large number of phase models for the engineering process or product development process based upon the above-mentioned levels have been proposed in the literature about product development. Examples of this have been published by Hansen (1976), Rodenacker (1976), Roth (1982), Pahl and Beitz (1988) and VDI 2221 (1986). These models all closely resemble each other and, for the most part, differ only with respect to the terminology used. The phase model proposed by the Verein Deutscher Ingenieure (VDI 2221 1986) is used here as the basis for designing the customer order driven engineering process. This model, in particular, is cited frequently in the international professional literature. In addition, the links to, and the definitions of, the various engineering stages are presented most clearly in the VDI model.

The VDI phase model is presented in Figure 4.7, with terminology which has been modified somewhat to relate better to the customer order driven engineering process. Four overlapping product development or engineering phases can be identified, namely: problem analysis, conceptualization (product concept development), detailed technical design (technical development) and production specification (generating the production documents). These four engineering phases can be divided into a total of seven concrete engineering steps and deliverables. The first engineering step is defining and analyzing the customer's problem. This results in a definition of the functional requirements for the custom-built product. This first engineering step is included in the problem analysis phase. The second engineering step involves defining the functions and sub-functions which must be included in the product. This results in a description of the functional structure of the product (see also Figure 4.4). The third engineering step concerns the development of solution principles. This results in a description of selected solution principles and alternatives which are related to the functional structure of the product. In the fourth engineering step, the sub-functions and associated solution principles are translated into feasible product modules which, together, form the modular structure. A *product module* is a collection of interrelated product components which perform one or more sub-functions. There are more interrelationships between product module components than between the components of different product modules. The overlap between product conceptualization and the detailed technical design of the product starts with the definition of the product modules. Defining the product modules results in a modular structure for the product. We refer to this as the product concept. The modular structure defines the interrelationships between the various product modules. Similar to the relationships between sub-functions, the relationships between two product modules can have various meanings, such as a functional dependency. The fifth engineering step provides for a general specification of the geometry and the materials to be used in the most important modules. This results in a preliminary draft of the product in the form of sketches and general specifications. The detailed geometry and materials are defined in the form of technical drawings and bills-of-materials during the sixth engineering step. The technical documentation for the equipment is also prepared. The (detailed, technical) product description can be considered to be complete after this engineering step. The manufacturing and assembly instructions for all of the product components and sub-assemblies are developed in the seventh and last engineering step. This activity is also referred to as process planning. This activity produces the production documentation needed to produce the product.

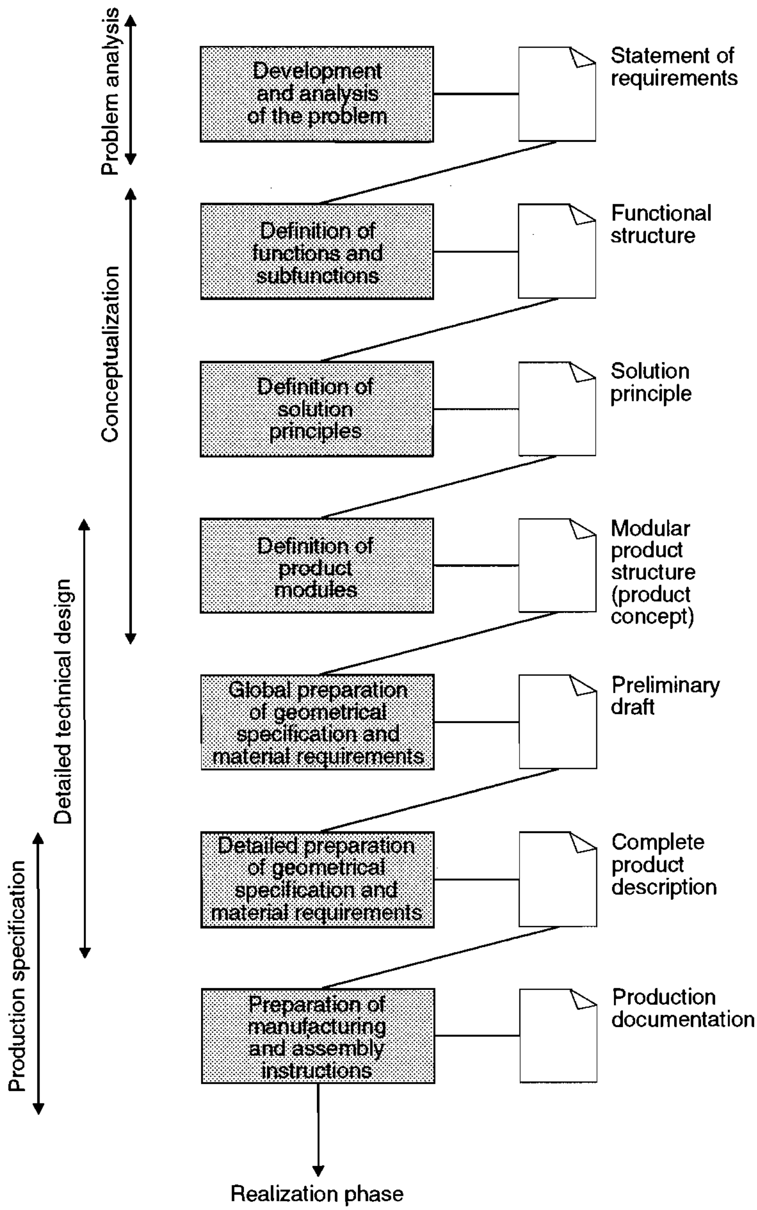


Figure 4.7. Phase model for the engineering process (based upon VDI 2221 1986)

4.4 Explanation of the terminology used

4.4.1 A customer order dependent product description

The structure of the engineering process and the associated engineering steps based upon the VDI phase model were described in the previous section. By following this approach for customer order driven engineering, we can conclude that a custom-built product should be developed based upon a number of successive engineering steps. In each step, the customer-specific product description is worked out in more detail at a more concrete level. In this way the customer's functional requirements are transformed into a detailed product description. Each engineering step results in a product description which represents a specific stage of development. The contents of these successive versions of the various product descriptions are similar in many respects since they, of course, describe the same future custom-built product in various stages of development. The relationships between the various product descriptions referred to in the previous section are represented in the form of a data structure diagram in Figure 4.8. The graphical notation used in the data structure diagram is based upon the conventions used by Martin (1987). The successive development stages of the custom-built product can be easily recognized via the data structure diagram in this way.

The most important entities and entity relationships are explained briefly here. A custom-built final product is initially specified in the form of a functional requirements document. The final product to be developed is then defined in terms of one or more interrelated sub-functions which can be represented in the form of a functional structure. A technical solution principle is chosen for each sub-function. This solution principle can be used a number of times for various sub-functions. The product modules are then defined. Each product module consists of a collection of associated components (items) which are ready to be assembled in order to carry out one or more sub-functions. A sub-function is, per definition, always performed by a single product module. The interrelationships between the various product modules are represented in the modular structure. A bill-of-materials is prepared for each item to be assembled when it concerns a sub-assembly. The production documents and drawings needed to produce each item are also prepared.

4.4.2 Standard product descriptions

An important aspect in connection with performing the various engineering steps is the use of standard product descriptions as starting points. A standard product description is a

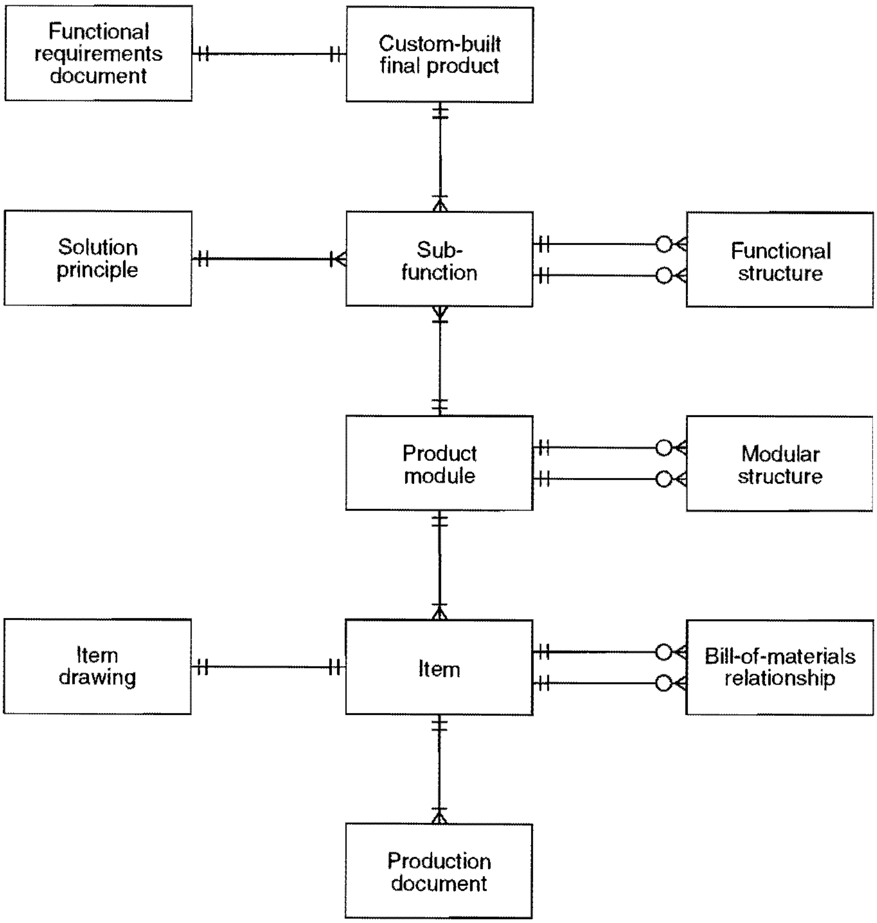


Figure 4.8. Data structure diagram for a customer order dependent product description

product description at a given stage of development (e.g., a sub-function) which has been developed and documented independently of any customer order. Standard product descriptions are used to support the engineer by providing reference examples for developing custom-built products. A number of important benefits in terms of quality, time and cost can be realized by developing or engineering a product, to a certain extent, independently of the customer order (see also Sub-section 1.4.2). The degree to which customer order independent engineering takes place can be expressed in terms of the OSL (see Sub-section 1.4.2). For each of the three product families in the selected case described in this book (see Sub-section 2.6.2 and Chapter 3), OSL-4 has been chosen. This means that standard functional structures for reference purposes and alternative solution principles have been defined to support the second and third engineering steps. In addition, a significant number of product modules have been defined and developed to support the fourth through the seventh engineering steps.

Similar to the data structure diagram for a customer order dependent final product, a data structure diagram can also be designed to define the interrelationships between the various standard product descriptions belonging to a product family (see Figure 4.9).

The most important entities and entity relationships are explained briefly here. Product families are defined based upon standard reference structures which are similar to each other with respect to the ultimate function of these products. One or more standard products may be maintained for each product family. The extent of the development of a standard product is dependent upon the extent to which the engineering has been independent of the customer order. One or more standard sub-functions may be maintained or, alternatively, a complete functional structure. One or more alternative solution principles may be documented per sub-function. These alternative solution principles could differ with respect to, for example, performance. One or more standard product modules may be defined or, alternatively, a complete modular structure may be defined.

Standard product modules to be used for reference purposes may vary with respect to their degree of customer order independence. A distinction can be made between the following three types of standard product modules:

- a *universal* product module; this type of standard product module is defined as an interrelated collection of components which performs one or more sub-functions based upon standard sub-functions and solution principles. As such, a product module is defined but the material composition has not yet been determined. This means that there is still an extremely high degree of uncertainty with respect to the product specifications;
- a *generic* product module; this type of standard product module is completely developed with the exception of one or more of the variable parameters (e.g., dimensioning). As soon as a value is assigned to the remaining parameter(s), the full specification of the product module can be generated automatically. This means that a consistent engineering result is obtained, regardless of the person assigned as the engineer. The uncertainty with respect to the product specifications in this case is limited to the values to be assigned to one or more of the engineering parameters;

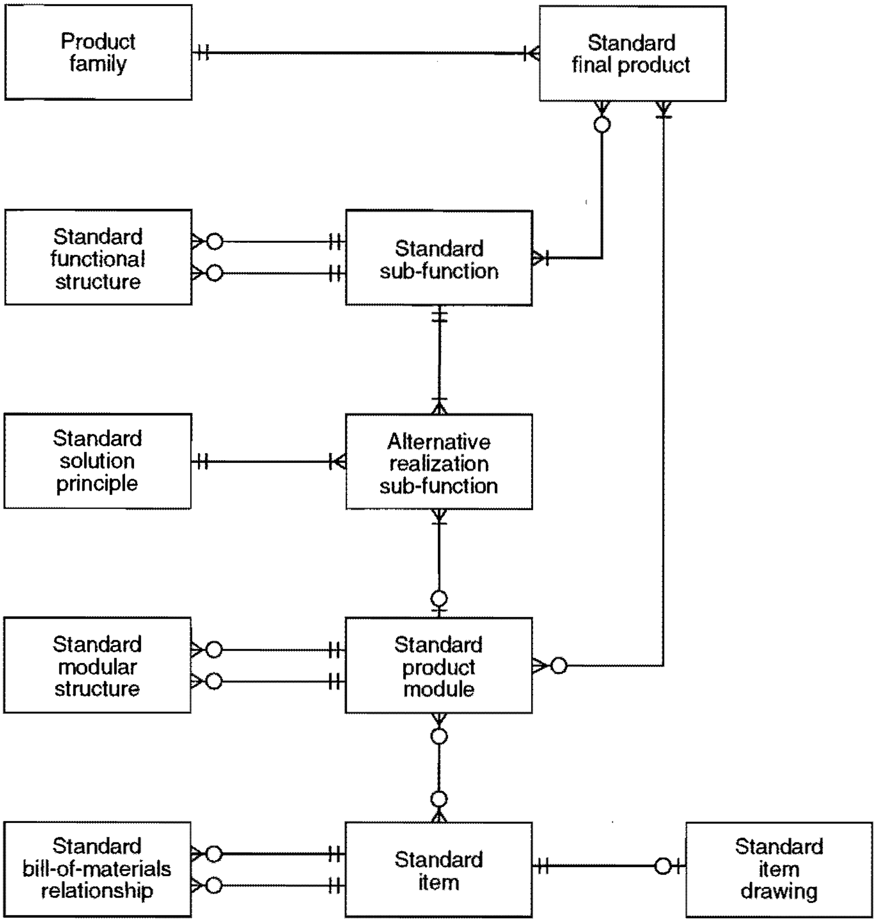


Figure 4.9. The interrelationships between standard product descriptions

- a *fully specified* product module; this type of standard product module is pre-defined to the extent that bills-of-materials, technical drawings and production documentation have already been prepared. These product modules could also be produced as intermediate products to be held in stock, completely independent of a customer order. There is no uncertainty with respect to the product specifications when a product module has been fully specified. The final product specifications can, of course, be modified in accordance with customization requirements.

Above all, the use of standard product descriptions as reference models enables the throughput time for the customer order dependent engineering steps to be reduced, especially when OSL-4 is used. The required engineering resource capacity and the related engineering throughput time can be reduced drastically by using previously defined standard product descriptions as much as possible. This is an important factor with respect to the engineering steps performed during the quotation phase. The use of standard product descriptions not only enables the company to produce a quotation within a relative short lead time (timeliness factor), but it also makes it possible to estimate the technical risk (quality factor) and the required resource capacity (cost factor) more accurately with respect to the further engineering and production of the envisioned product concept.

The model for the engineering process presented in Figure 4.7 will be used here as the basis for designing the customer order driven engineering process. The design requirements resulting from cost control, production control and quality assurance will be discussed in the following sections. The customer order driven engineering process is designed by the successive application of these design requirements to the structure modeled in Figure 4.7.

4.5 Design requirements resulting from cost control

Requirements are associated with the design of the customer order driven engineering process from a cost control point-of-view. During the customer order driven engineering process, the first contact with potential customers concerns the possibility of supplying specific equipment (see Chapter 3). Since the equipment is customized and generally one-of-a-kind, an initial discussion is held concerning the equipment specifications and functions. Based upon this, the company provides a quotation to the customer which confirms the company's ability to supply equipment with defined specifications for a certain price within a stated period of time. Since this type of equipment is normally seen as a capital investment, the potential customer typically requests quotations from various suppliers and then compares them. This means that there is a significant chance that the potential customer will end up ordering the equipment from a competitor. The average success rate for quotations becoming orders in this specific market is relatively low, approximately 15%. The financial consequences of this relatively low success rate is that resource capacity is utilized and costs are incurred in connection with a large number of quotations which generate no revenue. This can be seen as a certain financial risk. From a cost control point-of-view, an important design parameter with respect to the engineering process is the determination of which engineering steps are to be carried out during the quotation negotiation phase and which engineering steps are to be carried out after a firm order has been received. In this section, the alternative choices in this connection and the way in which this will be accommodated in the selected case situation are discussed in that order.

4.5.1 Differentiating between the quotation phase and the order phase

Two extreme alternatives are conceivable in connection with separating the quotation phase from the order phase. One alternative is that only the problem analysis step, and thus no other engineering step, is performed during the quotation phase. The significant advantage of taking this approach is that only a limited amount of resource capacity is spent when there is a possibility of no revenue being received to cover this expense. The other engineering steps are then carried out only after the customer order is received. The major disadvantage of this approach, however, is that a quotation is made which commits the company to a price and a delivery date for the equipment, but based upon extremely limited knowledge of the product to be produced. The product uncertainty is close to maximum since it is assumed that the quotation is for a complex, customized machine. There are very few insights into the product specifications when only the problem analysis step has been carried out. It is extremely difficult to estimate the resource capacity requirements and costs associated with engineering and producing the product. Committing to a price and a delivery date in this type of situation involves significant technical, time and financial risks (see also Section 3.7). With the other alternative, all of the engineering steps are performed during the quotation phase. The major advantage of this approach is that the complete product description is completed before the quotation is made. All of the product uncertainties are eliminated in this way. A reliable estimate of the resource capacity requirements and costs can be made since almost all of the technical risks have been covered. The technical risk and the associated financial and time risks involved in committing to a price and a delivery date are, thus, much less in this situation. This alternative has two major disadvantages, however. In the first place, a large amount of (scarce) resource capacity is utilized to perform all of the engineering steps during the quotation phase, with a significant risk that the quotation will not result in an order. In the second place, performing all of the engineering activities during the quotation phase would require a throughput time which would be unacceptably long for just providing a quotation.

N.B.: in certain market situations the costs of preparing a quotation are paid by the customer, regardless of whether an actual order is ever placed. The costs of preparing the quotation are thus compensated in this way (e.g., in the construction industry). Nevertheless, the market situation used as the example here does not provide for paid quotations.

4.5.2 Designing the quotation phase in the selected case situation

Both of the alternatives have major disadvantages in addition to their advantages. In view of the major disadvantages associated with both of these alternatives (a large risk versus the use of scarce resource capacity and a long throughput time), neither of these alternatives are acceptable. The design approach chosen for the selected case described in this book needs to lie somewhere between these two alternatives. There are two ways (see also Section 3.7) to limit the above-mentioned risks according to Galbraith (1973), namely: reducing the uncertainty, or managing or hedging against the uncertainty (creating slack). If the latter strategy is followed, then this means that a certain extra margin in the price and/or delivery date needs to be added to each quotation in order to be able to cover the risks. The utilization of scarce engineering capacity in the quotation phase can be limited in this way. If the first strategy is followed, then a relatively large amount of scarce engineering capacity will need to be utilized in the quotation phase in order to reduce the uncertainties with respect to the product specifications. The strategy of *uncertainty reduction* has been chosen as the basis for the design of the customer order driven engineering process for the selected case described in this book and used in the research presented here. This means that a proportional part of the engineering steps are carried out during the quotation phase, with the (financial) risk that this effort and use of resource capacity will not be productive in a number of instances. A choice has been made for uncertainty reduction rather than for managing or hedging against uncertainty for the following reasons.

- Including extra slack in the throughput time and an extra margin in the price in the quotations would have an adverse effect in view of the market situation of the selected case. Requests for quotation can vary widely with respect to the degree of product uncertainty and technical risk. If there is little engineering activity associated with the preparation of quotations, then there will be only a limited basis for making a distinction between high-risk and low-risk requests for quotation. This will result in quotations being issued for low-risk requests which are too costly or have a throughput time which is too long, and vice-versa. In a highly competitive market, this would lead to losing low-risk orders which are normally the types of orders which are most desirable.
- The company in the selected case has already made a significant investment in customer order independent engineering based upon a strategic choice for OSL-4. These standard product descriptions can be used very effectively in the quotation phase. A number of engineering activities can be carried out in a relatively short period of time by making use of the available standard product descriptions as reference models. A significant amount of product uncertainty can be eliminated within a short throughput time in this way so that the identified risks can be reduced.

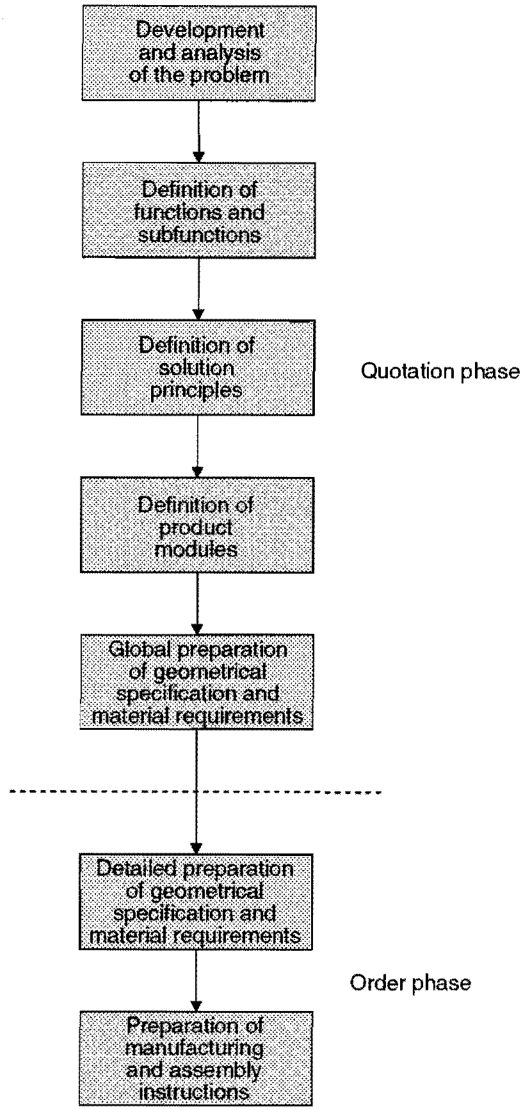


Figure 4.10. Splitting the customer order driven engineering process

Given the price level and delivery time restrictions, a sufficient number of engineering steps (but no more than this) need to be carried out during the quotation phase in order to be able to estimate the resource capacity requirements and costs with an acceptable level of risk. To estimate the material and manufacturing costs, the product description must be worked out to, minimally, the product concept level and the basic decisions regarding product geometry and composition of materials must have been made for the most important modules. In view of the chosen OSL in the selected case situation, it makes sense to perform the first five engineering steps (see Figure 4.7) during the quotation phase. This means that the product description is developed through to the preliminary draft in the quotation phase. The throughput time limitation imposed on the quotation phase is a significant factor here. If the customer requires a quotation quickly and the technical risk is limited, then it may be desirable to prepare the product description only through to the level of the modular structure. An assumption here is that a large number of standard product modules are applicable as reference models. Figure 4.10 illustrates how this customer order driven engineering process has been split into a quotation phase and an order phase for the selected case presented here.

4.6 Design requirements resulting from production control

Requirements for structuring the customer order driven engineering process can also be formulated from a production control point-of-view. For structuring the process for production control purposes, design guidelines will be used which have been developed for the production control of *physical* transformation processes. We will demonstrate that these principles can be adapted easily and used effectively for structuring the production control aspects of a non-physical transformation process such as customer order driven engineering. A number of basic design principles for structuring a physical transformation process, borrowed from Bertrand et al. (1990), are explained in this section. These basic principles will be adapted as necessary so that they can be used effectively for structuring a non-physical transformation process. The resulting design principles are then applied to the customer order driven engineering process in the selected case as illustrated in Figure 4.10.

4.6.1 Design principles for structuring the transformation process

From a production control point-of-view, two design principles have been formulated by Bertrand et al. (1990) for structuring a transformation process or primary process for the production of a finished product consisting of a specific set of production steps:

- defining operations;
- defining production phases and production units.

♦ *Defining operations*

A transformation process can be viewed as a set of production steps which must be completed in a certain sequence. Input materials and manufacturing resource capacity are both required to carry out each production step. The resource capacity is used to process and transform the input materials into output materials with a specified set of characteristics. The purpose of the production control is to coordinate all of the production steps included in the transformation process by assigning material and resource capacity to each of the production steps. It is sensible to aggregate a group of sequential production steps into a single "operation" when the same resource capacity is used and there are little or no intermediate waiting times. The production control problem can be simplified in this way since the total number of activities to be coordinated is reduced. An operation is thus the processing of a sequence of production steps whereby a certain amount of resource capacity is utilized to transform a specific input material or item into a new item with a specified set of characteristics. The selection of operations is an explicit step in structuring the transformation process.

♦ *Defining production phases and production units*

Even after the production steps have been aggregated into operations, the production control of the different operations is still typically a rather complex matter. The option of assigning all of the control activities to a single, centralized functional unit remains impractical. The complexity of the control requirements can be reduced further by aggregating operations into production phases. Each production phase then becomes a set of operations with an input material or product which is transformed to an output material or product. Subsequently, the production phases are assigned to a so-called production unit (PU). A PU is an organizational grouping of resource capacities with the following characteristics (Bertrand and Wijngaard 1986):

- internally organized such that the operations (associated with the assigned operations set) which are required to complete a given production phase can be performed independently, provided that the required materials and resource capacities are available;
- capable of making reliable commitments with respect to the specific conditions (such as utilization levels, throughput times, etc.) under which the operations belonging to a given production phase for a specified volume and for specified periods of time can be performed.

An illustration of the way in which a primary transformation process has been structured is presented below in Figure 4.11.

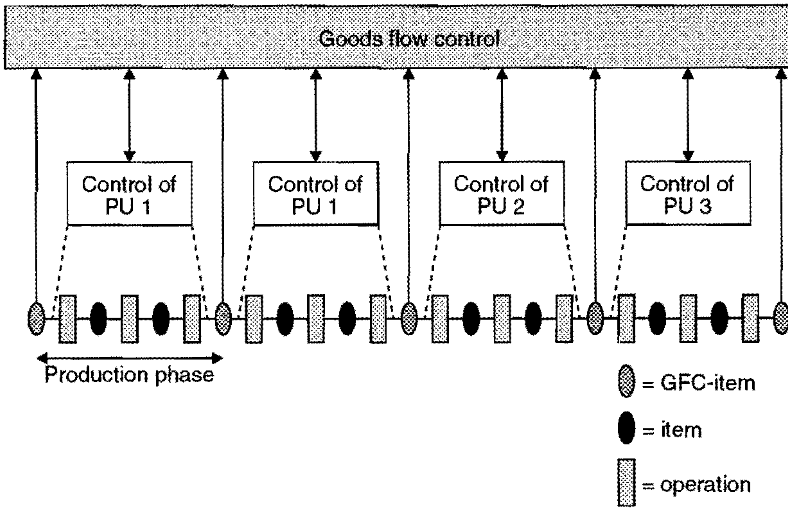


Figure 4.11. Structuring a primary transformation process

In this way the control problem is solved at two levels: the production unit control (PUC) level and the goods flow control (GFC) level. The use of GFC provides only for the coordination of the production phases in the transformation process. At this control level the total transformation process is defined only in terms of a set of production phases with relationships between these phases. Each production phase results in the delivery of a specified (intermediate) product which is referred to as a GFC item. Coordination of the production phases at the GFC level is accomplished by releasing work orders to the PU's to carrying out specific production phases to produce GFC items. A work order is therefore an instruction to initiate and complete a specific production phase. Execution of the work orders is subsequently controlled at the PUC level where the performance of the various work order operations are coordinated within a PU. Each individual PU is responsible for completing all of its work orders in accordance with the agreed conditions. It should be clear that the GFC cannot release work orders to the PU arbitrarily. The availability of resource capacity and materials must be taken into account when work orders are released. The decision to release work orders is made based upon information aggregated at a higher level, however. This is explained in more detail in Chapter 5.

The selection of production phases (and thus the GFC items) and the establishment of production units (by assigning production phases) are two explicit steps which need to be taken with respect to structuring the transformation process. A number of criteria can be identified for use in determining the GFC items and production phases as well as for establishing the production units (by assigning production phases).

4.6.2 Criteria for determining the GFC items and production phases

Four criteria can be identified for defining the GFC items and the resulting production phases (Bertrand et al. 1990 and Bertrand et al. 1992b).

Reducing uncertainty
The first criterion is the reduction of uncertainty. Whenever a significant reduction in uncertainty occurs at specific points in time during the transformation process, then it is advantageous to define GFC items at these points. In this way an opportunity can be created for reacting immediately to updated information at the GFC level. It is also desirable to create a buffer at each of these points so that the subsequent phase can be isolated from the uncertainties which exist in the previous phase. Examples of uncertainties in this sense are uncertainty of demand, uncertainty of yield, uncertainty with respect to resource capacity utilization and the uncertainty with respect to throughput time. By defining a GFC item directly following an operation for which the yield is uncertain, the actual yield information will be reported at the GFC level at the earliest possible point in time. In this way the updated information can be used to make adjustments as necessary to the production plan for the subsequent operations by changing the work orders and/or increasing safety stock or allocating additional production capacity.

Presence of a resource capacity bottleneck
The second criterion is the presence of a resource capacity bottleneck in the transformation process. A capacity bottleneck can be seen as a limiting resource for the transformation process which determines the maximum quantity of output per unit of time for the process. For this reason, it is of utmost importance to ensure an optimal utilization of the resource capacity at this bottleneck by controlling the release of work orders prudently at the GFC level. To achieve this, a GFC item should be defined immediately prior to the capacity bottleneck. In this way the most up-to-date information on progress will be available at the GFC level to determine which work orders should be treated with a higher priority or if capacity should be utilized to increase intermediate stock levels. A GFC item should also be defined after the bottleneck in the event that not all of the work processed at the bottleneck will be needed immediately by the subsequent operation in the transformation process.

The product structure

The third criterion is the product structure. Some components or sub-assemblies may be more critical than others for the overall coordination of the flow of goods. This is especially the case for situations in which complex assembly processes are required (for example, situations in which phantom parts are used in the MRP literature). When certain sub-assemblies are processed before others, this generally means that certain components will not be needed until a later point in time in the assembly process. Due to this type of sequential relationship between the components of an assembly process, an assembly process is often split up into phases. In this way the components which are not needed until a later phase of the assembly process can then be manufactured at a later date. This leads to the definition of additional GFC items (refer also to Bertrand et al. 1990, pages 30-31).

Materials intended for general use

The fourth criterion is the possibility that materials intended for general use may need to be allocated to specific semi-finished or finished goods. This decision should be made at the GFC level.

The four criteria described above are strongly oriented toward physical transformation processes and are, thus, not completely suitable in this form for defining GFC items within non-physical transformation processes such as customer order driven engineering. Nevertheless, specific criteria can be derived as special cases of the above-mentioned criteria; these criteria can then be used for defining the GFC items in the customer order driven engineering process. In contrast with physical transformation processes, the problems of an uncertain yield and an uncertain product demand are not found, as such, in connection with customer order driven engineering. The uncertainty which is foremost here with respect to the control aspects is the uncertainty about the exact product specifications, otherwise known as the product uncertainty. The product uncertainty decreases continually during the course of the engineering process, however, as the product specifications are defined in more detail. It is therefore important that this information is updated and reported to support an integral control and correction of the total transformation process as soon as a significant part of the product uncertainty has been eliminated. This is particularly important in view of the fact that the exact resource capacity requirements and the specific purpose of the various engineering steps are not known in advance. Information is only available in terms of which generic engineering steps need to be followed and which generic engineering documentation needs to be produced. The fact that the specific engineering activities to be carried out are not known ahead of time is primarily due to the creative nature of the engineering activities. For this reason, only a (rough) estimate of the resource capacity which will be required in the successive steps of the transformation process can be made in advance. It is not just the resource capacity requirements which are difficult to determine during the engineering process due to the fact that the product description is only defined in general terms when the customer order driven engineering is initiated. In addition, the resource capacity requirements for the physical production phase are not known and can, thus, only be estimated. Nevertheless, as the product uncertainty is reduced, a better estimate of the resource capacity requirements can be made for the remaining transformation processes (including the physical production). As better estimates are made, the previous control decisions can be evaluated and/or new control decisions made to redirect the remaining transformation processes as necessary. At these points in time, GFC items are needed in the customer order driven engineering process.

The criterion of the presence of a resource capacity bottleneck is directly applicable to the customer order driven engineering process and the definition of GFC items in connection with this. There is an analogous situation here in which a resource capacity bottleneck can occur, leading to the need for an optimal utilization which can be achieved via a separate procedure for releasing engineering orders.

The product structure in connection with the customer order driven engineering process (or, in other words, the structure of the product documentation) is relatively simple when compared with a physical transformation process in the selected case situation discussed here. The design of a product is accomplished by "producing" seven engineering documents (see Figure 4.7). There is no complex "assembly" activity. This means that the required GFC items are relatively easy to identify and define. Even so, this criterion is significant and applicable to customer order driven engineering due to the important sequential relationship between the customer order driven engineering process and the subsequent physical production. In the selected case situation, in particular, a complex assembly process is included as part of the physical production of the manufactured equipment. This assembly process is split into various sub-assembly activities and a final assembly stage. A certain sequential relationship is inherent in carrying out the various assembly processes. Certain sub-assemblies must be completed in advance of others. These sequential relationships have an important effect on the priority of carrying out certain engineering activities since the engineering activities related to the components which are needed first in the assembly processes, will need to be performed first. This can lead to a situation in which similar engineering activities for a given customer order are allocated to different engineering orders within the engineering process. This leads to different GFC items.

The fourth criterion which deals with materials intended for general use, is only relevant for physical transformation processes and, thus, will not be used in connection with customer order driven engineering.

4.6.3 Criteria for establishing the production units

A production unit is a set of resource capacities which can be utilized independently to carry out one or more production phases and, thus, to produce GFC items based upon released work orders. A set of related resource capacities is required for the processing of a production phase. Production units are established based upon the resource capacities needed for the processing in the production phases. Multiple production phases may be organized in such a way that they are included within a single production unit. In the event that a separate production unit is created for each production phase, then there will be an equal number of production units and production phases. This would generally be undesirable, however. In many situations it is likely that all of the resource capacities required by a number of different production phases will be included within a single production unit. In this case, all of the production phases assigned to a given production unit do not need to be linked together in the primary transformation process. We have identified two criteria for establishing production units by combining resource capacities (Bertrand et al. 1992b), namely:

- the nature of the required capability;
- the nature of the control issues.

Nature of the required capability

A production unit is defined as being a set of resource capacities which can perform a set of operations independently. The practical establishment of such a production unit is dictated partly by the particular technical and functional aspects of the primary transformation process. So-called "production departments" are typically established as the result of functional specialization, economies-of-scale and technical similarities. A production department is therefore an organizational grouping of resource capacities which are closely related with respect to the nature of the available capability. It is sensible to define the PU's along the same lines as the production departments whenever possible. This does not mean that a production department should always be defined to be the same as a PU, however. The PU's are typically product-oriented rather than operation-oriented. PU's are not based upon the functional specializations within the existing production organization. Normally, it does not make sense to create a PU and to assign production phases to it which require different and dissimilar skills and capabilities. This could lead to a resource capacity situation within the PU which is not easy to model at the GFC level, making it impossible to coordinate the aggregated resource capacities. The nature of the capabilities represented within a PU should be related in some way. The use of this criterion in practice may cause similar activities for different product families (e.g., engineering activities) to be assigned to different PU's when the required capabilities for one product family are significantly different than the required capabilities for a different product family. A clear product orientation may develop in this way.

Nature of the control issues

The complexity of the material coordination and the capacity coordination activities determines the complexity of the production control of a PU. Depending upon this complexity, four types of production situations can be identified (see Figure 4.12). The nature of the control issues may change at different points in time as the goods flow through the primary transformation process. In view of the different nature of the control issues, the control approach will be different in each of these production situations. Changes in the production situation can usually be identified as fixed points in the process. One example of this is the transition from manufacturing components to the assembly of components. In most situations involving the manufacturing of engineer-to-order equipment, the manufacturing of components can be characterized as a Job Shop situation while the assembly of components can be characterized as Project Assembly. It does not make sense to assign two production phases which require different control approaches to the same PU.

	Simple material coordination	Complex material coordination
Simple capacity coordination	Process manufacturing	Mass assembly
Complex capacity coordination	Job shop	Project Assembly

Figure 4.12. Classification of department situations (Bertrand 1989)

4.6.4 Applying production control design principles to the selected case

In the previous sections, the structuring requirements or design principles related to production control are identified which are to be applied to the design of a transformation process which needs to be controlled. These design requirements will be applied to the customer order driven engineering process in the selected case situation which is illustrated in Figure 4.10. The following topics will be discussed in sequence: defining the operations, defining the GFC items/production phases and creating production units.

♦ *Defining the operations*

The selected operations are named in each engineering step appearing in Figure 4.10. An operation in the customer order driven engineering process has a number of specific characteristics in comparison with an operation in a physical transformation process. In the first place, the input information in the customer order driven engineering process is transformed to other information (the output) while the input information remains intact. In this sense, new information is created. This is different in the case of a physical transformation in which the input materials are physically transformed into a material with different characteristics. In the second place, activities which take place within a given engineering step generally make use of a single type of resource capacity, which is typically one specific person. These activities can be combined into a single operation if no discernable delay is encountered between them. In this way an operation in a customer order driven engineering context may comprise many more different activities than an operation found within a physical transformation process. In the third place, a distinction can be made between (creative) information-generating activities and (repetitive) information processing activities. It is difficult to estimate the actual resource capacity requirements for the first category, in particular. We assume that every information-generating activity also implies the existence of one or more related information processing activities. In this way, the latter category can be viewed as an integral part of the first. In contrast with a physical transformation situation, it is possible that an engineer is busy with a single engineering activity for more than one machine at the same time. For the purpose of our model, an engineering operation is defined as a related set of engineering activities which are carried out sequentially. This assumes that an engineer first completes an engineering operation for one machine before he starts an engineering operation for a different machine.

The following operations can be identified based upon the engineering steps indicated in Figure 4.10. The first engineering step is problem analysis. The most important operation associated with this step is preparing the specification of the customer's functional requirements. This is generally performed by a single person and includes all of the related clerical activities. The second engineering step is determining the functional structure and the sub-functions of the machine. This can be combined into a single operation of developing the functional structure. This is also performed by a single person in the selected case. The third engineering step concerns developing solution principles.

This may require different capabilities, depending upon the types of sub-functions. This is carried out by a single person in the selected case in view of the general character of the development and the availability of standard sub-functions and solution principles (OSL-4). The development of solution principles for a complete machine is therefore seen as a single operation. The fourth engineering step concerns grouping sub-functions and solution principles into product modules. Determining the modular structure of the product is partially supported by the availability of standard product modules (OSL-4). This is also carried out by a single person in the selected case and is therefore defined as a single operation. A general specification of the geometry and materials for the most important modules is produced in the fifth engineering step. This can be seen as a preliminary draft of the product in the form of sketches and specifications. This effort is also performed by a single person in the selected case and, as such, has been defined as a single operation. The details of the geometry and the materials to be used for all of the components of the machine are determined and documented in technical drawings and bills-of-materials in the sixth engineering step. This is referred to as *detailing* or *detailed design* in the remainder of this book. In addition, the technical documentation for the machine is prepared. During the sixth engineering step, the assembly structure of the machine is taken into account to a significant extent as the machine specifications are worked out in further detail. The machine is split into so-called assembly modules for this purpose. An *assembly module* is defined as a set of one or more related product modules which are assembled together. Sequential relationships are defined between the assembly modules which indicate the assembly priorities. The detailed design activities are carried out per assembly module since the product modules and their components are assembled together and, thus, a strong interrelationship exists. In preparing the detailed design for an assembly module, a distinction is made with respect to:

- the general detailing of the assembly structure of an assembly module in the form of sub-assembly drawings; the definition of the interfaces between the product modules within the assembly module and the identification of the various components which constitute each product module; preparation of the bill-of-materials;
- the definition of the interfaces with other assembly modules;
- the detailed specification of the (non-standard) components (in terms of technical drawings and material specifications) and modifying/expanding the bill-of-materials if necessary.

Not all of the assembly modules belonging to a single machine are developed sequentially by a single person. This means that, in any case, multiple operations need to be defined for engineering step six. In addition, also for control reasons, the engineering activities related to a single assembly module as mentioned above are not performed sequentially. A clear idea of the components which constitute an assembly module is gained after the completion of, for example, the general configuration of the assembly module and the sub-assembly drawings. The amount of engineering resource capacity needed to complete the detailed design of the various components cannot be estimated until this point in time. In view of this, the following operations can be identified in the sixth engineering step:

- general detailing of an assembly module, sub-assembly drawings and the bill-of-materials;
- specifying the interfaces with other assembly modules;
- detailing of a (non-standard) component in the form of a technical drawing and material specifications;
- preparing the technical documentation for the machine.

Finally, the manufacturing and assembly instructions for the non-standard components and sub-assemblies are prepared during the seventh engineering step. In principle, this is carried out separately for each component or sub-assembly by a single person and, as such, is defined as being a single operation.

♦ *Defining the GFC items and production phases*

The transformation process can be aggregated at a higher level for control purposes by defining operations as described above. The control issues can be separated into Goods Flow Control and Production Unit Control issues (see also Chapter 5) by defining GFC items. Six different GFC items can be defined for the customer order driven engineering process based upon the criteria described in Sub-section 4.6.2. The first GFC item is defined as being the customer's *functional requirements specification* which documents the details of exactly what the customer wants. Based upon this, it should be determined whether it might be better to not comply with the customer's request for a quotation and, thus, not issue a quotation to the customer due to certain reasons (e.g., technical or business reasons) before time and effort is spent on the preparation of such a quotation (refer to Chapter 5 for a further explanation of this decision). The second GFC item is the *preliminary draft* of the design of the machine, including the modular structure. A significant portion of the product uncertainty has been eliminated at this stage. A general estimate can be made with respect to the degree to which standard product modules can be used and, thus, the number of customized elements which will be included in the product description. The preliminary draft of the product is, in principle, the level of engineering required for preparing a quotation. The third GFC item is a *generally detailed assembly module*. There are two reasons for defining a GFC item at this stage. In the first place, it is not sensible to view the complete detailed design of all of the assembly modules belonging to a given machine as being a single GFC item due to the sequential relationships between the assembly modules. These sequential relationships have an important effect on the priority of detailing certain assembly modules. The assembly modules with components which are defined as being on the critical path are detailed first. For this reason, it is useful to issue separate work orders for detailing the various assembly modules. In the second place, the general detailing of an assembly module provides insights into the resource capacity required for detailing the components of an assembly module. A significant portion of the product uncertainty is eliminated in this way. This leads to the fourth GFC item, *the description of a set of detailed components* belonging to a single assembly module. The fifth GFC item is the *set of production documents* for the manufacturing and assembly of an assembly module. For the present it will be assumed here that the preparation of production documents is carried out separately for each assembly module. The sixth and last GFC item is the preparation of the technical documentation for the machine. This activity is not included on the critical path for the engineering activities. As a result, it is normally completed just before the machine is delivered. The identified production phases are summarized in Table 4.1.

Production Phases
1. Determine the functional requirements
2. Complete the preliminary draft of the product
3. Complete the general detailing of the assembly module
4. Complete the detailing for the assembly module components
5. Prepare the assembly module production specifications
6. Prepare the technical documentation

Table 4.1. Production phases identified in the selected case

♦ *Creating production units*

Five production units can be created based upon the production phases and criteria defined in Sub-section 4.6.3. The sales organization is responsible for soliciting requests for quotation from prospective customers. The sales organization also works out a functional requirements specification for each request for quotation which is received from a customer. This is used here as the starting point for the customer order driven engineering process in the selected case. As a result, managing the sales organization and producing the functional requirements specification are not included as part of the customer order driven engineering in this book and are, as such, not included as an aspect of the control issues discussed here.

The production phase "Complete the preliminary draft of the product" is performed within a single production unit. Since the nature of the required capabilities is quite specialized, this activity is, in principle, carried out by a single person. This production unit is called *Product Engineering*. The persons employed in this production unit are referred to as *product engineers*. A distinction is made between the product families, however. The required capabilities for primary packaging (bottling), on the one hand, and secondary and tertiary packaging, on the other hand, are radically different and cannot (or almost never) be shared. Therefore, two production units have been defined, namely: Product Engineering - Bottling and Product Engineering - Packaging.

The production phases of "Detailing the assembly module" and "Detailing the assembly module components" are carried out within a single, separate production unit since the nature of the required capabilities is the same for both phases. This production unit is called *Detail Design*. The persons employed within this production unit will be referred to as *detail designers*. Analogous to the situation described above, a distinction is also made here between the product families so that two production units are required, Detail Design - Bottling and Detail Design - Packaging.

The production phase "Compile the assembly module production documents" is carried out separately within a single production unit in view of the specialized nature of the required capabilities. There is a strong focus here on technical production aspects which is not found in the previous production phases. In addition, the control issues and the elements of uncertainty are minimal in comparison with the previous production phases. This production unit is called *Process Planning*. The persons employed within this production unit will be referred to as *process planners*. There is no requirement for making a distinction between the product families within this production phase in view of the fact that the process planners are multi-skilled.

By defining operations, GFC items, production phases and production units in this way, the production control design requirements have been observed in structuring the customer order driven engineering process in the selected case.

4.7 Design requirements resulting from quality assurance

Design requirements from the point-of-view of quality assurance are also imposed on structuring the customer order driven engineering process. The design of the actual quality assurance aspects are covered in Chapter 6. The objective of quality assurance is to control the quality of the product description which is developed during the course of the engineering process. The quality assurance provides for a correct transformation of the customer's requirements into a feasible product design. Vorstman (1981) states that control and measurement of the quality of the output of a process occur at the interfaces between various process steps. The main idea behind this statement is to control and adjust the output of sub-processes as quickly as possible in order to prevent problems in a later stage as much as possible. In connection with this, a distinction needs to be made between the (formal) review of the output of engineering steps and the quality assurance which is an inherent part of the transformation process. During the execution of an engineering step, various reviews and calculations are performed by the engineer, himself, as an inherent part of the engineering process in order to review the quality of (parts) of the product description (this concerns the evaluation phase identified in Figure 4.2). Nevertheless, this should be distinguished from the more formal reviews (which are part of the quality assurance) which take place upon the completion of an engineering step.

When the engineering process is split into additional sub-steps with progressive engineering deliverables (output), more measuring points are created for monitoring the quality of the product description. The output of each engineering step is registered in the form of one or more documents which can be used to review the quality. The intensity of the quality assurance is thus dependent upon the degree to which the engineering process has been formally divided into engineering steps. This means that the engineerings steps should not be too large, incorporating too much of the total engineering process from a quality assurance point-of-view. It may be useful to review the quality of the product description as soon as part of the product uncertainty is eliminated based upon a further specification of the product description. Since there is a clear requirement for these measuring points, a correspondence can be found between the production phases which can be identified from a production control point-of-view. A separate engineering order with formally defined engineering deliverables is released for each production phase. In addition, most of the production phases have been defined from the point-of-view of uncertainty reduction (refer to the previous section). It may be desirable to carry out an engineering review following each production phase. Therefore, five measuring points with pre-defined output documents are created which can then be used to review the quality. If necessary, an engineering review can also be held after an individual engineering step has been completed for a specific customer order since formal engineering output has been defined for each engineering step.

4.8 Organizational aspects

In addition to the description of the (organizational) structure associated with the customer order driven engineering process in production units, a number of other important organizational aspects can be identified which are related to the typical character of an engineering process.

When we examine the internal composition of the "Product Engineering" PU, then most of the persons appear to be flexible and multi-skilled with respect to the operations which need to be performed within this PU. A distinction can be made with respect to the level of experience. Nevertheless, the less experienced product engineers who are involved in complex engineering activities are supported by their more experienced colleagues via meetings and other forms of collaboration. The degree of flexibility and availability of multi-skilled employees within the "Detail Design" PU is clearly less. There is such a difference in experience levels that certain detailing activities can only be performed by the most experienced detail designers. The activities which require experienced detail designers include the general detailing of assembly modules, the preparation of sub-assembly drawings and the development of interfaces. Lesser experienced detail designers are used primarily for detailing the component specifications and preparing the technical drawings. There are also certain specialized areas within the "Detail Design" PU which can only be supported by certain detail designers. One example of this is the detailing of the electronic control of a machine and developing the associated software.

Meetings and other forms of collaboration take place at various stages in the engineering of a machine. There is frequent collaboration among colleagues within a PU in connection with the preliminary product specifications. There is also frequent communication between the various disciplines involved in the engineering phase. Particularly in connection with projects with a large number of customization requirements and a high technical risk, discussions are continually taking place during the engineering phase between the sales organization, the product engineer and one or more of the detail designers concerning the feasibility of the envisioned solution alternatives. These discussions which are an integral part of the engineering activities have a more informal and ad hoc character and are difficult to formalize or to plan in advance. The transfer of product descriptions from one PU to the next transpires, of course, in combination with formalized communications to this effect.

Customer order independent or innovative engineering activities are also carried out in addition to the project-oriented and customer order driven engineering activities. This concerns product development activities which deal with new product families, products or functions to be supplied to the market, in general. In connection with this, a distinction can be made between the following (listed in according to increasing degree of innovation):

- the definition and development of new standards or adaptations to existing standards regarding (sub)functions, product modules and components within existing product families based upon actual experience with completed customer orders. This activity is generally initiated after a customer order has been completed and can be seen primarily as a clerical activity;
- the development of new and improved (sub)functions and product modules within the existing product families, independent of past customer orders. This concerns planned changes/improvements to an existing product family during its life cycle;
- the development of a new product family.

Whenever we refer to customer order independent engineering activities in the remainder of this book, we will be alluding to only the last two categories listed above. An important organizational issue in connection with the customer order independent engineering activities is the extent to which these activities should be performed by an organizational unit which is isolated from the customer order driven engineering activities. No clear answer can be provided for this question since it is dependent upon the specific company situation. The choice of which OSL will be supported is important in this respect, however. When an extremely high OSL is chosen (e.g., OSL-5: product-driven development), the customer order independent engineering activities play an extremely important role. In this case the aspect of market awareness in connection with product innovation falls under the responsibility of marketing rather than via the practical experience with specific customer orders. The best and most experienced persons are then assigned to the customer order independent engineering activities. Since there is a clear isolation of these activities from the customer orders and in view of the different characteristics, it is logical to create separate organizations. When the chosen OSL is extremely low (e.g., OSL-1: technology-driven development), then virtually no customer order independent engineering is carried out. The issue of creating separate organizations therefore does not arise in this situation. The customer order independent engineering activities are primarily strategic when OSL-2 (development based upon product families) is chosen. For this reason, these activities do not occur daily. The creation of separate organizations normally does not make sense in this situation. When one of the other OSL's is chosen (i.e., OSL-3 or OSL-4), however, both the customer order independent engineering activities as well as the customer order driven engineering activities are important. The interchange between these activities and the market intelligence which is acquired via customer orders is more prominent in these situations. This also makes it more difficult to isolate these two types of engineering activities in separate organizations. In general, the same employees should be involved in both of these types of activities in view of the similar objectives and the interchangeable tasks. Also due to the general lack of good and experienced engineers, it is difficult to create two separate organizations.

In view of the above-mentioned arguments, the choice has been made to include the customer order driven as well as the customer order independent engineering activities within the same PU's in the selected case. Persons who are specifically involved with innovation are therefore not isolated from the operational organization. This is an explicit choice which has been made based upon the premise that experience with customer orders and an affinity with the market are extremely important prerequisites for innovative development to support OSL-3 and OSL-4. Since only the best and most experienced persons, in particular, are in a position to develop truly innovative concepts, it is not feasible in practice to isolate this particular group from the ongoing activities in connection with preparing quotations and developing the specifications for customer orders. Nevertheless, the likelihood of significant conflicts resulting from different attitudes must be taken into account when these two types of engineering activities are combined within the same PU's (see also Sub-section 3.8.2). Customer order independent engineering ("it can always be improved") typically follows a different approach than customer order driven engineering ("good is good enough"). When both of these engineering activities are largely carried out by the same persons, there is then a danger that the wrong approach will be followed and the wrong attitude will prevail. A clear separation of the procedures to be followed for each of these types of activities will help in avoiding this problem. Combining both of these types of engineering activities can also have a positive influence on the quality of the standard product descriptions as well as the customer order driven product descriptions. An important part of the engineering is carried out independently of specific customer orders when OSL-4 is supported. When both types of engineering activities are carried out by the same person, the engineer can make his own job easier by ensuring that good standard product descriptions are available. This can lead to a more effective application of standard product descriptions and a more efficient customer order driven engineering. The control of the customer order independent, innovative engineering activities is not included within the scope of this research. Nevertheless, in connection with the control of the customer order driven engineering activities in the selected case situation, the resource capacity required for innovation must be taken into account since these innovation activities are performed by the same persons.

Chapter
5 DESIGNING THE CONTROLLING SYSTEM

5.1 Introduction

From the analysis of the selected case in Chapter 3 it is clear that little or no attention has been paid to the controlling system for customer order driven engineering. This may result in situations in which impractical delivery dates are approved and scarce engineering resource capacity is spent on the wrong requests such that a majority of the customer orders are then delivered too late and with insufficient profit margins. The required controlling system is designed in this chapter, based upon the engineering process designed in Chapter 4. By following this sequence, the dependency relationship between the controlling system and the transformation process illustrated in Figure 2.6a is emphasized. Particular attention is paid to the construction and structure of the controlling system in this chapter. A further explanation of the relationships and trade-offs between quality, timeliness and cost within the controlling system and further details about the control functions are provided in Chapter 6.

The customer order driven engineering process should be seen as a part of a much larger transformation process which includes the physical production of the equipment. The control of customer order driven engineering, therefore, cannot be viewed in isolation from the control of the total transformation process. Consequently, in this chapter some attention will be paid to the controlling system for the total organization in addition to the controlling system for customer order driven engineering. The design variables which have been chosen as well as some of those which have been ignored in the design of the controlling system are described in Section 5.2. The design principles which have provided the foundation for the design of the controlling system are then covered in Section 5.3. Based upon this, the design of the controlling system for the total organization and for the customer order driven engineering is described in Sections 5.4 and 5.5, respectively.

5.2 Design variables used

The design variables used to develop the controlling system for customer order driven engineering have been selected from an organizational/decisional point-of-view (see Chapter 2). In particular, attention has been paid to the structure of the controlling system in terms of:

- the identified control levels;
- the required control functions and control activities;
- the required control decisions.

Only a limited amount of attention has been paid to the organizational implications of the designed controlling system (see Sub-section 5.4.4) in terms of:

- the organizational responsibilities and authorities which can be derived from the design of the controlling system;
- the distribution of these responsibilities and authorities over the functions within the organization;
- the development of communication and consultation structures which can be derived from the realization of the controlling system.

These design variables have a pronounced influence on the proper functioning of the customer order driven engineering process, but have not been included in the design as described in this book with the exception of those aspects covered in Sub-section 5.4.4.

5.3 Control: basic design principles

Bertrand et al. (1990) have proposed that five general design principles be used for designing a production control system for physical production environments. These design principles are:

- the decision structure should be seen as the key aspect of a good controlling system;
- a distinction should be made between goods flow control en production unit control;
- a distinction should be made between the detailed item-oriented control and the aggregate capacity-oriented control;
- special attention needs to be paid to the interface between Production and Sales;
- the system boundaries need to be defined.

By applying these design principles to customer order driven engineering in the selected case situation, we will demonstrate that these design principles are also applicable to:

- the design of an integrated controlling system which takes quality and cost factors into account as well as the factor of timeliness. From the further development of the controlling system in Chapter 5 and, in particular, in Chapter 6, it is emphasized that the three aforementioned control factors are interrelated to such an extent that an integrated control approach is necessary in order to achieve an optimal performance;
- the design of a controlling system for a *non-physical* transformation process.

The aforementioned design principles are described further here.

♦ *The decision structure is the key element*

The design of a tailor-made set of feasible, organizational *decision functions* (see Bertrand and Wortmann 1981, and Meal 1984) is essential for establishing a good controlling system. With respect to structuring these decision functions, Meal as well as Bertrand et al. recommend the use of an (organizational) hierarchical decomposition technique to divide the total control problem into sub-problems with a (partial) hierarchical decision structure. The complexity of the control problem is reduced by defining a number of sub-problems, each of which can be solved independently. The assumption is that it is virtually impossible for a central control function within a given organization to work at both a global level and a detailed level. The top management level in an organization should not be involved in all of the decisions at a detailed level; these decisions need to be delegated to hierarchically lower levels in the organization. This delegation of (detailed) decision-making authority must nevertheless be structured in such a way that the control of the total process is still possible at the highest level of management in the organization. This can be achieved by decomposing the decision structure hierarchically into components in such a way that aggregate decisions include a definition of the boundaries within which the detailed decisions need to be made (refer also to Anthony 1988). The sub-problems which are defined in this way can then be solved independently and delegated to hierarchically lower functional units in the organization (comparable to autonomous groups as described by Burbidge 1971 and the work published by the Sociotechnology Section, for example, by Kuipers and Van Amelsvoort 1990).

♦ *Goods flow control versus production unit control*

The total control problem consists of coordinating the materials and the resource capacities for the whole chain of production activities starting with the purchase of materials through to the sale of finished goods. The control activities are numerous and (often) complex. In view of the different nature and timeframes associated with these activities, it is not sensible to have only a single central function in the organization which is responsible for carrying out all of these control tasks. The total control problem can be simplified by defining an equivalent set of (organizational) sub-problems (see also previous sections). In connection with this, two hierarchical control levels can be identified: the production unit control (PUC) level and the goods flow control (GFC) level. Goods flow control is concerned with the overall coordination for the chain of production units through the release of work orders to the production units. Each individual production unit (PU) is responsible for completing the work orders assigned to it in accordance with pre-agreed arrangements. It should be clear that the goods flow control cannot release work orders to the PU arbitrarily. The availability of sufficient resource capacity and materials, among other things, must be taken into account in connection with releasing work orders. This release decision is based upon aggregated data at a higher level, however. An important design aspect in connection with this is the identification of the various PU's (see also Section 4.6). The autonomy of the individual PU's and the importance of PUC both increase when there are fewer PU's in the transformation process.

♦ *Aggregate Production Planning versus Operational Production Planning*

The following two control aspects can be identified with respect to the coordination of PU's at the goods flow control level, each with its own control horizon:

- the coordination and matching at an aggregate level. This involves matching the available resource capacity to the capacity requirements. This is a medium/long term coordination activity primarily based upon aggregate data. We will refer to this control aspect as *Aggregate Production Planning (APP)*;
- the coordination and matching at the detail level. This involves the timing of work orders or, in other words, the periodic assignment of available resource capacity to individual products. This can be seen as the short-term coordination of specific products primarily based upon detailed information. We will refer to this control aspect as *Operational Production Planning (OPP)*. The two major components of OPP are Utilization Planning (capacity aspect) and Material Coordination (material aspect).

These two levels of goods flow control are represented in Figure 5.1.

♦ *Interface between Production and Sales*

The objective of goods flow control could be formulated as coordinating the interface

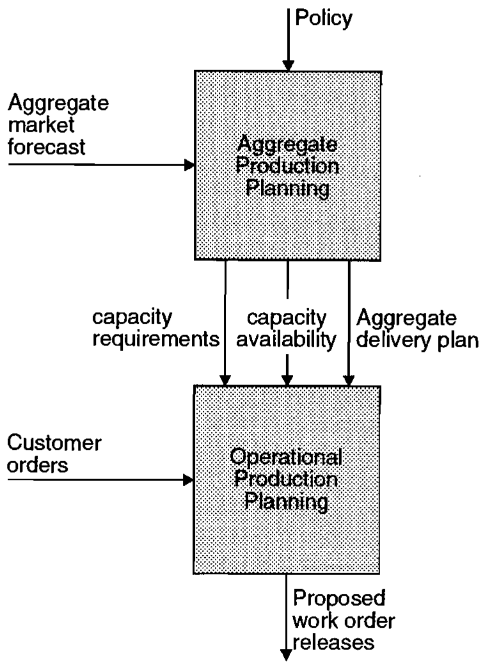


Figure 5.1 Components of the goods flow control

between Sales and Production, taking the resource capacity and the timeliness of product delivery into account. Sales is responsible for ensuring sufficient product demand and for accepting customer orders. Production is responsible for providing production capacity and ensuring that the customer order is delivered on schedule. At certain points in time, however, both Production and Sales will be confronted with limitations and requests which conflict with each other. These situations occur periodically when there is an imbalance between the required and the available resource capacity due to a certain amount of inflexibility in the production capacity, the current workload levels and the available stock. For this reason it is important that the interface between Production and Sales is included within the scope of the controlling system.

♦ *Defining the system boundaries*

It is sensible to define the boundaries of the production system which is being considered before starting to design a controlling system for (a part of) a production organization. The definition of the system boundaries should include documenting which part of the production environment is to be affected by the controlling system being designed and which part is to be excluded. A clear definition of the system boundaries can be made by describing the input and output flows between the system and its environment. The input flows can generally be defined in terms of materials, resource capacities and orders. The output flows are the orders for materials, the desired changes with respect to the resource capacities and the finished products (see Figure 5.2).

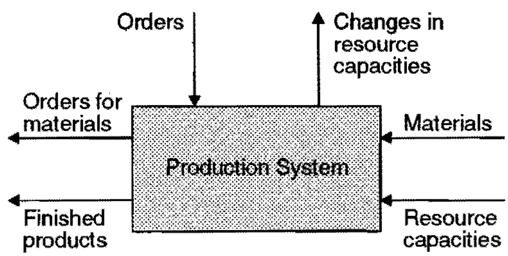


Figure 5.2 The system boundaries of a production system

In addition to (external) relationships with the environment, internal relationships can also be identified such as product structures, resource capacities, the manufacturing process and the amount of resource capacity required for each manufacturing step. In view of these internal relationships, the production control problem can be described as follows (Bertrand et al. 1990): given certain consistent objectives with respect to delivery performance and production costs and given the external relationships, how should we then proceed with respect to:

- accepting orders;
- ordering materials and releasing work orders;
- managing the availability of resource capacity;
- allocating the available resource capacity to the manufacturing steps.

These four basic decision functions are illustrated in Figure 5.3 in terms of regulating valves for controlling the flows of orders and resource capacities. The translation of the four above-mentioned decision functions to a certain level of detail for an actual situation is largely dependent upon the complexity and characteristics of the particular situation and may vary radically from one situation to another.

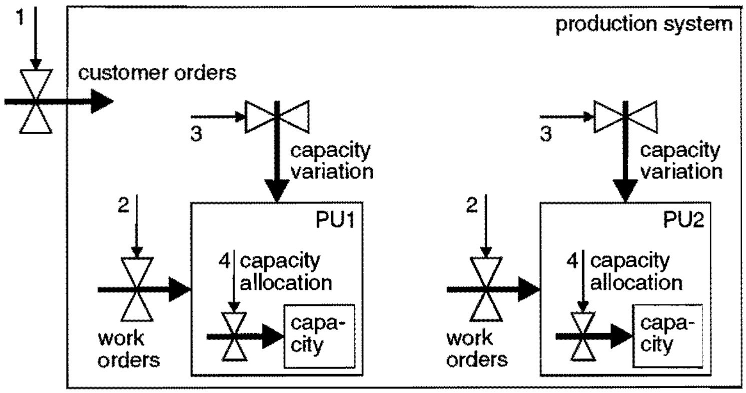


Figure 5.3 The basic decision functions in a controlling system (Bertrand et al. 1990)

An action plan for designing a controlling system for a production situation can be developed based upon the basic design principles as described above and a specifically defined transformation process (see Chapter 4). This action plan has the following steps:

- defining the system boundaries of the production system to be controlled;
- developing the structure of the controlling system. This step includes the identification of goods flow control and production unit control as well as the relationship between Sales and Production;
- incorporating the decision structure as the key element in the controlling system.

This action plan will be followed in the successive development of the controlling system for the total organization and the controlling system for customer order driven engineering.

5.4 The controlling system for the total organization

As indicated at the beginning of this chapter, the customer order driven engineering process should be seen as part of a much larger transformation process which includes the physical production of the machines. The control of customer order driven engineering may therefore not be seen as an activity which is isolated from the control of the total transformation process. Consequently, a general description of the controlling system for the total organization is provided in this section. This subject will not be covered here in detail, however, since only those elements will be discussed which are of importance for a better understanding of the controlling system for customer order driven engineering. The action plan steps described in the previous section are used here for structuring the design activities of the (high-level) controlling system for the total organization. The selected case description presented in Chapter 3 is used here as a starting point.

5.4.1 System boundaries for the total organization

The input flows with respect to the production system under consideration are:

- requests for quotation received from potential customers. The interaction between the sales organization and management of the sales organization with respect to soliciting these requests is considered to be outside of the scope of this research;
- customer orders which are received as the result of issued quotations;
- materials or products which are ordered from external suppliers or are outsourced due to internal requirements or for customer orders;
- (additional) resource capacities needed for carrying out the production activities.

The output flows with respect to the production system under consideration are:

- quotations (or rejections of requests for quotation) sent to customers in response to their requests for quotation;
- purchase orders for materials needed for internal requirements or for customer orders;
- outsourcing of the production of components and semi-finished products;
- shipments of finished goods to customers. The installation of the equipment at the customer's site is not included in the production system under consideration. The date upon which the equipment must leave the plant is used as the delivery date.

A diagram of the production system under consideration and the interrelationships with its environment is presented in Figure 5.4. In connection with the input and output flows of the production system under consideration as indicated above, two flows which might normally be expected are missing: the flow of human resources and the monetary flow. It has already been stated in Chapter 4 that a number of human resource aspects have not been included within the scope of this research. In addition, the control of incoming and outgoing monetary flows has also be excluded from the design of the controlling system. The control of monetary aspects can be interpreted in two ways:

- the cost (control) aspect of the physical and non-physical flows associated with the total production system which are identified above;
- the operational flow of funds which must also be controlled; this concerns cash management and the management of other liquid assets.

Whenever financial aspects are discussed in subsequent chapters of this book, the first interpretation listed above is implied. In connection with the design of the controlling system, it is assumed that the cash management function in the selected case has already been implemented in a suitable manner. As such, this is viewed as a fixed design variable which cannot be changed (see Sub-section 2.6.1).

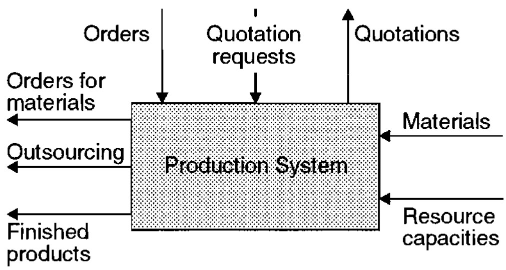


Figure 5.4 System boundaries for the total organization in the selected case

The customer order driven engineering process consisting of a number of production units (PU's) was designed based upon several design principles in Chapter 4. The derivation of the total transformation process, including the manufacturing and assembly of components, for the selected case can be seen as an analogous activity. Since the focus of this book is primarily on the customer order driven engineering, the derivation of the total transformation process will not be covered here. Instead, we will just present the result of this derivation (see Figure 5.5). An example of this type of design has been described in detail by Bertrand et al. (1992b). The manufacturing of components in the selected case is distributed over two PU's, namely, a Milling Shop and a Stamping Shop. The assembly activities are divided into two PU's, namely, Pre-assembly and Final Assembly. The transformation process as presented in Figure 5.5 has been simplified to some degree. The Universal Group (see Chapter 3) has not been included here since this PU is primarily involved in supporting the Service Department and, thus, has not been included within the scope of the research here. Two important differences are apparent when comparing the customer order driven engineering process presented in Chapter 4 with the diagram in Figure 5.5:

- in connection with the manufacturing and assembly of components, no distinction is made between product families. The required production capabilities, in contrast with the required engineering capabilities, are not significantly different from one product family to the next;

- the Process Planning PU indicated in Chapter 4 does not appear as part of the total transformation process. This is because there is no need for the separate Process Planning PU which appears in the customer order driven engineering process when the total transformation process is taken into account. This is integrated within the PU's for the manufacturing and assembly of components. The reasons behind this are explained in more detail in connection with the further development of the controlling system for customer order driven engineering covered in Section 5.5;
- the Product Engineering PU and the Detail Design PU have been combined for the Bottling and Packaging product families in order to simplify the diagram. The distinction between these two PU's should not be ignored, however.

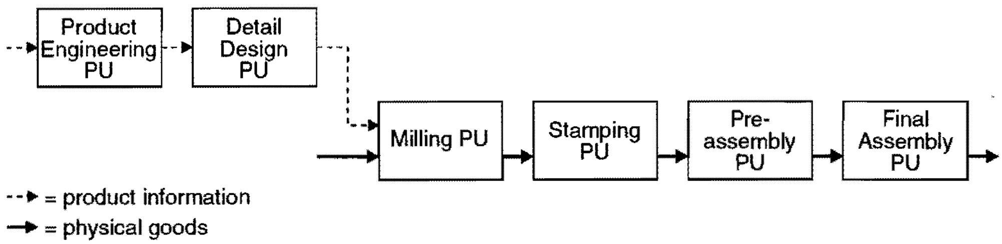


Figure 5.5 The transformation process for the total organization

5.4.2 Structuring the controlling system

Two levels for control can be identified within the controlling system based upon the general design principles presented in Section 5.4: Production Unit Control (PUC) and Goods Flow Control (GFC). The transformation process contains both physical and non-physical stages and consists of eight PU's in total. A local control function can be defined for each of these PU's. GFC provides for coordination during the non-physical as well as the physical stages in the transformation process. The GFC is also referred to as High-level Planning and Order Planning in engineer-to-order production plants. The control diagram in which the different control levels are identified is presented in Figure 5.6.

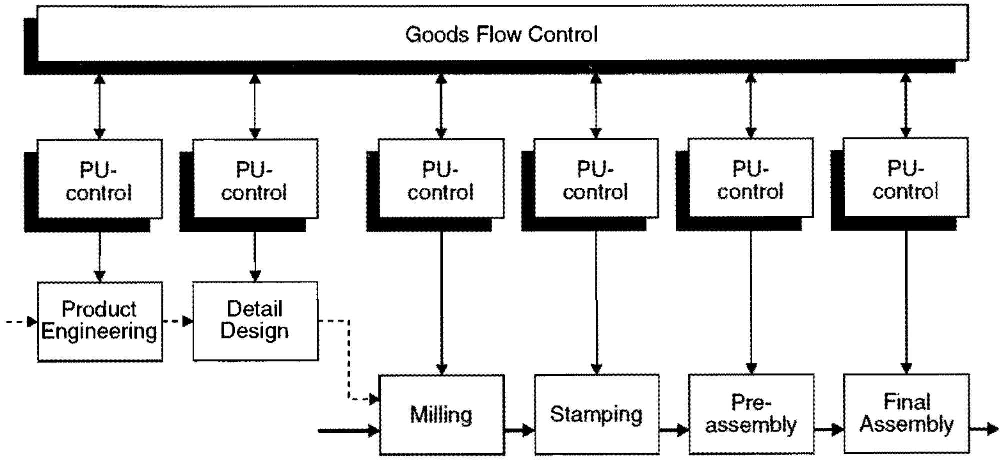


Figure 5.6 The control diagram for the total process

At this point it is useful to investigate the characteristics of GFC in more detail. Three control aspects can be identified within the GFC (refer also to Section 5.3):

- Aggregate Production Planning (APP);
- Operational Production Planning (OPP);
- the interface between Production and Sales.

♦ *Aggregate Production Planning (APP)*

An Aggregate Production Planning (APP) activity is included within GFC which is independent of the operational control of customer orders. This concerns the medium-term matching of required resource capacity with the available capacity. The available capacity is adjusted as much as possible to be able to meet the estimated future capacity requirements through the use of, for example:

- arrangements with external suppliers for outsourcing capacity;
- fewer or extra work shifts;
- temporary employees to provide additional assembly capacity, etc.

The APP represents an important (medium-term) control function in engineer-to-order manufacturing situations. These types of products are generally capital goods for which the demand may vary widely depending upon the economic climate. This means that the demand for production capacity can be radically different from one period to the next. It is important to be able to anticipate such changes as early as possible. The APP is not discussed further in the present context since this control function is not included as part of the operational coordination of quotations and customer orders within customer order driven engineering.

♦ *Operational Production Planning (OPP)*

In addition to APP, the operational coordination of the customer orders is covered by GFC. This control aspect is also referred to as Operational Production Planning (OPP). This involves the coordination of materials as well as the capacity scheduling for the various flows of goods. The available resource capacity is assigned to customer orders and work orders at this point. The characteristics of OPP are different in the different parts of the transformation process. Specifically, the control of the (potential) customer orders at the start of the transformation process (i.e., during the non-physical processing stage) is carried out based upon aggregate data. This is due to the relatively large amount of uncertainty at this point and the lack of detailed information about the product to be produced. The OPP function focuses primarily on the resource capacity aspect at this stage. The material aspect here is limited to the acquisition of the critical materials and components with a long delivery lead time. During the quotation phase, a high-level network plan is prepared for each potential customer order. This network plan consists of aggregate activities which are used as the basis for capacity planning and estimating throughput times. As more product information becomes available during the customer order driven engineering phase, the high-level network plan can be adjusted and more details can be added. This high-level network plan is also used to monitor the progress of each individual customer order. The control activities are similarly performed at a more detailed level and the material aspect receives more attention within the scope of the OPP activities when additional product information becomes available. This essentially concerns the coordination of materials and the determination of relative priorities for the work orders in the PU's during the physical processing stage. All of the product details are known by the time that the process planning has been completed for a customer order. A detailed planning is prepared for the various work orders associated with a given customer order, based upon the high-level network plan with the aggregated activities. The work orders are then released in collaboration with the heads of the various PU's. Even after the detailed information about a customer order is known, it is still convenient to track the progress of a customer order during the physical processing stage using the customer order network. The aggregated data used in this network provides a good basis for tracking the progress of each customer order.

♦ *The interface between Production and Sales*

In view of the fact that the requests for quotation and the customer orders arrive at the start of the transformation process and that the degree of uncertainty is the highest at this stage, the most important control decisions are made at the GFC level. The operational arrangements between Sales and Production, in particular, are important at this stage and are included as an explicit part of GFC. This is especially true in the selected case situation. An open and intensive exchange of communications between Sales and Production is especially important during the quotation phase (refer also to Kingsman et al. 1989). A preliminary draft of the product is prepared in a number of engineering steps based upon specific customer requirements. This is then used as the basis for calculating the price and delivery schedule (based upon the high-level network plan) for inclusion in the quotation. The resource capacity requirements are still quite indefinite at this stage, however, since the products to be produced are more-or-less unique and customized. Conditions and circumstances may change during the customer order negotiation phase, for example:

- the customer may change his original specifications, with significant implications for the required resource capacities;
- a number of other customer orders may have been accepted while the negotiations were taking place, reducing the availability of future resource capacity;
- the capacity requirements of previously accepted orders appear to be greater than originally anticipated. This reduces the amount of capacity which is available for new orders;
- the order negotiations extend over an extremely long period of time, leading to changes in the original estimates of the total capacity requirements.

Each of these situations can have an effect on the delivery date to be specified in a quotation. A continuous revision and reconfirmation of the relevant conditions between Sales and Production is therefore essential. The point in time at which the customer order is actually placed is also an important factor in coordinating efforts in this area. Due to the competitive market situation in the selected case, any quotation for new work will generally have a relatively low probability of being accepted. A potential customer normally asks for several quotations from different suppliers in view of the large size of the investment and the type of product (industrial equipment). This means that a potential customer may not decide to place an actual order. If he does, however, it is usually not clear when the order will be placed. A long period of time may elapse between submitting the quotation and placement of the corresponding order. Nevertheless, by keeping in touch with the potential customer, Sales is often able to provide a reliable estimate of when a quotation is likely to result in the placement of an order. Production needs to be aware of this so that orders do not arrive unexpectedly with commitments for delivery which can no longer be realized.

5.4.3 The decision structure for the total organization

Up to this point we have been able to identify the major functions with respect to control. A distinction has been made between an integral Goods Flow Control and local control at the PU level. More substance can be given to the various control functions by designing a decision structure and to place this in the context of Figure 5.6. The decision structure designed for the selected case situation is comprised of the following four key control decisions at the GFC and PUC levels (see also Bertrand et al. 1992b):

1. Customer order acceptance, pricing and due date assignment (GFC); is a timely completion of the production of the customer order possible?
2. Sub-order assignment and outsourcing (GFC); which production unit will be producing which components or assemblies and what part of the work will need to be contracted out (outsourced)?
3. Work order release (PUC); when will the work be released to the production unit?
4. Work sequencing (PUC); in which sequence will the work be performed within the production unit?

These four key control decisions are discussed in more detail in the following sub-sections.

♦ *1. Customer order acceptance, pricing and due date assignment*

Control over the individual production units is a necessary but not a sufficient condition for being able to control the whole customer order. This is because the internal control within a PU is only done at the PUC level. In particular, the integral coordination between Sales and Production should take place at the GFC level (refer to the previous section). The most important decision in this respect is the internal order acceptance, the pricing and the due date assignment. A major part of the production organization is, in fact, driven by this decision. This includes deciding how much effort is to be spent preparing a quotation in each specific case, what delivery lead time will be quoted and what the price will be. A good structural and operational interface between Sales and Production is needed in view of the prevailing uncertainties.

If we visualize the order acceptance, pricing and due date assignment decision as being a regulating valve, then the total quantity of work flowing into the production organization can be controlled by opening and closing this valve. The lack of a properly functioning valve in this sense (see Chapter 3), can be seen as the source of many of the technical, production control and financial problems which occur in practical situations. It is apparent that this key decision deserves more attention than it currently receives in the literature as well as in practice (see also Kingsman et al. 1989). A large number of variables and other factors need to be taken into consideration in making this decision. These factors include the future capacity loading, the relative attractiveness of a potential order for the plant, the desired delivery lead time, the probability of a quotation becoming a firm order and the technical risk. Various business disciplines such as Sales, Engineering and Production/Production Control are involved in the order acceptance and due date assignment decision. Sales is responsible for determining which price will be quoted and also plays an important part in compiling all of the customer specifications. The Engineering Division (Product Engineering) is responsible for translating the customer specifications into the technical specifications for a feasible product. The Engineering Division must also provide an estimate of the technical risks associated with accepting all of the customer's wishes when the order is accepted and the due date is assigned. For this purpose a risk analysis, a preliminary draft of the product and an estimate of the resource capacity requirements are prepared. This is then used by Sales to determine the quotation price and by Production/Production Control to determine the delivery lead time. This decision is made at the GFC level since it can be characterized as being an integral decision.

◆ *2. Sub-order assignment and outsourcing*

The first key decision is typically made when there is still a great deal of uncertainty. Usually only a part of the product characteristics of a customized product will be known at the point in time when such a customer order is accepted and the due date is assigned. Nevertheless, a delivery lead time and a price have already been set. A major part of this product uncertainty disappears when the customized product is fully developed within the Detail Design PU's. A much better estimate of the required quantities and types of resource capacities can be made at this point. Even before the process planning takes place, it is still possible to assign the production of components to a specific PU (assuming that there are two or more PU's for component manufacturing and/or assembly activities) based upon the technical content of the work and an estimate of the required (critical) production resource capacities or to decide whether components should be purchased. The customer order is split into so-called *sub-orders* for this purpose. A sub-order is defined as being the collection of all of the work associated with a single customer order which is to be processed during a given period of time in a given PU. Each sub-order is assigned to a specific PU before the capacity loading is analyzed. If one or more of the PU's have insufficient capacity, then a number of the sub-orders could be contracted out to an external supplier. A customer order is split into sub-orders in a similar way, for example, within the equipment manufacturing plants of Philips.

In view of the external volume flexibility for manufacturing components which can be created through outsourcing in this way, the second key decision has the following two objectives.

- Assigning the sub-orders to PU's as quickly as possible to enable an evaluation of the capacity loading situation within the PU's as soon as possible. This evaluation can then be used to determine which sub-orders are to be processed internally and which sub-orders, if any, are to be contracted out. When sub-orders are assigned at an early stage in this way, the PU department heads are then able to evaluate the future demand for their resource capacity and take timely action as appropriate.
- Review of the first key decision in the light of new information which has reduced the level of product uncertainty. Corrective measures will need to be implemented in connection with the second key decision if it appears that certain variables have developed in a way which is contrary to the original expectations. Examples of corrective measures are, for example, the use of available slack time, extra outsourcing and the use of internal flexibility.

It is extremely important to make arrangements for outsourcing as early as possible. A plant can be more flexible and react quicker to changes in the market when it is able to arrange for outsourcing more quickly than its competitors. Delivery problems typically occur in practice when the work to be contracted out is not released at an early date. The positions of the first and second key decisions in the control diagram are illustrated in Figure 5.7.

The concept of *sub-orders* is of primary importance for the controlling system presented here because this provides the most important link between the customer order driven engineering and the physical production. The use of sub-orders also implicitly provides a vehicle for communicating product information to the component manufacturing unit. All of the component drawings for a given sub-order are first completed within the Detail Design PU before the complete sub-order is transferred to the PU where the components are to be manufactured. Agreement is achieved between the GFC and the PUC concerning the internal due dates for the sub-orders. The PUC of the components manufacturing unit controls its own process planning, materials requisition and manufacturing for the various components included in each sub-order.

A sub-order is divided further into production orders or *work orders* by the process planning function. A work order is the means of providing instructions to a PU for the production of a component or a series of components.

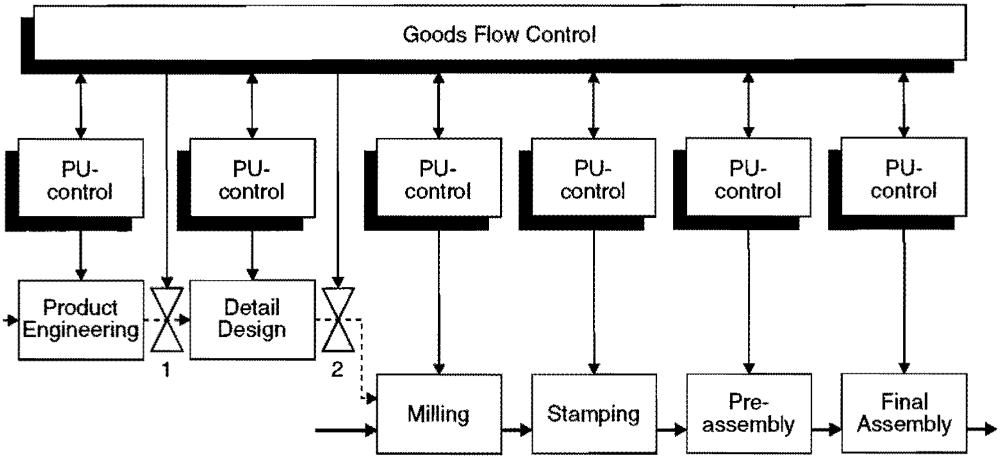


Figure 5.7 Key decisions 1 and 2 in the control diagram

♦ *3. Work order release*

A detailed discussion of the added value associated with the identification of production phases and GFC items was presented in Chapter 4. A transformation process is split into production phases and each of these is assigned to production units. Performing a production phase then becomes the responsibility of the respective PU's. This is carried out on the basis of a production order or work order. When there is a transition from one production phase to the next production phase, then a review point is created here from a control point-of-view at which an evaluation can be made at the GFC level. After the completion of each production phase, a new evaluation of the situation is made to determine which work orders can be released to which PU's for the next production phase associated with a specific customer order. The objective of a PU is to accept work orders and to complete the processing of these work orders within the agreed throughput time, given the conditions which have been pre-defined with respect to utilization levels, throughput times and batch sizes. Based upon this objective and the work situation on the shop floor, periodic decisions are made concerning which work orders will actually be released for processing. This type of release decision plays an important role in the cost control of a customer order as well as in the control of the internal throughput times within a PU (the timeliness factor, see Bertrand and Wortmann 1981, Bechte 1988 and Wiendahl 1987). This is discussed in more detail in Chapter 6. The decision to release work to a PU (key decision 3) is the first control decision at the PUC level. It is important to note that this type of release decision also occurs with respect to the PU's in the non-physical phase as well as for the PU's in the physical phase. This is also true for the fourth key decision.

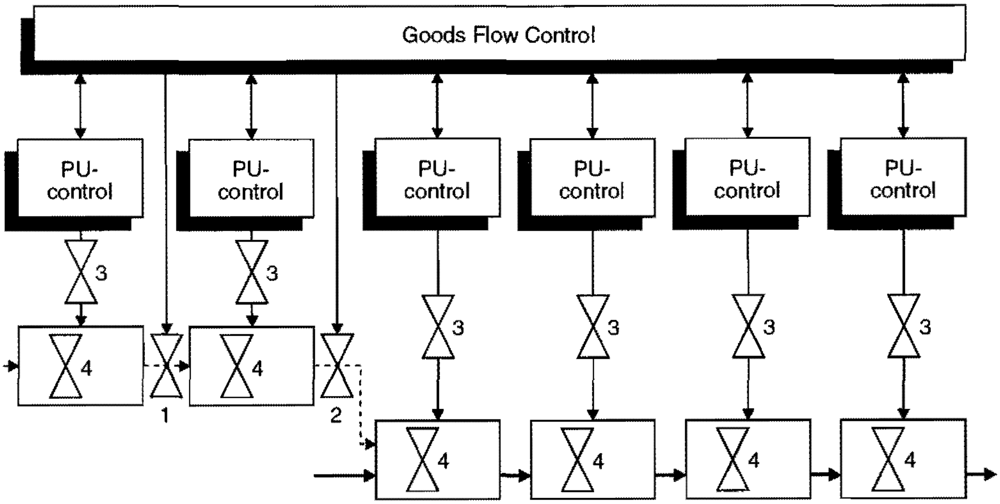


Figure 5.8 Key decisions 3 and 4 in the control diagram

♦ *4. Work sequencing*

An additional (combined) control decision is made within the production unit which influences the throughput time performance of the PU after the work is released to the production unit. Within each PU there is a certain amount of work present (the workload) which has been completed to various degrees. Each day it is necessary to determine which resource capacities are to be allocated to which work and in which sequence the work will be completed. In other words, the sequencing of processing the work orders within the production unit must be determined. A multitude of details and conditions are taken into account and anticipated at this stage which could not be included in earlier versions of the plans, such as: combining similar types of work, utilizing alternative equipment and machinery, reallocating human resources from other work stations. A certain amount of flexibility and freedom is required on the shop floor to allow for an adequate coordination of the various work orders in view of the uncertainties and the stochastic nature of this type of manufacturing environment.

The fourth key decision, the sequencing decision, is the second decision at the PUC level. The positioning of the third and fourth key decisions in the control diagram is illustrated in Figure 5.8.

5.4.4 Organizational aspects of the decision structure

The decision structure described here is also based upon a clear organizational concept. Each decision is associated with a specific organizational entity with the associated responsibilities and authorities. The delegation of control responsibilities to the shop floor, to the greatest extent possible, is of utmost importance in the selected case situation with its specific characteristics (uncertainties, etc.). As one gets closer to the actual production processes, one gains a better feeling for the changes which are occurring, enabling a quicker and more effective response. This means that the creation of a central control function in which all of the control decisions are concentrated would be counter-productive. Nevertheless, there is always some basic requirement for central coordination. The delegation of decision-making responsibilities is explicitly included in the decision structure described here. The first key decision is made collectively by the complete management team. The second key decision is made by the production control manager together with the heads of the production departments. A meeting is held with the heads of the production departments at the earliest possible moment to discuss the implications of the quantity of work which is expected. In this way they are given adequate time to take any measures which may be appropriate. The third key decision is made by each head of a production department together with the group leaders within his department. Finally, the fourth key decision is made by each group leader together with the individual workers in his group. Each decision can be seen in this way as an organizational transfer point. As the order progresses within the transformation process, the responsibility for making control decisions becomes increasingly closer to the operations on the shop floor. The requisite authorities for taking these decisions must, of course, also be established.

5.4.5 Material coordination in connection with the controlling system

Attention has been focused primarily on the controlling system's role in coordinating the resource capacity in connection with the design of the controlling system for the total transformation process in the selected case in the previous sections. Until now, little attention has been paid to the coordination of the materials which are required for processing a customer order. This limited attention to the coordination of materials is due to the fact that this control aspect is relatively simple and straightforward for the customer order driven engineering in the selected case situation. This is not true, however, for the coordination of materials for the physical production of the equipment. In connection with the coordination of materials for the physical production, a distinction can be made between the coordination of:

- customer-specific materials and components which are unique and will be used for a specific customer order;
- standard materials and components which may be used for a variety of customer orders.

The acquisition of these two types of material flows is done (partially) in different ways, however. The requisition of customer-specific materials is initiated via the engineering of the product and production specification for a customer order. This is also the case for the standard materials which are acquired only when they are needed for completing a specific customer order. Other standard materials are kept in stock, however, independent of specific customer orders and produced as unallocated production series. In view of the fact that every customer order requires some of the materials which are produced in an unallocated production series, a relationship needs to be established between the customized projects and the unallocated acquisition in terms of:

- reserving unallocated acquired materials and components for specific customer orders;
- a dynamic coordination activity based upon the data from the individual project network plans which so that proper arrangements are made for acquiring the unallocated materials.

It is apparent to the author that very few studies have been published which deal with developing the theory on coordinating the unallocated and customer-specific acquisition of materials within the controlling system for engineer-to-order production. In addition, this type of coordination also has important implications for the management information system for the total organization. Since the focus of this book is on customer order driven engineering, however, this subject is considered to be outside of the scope of the present research.

5.5 The controlling system for customer order driven engineering

A controlling system for the total organization was designed in the previous section. This can be seen as a framework within which the controlling system for customer order driven engineering must be able to function. The part of the control diagram presented in Figure 5.8 which is related to customer order driven engineering is examined in further detail in this section. The action plan steps outlined in Section 5.3 are, again, used here for designing the controlling system.

5.5.1 System boundaries for customer order driven engineering

The input flows with respect to the production system under consideration are:

- the requests for quotation for a specific machine which are received by Sales from customers. This includes a specification of the customer's requirements;
- customer orders which are received as the result of issued quotations.

The output flows with respect to the production system under consideration are:

- quotations (or rejections of requests for quotation) sent to customers in response to their requests for quotation;
- order confirmations sent to customers, resulting from the receipt of customer orders;
- drawings and bills-of-materials as required for the physical production.

It can be seen from the system boundaries defined above for customer order driven engineering in the selected case situation that the preparation of production documentation (process planning) has not been included within the system. This activity is carried out as part of the manufacturing and assembly of components in the selected case. As a result, no separate PU has been defined for this activity. In the design of the customer order driven engineering process in Chapter 4, however, the initial assumption was made that a separate PU would be defined. The decision to eliminate the separate production phase for process planning was based upon the control characteristics of the selected case. In view of the prevailing uncertainty, it was found to be extremely important to delegate the control responsibilities as much as possible to the shop floor level. If a separate production phase (i.e., a separate Process Planning PU) were to be created, then this would mean an extra control burden at the GFC level. By delegating the responsibilities for all of the production planning activities (including the ordering of materials and process planning) to the manufacturing and assembly of components, the control at the GFC level needs only be concerned with aggregated information. The concept of a sub-order is of primary importance in connection with the delegation of these control responsibilities to the PU's. A manufacturing sub-order, for example, consists of a set of components to be produced. Sub-orders are assigned to PU's at the GFC level and arrangements are made with the PUC concerning the internal throughput time for these sub-orders. The delivery lead time for ordering materials and the throughput time for carrying out the process planning are taken into account. The sub-order represents the lowest level of aggregation for the GFC in connection with controlling a customer order. Sub-orders are scheduled based upon the aggregate information. For this reason, the GFC is not interested in detailed information such as process planning data and material requisitions concerning the components within the sub-orders. This responsibility belongs to the PU's. In this way the GFC only needs to be concerned about the situation at the sub-order level. This decision not to include the (customer order dependent) process planning activities as a part of the customer order driven engineering process was made for various reasons. In recent publications about product development (see, for example, Nevins and Whitney 1990) from the point-of-view of "design for manufacturing" and "concurrent engineering", it is recommended to include technical production considerations (among other factors) in the engineering decisions and even to integrate the process planning activities into the engineering process (Krikhaar 1992). Nevertheless, this is only sensible for the customer order independent or innovative engineering activities in the selected case situation. The customer order driven engineering can be characterized, in principle, as being unique and one-of-a-kind. This means that there is an extremely limited learning curve due to the one-time nature of the process planning and production activities. A part of the process planning for the manufacturing of components and the complete process planning for the assembly are even left to the experienced worker on the shop floor in the selected case. The process planning is so close to the actual operations in this production situation that it is then obvious that this activity should be included as part of the physical production process. As a result, the operational instructions are not very detailed in many instances. So-called reference routings are often used due to the one-time nature of many of the components and the absence of a learning curve. These can be seen as standard operation sequences for which (general) normative processing times have been established.

5.5.2 Supplementary decision structure for customer order driven engineering

Customer order driven engineering is performed at the beginning of the total transformation process. Contact is maintained with the market during this phase in the form of receiving requests for quotation, sending quotations to customers and receiving customer orders. More quotations are prepared within the customer order driven engineering than the number of customer orders which are received since the success rate of quotations is relatively low. This means that an important objective for the control of the customer order driven engineering at the GFC level is to channel the flows of requests and quotations and to make selections in such a way that:

- the resulting customer orders provide a maximum contribution to the realization of the business objectives;

- the company receives a balanced flow of customer orders to be processed, matched to the processing capacity of the production organization and satisfying the conditions which have been established for being able to meet the agreed due dates.

The channelling and selection of potential orders is carried out based upon a large degree of uncertainty, however (see also Chapter 3). The designed decision structure should take this into account by monitoring and repeatedly reviewing the requests currently being processed in the light of the basic assumptions which have been established and the current circumstances. If we examine the decision structure developed for the total transformation process as presented in Figure 5.8 with this in mind, then we arrive at the conclusion that using only the decisions regarding "Customer order acceptance, pricing and due date assignment" and "Sub-order assignment and outsourcing" at the GFC level is insufficient for realizing this objective. In order to be able to achieve the aforementioned objectives at the GFC level, the decision structure needs to be supplemented with three additional control decisions to be added to the two decisions already mentioned. This creates a decision structure consisting of a total of five decisions at the GFC level for controlling the customer order driven engineering process:

a. Evaluating and selecting requests for quotation: which of the received requests for quotation will be selected as the basis for preparing quotations?
b. Issuing quotations: which quotations will be sent out and which conditions will be stated regarding the price and delivery time?
c. Reserving resource capacity within the Detail Design PU: will (scarce) resource capacity be reserved ahead of time during the quotation phase for a potential customer order?
d. Internal order acceptance: what price and due date will be quoted for the customer order and what will the consequences be for the production organization?
e. Sub-order assignment and outsourcing: which production unit will be producing which components or assemblies and what part of the work will need to be outsourced?

Two levels can be defined for these five GFC decisions in view of the different degrees of importance. Decisions regarding "Evaluating and selecting requests for quotation", "Issuing quotations" and "Internal order acceptance" are seen as a shared responsibility of all of the members of the management team due to the possible (integral) impact on the organization. The decisions regarding "Reserving resource capacity within the Detail Design PU" and "Sub-order assignment and outsourcing" are seen as the responsibility of the respective line managers due to the local impact of these decisions. The three supplementary control decisions at the GFC level are described in further detail below, including the reasons why each of these additional decisions is required.

♦ *Evaluating and selecting requests for quotation*

The purpose of the decision regarding "Evaluating and selecting requests for quotation" is to chose a subset of the requests which are received by Sales in such a way that the quotation preparation capacity which is available within the Product Engineering PU can be optimally utilized. The questions here are which requests should be honored in the sense that a quotation will be prepared, and how much resource capacity should be made available to prepare these quotations. The received requests for quotation are reviewed to determine their desirability in terms of several criteria. These criteria fall into a number of general categories:

- product/market policies; how the request fits in with the product/market policies;
- financial attractiveness;
- the probability that a firm order will result from the quotation;
- strategic potential;
- technical risk; the risk of not being able to produce the product or not being able to produce the product at an acceptable cost level;
- requirement for product engineering capacity to prepare the quotation (related to the technical risk);
- current utilization level of the product engineering capacity;
- the current market situation (positive or negative economic climate).

There are two reasons at this stage for taking little notice of the expected future utilization of the physical production capacity. In the first place, there is a large amount of uncertainty regarding the equipment specifications and regarding the chance of actually winning the order and the actual production start date. This means that any assumptions which could be used to determine the availability of future resource capacity will not be reliable. In the second place, the production organization can always make use of outsourcing to increase its flexibility, if necessary. By selecting requests for quotation based upon these criteria, every effort is made to ensure that a significant amount of resource capacity and time will not be wasted on requests which, for example, do not fit in with the company's product/market policies and/or have an extremely high technical risk and/or are not really interesting from a financial point-of-view. The likelihood is extremely small that a request which is not selected based upon these criteria, could ever provide a positive contribution to the realization of the business objectives. In fact, the use of resource capacity for requests which would not be selected based upon these criteria, would introduce a significant financial risk since there is only a small probability that such customer orders would be profitable.

"Evaluating and selecting requests for quotation" takes place weekly at a meeting of the Quotation Team in the selected case situation. This Quotation Team is comprised of the members of the Management Team, the heads of the Packaging Technology and Bottling Technology sections and the Materials Manager.

♦ *Issuing quotations*

After a request has made it through the evaluation and selection stage, it is ready for release to the Product Engineering PU. A preliminary draft of the product is prepared at this point and used as the basis for a quotation. The product description is developed to the extent necessary for establishing an acceptable price and delivery due date with a limited risk. Nevertheless, it is important that a periodic review is carried out at the aggregate control level to evaluate the criteria for the quotations to be issued. The reasons for this review are as follows. In the first place, the preparation of a quotation may take a significant amount of time. It is possible that, in the meantime, the basic assumptions that were used for selecting and accepting the request have changed to the extent that the reasons for accepting the request are no longer valid. For example, if a relatively large number of quotations were accepted by the potential customers and have since become firm orders, then the production organization could end up with a surplus of work. In the second place, the basic assumptions underlying the request could change during the negotiation phase to the extent that the reasons for accepting the request are, similarly, no longer valid. For example, it is possible that the customer has changed the original specifications with the result that the technical risk has become too great in relation to the financial attractiveness. The decision concerning "Issuing quotations" is also made at the meeting of the Quotation Team.

♦ *Reserving resource capacity within the Detail Design PU*

Reserving resource capacity for potential orders within the Detail Design PU is an important interim control decision in which timing considerations play a significant role. In most cases, the current utilization levels of the resource capacities are not considered in connection with issuing quotations. The Detail Design PU may be an exception, however. In view of the fact that this resource capacity is the critical, limiting capacity during the order phase, a majority of the problems are likely to occur in this area. Under certain circumstances it may be decided to include the influence of certain quotations in the evaluation of the capacity loading within the Detail Design PU. In this way it is possible to determine whether a specified delivery due date is feasible if the customer decides to place the order at a certain point in time. In addition, it is also possible to actually reserve future resource capacity within the Detail Design PU for a potential future order. Since the probability of winning most orders is relatively low, reserving capacity in advance in this way will certainly not be done for every quotation. Any reservations of capacity for potential future orders should be evaluated carefully. By not reserving capacity in advance, delivery problems may occur. On the other hand, reserving capacity which may never be used can lead to an under-utilization of future capacity or a loss of future customer orders. The decision to reserve capacity in advance is made based upon the consensus of Sales, Engineering and Materials Management.

Figure 5.9 illustrates the positioning of the various decisions within the decision structure for customer order driven engineering in relation to the identified control levels which were presented in Figure 5.6.

A supplementary control function at the GFC level can be identified in addition to the aforementioned five decisions at the GFC level. This function is concerned with the periodic monitoring of progress and taking any corrective measures which may be needed with respect to the customer orders during the order phase. A further explanation of this control function and the other control decisions is provided in Chapter 6.

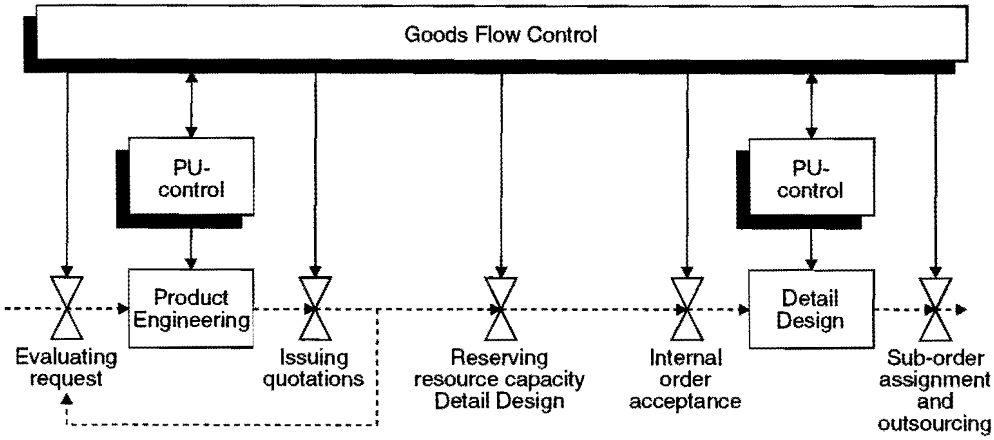


Figure 5.9 The control diagram for customer order driven engineering

Chapter
6 INTERRELATIONSHIPS BETWEEN THE CONTROL FACTORS WITHIN THE CONTROLLING SYSTEM

6.1 Introduction

The structure of the controlling system has been developed in detail for the selected case and was presented in Chapter 5. Nevertheless, no detailed explanation has been provided so far concerning the interpretation of the control factors of quality, timeliness and cost and the interrelationships between these factors within the controlling system. A further explanation of this is presented in this chapter. In addition, references will be made to the characteristics of the selected case situation as described in Chapter 3. The three aforementioned control factors will be described in detail in separate sections in the first part of this chapter. Subsequently, the following topics will be discussed in the following order:

- what is understood by the particular control factor under discussion within the context of the controlling system for customer order driven engineering as described in Chapter 5;
- which characteristics of customer order driven engineering in the selected case are of importance in describing the control factor within the context of the controlling system;
- at which point in time the control factor under discussion (e.g., the timeliness factor) is considered within the context of the controlling system;
- which existing concepts and methods can be used which are related to the control factor;
- how the aforementioned considerations are interpreted within the context of the controlling system.

In connection with describing the controlling system, the specific control data to be stored and maintained in the management information system will also be mentioned whenever this is thought to be useful and illustrative. This will provide an initial indication of how the connection will be made between this topic and the management information system designed in Chapter 7.

The second part of this chapter describes the interrelationships and the balance between the three control factors within the controlling system. The control factors of quality, timeliness and cost are discussed, in turn, in Sections 6.2 through 6.4. The interrelationships and the trade-offs between these control factors within the controlling system are considered in Section 6.5.

6.2 The quality factor within the controlling system

6.2.1 Approaches to quality

It is difficult to define the concept of quality, particularly within the context of customer order driven engineering. We are concerned here with product descriptions which represent an ultimate physical product at various stages of engineering. An important initial distinction to be made in connection with the discussion about defining the concept of quality is the difference between product quality and process quality. The concept of *product* quality is discussed here, first, followed by a discussion of the concept of *process* quality.

♦ *Product quality*

There are as many definitions of quality to be found in the literature as there are authors. Nevertheless, in order to be able to provide some sort of definition for the concepts of "product quality" and "quality of the information products of customer order driven engineering", the various opinions about the definition of quality will be reviewed here by identifying five different approaches which could be followed (Garvin 1988):

- the transcendental approach;
- the product-oriented approach;
- the user-oriented approach;
- the production-oriented approach;
- the value-oriented approach.

The transcendental approach
When following this approach, quality is assumed to be a concept which is undisputed and universally recognized. In spite of the difficulty in defining quality, everyone can still tell

the difference between good quality and poor quality. The ability to recognize quality is based upon experience. The problem with this approach is that it provides very few aspects which can be used to translate the concept of quality into operational terms. For this reason, this approach to defining quality will not be used in the remainder of this research.

The product-oriented approach
This approach is based upon the assumption that quality is something which can be defined precisely and measured objectively. The quality of a product is based upon specific characteristics which may or may not be present to a certain degree. Higher quality means that the product has more of a certain positive characteristic.

The user-oriented approach
Using this approach, the quality of a product is determined by the end-user in relation to the purpose for which it was acquired ('Fitness for use', Juran 1988). A given product can be qualified by a user as being good in one situation and poor in a different situation.

The production-oriented approach
This approach is based upon the assumption that quality can be translated into specifications with which the product must comply. Provided that the product specifications are correct, the production process then needs to be designed to ensure that the specifications can be met. This type of approach to quality assurance is focused primarily on the internal processes. A good product is a product which has been produced exactly in accordance with the product specifications which have been issued. The influence of engineering on the final quality is underestimated when this approach is used, however (Garvin 1988). A product which is produced exactly in accordance with the specifications can hardly be qualified as being "good" if the product description does not meet the requirements of the market.

The value-oriented approach
This approach goes one step further than all of the previously described approaches. The price factor is included along with the assumption that quality is determined by the degree to which the user requirements are satisfied (the user-oriented approach). With this approach, the relationship of quality and price is considered to be important as well as the absolute quality (in terms of 'Fitness for use'). This approach to quality assurance is not used here since we have identified "cost" as being a separate control factor.

To summarize, three (product) quality approaches will be used here for describing the control factor related to quality in customer order driven engineering: the product-oriented, the user-oriented and the production-oriented approaches.

◆ *Process quality*

The discussion so far has been limited to product quality. This discussion would not be complete if the subject of process quality were not included. It should be clear that these two aspects regarding quality are closely related to each other (see also Van Genuchten 1991). This relationship can be found, for example, in Juran's definition of a product as being the output of a specific process (Juran 1988). The existence of a high-quality transformation process is, of course, an essential prerequisite for being able to produce high-quality products. Quality and quality improvement can therefore also be approached from the point-of-view of the transformation process. The definition of the transformation process in Section 4.3 can be seen as an example of this. The total transformation process is split into formally defined production phases with specifically measurable inputs and outputs in order to be able to guarantee the quality of the product description. The quality of the process and the product can be guaranteed to some extent just by ensuring that the process has been designed properly in this way, regardless of how the controlling system is designed. There is a great deal of similarity between the approach needed to ensure process quality and the production-oriented approach to ensuring product quality. Both of these approaches focus on the influence of the "production process" on the product quality. These two approaches will be considered to be essentially the same in the remainder of this book.

6.2.2 Defining quality in customer order driven engineering

Garvin (1988) has demonstrated that no single approach to quality assurance can be considered to be the correct approach, but that the use of an integrated combination of different approaches within an organization is a good alternative. This is particularly true in the case of customer order driven engineering. The three chosen approaches to quality assurance are all applicable to customer order driven engineering. The *product-oriented* approach provides for the possibility of identifying certain product variables associated with a product description in various stages of engineering. The values of these product variables can be measured independently of the user specifications. This is referred to here as *objective quality*. Following the *user-oriented* approach means that there is a requirement for a good translation of the user requirements in product specifications. This will be referred to as *subjective quality*. We can make a distinction between the different users of product specifications, namely:

- external users. This refers to the customers. Each individual customer has his or her own product requirements such that each product is considered to be customized and one-of-a-kind;

- internal users. This refers to the users of the product specifications which are found within the plant, such as: various engineering disciplines, process planners, material managers and employees within component manufacturing and assembly.

The *production-oriented* approach (and the process quality approach) serve to emphasize the fact that the design and organization of the customer order driven engineering process have a pronounced influence on the final quality of the product description.

6.2.3 Quality aspects of customer order driven engineering

In contrast with a customer order independent engineering situation, several typical quality aspects can be identified in a customer order driven engineering situation which need to be considered in the design of the controlling system. In the first place, customer order driven engineering is initiated only after the point in time at which a request for quotation is received from a customer. This means that the quality assurance is concerned with the extent to which the product specifications satisfy the specific customer requirements rather than general market requirements. A precise formulation of the customer requirements is therefore necessary. The problem in connection with this is that customers are often not able to formulate their requirements in an adequate way, leading in many instances to changes in the customer requirements after the engineering activities have already started. It is important in this situation that the proper OSL and degree of customer specification freedom is chosen (see Chapter 1). The number of customer-specific requirements becomes less when a higher OSL is chosen and the customer specification freedom is limited. In the second place, the focus in terms of the required level of quality is different for customer order driven engineering as compared to customer order independent engineering. Since the product is customized and is, in principle, one-of-a-kind, the product description should satisfy the specific customer requirements and nothing else. The required level of quality for customer order driven engineering can therefore be characterized as "good is good enough" in comparison with customer order independent engineering which is more oriented toward "improvement is always possible" (see also Sub-section 3.8.2 and Section 4.8). In the third place, customer order driven engineering includes a certain amount of quality or technical risk. A customer order is preceded by a quotation. In view of the relatively low success rate for turning quotations into firm orders, just enough engineering capacity is committed to preparing the quotation so that an estimate can be made for the quotation price, the required throughput time and the technical risks. A certain technical risk is always present since the engineering effort spent in the quotation phase is relatively limited. In fact, the amount of technical risk is also dependent upon the chosen OSL and degree of customer specification freedom. It is thus also important to make use of proven technology as much as possible for customized engineering in order to keep the risk to a minimum. In the fourth place, part of the customer order driven engineering activities are incorporated within the customer order throughput time. This means that there is a certain amount of time pressure in connection with performing these activities and that there is relatively little time to evaluate certain alternative engineering solutions.

6.2.4 Quality considerations within the controlling system

Based upon the controlling system for customer order driven engineering described in Chapter 5, several points in time can be identified during the control process at which the quality could be considered and reviewed. These points in time are identified here and discussed in further detail in Sub-sections 6.2.6 and 6.2.7. The first opportunity for considering and reviewing the quality within the controlling system is when a request for quotation is evaluated. At this point the factors of technical risk and special customer requirements are considered in connection with the decision of whether to accept a request for quotation. The second point in time is when the quotation is to be issued. The quotation price and the delivery lead time are determined at this point, based upon the preliminary draft of the product and the specification of a modular product structure. The remaining technical risk is important in connection with these decisions. The third point in time is in connection with monitoring the progress of customer orders. This last-mentioned opportunity for considering and reviewing the quality does not necessarily occur at a fixed point in time, but may occur at various points in the control process.

In addition, important opportunities for considering and reviewing the quality are found at the end of each production phase of the customer order driven engineering process (product engineering and detailed design). At each of these points it is determined to what extent the result of the current production phase represents a high-quality transformation of the original input information and complies with all of the quality specifications, including the input requirements for the next phase or stage in the process.

6.2.5 Using existing methods and techniques for quality assurance

A number of methods and techniques can be found in the literature and used within the controlling system for controlling the quality factor with respect to customer order driven engineering, namely:

- risk analysis;
- the inclusion of control loops in the design as a basis for quality assurance.

♦ *Risk analysis*

As indicated in Chapter 3, the technical risk may increase if the uncertainty concerning the product specifications increases. In most instances, the presence of technical risk in the selected case situation does not necessarily mean that producing the product may not be feasible, but rather that more time and resource capacity will be required to formulate the product specifications and/or more material will be required than originally estimated. Technical risk generally leads directly to a time risk and a financial risk. As a part of the control process, the use of risk analysis can provide an important contribution in connection with managing these types of risks. If a reliable estimate of the potential technical risk can be made ahead of time, then provisions can be made within the controlling system to take this risk into account. The OSL and the available standard product descriptions are important factors in determining the potential technical risk. A high technical risk means, among other things, that a relatively large amount of product engineering and detailed design resource capacity may be required for completing the product description. As the technical risk increases, the amount of extra resource capacity (for engineering as well as production) and/or the cost of materials which may be needed will also increase in comparison with the original estimates.

♦ *Quality assurance and control loops*

Quality assurance focuses on controlling the quality of the product description which is produced during the engineering process. Three methods which have originated from systems theory can be considered for use in designing the quality assurance approach (In 't Veld 1983, Mulder et al. 1988):

- *Feedback*, whereby the output of the process is measured by a comparator and compared with a normative value. If a discrepancy is found, then control is passed to a regulator. The regulator determines what measures are to be taken to make a correction in the process (process feedback). The essence of feedback is that the result influences the corrective measure which is taken (Figure 6.1a);
- *Feed forward,* whereby the input to the process is measured by a comparator and compared with a normative value. Similar to the situation described above, if a discrepancy is found, then control is passed to a regulator which determines what corrective measures are to be taken. The essence of feed forward is that the input influences the corrective measure which is taken (Figure 6.1b);
- *Correcting the deficiency*, whereby the missing element is added to the output, independently from any corrective measures taken with respect to the process, in such a way that the output then satisfies the norm.

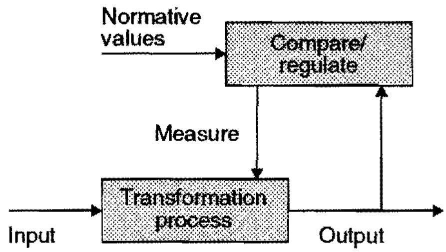


Figure 6.1a Methods for quality assurance: feed back

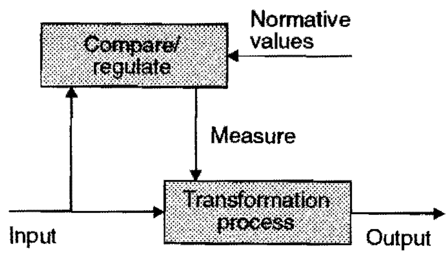


Figure 6.1b Methods for quality assurance: feed forward

Quality assurance as defined here is concerned with controlling the quality of the *product* as well as the quality of the engineering *process*. The quality of the input and the output of each production phase can now be controlled by incorporating the following control methods in the design: feed forward from the input, feedback from the output of the production phase and correcting any deficiency which may have been discovered. By logically sequencing the production phases, it is then possible to have the feed forward from production phase N correspond with the feedback from production phase N-1 (see Figure 6.2). In practice, this means that quality assurance for the customer order driven engineering process includes an engineering review held at the start of each production phase described in Figure 4.7, based upon the input information for that production phase. This review is, in fact, independent of the more detailed evaluations which are performed as part of the engineering process (see also Section 4.3). The engineering review is incorporated in the feedback to the previous production phase as well as in the feed forward to the subsequent production phase. The engineering review includes the comparison of the product specifications (such as a modular product structure) with the quality norms. If discrepancies are discovered, then:

- either the engineering document is returned to be modified (e.g., "correcting the deficiency") or special measures are taken to ensure that the deficiency is corrected in the subsequent production phase (feed forward);
- or corrective measures must be taken with respect to the current production phase in order to prevent the occurrence of quality aberrations in the future (process feedback).

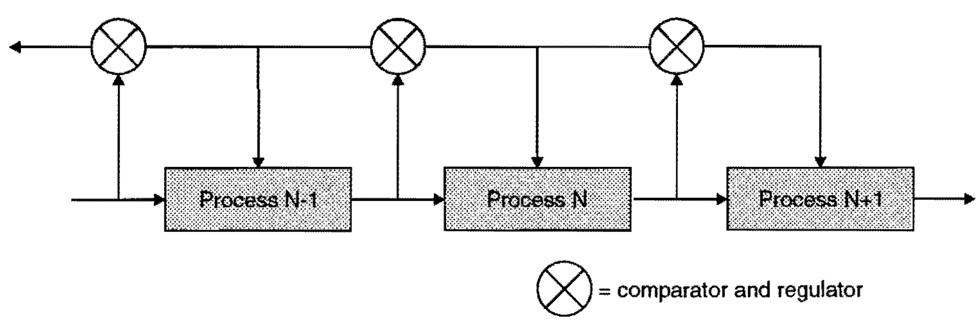


Figure 6.2 Quality assurance using control loops

In this way the quality of the *product* as well as the *process* can be assured. The quality of both the product and the process is dependent upon the design of the quality assurance process based upon the control loops described here as well as the process design (see Chapter 4).

The main idea behind this type of quality assurance is to control the output of a sub-process before the subsequent sub-processes in the engineering process are affected. Make corrections to the intermediate output if necessary to prevent errors from occurring in the remainder of the process. Take corrective measures, when warranted, to change the process so that similar errors will not occur in the future. The prevention of engineering mistakes as early as possible in the process is extremely important in view of the customer-specific and one-of-a-kind nature of the product description and the fact that the duration of the engineering process is (partially) included in the delivery lead time for the customer.

The quality of the design of this type of quality assurance process is dependent upon a proper definition of the quality norms for the engineering documentation associated with the various production phases. Based upon the definition of product quality, this means translating the degree of suitability of each type of engineering document for the specific users into quality norms for these documents. It is therefore extremely important to include the users of the engineering information in the quality assurance process. The way in which the previously mentioned quality considerations have been included in the controlling system is explained in the following sections. The aforementioned characteristics and the existing methods and techniques play an important role in this context.

6.2.6 Including quality considerations within the controlling system

The way in which the three quality considerations identified in Sub-section 6.2.4 are to be included in the design of the controlling system is described in more detail in this Sub-section. In the next Sub-section, special attention is subsequently paid to the various engineering reviews during the customer order driven engineering process.

♦ *Quality considerations with respect to evaluating requests for quotation*

In addition to a number of other evaluations, a *technical evaluation* in the form of a risk analysis is carried out for each request for quotation before a decision is made whether to accept the request. As soon as a request is received, this is reformulated in the form of a functional requirements specification (see Chapter 4) within the Sales organization. The technical evaluation is then performed by the Product Engineering PU based upon a standard technical evaluation questionnaire. The purpose of this activity is to estimate the technical risk associated with the request, based upon the functional requirements specification. If the request includes a relatively large number of customer-specific requirements, then there is a greater likelihood that more product engineering and detailed design hours will be required than will be originally estimated. The technical risk becomes greater as the probability of more hours being required increases and/or the possibility of a larger overrun in the originally estimated number of hours increases.

The potential technical risk is closely related to the chosen OSL and the degree to which the customer is allowed to formulate his own individual product specifications. The product engineer translates the request into the major product functions. Each major function is evaluated in terms of one or more risk factors. Each risk factor is reviewed for each function and an evaluation is made to determine whether there is a large, a limited or no technical risk with respect to each factor. The outcome of this evaluation is dependent upon whether existing standard product functions can be used as reference models. The technical risk is reduced when more use can be made of product standards. The technical evaluation is summarized in the form of a final opinion concerning the total technical risk. This technical risk can be seen as a quality indicator and important input data for the evaluation of the request. In addition to evaluating the technical risk, an estimate is also prepared as part of the technical evaluation activity to indicate the required product engineering and detailed design resource capacity needed to translate the request into a complete technical product description. The estimation of these hours is important input data for the time-related considerations as well as the financial considerations within the controlling system (see further in this chapter). Based upon the estimate of the technical risk, a decision is also made regarding the extent to which a formal engineering review will need to be held upon completion of the various engineering activities.

In view of the importance of the risk estimate, the result of the technical evaluation of each request for quotation is stored and maintained in the management information system.

♦ *Quality considerations with respect to issuing quotations*

The contents of the quotation can be considered to be complete as soon as the product description has been prepared in the form of a modular product structure and a preliminary draft of the product. A delivery lead time and a quotation price is then determined based upon these product specifications. A part of the product uncertainty and the associated technical risk is reduced as a result of this engineering activity. The product is not yet fully specified at this stage, however, since the detailed design still needs to be carried out. In order to determine the delivery lead time and quotation price, another technical evaluation is performed at this point to estimate the remaining level of technical risk which is associated with the product description at this stage. The result of this evaluation is also entered and stored in the management information system. The evaluation of the remaining technical risk is important input data for determining the slack which needs to be included in the delivery lead time in the quotation as well as the margin which needs to be included in the quotation price (see further in this chapter). In addition, the remaining technical risk plays an important role in determining how many engineering reviews will need to be held during the order phase. An important indicator for the technical risk is the revised estimate of the detailed design resource capacity which will be required in the order phase.

♦ *Quality considerations with respect to monitoring the progress of customer orders*

An estimate of the remaining technical risk is prepared to support the decision regarding issuing the quotation, based upon a preliminary draft of the product and a specification of the modular product structure. Based upon this, a decision is also made regarding the extent to which engineering reviews will be needed during the order phase to adequately control the quality of the product description. Nevertheless, unexpected quality problems may occur during the detailed design of the customer order. It may be decided that extra engineering reviews are needed in the event that such (technical) problems arise. The consequence of deciding to hold extra engineering reviews (due to quality considerations) is that extra (scarce) resource capacity will be required. In addition, holding extra engineering reviews could affect the throughput time of the customer order. In connection with monitoring the progress, independent quality considerations are generally not involved; this is typically more of a trade-off between quality, on the one hand, and extra costs and/or throughput time, on the other hand. A discussion of the possible relationships and trade-offs between the three control factors within the controlling system is presented in Section 6.5.

6.2.7 Using engineering reviews for quality assurance

Using the systems theory model shown in Figure 6.2, a method has been designed for conducting engineering reviews specifically for evaluating the engineering specifications in connection with customer order driven engineering activities. This method has been developed based upon the review method published by Fagan (1986) for evaluating software engineering documents (see also Humphrey 1990). The engineering of (complex) customized products is quite similar to software engineering in the following respects:

- the development of software also involves the production of "information products";
- similar phases in the engineering process can be identified in the field of software engineering;
- the use of product standards (i.e., the re-use of standard software modules) is an increasingly important topic in the field of software engineering.

♦ *Design of the method*

The method developed for conducting engineering reviews is based upon the following principles:

- the purpose of the review is to answer the question of whether the engineering process has translated the engineering input properly into the engineering output;
- the information user needs to be involved in the review to a significant extent (consider 'Fitness for use');
- any unclear aspects for the user are to be noted as faults;
- faults are to be classified according to degree of importance;
- statistical process control is to be used.

The review process is not only oriented toward the direct improvement of the inspected engineering documents (controlling the product quality). An important contribution is also provided with respect to the continual improvement of engineering products and engineering processes via a direct feedback to the process, itself (controlling the process quality). A picture of the quality of the engineering process over a period of time is established via the collection of statistical information about the quality of the product description. An illustration of this review concept is presented in Figure 6.3. The engineering document to be reviewed is compared with the original document (the source document) which was used as the input for creating the engineering document under review. The purpose of this comparison is to determine whether the transformation of the product specifications used as the input has been performed correctly during the production phase under consideration. If the preliminary draft of the product is being reviewed, then the main issue to be addressed by the review is determining the extent to which the transformation of the functional requirements specification has been performed correctly. All of the errors and unclear aspects with respect to the transformation of the input document to the output document are to be identified as faults.

Two supporting documents are used in connection with the review. The first document is a so-called *Standards Specification* in which rules are formulated with respect to:

- how the transformation process for engineering input to engineering output is to be carried out (production-oriented approach);
- the form and content of the engineering output (product-oriented approach);
- how the differentiation between product standards and customized elements is to be made.

The second document is a so-called *Checklist* in which the important evaluation points for the review process are listed. The Checklist also includes tips based upon past experience regarding aspects which are often overlooked and/or may cause problems in a later stage of the engineering or production. Both the Standards Specification and the Checklist are maintained as paper documents and are not stored, as such, in the management information system.

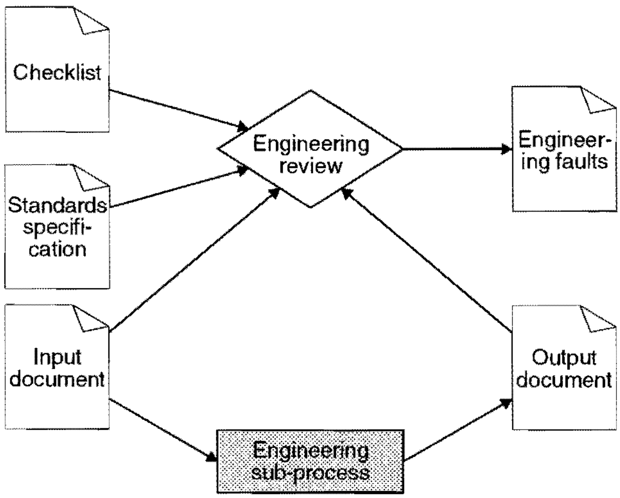


Figure 6.3 The engineering review concept

♦ *The engineering review process*

The engineering review process, itself, can be split into six separate activities (see figure 6.4). The first activity in the review process is the Kick-off Meeting of the review team. The relevant documents are distributed at this meeting, the review tasks are assigned to the team members and the duration and deadlines for the review are established. The review team consists of:

- a chairperson;
- the author(s) of the engineering document to be reviewed;
- one or more of the author's colleagues;
- the user(s) of the engineering document.

The Kick-off Meeting is followed by an individual Preparation activity. Each member of the review team (with the exception of the chairperson and the author) is responsible for reviewing the engineering document based upon the input document, the Standards Specification and the Checklist. Each error, imperfection or unclear aspect is noted as a fault. The seriousness of each fault is indicated by assigning a code which places it in one of the following categories: an extremely serious fault (ES), a serious fault (S) or a minor fault (M). The fault category of ES, S or M is determined based upon the number of hours which would be involved for the organization to correct the fault. Following this individual Preparation activity, a collective Fault Registration activity is initiated. The purpose of this phase is to register as many faults as possible, collectively. The intention is not to discuss each of the faults, but rather to generate a complete list of the identified faults. A Cause Analysis activity is then carried out as soon as all of the faults have been compiled in the Fault Registration phase. A "cause category" is assigned to each of the identified faults for the purpose of taking corrective and preventative measures. Then in the Correction phase, the author is responsible for making changes to the engineering document under review based upon the results of the engineering review. Depending upon the number of faults and the seriousness of the faults, the chairperson then decides to what extent the revised document should be reviewed during the Follow-up activity. If the engineering document does not need to be reviewed again, then it is released immediately for further processing.

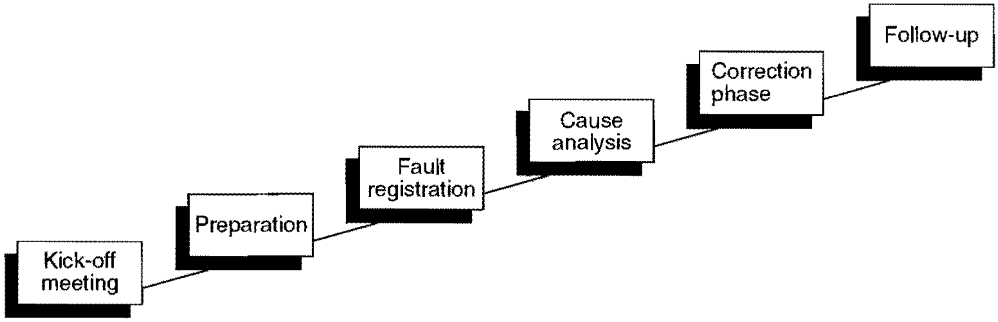


Figure 6.4 The engineering review process

The results of the engineering reviews of the various engineering documents are registered in the management information system in terms of the number of faults identified and the associated fault categories. This is important control information with respect to controlling the quality of the process, in particular. Based upon this, periodic quality indicators can be defined for each engineering document and production phase, such as:

- the average number of faults identified and the distribution spread of this average;
- the relative seriousness of the identified faults;
- the increase or decrease in the number of faults during a specific period of time.

This data is subsequently used to monitor the quality of the engineering process on an ongoing basis. If, for example, the average number of faults found in a specific document increases over a period of time and exceeds a certain normative value, then it would be advisable to review this production phase and to implement corrective measures as may be appropriate. The review method designed here for the selected case has a number of important advantages over other review methods such as review meetings and traditional engineering reviews (see, for example Jacobs 1975, Flurscheim 1983 and Maas and Bollen 1992):

- the use of statistical process control with respect to the engineering process;
- the direct involvement of the user in the reviews;
- the use of checklists designed specifically for each engineering document.

In view of the number of persons involved, reviewing each of the engineering documents produced during the customer order driven engineering process would require a major commitment in terms of resource capacity from the engineering organization. Therefore, it is prudent to consider whether all of the production phases for each customer order should be subjected to this type of review method. This is strongly dependent upon:

- the average number of faults and the seriousness of the identified faults. When the cost of correcting faults is significant, then it becomes more useful to spend time and resource capacity on engineering reviews;
- the OSL chosen by the organization. When the product description is largely customized, then the technical risk and the usefulness of engineering reviews are greater;
- the technical risk which is estimated during the quotation phase.

The quality of the control of the engineering process and the product descriptions improves when engineering reviews are conducted more frequently. When a certain level of quality is attained, it is then possible to carry out engineering reviews more selectively, for example for customer orders with a relatively large technical risk.

6.3 The timeliness factor within the controlling system

6.3.1 The distinction between throughput time and resource capacity

The timeliness factor or the production control aspect within the controlling system for customer order driven engineering concerns the control of two interrelated concepts, namely *throughput time* and *resource capacity*. These two concepts are interrelated to some extent under certain circumstances, but they are definitely not the same and thus need to be treated separately. Both of these concepts have a time dimension, such as *hours*, but the use of time in these contexts is as different as the use of *degrees* for expressing temperature and the size of an angle. A simple example is used here to illustrate the difference between these two concepts.

Assume that there is a production line consisting of N (e.g., five) sequential work stations. The processing time at each work station is fixed at a value ranging from one minute to ten minutes. The production line capacity is determined by the work station with the longest processing time. The *available production line capacity* can then be expressed as M products per unit of time (or six products per hour in this example). The *capacity requirement for a single product* then becomes 1/M (or 1/6 of an hour per product in this example). This is equal to the *cycle time* of the production line or, in other words, the speed at which the products move through the line. The *product throughput time* for the complete production process thus becomes the total number of work stations times the cycle time of the production line (N/M) (or 5/6 hour in this example). From this example it should be clear that the available production line capacity, the capacity requirement for a single product and the product throughput time are three completely different concepts. Nevertheless, all three of these factors play an important role in controlling the time-related aspects within customer order driven engineering. Special attention will be paid to each of these factors, separately, since they measure three different things. A certain relationship exists between capacity and throughput time under specific circumstances, particularly when the utilization level of the production capacity is high (see Bertrand and Wortmann 1981 for a further explanation). The capacity (utilization) is directly related to the production throughput time in this type of situation.

6.3.2 Time-related characteristics of customer order driven engineering

Two characteristics of the customer order driven engineering in the selected case situation play an important role in connection with controlling the time-related aspects. These characteristics are described briefly here.

♦ *Project-oriented work*

An important characteristic of the customer orders in the selected case situation is that they are project-oriented. This is not related to the organizational structure of the projects. In fact, the organization in the selected case situation is functionally oriented. The project-oriented character is related to the structure of the activities needed to process a customer order (the work breakdown structure). These activities and their relationships can be represented by a so-called project network structure. Each project (i.e., customer order) can be defined in terms of a starting point, an end point and a number of activities of which some can be performed simultaneously and between which certain sequential relationships have been defined. The throughput time as well as the required amount and type of resource capacity play an important role with respect to each of the activities within the project network.

♦ *Uncertainty and time risk*

The aforementioned project networks are not fully defined, particularly in the quotation phase (prevailing uncertainty). The project network becomes more complete and may be worked out in more detail as the customer order is processed. The three uncertainty factors mentioned in Section 3.6 have an important effect on the degree to which a project network is defined and, thus, the amount of time risk associated with a given project. A large time risk means that the timeliness factor (as well as the resource capacity) is relatively difficult to control. For this reason, attention should be focused on the areas of uncertainty in connection with controlling the time-related aspects. In fact, when a project network is not completely defined, this has consequences for the quality and cost factors as well as the timeliness factor. This is discussed in more detail in other sections of this chapter.

6.3.3 Time-related considerations within the controlling system

The eighth point in time is when time-related considerations may need to be reviewed in connection with control, based upon the controlling system for customer order driven engineering as described in Chapter 5. These points in time are mentioned briefly, here, and subsequently explained in more detail in Sub-section 6.3.5. The first opportunity for reviewing the time-related considerations coincides with the evaluation of a request for quotation (GFC level). The aspects considered here include the effort/capacity needed to prepare a quotation based upon a given request and the throughput time which will be required. The second opportunity for reviewing the time-related considerations is when the work orders are released to the Product Engineering PU (PUC level). The time-related considerations associated with releasing work orders are concerned with controlling the throughput times of the product engineering activities as well as possible. The third opportunity for reviewing the time-related considerations deals with determining the required delivery lead time for inclusion in the quotation to be issued (GFC level). The delivery lead time must be determined based upon whatever data is currently available about the potential order. The fourth point in time coincides with the reservation of resource capacity for processing the order within the Detail Design PU (GFC level) when it is clear that the potential order is likely to become a firm customer order. The fifth opportunity for reviewing the time-related considerations is when the final delivery date for a customer order is agreed (GFC level). This is determined at the time of internal order acceptance and may differ from the originally quoted delivery lead time. The sixth opportunity for reviewing the time-related considerations is when work orders are released to the Detail Design PU (GFC level). The considerations here are similar to those in the situation when work orders are released to the Product Engineering PU. The seventh point in time coincides with the assignment of sub-orders and decisions regarding outsourcing (GFC level). Sub-orders can be assigned to PU's in the component manufacturing and assembly phase after the detailed design activities have been completed. Based upon the evaluation of available resource capacity, the individual project network structures are modified as may be required and decisions are made concerning which sub-orders are to be outsourced. The eighth point in time coincides with the monitoring of progress and taking corrective measures with regard to the customer orders (GFC level). The progress of individual customer orders is tracked based upon the project network. Relevant measures are then taken here to rectify any project problems which may occur in connection with meeting the scheduled project deadlines.

It can be seen from the points in time identified in this way that the timeliness factor plays an important role at every decision point within the controlling system. This is true for the integral decisions at the GFC level (evaluation of requests for quotation, issuing quotations, order acceptance and sub-order assignment), for the integral progress monitoring and for the local decisions at the PUC level (work order release and work sequencing for the PU's) as well.

6.3.4 Using existing production control methods and techniques

To support the review of time-related considerations within the controlling system, a number of existing methods and techniques are used here, namely:

- network planning, slack management and capacity loading evaluation to support an integral control of customer orders and sub-orders;
- work load control to support the local control of PU's and production work orders.

♦ *Network planning, slack management and capacity loading evaluation*

As discussed in the first part of this chapter, the activities related to processing customer orders can be represented in terms of a network structure in the selected case. Network planning techniques (see Meredith and Mantel 1989) are used here to support the decision-making related to the time-related aspects within the controlling system. There are several reasons for using network planning within the controlling system for customer order driven engineering, namely:

- to determine the throughput time for future projects;
- to calculate the throughput time of projects, taking the available resource capacity into account;
- to calculate the throughput time of projects, taking the uncertainties into account;
- to support the monitoring of progress and control of throughput times of the projects;
- to identify the activities which lie on the critical path and, thus, determine the throughput time.

In view of these possible reasons and the required functions, a planning method which represents activities as nodes rather than as connecting arrows is the preferred choice (Kerbosch and Schell 1972). An example of this type of network structure is presented in Figure 6.5. An expected throughput time is registered for each activity. Each project is comprised of a network of (to some extent, simultaneous) activities. Slack can be found in some parts of the network whenever a critical path of activities can be identified. This slack can be calculated and represented in a visual form for each activity. Slack in the form of extra throughput time can be added to the critical activities as a buffer to compensate for the uncertainty in customer order driven engineering and to eliminate some of the time risk. Slack in the form of extra *resource capacity* may also be required for some activities in view of the uncertainty regarding the amount of resource capacity which will be required.

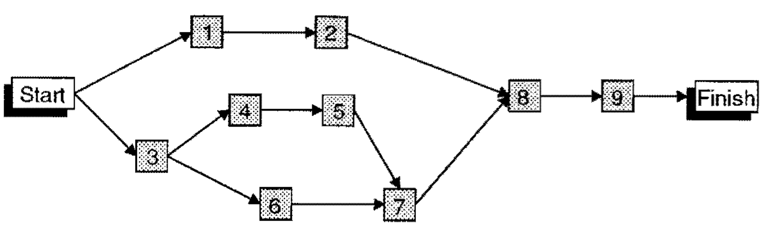


Figure 6.5 Simple example of a project network

The use of project networks is not restricted to the initial phase of customer order driven engineering when the uncertainty is relatively great. The project network can also play an important role in the subsequent phases of the customer order driven engineering and physical production. As soon as more detailed information is available concerning the product and process specifications, the aggregate activities included within the project network structure can be planned in more detail. The network can then play an important role in monitoring the progress of a project. An overall view can always be maintained at the GFC level based upon the project network, even when the project is subdivided further into a large number of sub-activities. In this way the network remains useful as an important control instrument, even after the detailed scheduling of activities has started.

The slack associated with each activity in the project network represents important decision-support information in connection with monitoring the progress of the active projects as well as accepting new requests for quotation and customer orders. Maintaining sufficient slack in project networks (slack management) should, thus, be seen as an important control activity within the controlling system for customer order driven engineering.

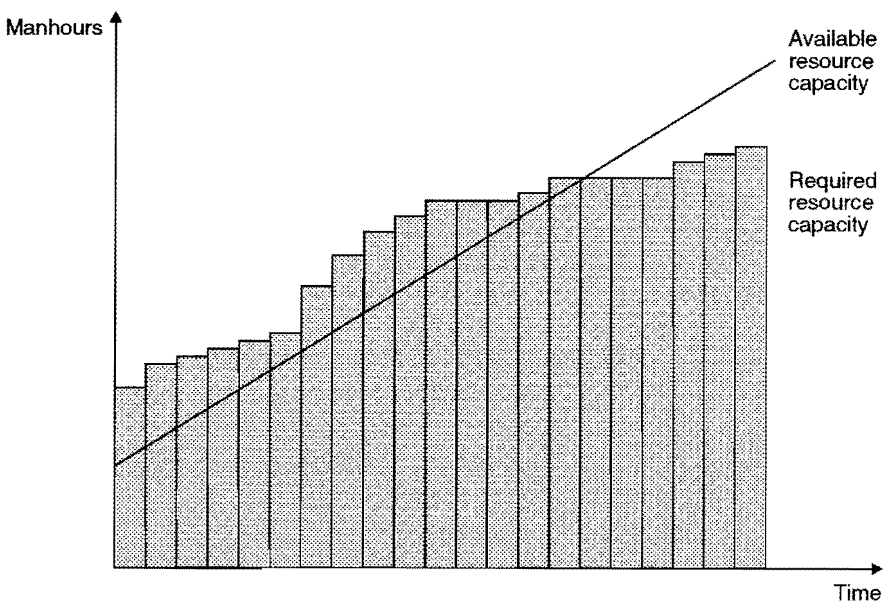


Figure 6.6 Example of a capacity loading profile (cumulative)

In addition to the calculation of throughput times, project networks can also be used as a basis for resource capacity evaluations. The start dates and completion dates are registered per activity in the project network along with the required amount of resource capacity. A capacity loading evaluation for each type of capacity can be performed by generating capacity loading profiles (see Figure 6.6) based upon this information. The network planning technique should provide support for matching the resource capacity requirements with the available capacity, taking the slack which is included in the various networks into consideration. This type of technique is referred to as *resource levelling*. Capacity loading profiles should be designed to provide decision support information for, for example, assigning due dates and selecting activities to be outsourced.

♦ *Workload control*

From the point-of-view of controlling the time-related aspects, the decision structure should be designed in such a way that it can be used effectively to control the throughput times of the customer orders and to achieve the desired level of capacity utilization. The customer order throughput time is determined by the throughput time of the customer order dependent activities within the various production units processing the activities which lie on the critical path. The purpose of production unit control (PUC) from the point-of-view of controlling the time-related aspects is to accept production work orders and to complete the production of the accepted work orders within the agreed throughput time, taking the agreed conditions concerning the utilization levels, throughput times and batch sizes into account. A significant amount of research has been carried out on the subject of controlling the throughput times within production units by, for example, Bertrand and Wortmann (1981), Bechte (1988) and Wiendahl (1987). One result of this research was that throughput times are dependent upon various factors, including the size of the workload within the production unit. More work on the shop floor means that the average throughput time for newly accepted work orders will tend to increase. Throughput times can therefore be controlled by *controlling the workload* via a controlled release of work to the production unit (Bertrand and Wortmann 1981, Kingsman et al. 1989, Van de Wakker 1993). A controlled release of production work orders to the PU provides the additional significant organizational benefit of identifying capacity problems as early as possible. If, for example, the workload within a PU increases to a high level due to equipment failure or employee illness, then the scheduled quantity of work is not released. This can be recognized and reported immediately so that the GFC can then evaluate the consequences of the delay and any corrective measures which may be required can be taken. If this control is not present and the work orders are released to the PU in this situation, the consequences will not be visible until a much later point in time when corrective measures may be too late to be effective. The principle of workload control is illustrated in the diagram in Figure 6.7

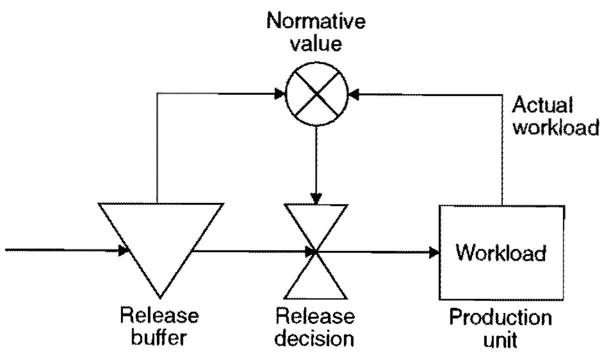


Figure 6.7 The principle of workload control

The principle of workload control as an instrument for controlling the throughput times in a PU could be used as a basis for releasing work orders to the Product Engineering and the Detail Design PU's within customer order driven engineering. This is explained in more detail in the following sub-section.

6.3.5 Including time-related considerations within the controlling system

This sub-section provides an explanation of how the eight time-related considerations as identified in Sub-section 6.3.3 have been interpreted within the context of the controlling system. The previously described characteristics of customer order driven engineering and the aforementioned methods and techniques are important factors in this respect.

♦ *Time-related considerations when requests for quotation are evaluated*

In addition to the business considerations and issues concerning the technical content of requests of quotation, there are also time-related aspects to be considered when such requests are evaluated. The future utilization of the physical production capacity and the possible throughput time of a future customer order are taken into account only minimally at this stage. The reason for this is the relatively high degree of uncertainty about the machine specifications, the expected probability of winning the order and the uncertainty about when a firm order might actually be placed. As a result of this uncertainty, it is not worthwhile to try to determine whether sufficient resource capacity will be available. The major time-related consideration in connection with evaluating the requests for quotation concerns the throughput time and capacity within the Product Engineering PU which will be required to respond to the request. An estimate of the product engineering capacity required to process the request is made based upon technical evaluation of the request (see Sub-section 6.2.6). An estimate of the throughput time needed to process the request can be made based upon the resource capacity requirements in connection with the request and the amount of work in process (including the scheduled work which is waiting to be released) within the Product Engineering PU. If the planned throughput time is significantly longer than the normal lead time in this market or longer than the customer is willing to accept, then the decision may be made to reject the request for this reason. If the potential order is attractive from a business point-of-view or for any other reason, then the decision may be made to assign a high priority to this request. This means that the request will be processed, but at the cost of another request that arrived earlier and is waiting in the buffer of work to be released to the Product Engineering PU. Each request for quotation (and its status) is registered in the management information system.

♦ *Time-related considerations when orders are released to the Product Engineering PU*

As described in Chapter 4, a single production phase is performed within the Product Engineering PU. This phase involves developing the modular structure and the preliminary draft of the product. The average throughput time for performing this production phase in the selected case situation is relatively short (one to five days, on the average). A single *product engineering* order is released to initiate this production phase.

In principle, a product engineering order is carried out by a single person and consists of a number of operations. Examples of the operations required to complete the preliminary draft include:

- defining the functional structure;
- developing the solution principles;
- determining the product modules (modular product structure);
- preparing general specifications for the form and the materials for the most important product modules.

The description of the request for quotation which includes the Functional Requirements Specification, the business evaluation and the technical evaluation is used as the input information for processing the "Preliminary Draft" product engineering order. A distinction is made between the various operations, corresponding to the engineering steps outlined in Chapter 4, in spite of the fact that normally only one person is responsible for carrying out the whole product engineering order. Each of these is viewed as a formal step in the engineering process for which a formal engineering output has been specified (such as a functional structure). In this way, an opportunity for an engineering review is created after the completion of one or more of the operations. A certain amount of resource capacity is also reserved especially for this purpose. The product engineering orders, the product engineering operations, the required amount and type of engineering capacity and the required engineering reviews are registered in the management information system for each request for quotation for the purpose of controlling the PU's.

The control of the PU's focuses on an optimal coordination and management of the throughput times of the product engineering activities associated with the quotation. This is accomplished by controlling the release of product engineering orders to the PU (key decision 3) and a clear definition of the priorities within the PU (key decision 4). In view of the nature of this work, the control of this PU really only concerns coordinating the resource capacity. The availability and coordination of materials is not a significant activity here. As a result, this production control situation can be seen as being relatively simple in comparison with the control of a physical production unit. A normative processing time for completion of the total product engineering order is estimated as part of the technical evaluation. The need to conduct one or more engineering reviews is taken into account, if relevant. In addition, a certain amount of slack is included with respect to the throughput time and/or the resource capacity requirements, depending upon the technical risk, in order to compensate for the resource capacity requirement uncertainty. As the technical risk increases, the chance that more resource capacity will be required than was originally estimated also increases.

It is sufficient to look only at the total amount of available human resource capacity since the employees in this area are multi-skilled to a large degree. This means that there is only a single input queue to be managed. Normative workload levels are determined based upon a certain fixed relationship between the PU workload (in hours) and the average throughput time for processing a request for quotation. Periodically, product engineering orders (i.e., requests for quotation) are released to the PU (key decision 3) based upon a comparison between the current and the normative workload. The Sales organization assigns priorities to the released requests for quotation for the purpose of allocating resource capacity and setting priorities within the PU (key decision 4). By controlling the release process to the Product Engineering PU in this way, it is possible that a number of requests will not be released immediately. This results in a buffer of requests which are waiting to be released. The requests waiting in this buffer represent an important factor in the weekly selection of requests for quotation by the Quotation Team. If requests remain in the buffer too long (thus, retaining a low priority) they are eventually removed from the buffer and rejected. The degree to which requests are rejected due to resource capacity limitations, after they have already passed the request evaluation selection, can be seen as important management information for the longer term. This can provide an indication of the requirement for additional product engineering capacity. The management information system provides information to support this release decision. Certain data is stored and maintained per PU for this purpose such as the current workload, the normative workload and the priority of each product engineering order waiting to be released.

The iterative character of the process in the quotation phase is a significant factor which makes controlling the Product Engineering PU much more complicated. For a large majority of the requests, the first quotation leads to further discussions and subsequent changes to certain specifications. This means that a request is subsequently released, again, to the Product Engineering PU. A revised request is reviewed and evaluated once more by the Quotation Team to determine whether the processing of the request should be continued. Revised requests for quotation are already linked to a specific person, however, in contrast with the situation of a new request. This aspect must be taken into consideration when a revised request is released. It is also possible that a higher priority will be assigned to revised requests for work order release and in connection with priorities within the Product Engineering PU since such requests are already at an advanced stage of completion.

The modular product structure and the preliminary draft developed at this point represent the level of product description which is used as the basis for determining the delivery lead time and the quotation price and the final decision with respect to issuing the quotation.

◆ *Time-related considerations in connection with quoting a delivery lead time*

The technical budgeting specialist estimates the required resource capacity and materials for each product module, based upon the modular product structure and the preliminary draft. The resource capacity requirements for each product module are specified per aggregate activity. The following aggregate activities can be identified at this stage:

- detailed design;
- component manufacturing;
- assembly and testing.

The estimate of the required materials and the required resource capacity for each product module per aggregate activity provides the basis for determining the price as well as the delivery lead time. A quotation network structure is defined for each quotation in which the aggregate activities are defined to the extent necessary to be able to determine the delivery lead time. The available standard project network structures can be used here. A number of standard project network structures based upon experience with previously completed customer orders are stored and maintained in the management information system for this purpose. These network structures provide a variety of options with respect to the relationships between aggregate activities (in terms of throughput time, relative sequence and slack in the throughput time). A throughput time for each aggregate activity is determined based upon the selected project network and the required resource capacity per aggregate activity. Historical data from which the relationships between resource capacity requirements and throughput times can be derived is used for this purpose. In connection with determining the normative throughput time for each aggregate activity, a certain amount of slack (in the capacity requirements and/or throughput time) is added to one or more of the (critical path) activities in order to compensate for uncertainties, if required. The amount of slack to be added to the network is dependent upon:

- the technical risk associated with the request;
- the number of engineering reviews planned;
- the current composition and mix of the requests for quotation being processed.

Each quotation network structure consisting of various aggregate activities, the estimate of required resource capacity for each activity and the chosen amount of slack is registered in the management information system.

A delivery lead time indication for inclusion in the quotation is determined using calculations based upon the quotation network. An evaluation of the resource capacity requirements is not carried out at this point due to the length of time that may lapse between issuing the quotation and receiving the firm customer order. It is assumed that the normative throughput times will be valid when the plant is operating at a normal utilization level. An exception is made with respect to the evaluation of the available resource capacity within the Detail Design PU, however. The throughput reliability of this activity, in particular, determines the throughput reliability of the whole customer order. In some instances the resource capacity evaluation is carried out for Detail Design and resource capacity is reserved in advance (this is also discussed in subsequent sections). In view of the uncertainties, a delivery lead time, which starts when the firm customer order is received, is quoted instead of a specific delivery due date. The quotation always includes a specific expiration date to prevent capacity problems which may occur within Detail Design, in particular, if the customer decision process takes an inordinate amount of time. This essentially means that if the expiration date of the quotation has passed by the time that the customer places the order, then there is an opportunity for making adjustments to the quoted delivery lead time.

The management information system provides support for the calculations based upon the quotation network structures and maintains the data related to the resource capacity utilization within the Detail Design PU.

♦ *Time-related considerations in connection with reserving resource capacity within the Detail Design PU*

There are two instances when the available resource capacity may be evaluated and capacity may be reserved in advance for quotations. In the first place, it is possible that one or more quotations have already been issued in response to a given request and that the next version of the quotation will be the final version. In this instance the sales organization may be able to draw the conclusion that the customer will decide whether to place an order fairly soon after the final version of the quotation is issued. The resource capacity requirements for Detail Design are then included in the load planning for the PU to determine if the desired delivery lead time is actually feasible when the current capacity utilization situation is taken into account. If the sales organization believes that the customer will be placing a firm order in the near future, then the resource capacity required to process this order may even be reserved in advance when the quotation is issued, as if it were already an accepted customer order. In the second place, the list of issued quotations waiting for customer acceptance is reviewed by the Quotation Team. The sales organization maintains ongoing contact with the potential customers concerning the issued quotations. The issued quotations which have a high probability of becoming firm orders and which the sales organization expects will be decided upon in the near future, may also be included in the resource capacity load planning for the Detail Design PU. The resource capacity which will be required to process an order resulting from this quotation may also be reserved in advance. In connection with this, it is extremely important that the Quotation Team actively and continually reviews the current status and mix of the issued quotations waiting for acceptance.

♦ *Time-related considerations when an order is accepted internally*

The sales organization notifies the rest of the organization as soon as possible when a customer places a firm order. A resource capacity evaluation is then carried out to determine the consequences of the new customer order for the production organization. To do this, the resource capacity requirements based upon the network structure from the quotation is added to the existing requirements of the customer orders already being processed. The purpose of this is to determine to what extent the agreed delivery lead time in the quotation is actually feasible and where any problems could be expected. The status of the customer orders already being processed and the degree to which slack still exists in these project networks are important factors in deciding how to proceed. Using this information, it can be determined whether a decision to accept a project with no slack or even negative slack could be justified. Information about the (remaining) slack is stored and maintained in the management information system.

A possible result of this evaluation is that completion of the customer order is not feasible within the agreed delivery lead time. In view of the uncertainties which influence the order, it is possible that it is already evident in advance that the delivery lead times promised in the quotation cannot be met, in spite of the slack which has been included in the network, and that the customer is also not willing to accept a revised due date. The company may still decide to accept the customer order based upon the quoted terms and conditions. This implies that the company has decided, internally, to deliver one or more of the customer orders later than the scheduled due date. This type of decision is referred to here as *acceptance flexibility*. Following this type of policy will, of course, only be tolerated externally if the competition is dealing with similar uncertainties and delivery problems to the extent that they would also deliver later than the agreed due date. Acceptance flexibility should only be used under exceptional circumstances in the selected case. In this type of situation, it is important that the controlling system does not try to deal with the externally promised due dates. This would lead to significant disruptions in connection with controlling the customer orders currently being processed. This means that a distinction must be made between an internal and an external due date. The external due date in this situation is not realistic, even though it has been agreed with the customer. The internal due date, on the other hand, should be considered to be the realistic due date for internal control purposes. Deciding when to tell the customer about the tardiness of completing the order then becomes a business decision. The considerations involved in making this decision do not fall within the scope of this book. The result of the time-related considerations when an order is accepted internally is the determination of a final delivery *due date* for the accepted customer order. This date is mentioned in the order confirmation to the customer. The finalized start dates and completion dates are stored and maintained in the management information system for each aggregate activity defined in the project network.

♦ *Time-related considerations when work orders are released to the Detail Design PU*

The description of the time-related considerations involved in releasing work orders is similar to the situation with the Product Engineering PU. As indicated in Chapter 4, three production phases are carried out within the Detail Design PU, namely: (1) detailing the assembly modules; (2) detailing the components within an assembly module; and (3) preparing the technical documentation for the product. The production phases within the Detail Design PU are performed in several steps. These steps can be understood most clearly by referring to Figure 6.8. Where possible, use is made of the standard product descriptions stored in the management information system during the execution of each of these steps.

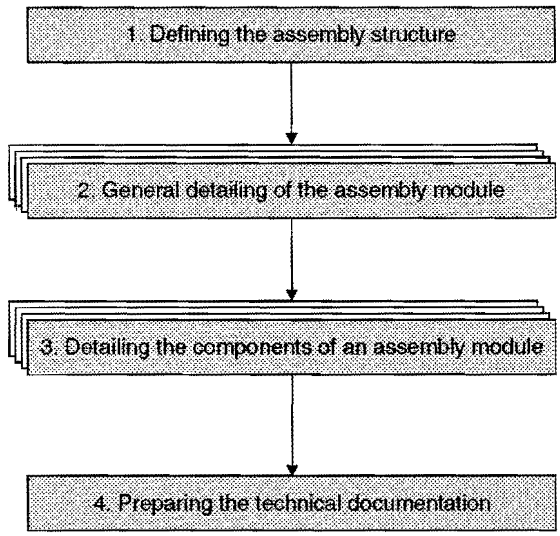


Figure 6.8 The detailed design of a machine in sequential steps

Defining the assembly structure

A number of preparatory activities need to be carried out, first, before the detailed machine design activities can be initiated. These preparatory (control) activities are concerned with the way in which the work associated with a customer order should be split up. The major problem, however, is that part of the work to be done has not yet been defined. The assembly structure for the machine is defined based upon the modular product structure and the preliminary draft. So-called *assembly modules* with a certain priority sequence are created in this way. The assembly structure can be seen as a further specification of the aggregate activity of Assembly and Testing defined in the project network. This results in a more detailed specification of the project network whereby the start dates and completion dates for the various assembly modules are scheduled within the period defined by the start date and completion date for the aggregate activity. An *assembly sub-order* is added to each of the assembly modules to include an order for the assembly of an assembly module. The assembly structure and the assembly sub-orders with their scheduled start dates and completion dates are registered in the management information system as a further specification of the aggregate activity Assembly and Testing in the project network. Subsequently, the necessary attention is paid to defining the interfaces between the assembly modules before the further detailing is carried out. Then the detailed design of the assembly modules within a customer order can be performed.

General detailing of the assembly module

Each assembly module is detailed separately in two production phases (see Section 4.7). A general detailing of the assembly module is carried out in the first production phase by a further development of the sub-assembly drawings, the interfaces between the product modules and identifying the various assembly components. The assembly module detailing is performed based upon a single detailed design order within the PU, the so-called *"A" Design Order*. The priority of the "A" Design Orders is determined by the scheduled start date for the assembly sub-order in the project network. In view of the diversity of skills required to complete a customer order, the various "A" Design Orders belonging to a given customer order are generally carried out by different detail designers. Each individual "A" Design Order is only carried out by a single person, however. When an "A" Design Order is carried out to detail an assembly module, this results in more information about the detailed design resource capacity which will be needed at the component level and, thus, reduces a significant amount of the prevailing product uncertainty. For this reason, it is sensible to create a separate detailed design order to detail the components of an assembly module so that progress can be made at the GFC level (see also Bertrand et al. 1990, page 38).

Detailing the components of an assembly module

The subsequent detailing of the components (to the extent that they are non-standard) within an assembly module is included in a single detailed design order, referred to as the *"F" Design Order*, within the PU. The details regarding the interfaces between the assembly modules are defined, first, before the "F" Design Orders are carried out. The required detailed design resource capacity is estimated for scheduling purposes for each "F" Order. In principle, the priority of the "F" Orders is also determined based upon the start date for the assembly sub-order as scheduled in the project network. In addition, the nature of the components is taken into account. Components which are on the critical path of a customer order and have a (very) long delivery lead time or production throughput time are assigned the highest priority within a customer order.

Preparing the technical documentation

The preparation of the technical documentation for a complete customer order is combined within a single detailed design order, the so-called "D" Order. This order is generally carried out only after the final detailed design activities for a customer order have been fully completed.

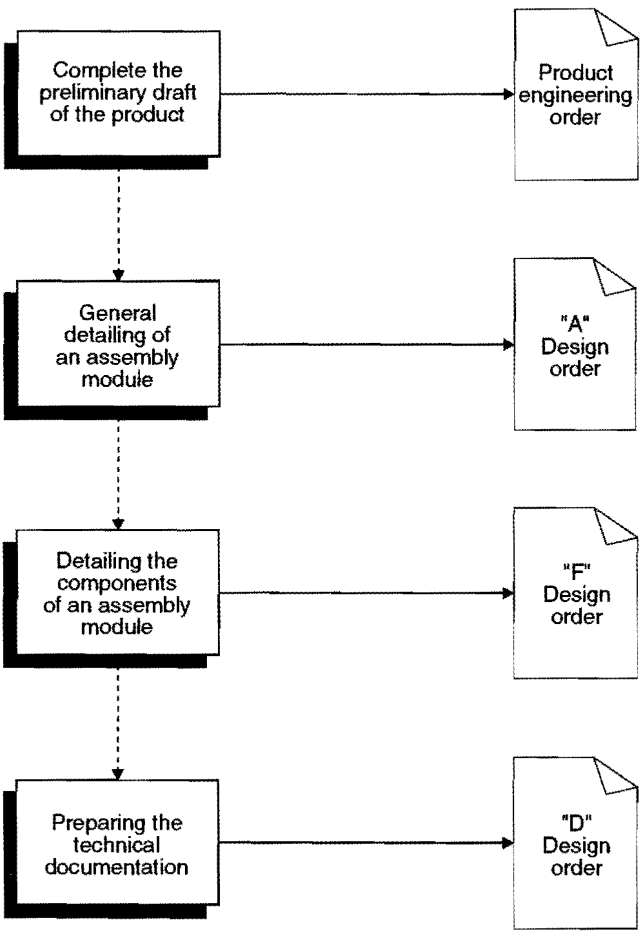


Figure 6.9 Relationships between production phases and the order structure

The "A" Design Orders and the "F" Design Orders within the Detail Design PU are scheduled within the period defined by the start date and the completion date of the aggregate activity Detail Design defined in the project network. The various detailed design orders are registered in the management information system as a further specification of the aggregate activity Detail Design in the project network. The detailed design orders are released to the PU (key decision 3) in a manner similar to that found in the Product Engineering PU. The priorities (key decision 4) are established based upon the scheduled completion dates of the detailed design orders. The relationships between the various production phases and product descriptions (see also Table 4.1 and Figure 4.7) and the various types of orders are illustrated in Figure 6.9.

♦ *Time-related considerations in connection with sub-order assignment and outsourcing*

Preparations are made for manufacturing the components of the assembly module by defining manufacturing sub-orders after the "A" Design Order as well as the "F" Design Orders have been detailed for the assembly module. This can be seen as a further specification of the aggregate activity Component Manufacturing in the project network. A manufacturing sub-order was previously defined as an order for the production of one or more technically similar components of a single customer order which must be produced within the same PU during approximately the same period of time (see Subsection 5.4.3). Components which need to be manufactured in the same Component Manufacturing PU during approximately the same period of time are combined together in a single manufacturing sub-order after the detailed design work has been completed for the assembly module. The assembly module is split up into a number of portions of similar work for a specific PU for component manufacturing in this way. In principle, the product documentation can then be transferred to the component manufacturing activity for each assembly module. This transfer is carried out in the sequence dictated by the priority sequence defined for the assembly modules since this has taken the priorities within the Detail Design PU into account. The various manufacturing sub-orders are defined, successively, as the detailed design of a customer order progresses. The manufacturing sub-orders are scheduled within the period between the start date and the completion date of the aggregate activity Component Manufacturing in the project network. The various manufacturing sub-orders are registered in the management information system as a further specification of the aggregate activity Component Manufacturing in the project network. The throughput time needed for requisitioning the required materials is an important factor in connection with scheduling the start dates for the manufacturing sub-orders. Some of the components within a project can be characterized as standard components. Some of these standard components are produced as customer order dependent components. In contrast with the customized components, the specifications of these components are known at an early stage. The rest of the standard components are produced as unallocated stock, independent of the customer order (see also Chapter 5). The coordination between the project network planning and the availability of the components produced as unallocated stock is certainly important, however, this topic is not included within the scope of this book (see also Sub-section 5.4.5).

After the detailed design of the product, the project network consists of a network of scheduled manufacturing and assembly sub-orders. The resource capacity requirements (for each type of critical resource capacity) can be estimated at this point since there is some knowledge of the content of the various sub-orders (since the drawings have been prepared). The amount and type of (critical) resource capacity required for each sub-order is registered in the management information system. Knowledge of the resource capacity requirements for each sub-order is the most important input for key decision 2: Sub-order assignment and outsourcing. As described earlier in this chapter, there is a large degree of uncertainty in connection with the delivery lead time which is quoted for a customer order. The detailed design, however, removes much of this uncertainty. A reliable estimate of the required production resource capacity (at the aggregate level) can be made for each manufacturing and assembly sub-order after the detailed design has been carried out. In addition, the network structure includes information about the scheduled start dates and completion dates for the sub-orders and in which PU the sub-order should be processed, in principle. Key decision 2, Sub-order assignment and outsourcing, therefore has two objectives with respect to time-related considerations (see also Sub-section 5.4.3).

a. By assigning sub-orders to PU's as soon as possible, the consequences for the PU's resource capacities can be identified at an early stage. These consequences are the major factors for deciding which manufacturing orders, if any, should be produced internally and which could be outsourced. In addition, insights into the future resource capacity requirements for the assembly activities are gained sooner rather than later. By assigning the sub-orders as soon as possible in this way, the PU production managers are in a position to quickly determine what the future demand for resource capacity is likely to be.
b. An evaluation of key decision 1 can be carried out at this point in time since the product uncertainty has diminished. If it turns out that certain variables have different values than originally anticipated, then corrective measures can still be taken in connection with key decision 2. Examples of corrective measures include the use of available slack, extra outsourcing and taking advantage of internal flexibility.

An evaluation of the resource capacity is carried out for each PU in the form of capacity loading profiles based upon the projections of capacity utilization over a certain period of time which can be derived from the sub-order network (see also Figure 6.6). In connection with this, use is made of the start dates and completion dates which have been defined for the sub-orders. This provides a basis for determining whether sufficient resource capacity is available, which manufacturing sub-orders may need to be outsourced and when corrective measures, if any, may need to be taken with respect to the assembly resource capacity. Use is made of the guidelines prepared by the detail designers for determining which manufacturing sub-orders are to be outsourced. One of the following qualifications is added to each of the manufacturing sub-orders which has, technically, been released:

- may never be produced externally;
- could possibly be produced externally.

Use is made of *resource levelling* as a technique to support the decision-making in connection with the evaluation of the capacity loading. An effort is made to use the slack in the project networks to find a close match between the available resource capacity and the capacity requirements. Decision support information is provided by the management information system in connection with evaluating the resource capacity utilization (capacity loading graphs) as well as with the resource levelling.

When the product specifications are known, the manufacturing sub-orders for the components to be produced internally are released as soon as possible to the production manager of the relevant PU. This is not the production control release to the shop floor, but rather the technical release of the product specifications for each of the manufacturing sub-orders. The PU is responsible for the further detailing and scheduling of a manufacturing sub-order in the form of work orders for the production of components and the requisition of the required materials. The description of these activities is not included within the scope of this book, however. An extensive discussion concerning the scheduling and release of sub-orders and work orders to Components Manufacturing has been published by Van de Wakker (1993).

♦ *Time-related considerations related to monitoring progress based upon project networks*

A project network structure in which the aggregate activities have been defined is created and registered for each customer order in the management information system during the quotation phase. In addition to using this for planning the throughput times and (high-level) resource capacity utilization within the GFC, it can also be used for monitoring the progress of the customer order processing. A start date, completion date and the utilization of capacity are scheduled for each aggregate activity. Upon completion of an aggregate activity, the actual completion date and the actual resource capacity utilization are reported to the GFC and registered in the management information system. The progress of each individual customer order can be monitored based upon this information during the customer order driven engineering as well as during the physical production. This information also provides a basis for taking corrective measures whenever necessary. The prevailing uncertainty becomes less as the customer order progresses through the transformation process. New information is added to the project network as it becomes available. This detailed information is used continually to provide a more detailed specification of the aggregate activities in the project network. This means that this project network is used during the whole throughput time as the basis for the further scheduling and control of the customer order. The purpose of monitoring the progress is to identify any bottlenecks as soon as possible, making it possible to ensure that the internal throughput times are reliable and are achieved. An important aspect in connection with this is identifying the effect that the problems of a given customer order may have on the other orders being processed. Such indirect consequences with respect to other orders are generally more serious than the initial problem. Bottlenecks encountered by an individual order can often be resolved by using the existing slack in the project networks or by making use of external flexibility. The project network should only be modified in extreme situations in which the backlog of work is so extensive that there is no other possibility for meeting the due dates. This type of situation may lead to negotiations with the customer, midway through the production process, concerning a revision of the due date. The management information system provides control information regarding the status of the individual project networks to support monitoring the progress of customer orders.

6.4 The cost factor within the controlling system

An explanation of the cost factor, the last of the three control factors within the controlling system for customer order driven engineering, is presented here. This can be interpreted to include a large number of aspects associated with the field of *management accounting*, such as (Horngren and Foster 1991):

- cost calculations and pricing;
- decision-support calculations (cost comparison of decision alternatives);
- performance measurement;
- budgeting.

In view of the operational character of the controlling system which is oriented toward controlling the various customer orders, only the cost control aspects of cost calculations and pricing, decision-support calculations and performance measurement are included here. These terms have been interpreted here as follows:

- cost calculations and pricing: the methods and techniques which deal with the way in which costs can be allocated to customer orders and the way in which selling prices are determined;
- decision-support calculations: the methods and techniques which deal with the way in which decision alternatives should be compared from a cost point-of-view;
- performance measurement: limited in the research presented here to measuring and reporting the actual effort spent on processing the order as feedback to the control activity (learning from experience).

The way in which cost analysis methods and techniques have been used is explained in further detail in Sub-sections 6.4.3 and 6.4.4. Designing and structuring the performance measurement is discussed in Sub-section 6.4.5.

6.4.1 Cost characteristics of customer order driven engineering

Two characteristics of customer order driven engineering in the selected case situation play an important role with respect to the cost factor within the controlling system: characteristics of the resource capacity situation and uncertainty and financial risk.

♦ *Characteristics of the resource capacity situation*

Several characteristics of the resource capacity situation for customer order driven engineering are important for describing the various financial considerations. These characteristics are described below.

Capacity of the Product Engineering PU
The capacity of the Product Engineering PU is the limiting factor in the quotation phase. This capacity cannot be expanded on short notice in view of the scarcity of good, experienced product engineers. This capacity governs the number of potential orders which are processed by the total organization since this capacity limits the number of quotations which can be issued. Part of the capacity of the PU is used for engineering reviews of quotations as well as customer orders. In addition, part of the capacity is used to support customer orders in the order phase, particularly in connection with the transfer of information to the Detail Design PU. The requirement for customer order independent engineering is also taken into account in determining the amount of available resource capacity. Volume flexibility can only be found in the form of overtime hours which are only available to a limited extent due to the personnel policies. The resource capacities belonging to the separate PU's for the different product groups (see Chapter 4) can almost never be shared. The amount of resource capacity belonging to a PU is matched to the

number of requests for quotation to be processed (split into specific effort categories). The number of requests for quotation to be processed is dependent upon the average success rate for issued quotations becoming firm orders and the total number of customer orders required to meet the sales targets. It may be worth noting that the use of a success rate or probability within the controlling system at the level of an individual request for quotation is not really useful since the probability of success for a single request is always either 0 or 1.

Capacity of the Detail Design PU

The capacity of the Detail Design PU is the limiting factor in the order phase. This capacity determines the throughput of work for the total organization in the order phase. Volume flexibility can be found here, too, primarily in the form of overtime hours which are only available to a limited extent. An additional possibility for flexibility is available in the form of outsourcing the relatively simple drafting tasks, however, this option is rarely used in the selected case situation. A portion of the detailed design capacity is used for customer order independent engineering. The amount of resource capacity used for this purpose is determined annually and is subtracted from the total capacity, leaving the remainder as capacity which is available for detailed design activities related to customer orders.

Capacity for component manufacturing

The capacity for component manufacturing has been kept to a minimum level in the selected case situation as a result of a business strategy which can be seen as being appropriate in the face of unfavorable economic conditions. The average utilization of the available resource capacity is, thus, maintained at a high level. Volume flexibility is found by outsourcing work to suppliers. It is, of course, possible that a certain amount of under-utilization of resource capacity may occur during any given period of time. Nevertheless, the average utilization in each period is at a high level.

The assembly capacity

The Assembly department's resource capacity is flexible to a certain extent. A specific amount of additional internal resource capacity can be found when necessary in view of the fact that the mechanics in the Assembly department who normally work outside of the plant at the customer site are multi-skilled. Temporary workers can also be engaged whenever necessary to carry out simple assembly work.

♦ *Uncertainty and financial risk*

As previously described in Section 3.7, the three forms of uncertainty which are typical in customer order driven engineering situations imply varying degrees of financial risk. As the uncertainty surrounding a customer order increases, it becomes more difficult to estimate the costs associated with a customer order and the probability of incurring a cost overrun (the financial risk) increases. The degree of uncertainty in the selected case situation may vary radically from one customer order to the next. A number of risk categories have been differentiated for the purpose of (cost) control in view of the influence of the uncertainty on the financial risk. The use of these risk categories is explained in detail in Sub-section 6.4.3.

6.4.2 Financial considerations within the controlling system

Six points in time can be identified at which financial considerations are particularly relevant for control purposes, based upon the controlling system for customer order driven engineering as described in Chapter 5. These points in time are summarized here and described in more detail in Sub-section 6.4.4. The first opportunity for considering the financial aspects is when a request for quotation is evaluated (GFC level). At this point the factors of financial attractiveness and the potential technical risk of a request are considered in connection with the decision of whether to accept a request for quotation. The second point in time is when the decision is made regarding when the order is to be released to the Product Engineering PU (PUC level). The priority sequence is determined by financial considerations, in addition to other factors, in view of the fact that the capacity of this PU is the limiting factor in the quotation phase. The third point in time is when the quotation price is set, preceding the quotation issue decision (GFC level). Financial considerations, of course, play a role here. The issues of estimating and allocating the costs associated with a potential order are prominent here, in addition to setting the policies for pricing and sales margins. The fourth point in time involves reserving the resource capacity for the Detail Design PU. The fifth point in time is concerned with the internal order acceptance; this is when the final delivery due date and price are set. The sixth and last point in time concerns monitoring the progress and taking corrective measures with respect to the customer orders (GFC level).

6.4.3 Using existing cost control methods and techniques

A number of existing methods and techniques have been published in the literature and could be useful in supporting the cost control within the controlling system:

- risk management and profit margin differentiation;
- cost calculation and pricing methods;
- the principle of bottleneck calculation.

♦ *Risk management and profit margin differentiation*

As previously described in Section 3.7, the forms of uncertainty which are apparent in the selected case situation lead to technical, time and financial risks. Requests for quotation as well as customer orders may vary widely with respect to the degree of (primarily, product) uncertainty. This means that requests for quotation as well as customer orders may have a wide range of (potential) risks. In the selected case situation, it is primarily the technical risk which determines the extent of the financial risk. A number of risk categories have been defined based upon the degree of technical risk for the purpose of risk management. A type of portfolio management can then be used in this situation (cf. portfolio theory in the field of finance and treasury management: Markowitz 1959, Lintner 1965 and Soenen 1981). Following this approach, certain percentages of the projected sales are allocated, periodically, to the various risk categories. In this way the acceptance of too many customer orders in a high (technical) risk category can be prevented. A policy is effectively established in this way which governs the maximum technical risk which is allowed to exist in the portfolio, expressed in terms of the relative sales per risk category. The realized sales in each risk category as compared to the projected sales and the contents of the quotation portfolio (expressed in the same form) thus becomes important decision support information for making control decisions.

In addition to a proper portfolio management, risk management is carried out based upon a differentiation in the profit margins between the risk categories. The realization of a certain annual profit margin is the ultimate goal at the company level. This profit margin is based upon the acquisition and realization of a certain number of customer orders each year. A certain profit (the target profit margin) must also be realized for each order; this is equal to the revenue minus the costs. The company's business strategy is translated into a certain profit margin which is budgeted each year for the total organization in terms of a total margin based upon the projected sales revenue. The total margin can then be differentiated by PMC (Product Market Combination) in accordance with the company's product/market strategy. A higher financial risk with respect to a (potential) customer order means that there is a greater likelihood that the cost of the customer order will turn out to be higher that originally estimated in the quotation phase, leading to a lower profit margin. Risk management takes this into account by requiring an extra profit margin in addition to the normal profit margin for the orders which fall into a higher risk category. This extra profit margin should be equal to the expected financial risk in the event that the technical risk becomes a fact. An example of this type of profit margin differentiation is presented in Table 6.1. The assumption here is that there are two PMC's, each one divided into two risk categories. The projected sales revenue and the target margins corresponding to the desired profit levels are worked out for each PMC/risk category combination.

	PMC I		PMC II	
	Risk Category A (high)	Risk Category B (low)	Risk Category A (high)	Risk Category B (low)
Projected sales	10 million	20 million	15 million	25 million
Target profit margin	8%	8%	10%	10%
Extra margin to cover extra risk	4%	---	5%	---
Total target margin	12%	8%	15%	10%

Table 6.1
Distribution of projected sales and targets per PMC/risk category (an example)

A differentiation by market situation (e.g., positive or negative economic climate) is also desired in addition to the differentiation by risk category. When the economic climate is poor, a lower margin may be appropriate in order to ensure that sufficient sales can be realized. This implies that an important premise in connection with the cost control in the selected case situation is a policy decision regarding the sales levels and the target profit margins per PMC/risk category/market situation which should be achieved.

♦ *Cost calculation method*

The quotation price which is used as the basis for the ultimate selling price determines, to a large extent, the profit margin for a customer order. A cost price calculation in the form of an order budget can play an important role in determining the quotation price. Other factors and other information such as the market situation and the positioning of the company in the market are also important, of course, in determining the quotation price. A number of different methods for calculating cost prices can be identified. Several examples of such methods are the burden method, the equivalent amount method, the cost center method and ABC costing (Horngren and Foster 1991, Blommaert et al. 1991). In determining a full, or *integral*, cost price, all of the costs associated with the engineering and production of a product are allocated to the potential order. This means that the indirect costs as well as the direct costs are to be included. The various methods of calculating cost prices differ primarily with respect to the way in which the indirect costs are allocated to a product. Much attention has been paid to improving the accuracy of allocating indirect costs in recently published studies. An important development in connection with this has been the introduction of *Activity-based costing* (ABC costing, see for example, Cooper 1988a and 1988b). A variety of allocation formulas are used in an ABC system in order to achieve a more accurate allocation of indirect costs than in a situation in which only a simple cost allocation scheme is used. More accuracy suggests that the allocations will need to be carried out at a more detailed level. This would not be appropriate in the present situation, however. A number of arguments can be brought forward to support the opinion that a more detailed allocation of indirect costs to the potential orders in the selected case situation would not provide any additional benefit (see also Sub-section 3.8.3):

- in view of the wide range of different products and product groups in the selected case situation, it is virtually impossible to find a causal relationship between a number of indirect cost categories and the potential customer order. Examples of such indirect cost categories are the data processing costs, office space and the costs of customer order independent engineering. An arbitrary, detailed allocation of these costs would have no predictive value with respect to the actual costs for a customer order since an accurate allocation of these costs is not really feasible;
- the ultimate price level in the selected case situation is dictated to a great extent by the market situation and is not set by the company based upon the cost price. This means that there is no requirement for calculating a detailed and accurate integral cost price for this purpose;
- the extent of the uncertainty in the selected case situation is such that no reliable forecast can be made with respect to the future content and mix of the order portfolio. If costs are allocated arbitrarily, then there is certainly no requirement for doing this at a detailed level.

The calculation of an integral cost price to be used as the basis for the quotation price in the selected case situation is not worthwhile in view of the fact that the price level for a potential order is dictated by the market conditions to a great extent and in view of the problems involved in allocating indirect costs to potential orders. The price level of a potential order is reviewed by evaluating the potential (gross) contribution to profit of the potential order as soon as this price level is known. The potential (gross) contribution to profit is calculated by subtracting the direct allocatable costs of the potential order from the price level dictated by the market. This potential contribution to profit can be expressed as a percentage of the price level (potential profit margin). The price level is evaluated by comparing the potential margin to a target margin which has been established based upon the company business strategy and pricing policy (see also Figure 6.10).

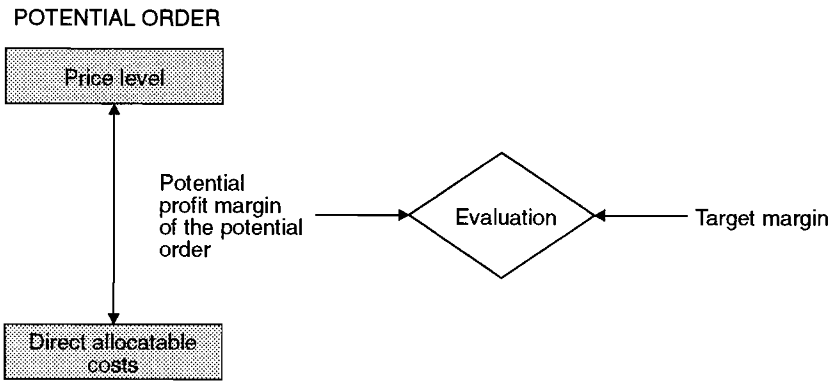


Figure 6.10 Evaluating the price level of a potential order

The target margin established based upon the company business strategy and pricing policy serves to:

- cover the other, general costs which are incurred in connection with activities related to the various customer orders;
- establish a reference point for ensuring that a certain minimum margin is realized with respect to the customer order.

A differentiation is made for each PMC/risk category with respect to the minimum margin for a customer order as a result of the PMC strategy and the chosen approach for risk management (see Table 6.1). The portion of the total target profit margin per PMC/risk category which is used to cover the other (indirect) costs can be determined by allocating these costs to the various PMC/risk categories. In contrast with the individual customer orders, a causal relationship can be found between the other indirect costs and the activities associated with the orders falling within a specific PMC/risk category combination or associated with the organization as a whole.

This first category of indirect costs which have a causal relationship with a PMC/risk category combination is allocated directly. Examples of these costs include:

- sales and marketing expenses associated with the various geographically distributed sales offices. These costs can be allocated to specific PMC's;
- costs associated with the Product Engineering PU. More product engineering resource capacity is generally spent on quotations involving a greater technical risk. A larger portion of these costs is allocated to categories with a higher risk.

The second category of indirect costs which have a causal relationship with the company as a whole is allocated to the PMC/risk category combinations based upon the distribution of projected sales revenue. In view of the general nature of these costs, they should be allocated proportionally based upon the distribution of the projected sales revenue such that no differentiation is made based upon PMC/risk category combination. In this way, each dollar of revenue contributes to the coverage of these costs to the same extent.

	PMC I		PMC II	
	Risk Category A (high)	Risk Category B (low)	Risk Category A (high)	Risk Category B (low)
Projected sales	10 million	20 million	15 million	25 million
Indirect costs (based on sales revenue)	1 million	2 million	1.5 million	2.5 million
Indirect costs (based on causal relationships	2 million	1 million	2.5 million	1.5 million
Burden percentage indirect costs	30%	15%	28%	16%
Target profit margin	12%	8%	15%	10%
Total target margin	42%	23%	43%	26%

Table 6.2 Determining the total target margin (an example)

After the two categories of indirect costs have been allocated to the various PMC/risk category combinations, the margin can be determined for indirect costs (as a percentage of the projected sales) and, subsequently, the total target profit margin can be calculated for each PMC/risk category combination. The determination of the total target profit margin per PMC/risk category combination is presented in Table 6.2, using the example from Table 6.1.

♦ *Principle of bottleneck calculation*

A company tries to generate a contribution to profit (i.e., revenue less costs) which is as large as possible through the utilization of production capacity. There is always at least one resource capacity within the production plant which is in limited supply and cannot be expanded to meet all of the short term requirements. This is referred to as the bottleneck resource capacity. In this way the bottleneck determines the maximum output of the production system. The maximum contribution is therefore defined as being the contribution provided by maximizing the contribution per unit of bottleneck capacity (see, for example, Kaplan and Atkinson 1989). If an alternative use is planned for the bottleneck capacity, then the utilization should be chosen which provides a maximum contribution per unit. Two bottleneck capacities can be identified within the capacity situation of the customer order driven engineering in the selected case (see also Sub-section 6.4.1), namely:

- the capacity of the Product Engineering PU in the quotation phase, and
- the capacity of the Detail Design PU in the order phase.

From the point-of-view of cost control, the objective of maximizing the contribution per unit of bottleneck capacity can be applied to releasing and sequencing the orders for the above-mentioned PU's.

6.4.4 Including financial considerations within the controlling system

An explanation of how the five financial considerations referred to in Sub-section 6.4.2 have been included in the controlling system is presented in this sub-section. The aforementioned characteristics of customer order driven engineering and the previously described methods and techniques play an important role here.

♦ *Financial considerations when requests for quotation are evaluated*

The evaluation of requests for quotation results in a decision regarding which requests will and will not be accepted for further processing. For each request the financial attractiveness is weighed against the technical risk in order to make this decision. The final decision of whether to accept the request for quotation is also dependent upon the company's PMC strategy and the availability of product engineering capacity. A technical evaluation is carried out as part of the request evaluation procedure (see Sub-section 6.2.6). This results in an evaluation of the technical risk and an initial estimate of the required product engineering and detailed design resource capacity needed to prepare a complete product description. Based upon these results, the request can be classified under a specific risk category.

The financial consideration when requests for quotation are evaluated involves a (general) decision about the financial attractiveness of the request for quotation. A business evaluation is carried out to provide input for making this decision. At this stage, however, only an initial conception of the customer's requirements is available. There is little certainty about the ultimate product which will need to be produced. This means that obtaining an exact estimate of the costs and sales revenue is virtually impossible at this stage. The business evaluation therefore appraises the financial attractiveness of a request in terms of:

- an estimate of the potential sales revenue (the price level dictated by the market);
- the possibility for potential follow-on orders.

In connection with the decision whether to accept a request, the company's current situation is an important factor in addition to the actual content of the request and the availability of product engineering capacity. The company situation is evaluated in terms of:

- the degree to which the relative sales revenues and contributions to profit from the respective PMC have progressed so far in comparison with the budgeted projections (i.e., the current status of the portfolio in relation to the distribution of sales revenue). If the sales revenue in a certain PMC is lagging, then any requests which fall into this PMC should be treated with a higher priority;
- the size and mix of the quotations which have been issued and are still waiting for customer acceptance. The mix of these quotations in terms of the technical risk is an important factor (i.e., the status of the portfolio with respect to the risk distribution).

The result of the business evaluation of each request for quotation is registered in the management information system.

♦ *Financial considerations when orders are released to the Product Engineering PU*

In addition to production control considerations (see Sub-section 6.5.3), financial considerations also play a role in the release of product engineering orders to the Product Engineering PU. The capacity of this PU is the limiting factor in the quotation phase. This capacity can be seen as the bottleneck capacity because of its inflexibility. The available product engineering capacity is expected to generate a certain amount of sales revenue in each period with the associated contribution to profit by processing the requests for quotation which correspond to this sales revenue. The requests for quotation which are received may differ with respect to the projected sales revenue and the amount of product engineering capacity which will be required. The potential contribution to profit to be generated by a request for quotation is determined based upon the price level and the current target profit margin. The (potential) contribution to profit per required unit of engineering capacity (i.e., the revenue per unit bottleneck capacity) can be an important indicator for determining the priority for releasing the order when the method of bottleneck calculation is used. Requests with a larger contribution to profit per unit of utilized product engineering capacity are assigned a higher priority in this case. When a request has a high technical risk, then the target profit margin should, in fact, be used for determining the contribution to profit per unit of bottleneck capacity, excluding the extra margin intended for covering the higher risk. The target profit margins for each PMC/risk category combination are to be registered in the management information system.

♦ *Evaluating the potential contribution to profit (when issuing quotations)*

A quotation price is determined for each quotation during the customer order driven engineering. This is an extremely important decision from a financial point-of-view. At this point the company creates an external commitment (to the customer). In particular, the quotation specifies what will be delivered (the quality factor) for what price (the cost factor) and within what delivery lead time (the timeliness factor). Decisions concerning the quotation price are made in the face of a relatively large amount of uncertainty, namely:

- the point in time at which a quotation may be accepted by the customer and converted to a firm order is unknown and may vary widely;
- a large number of the quotations never become orders; the success rate for the quotations in the selected case situation is approximately 15%, on the average;
- the detailed design for parts of the product will be complete only after the firm order is received since part of the product is customized. The product description is worked out to a certain level of detail during the quotation phase, but at this level there will always be a certain amount of technical risk. It is possible that it will be discovered at a later stage that the envisioned product concept is not feasible or can only be realized by incurring (significantly) higher costs over a longer throughput time.

As explained in detail in the previous section, the price level of the quotation is dictated to a large extent by the market and is dependent upon factors such as the current market situation and competitive positioning. The financial consideration which precedes the issuing of a quotation, thus, is not particularly concerned with setting the quotation price, but is concerned instead with evaluating the contribution to profit which could be expected from the potential order, given the price level dictated by the market. This potential contribution to profit is calculated based upon the difference between the price level and the costs which would be directly related to processing the customer order if it is placed by the customer (refer also to Figure 6.10), expressed as a percentage of the price level. This is then compared with the established target profit margin for the respective PMC/risk category combination. The decision of whether to issue the quotation at the dictated price level is based upon this evaluation of the potential contribution and an evaluation of the current situation, taking into consideration all of the important factors of market situation, competitive positioning, the status of other quotations issued in the same period and the firm customer orders which have been received. The ultimate selling price for the customer order is established as a result of the pricing policy which is subsequently followed and the negotiations with the customer. The potential contribution to profit associated with each quotation is registered in the form of a quotation calculation in the management information system.

The different types of direct allocatable costs and the way in which these costs are allocated to potential orders is described briefly below. The types of costs included here are the cost of:

- materials;
- detailed design resource capacity;
- direct internal and external production capacity.

Cost of materials
Based upon the preliminary draft and the definition of the modular structure, and depending upon the product family, an estimate is made of the cost of the materials which will be required to produce the product. The available standard product modules are used in connection with this as much as possible since it is known (often in detail) what quantity of which materials are required to produce the standard product modules. The costs of materials can be allocated directly to the potential order.

Cost of detailed design resource capacity
This type of resource capacity is the bottleneck capacity in the order phase and is, therefore, assumed to be 100% utilized. Based upon this assumption, the cost price per hour can be calculated for this type of resource capacity. All of the costs which are directly related to the detailed design resource capacity should be included here, such as floor space, computer and other equipment, lighting, etc. The detailed design resource capacity reserved for customer order independent engineering is not included here and is not allocated to the potential orders. The costs related to this activity are covered by the

margin. The cost of detailed design resource capacity can be calculated for each quotation (based upon hours x cost price) using the estimate of the detailed design resource capacity requirements which is specified for each request for quotation.

Cost of direct internal/external production capacity
The size of the internal manufacturing capacity has been kept to a minimum level in view of possibly depressed market conditions. This means that the utilization of this capacity will be extremely high, e.g., between 90% and 95%, for the year as a whole. Based upon this assumption, a cost price per hour can be calculated. Here, too, all of the costs related to the internal manufacturing capacity can be included. A similar approach can be taken with respect to the internal assembly capacity. In this case, however, the option of outsourcing is never considered. When necessary, temporary employees are hired to carry out a number of the simpler assembly tasks.

In contrast with the internal manufacturing capacity, the external (flexible) manufacturing capacity is seen as being variable rather than fixed. Flexible external manufacturing capacity is used only for a limited period of time in the event that there is insufficient internal resource capacity. Due to the prevailing uncertainty in the quotation phase, it is impossible to determine to what extent a potential order will need to be produced in a period in which external manufacturing capacity will be required. As a result, it is impossible to allocate these costs directly to a potential order. From a manufacturing engineering point-of-view, it makes no difference whether internal or external manufacturing hours are used to process a customer order. In calculating the potential contribution to the profit, it is sufficient to use a weighted average cost price per hour for the manufacturing capacity. The total requirements for external capacity are forecasted annually and an estimate is made of the related costs. This is based partially on the sales forecasts and the historical data related to external capacity requirements. The cost of external manufacturing capacity can be expressed in terms of a cost price per hour. When both the internally available manufacturing capacity and a forecast of the required external manufacturing capacity are known, then a weighted cost price calculation for the use of manufacturing capacity can be made. The cost price for using external manufacturing capacity is higher than the cost price for internal manufacturing capacity in the selected case situation. This would normally be expected. The manufacturing cost for each quotation can be calculated (based upon hours x cost price per hour) using the estimated manufacturing capacity requirements associated with each request for quotation. A similar approach can be followed for calculating the cost price per hour for the assembly capacity.

♦ *Financial considerations in reserving resource capacity within the Detail Design PU*

Financial considerations can also be found in connection with the decision to reserve resource capacity within the Detail Design PU, in spite of the fact that this decision is primarily concerned with preventing potential problems in the realization of due dates. In view of the fact that time risks often lead to financial risks (see Section 3.7), a decision may be made to reserve capacity in advance, partially based upon financial considerations. One of the possible situations in which financial considerations may be significant in connection with this decision is when one or more quotations in the quotation portfolio are waiting for a decision in the near term regarding whether a firm order will be placed, including a severe penalty clause if delivery is not made on time. A similar situation may also exist with respect to the current order portfolio.

♦ *Financial considerations when the internal order is accepted*

The resource capacity situation is evaluated as soon as the customer places an order so that the consequences of this order for the total organization can be determined. Based upon this evaluation, it is determined to what extent the agreed delivery lead time can actually be met. If the promised due date poses no problems for the organization, then there are no financial aspects to be considered in connection with the internal order acceptance. A financial consideration does arise, however, in the event that it appears that the agreed delivery lead time cannot be met due to expected capacity bottlenecks and the customer will not agree to accepting a longer delivery lead time. The trade-off must be considered between the cost of taking measures to resolve the capacity bottlenecks (e.g., paying for overtime hours to complete the detailed design tasks sooner) and the cost of delivering the product too late (e.g., penalties and/or loss of reputation and goodwill in the market). In reality, the timeliness factor (delivery performance) is translated into the cost associated with the timeliness factor (e.g., penalty clauses). In connection with determining the cost of possible measures to resolve capacity bottlenecks, only the *relevant costs* should be considered which are related to these measures (Corbey 1991a and 1991b). Any costs which are not influenced by these measures should not be included in the evaluation. In comparison with the other types of costs, the loss of goodwill is especially difficult to translate into a monetary valuation. For this reason, the decision will be made to expand the resource capacity (temporarily) whenever this is financially more attractive (and certainly whenever there is a penalty clause).

♦ *Financial considerations related to monitoring the progress of customer orders*

The direct allocatable costs related to processing a customer order are estimated in connection with determining the quotation price. These costs are estimated based upon estimates of the total material costs and the required hours of directly related detailed design and production resource capacities. During the course of the project, further insights are obtained in terms of:

- a more detailed calculation of the cost of materials and the resource capacity requirements. A more accurate calculation can be carried out after the detailed design and process planning activities are completed. This calculation can be used as an operational objective for the organization;
- the actual cost of materials and the actual use of resource capacity for producing the machine.

Corrective measures can be taken as necessary whenever exceptions are reported. Exceptions can only be reported reliably, however, when the relevant data is registered accurately and managed properly. In general, it will not be possible to do anything about the exceptions which are reported. Indications of pending overruns are often the result of technical and/or production control problems (see also Sub-sections 6.2.6 and 6.3.5). An example of this type of problem is the projected tardiness of a customer order due to an error during the engineering of the product. When such a problem occurs, an evaluation can be made to determine to what extent the quality and delivery lead time problems can be resolved by arranging for extra resource capacity. The use of extra resource capacity may involve additional actual costs, however. In connection with monitoring progress, there are generally no independent financial aspects to be considered other than the cost of materials. The financial considerations normally involve the trade-off between quality and/or the throughput time, on the one hand, and the actual costs related to possible corrective measures, on the other hand. Additional examples of this type of trade-off have been investigated by Corbey (1992). The possible interrelationships and trade-offs between the three control factors within the controlling system are described in more detail in Section 6.5.

6.4.5 *Measuring performance in connection with the control of customer orders*

The actual cost of materials and the actual resource capacity requirements (in hours) are registered for the purpose of monitoring the progress of each of the customer orders. This type of data registration activity can provide insights into whether the actual costs and hours reported during the realization of a product are being spent as expected, providing management information for controlling and correcting the processing of the customer order. In addition, the actual contribution to profit can be determined for each of the customer orders. The determination of the actual contribution to profit does not, as such, provide information which is useful for the cost control of customer orders since this is based upon actual results which cannot be changed.

A number of supplementary measurements are required in addition to the performance measurement at the order level to support the financial evaluations, in particular, which were described in the previous sub-section. The following data should be stored and maintained:

- the number of qualifying requests for quotation which were turned down due to a shortage of product engineering capacity. This indicator can be used to determine to what extent a structural shortage of product engineering capacity is present;
- the discrepancies (in hours) between the actual and the budgeted use of product engineering capacity for each request for quotation. This indicator is used as feedback to revise the norms used for the evaluation of requests for quotation;
- the actual level of utilization of the internal detailed design and manufacturing capacities. The allocation of resource capacity costs to potential orders and setting the priorities for the orders to be released are based upon the full utilization of the internal detailed design capacity as well as the manufacturing capacity (see earlier sections of this chapter). The registration of the actual utilization levels provides a basis for determining to what extent the assumption of full utilization may not be valid;
- the sales revenue and profit margins realized per PMC/risk category combination. This is important management information for the selection of future requests for quotation (see also Sub-section 6.4.3);
- the cumulative amount of external production capacity (in terms of hours and cost) which has been used.

The last indicator, in particular, can be used as the basis for providing important management information which can be used to define optimal pricing policies for individual quotations. A reliable analysis of the discrepancies between the forecasted requirements and the actual requirements for production capacity (for manufacturing as well as assembly) is important for this purpose. This analysis is especially useful when the cost price for internal production capacity is different from the cost price for external production capacity. If the actual requirement for manufacturing capacity, for example, is higher or lower than the forecasted requirement, then a cumulative variance in the coverage of costs results. This is caused by the use of more or less external manufacturing capacity than was originally budgeted. Three different situations may occur under these circumstances:

- The actual resource capacity requirement is higher than originally anticipated. This means that the required external manufacturing capacity will also be higher than originally anticipated. Since the cost of the internal manufacturing capacity is lower than the cost of the external capacity, there will be insufficient coverage of the total manufacturing costs due to the method of calculating a weighted cost price (see previous section);
- The actual resource capacity requirement is lower than originally anticipated, but still exceeds the amount of internally available manufacturing capacity. This means that the required external manufacturing capacity will be lower than originally anticipated. Since the cost of the internal manufacturing capacity is lower than the cost of the external capacity, there will be a surplus coverage of the total manufacturing costs;
- The actual resource capacity requirement is lower than originally anticipated and also lower than the amount of internally available manufacturing capacity. This means that there will be no requirement for external manufacturing capacity. Since the cost of the internal manufacturing capacity is lower than the weighted cost price per hour, the under-utilization of capacity will result in a surplus coverage of the total manufacturing costs. There will be insufficient coverage of the total manufacturing costs only when the amount of under-utilized manufacturing capacity exceeds the amount of surplus coverage.

The weighted cost price is revised only periodically and is therefore not adjusted immediately for every discrepancy which is registered. Each adjustment leads to a new price; frequent adjustments could therefore easily lead to confusion with respect to the pricing policies. Providing up-to-date information about these discrepancies is important input data for determining the pricing policies for individual orders during the period, however. The price level of a given quotation should always be seen in the light of the current situation at that point in time whereby the quotations waiting for customer acceptance and the firm orders received in the same period are important factors. In a situation in which a surplus coverage of allocated costs exists, a decision to accept a potential contribution to the profit which is lower than the target profit margin is then easier to justify under difficult market circumstances.

6.5 Relationships and trade-offs between the control factors

An explanation has been provided for the three control factors of quality, timeliness and cost within the controlling system as independent topics in the previous sections of this chapter. In practice, however, the described controlling system must function in such a way that all three of these factors are controlled as an integrated whole. Important interrelationships can be identified between these control factors at certain points in time in the control process. These interrelationships and the trade-offs between these control factors are described in more detail in this section. A summary of which control factors are relevant in connection with the various control decisions is presented in Table 6.3 so that an impression can be gained regarding the degree to which the three control factors play a role within the controlling system. A further description is provided here concerning the interrelationships between the three control factors based to some extent on this table.

Control decision	Quality	Timeliness	Cost
Request evaluation	×	×	×
Order release to Product Engineering PU		×	×
Issuing a quotation	×	×	×
Reserving Detail Design PU capacity		×	×
Internal order acceptance		×	×
Order release to Detail Design PU		×	
Sub-order assignment and outsourcing		×	
Monitoring progress	×	×	×

Table 6.3 Control decisions and control factors

It can be seen from Table 6.3 that there are various points in time at which interrelationships exist between the three control factors within the controlling system. The interrelationships between the three control factors within the controlling system can be seen in various ways, however. A differentiation can be made between *coordination* and *trade-off decisions* with respect to two or more control factors within the controlling system based upon the explanation of these three control factors presented in this chapter. Coordination is applicable in the control decision situations where two or more control factors are considered together at the same time. Issuing a quotation is a good example of this whereby the technical risk (the quality factor) is important in connection with determining the delivery lead time and evaluating the potential contribution to the profit this whereby the technical risk (the quality factor) is important in connection with determining the delivery lead time and evaluating the potential contribution to the profit (refer to previous sections in this chapter). It is not necessary to choose one factor as being more important than the other factor in this situation. Both control factors must be considered together in order to make the decision. Trade-off decisions, on the other hand, are interpreted here as being situations in which one control factor is chosen above the other. An example of a trade-off decision is the internal order acceptance. If it is recognized that the quoted delivery lead time will not be feasible when the firm order is received, then a decision may be made to incur extra costs with respect to the customer order (the cost factor) so that the customer order can still be delivered by the agreed due date (see previous sections in this chapter). Based upon the explanations in this chapter, the conclusion can be made that the interrelationships between the control factors within the controlling system are primarily concerned with *coordination* and to a lesser extent with *trade-off decisions*. An interrelated control of these three factors therefore focuses on an integrated approach to these factors. The added value to be found in an integrated approach to all three of these control factors within a single controlling system is the realization of an optimal coordination of these three factors rather than a continual sequence of trade-off decisions.

Trade-off decisions occur only when circumstances concerning the customer orders arise which were not originally anticipated. This type of circumstance is found in connection with the internal order acceptance decision and monitoring the progress of the customer orders. The internal order acceptance decision deals with the trade-off between the cost factor and the timeliness factor. When possible, this trade-off is expressed in financial terms (see Sub-section 6.5.3). In connection with monitoring the progress of the customer orders, a trade-off may occur between all three of the control factors. The trade-off is based upon the interrelationships which exist between technical risks, time risks and financial risks (see Section 3.7). If, for example, technical risks materialize into actual technical problems, then time risks and/or financial risks may also appear. A trade-off is then required in which case one of the control factors takes priority over the others.

Each of the control decisions is discussed separately here with a brief explanation of the nature of the interrelationship between the control factors in each instance. In some instances, only one or two of the control factors are involved in the control decision. The control factor of quality appears least frequently within the decision structure (see Table 6.3). This may give the wrong impression, however, since a portion of the quality assurance is found at the lower operational levels of the transformation process in the form of engineering reviews and a proper structuring of the engineering process. When a control factor is not involved in a given control decision, this means that this factor is not affected by the decision and therefore remains fixed. This is explained in more detail below.

Request evaluation and selection

The evaluation of requests for quotation concerns the decision regarding which requests will be accepted for further processing. This decision controls the future flow of orders and thus determines the boundaries for the future performance to a great extent. All three of the control factors are involved in this decision. This is not surprising in view of the importance of this decision. No trade-offs are involved in the evaluation of the requests for quotation. The primary concern here is to provide for an integrated coordination of the three control factors in connection with the selection of requests for quotation.

Order release to Product Engineering PU

Only the factors of timeliness and cost are involved in the decision to release orders to the Product Engineering PU. The quality of the product description is not affected by this decision. The release of product engineering orders serves two purposes in terms of timeliness and cost, namely, the release of product engineering orders such that:

- the average throughput time for processing the product engineering orders can be controlled (the timeliness factor, see Sub-section 6.3.5);
- the contribution to profit provided by each utilized unit of scarce product engineering capacity is maximized (the cost factor, see Sub-section 6.4.4).

There are also no trade-offs between the control factors involved in this decision. The control factors are treated as an integrated set of factors in connection with this decision.

Issuing a quotation

The quotation price and delivery lead time are determined for the delivery of a specific product (the quality) in connection with the decision to issue a quotation. The company establishes an external commitment in this way and is expected to be able to deliver the product according to the stated terms and conditions if the customer decides to accept the quotation and place a firm order. Similar to the situation of evaluating a request for quotation, all three of the control factors are involved here. Here, too, this is not surprising in view of the importance of this decision. In connection with issuing a quotation there are, similarly, no trade-off situations. The primary concern here is to provide for an integrated coordination of the three control factors in connection with issuing a quotation.

Reserving Detail Design PU capacity

The control factors of timeliness and cost may be involved in the decision of whether to reserve resource capacity within the Detail Design PU ahead of time during the quotation phase. This decision does not affect the control factor of quality. Since this decision is focused primarily on controlling the delivery lead time, the possible financial risks can be significant to the extent that financial considerations become important. The concern here is to provide for an integrated coordination of the timeliness and cost control factors.

Internal order acceptance
The control factors of timeliness and cost are involved in the internal order acceptance decision. This decision only occurs, however, in the event that circumstances are different than originally expected (see Sub-sections 6.3.5 and 6.4.4). There is no coordination involved in this decision, but rather a trade-off between the factors of timeliness and cost. The quality of the product description is not affected by this decision and thus is not considered within this context.

Order release to Detail Design PU
Only the control factor of timeliness is relevant in connection with releasing orders to the Detail Design PU. In contrast with the release of orders to the Product Engineering PU, the cost factor is no longer of importance here. Priority can be given to the most financially attractive requests for quotation in the quotation phase via the release to the Product Engineering PU. The performance of the company can no longer be influenced in a positive way during the order phase by better order release decisions at this stage since the price agreement has already been established and all of the completed detailed design tasks must now be carried out (in contrast with the product engineering tasks in the quotation phase).

Sub-order assignment and outsourcing
Similar to the previous decision, only the control factor of timeliness is relevant in connection with sub-order assignment and outsourcing. The purpose of this decision is to determine what should be outsourced in order to comply with the delivery lead time agreements for the various customer orders. The possible costs associated with outsourcing are taken into account at an earlier point in time (see Sub-section 6.4.4). The quality of the product description is also not affected by this decision.

Monitoring progress
As previously indicated, a trade-off decision is possible between all three of the control factors in connection with monitoring the progress of customer orders. The need for a trade-off decision stems from the nature of the interrelationships between the technical risks, time risks and financial risks (see Section 3.7). If, for example, technical risks materialize into actual technical problems in connection with processing a customer order, then time risks and/or financial risks may also appear. When this type of situation occurs, a decision must be made to determine which one of the control factors will take priority over the others and what the consequences will be.

The descriptions provided above present a summary of the interrelationships between the three control factors within the controlling system. A conclusion which can be made here is that a trade-off relationship and, even more so, a coordination relationship both exist between the three control factors. The nature of these relationships requires an integrated control within a single controlling system to enable an optimal control of the customer order driven engineering in the selected case situation.

Chapter
7 DESIGNING THE MANAGEMENT INFORMATION SYSTEM

7.1 Introduction

In Chapters 4 through 6, the transformation process as well as the controlling system for customer order driven engineering have been designed for the selected case situation described in Chapter 3. Following the structured approach used in this book for the organizational design as described in Section 2.5, the characteristics of the (management) information system can be derived from the characteristics of the transformation process and the controlling system. An information architecture for the control of customer order driven engineering is designed in this chapter; this can be seen as an extension of the topics discussed in Chapters 4 through 6.

The use of information technology within customer order driven engineering concerns two areas which are interrelated to a certain extent (see also Section 2.5), namely:

- *management information systems*: information systems which support the registration and control of the transformation process;
- *computer-aided development systems*: this involves the use of information technology to support product development activities. Computer-aided Drafting (2D-CAD) systems can be seen as an example of this.

The architecture of management information systems within customer order driven engineering, in particular, will be discussed in this chapter. Attention will also be focused on the relationship between management information systems and computer-aided development systems and the influence of the last category of systems on structuring and controlling the engineering process.

A general architecture for management information systems is described in Section 7.2.

This is subsequently applied to customer order driven engineering in Section 7.3. The data model within the information architecture is developed further as the core of the management information system in Sections 7.4 through 7.6. Finally, in Section 7.7, attention is paid to the relationship with computer-aided development systems.

7.2 An architecture for management information systems

We will make use of a general architecture for management information systems which has been proposed by Bertrand et al. (1990) (Chapter 6) for the development of an architecture here for a management information system for customer order driven engineering. This general architecture is presented in Figure 7.1. This figure shows that a management information system can be viewed as a number of concentric circles representing the various system layers. The innermost circle represents the system platform which supports different system programs such as an operating system, a data base management system and a query language. The subsequent layers represent the different user applications. The applications which support the registration of *state-independent* data are found on the second layer. This data describes the products, technology, resource capacities, operations, etc. which are independent of the state of the transformation process at any particular point in time. Examples of state-independent data include: standard products, bills-of-materials, standard routings, resource capacities, standard throughput times, etc. State-independent data can refer to *product* data as well as *process* data. State-independent data provides a basis for the registration of state-dependent data. This will be explained in more detail in connection with the development of the architecture for customer order driven engineering.

The applications for the registration of the *state-dependent* data are found on the third layer which rests on top of the state-independent data. This data describes the state or condition of materials and orders in the transformation process which need to be controlled. Examples of state-dependent data include: quotations, customer orders, work orders and the movement of goods. This layer also includes product data as well as process data. Finally, the outermost layer is comprised of the applications which make use of the data registration systems found on the other layers. To start with, the *decision support* systems are found here which provide support to the human decision process. The structured decision systems which are able to carry out a decision process without human intervention are also found here. In connection with production control, an emphasis is placed on the decision support systems.

In addition to the different layers which have been defined in this way, the information architecture also provides a structure for distinguishing between various control levels.

The upper half of each layer is reserved for the applications which support the goods flow control (GFC) level. the lower half of each layer is used for the applications which support the production unit control (PUC) level. In this way it should be clear that the data registration systems (and the data which is registered) as well as the decision support systems can be different at each control level.

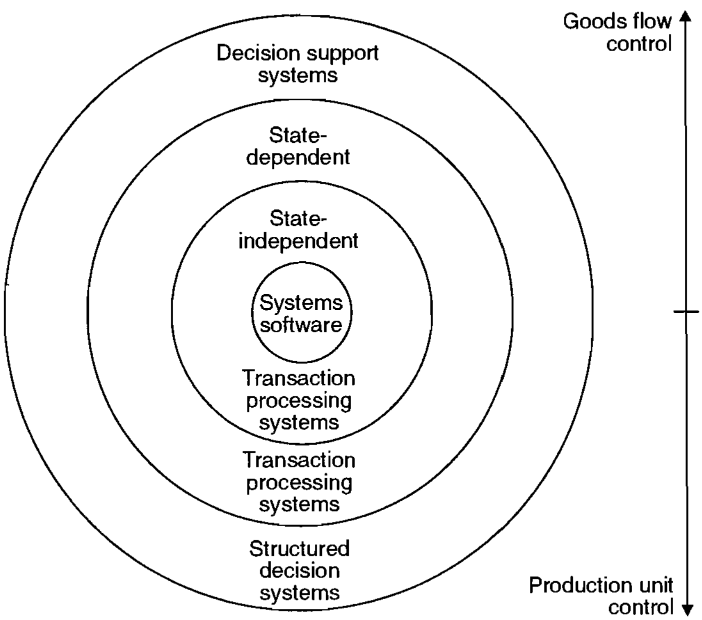


Figure 7.1 A general architecture for management information systems

7.3 An architecture for customer order driven engineering

The general architecture with three distinct application layers, as illustrated in Figure 7.1, can be used to develop an information architecture for customer order driven engineering. First, however, a further explanation of the state-independent data and the state-dependent data is needed. Subsequently, the decision support will be described.

♦ *State-independent data*

In contrast with the production of standard products in batches, the state-independent data in customer order driven engineering can be characterized as being primarily *reference* data, i.e. data which is searched and retrieved so that it can be modified or extended for use in a specific application (Wortmann 1992). In general, this data cannot be used directly by an application since it must first be accessed and interpreted by a specialist. It is necessary to explain exactly what is included in the registration of state-independent data in connection with customer order driven engineering before the nature of the state-independent data can be discussed. In the first place, this data category includes data which describes *products*. All of the accumulated knowledge concerning product descriptions is registered here so that it can be referenced easily for use in developing the specifications for customized products. These standard product descriptions can be seen as the results of previous customer independent engineering activities which are intended to be used to support the engineering of customized products. Included here are not only standard drawings and examples of bills-of-materials, but also standard descriptions of product structures in the earlier stages of development (e.g., functional structures). When the standard product data is used, its use should be clearly documented as part of the customized engineering work. In this way, an analysis can be made regarding how and how frequently this data is used. This is important:

- from the point-of-view of quality assurance since a frequent and correct use of reference data reduces the technical risk;
- from a general control point-of-view since reliable norms have been established for the standard product data, thereby reducing the uncertainty and increasing the controllability;
- since the success of the customer order independent engineering can be determined based upon the frequency and degree of usage of the standard product descriptions.

In the second place, the registration of state-independent data includes *process* data. This also concerns reference data about the structure of the transformation process which is useful in conjunction with the control of customer orders. To a large extent, this process data is comprised of data which is known to be the same for each occurrence of the process. By maintaining the data in this way, it is then unnecessary to register the data again, repeatedly, for each new customer order. For control purposes, data is maintained here concerning the customer order driven engineering process as well as the subsequent physical production process.

A distinction can be made between the data which is required at the GFC level and the data required at the PUC level with respect to the product data as well as the process data. The required state-independent data related to customer order driven engineering is outlined in Table 7.1. The state-independent data which is required with respect to the subsequent physical production process is listed in Table 7.2. This only concerns the data at the GFC level. The PUC level for the physical production is considered to be outside of the scope of the control of customer order driven engineering and is, therefore, not required within the scope of this information architecture.

Aggregate reference data is required at the GFC level to specify how the customer order driven engineering process and the physical production process should be carried out. For this reason, the PU structure, the critical resource capacities and standard networks of aggregate activities are documented for both processes. In addition, data is required at this level about standard engineering documentation and standard models for product structures. Standard engineering documents provide examples for the separate GFC items (e.g., a preliminary draft of the design) which are used to control the process at the GFC level (see also Sub-section 4.6.4). Standard product structures (e.g., for sub-functions) are needed for determining, for example, throughput times and quotation prices. Product data for the physical production process can also be derived from these standard product structures (see Table 7.2).

	Process data	Product data
GFC level	• PU structure • critical resource capacities • standard network of engineering activities	• standard engineering documents • standard product structures
PUC level	• detailed resource capacities • standard routings	• standard product structures

Table 7.1 State-independent data related to customer order driven engineering

Detailed reference data is necessary at the PUC level with respect to the customer order driven engineering process as well as the product structures. Nevertheless, there is no requirement for data related to the physical production process at the PUC level for controlling the customer order driven engineering since the focus of the PUC is only on the local PU's within the customer order driven engineering. The aforementioned data elements are included in the state-independent layer of the information architecture presented in Figure 7.2

	Process data	Product data
GFC level	• PU structure for physical production • critical resource capacities • standard networks of aggregate activities and sub-orders	• standard product structures

Table 7.2 State-independent data related to the physical production process

♦ *State-dependent data*

The registration of state-dependent product data and process data is also found at both control levels. The state-dependent data is related to the registration of the progress of the customer-dependent activities in the quotation and order phases within customer order driven engineering, however. *Requests for quotation* in the quotation phase and *customer orders* in the order phase are the primary entities which form the basis for the registration of the state-dependent data. A significant part of the data registration associated with monitoring progress and the data concerning the requests for quotation and the customer orders takes place at the GFC level through the registration and progress monitoring of the actual project networks of aggregate activities and sub-orders. In addition, the registration of the customized product structures (the GFC items) which result from the various production phases (see Section 4.7) occurs at this level. Progress monitoring and the registration of requests for quotation and customer orders at the PUC level is accomplished, in fact, via the registration of engineering orders and detailed design orders and the (planned and actual) resource capacity utilization of these orders. This data can be used to determine the actual resource capacity availability (phased in time). The registration of the results of technical evaluation and the various engineering reviews used for quality assurance is also found within the state-dependent layer. The aforementioned data elements are included in the state-dependent layer of the information architecture as illustrated in Figure 7.2.

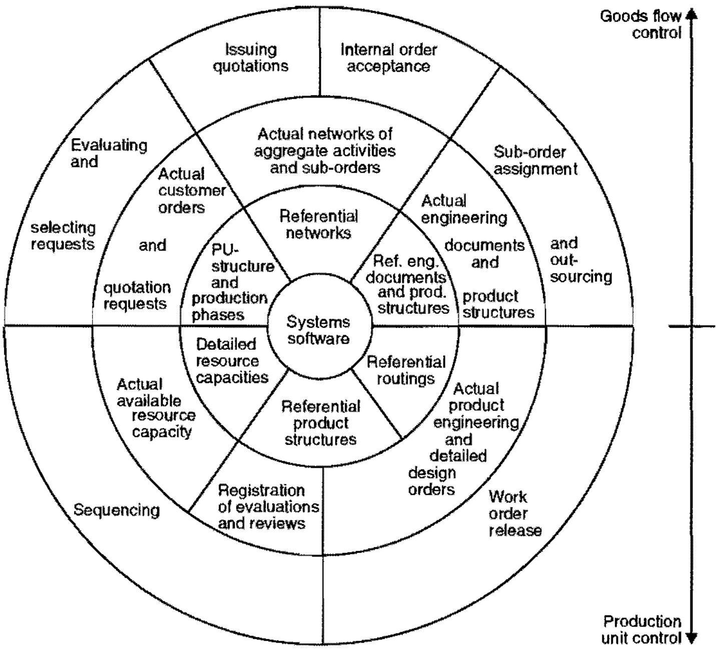


Figure 7.2 An information architecture for customer order driven engineering

♦ *Decision support*

The decision structure presented in Chapter 5 is seen as the core of the controlling system for customer order driven engineering. Within this structure, five decisions at the GFC level and four decisions at the PUC level have been identified:

- Evaluating and selecting requests for quotation (GFC);
- Work order release (and sequencing) for the Product Engineering PU (PUC);

- Issuing quotations, pricing and due date assignment (GFC);
- Reserving resource capacity within the Detail Design PU (GFC);
- Internal order acceptance (GFC);
- Work order release (and sequencing) for the Detail Design PU (PUC)
- Sub-order assignment and outsourcing (GFC).

A number of decision support systems can be identified in the outermost layer of the information architecture which support the above-mentioned decision processes. Wortmann (1992) has shown that a broad range of planning techniques exist, of which a few also appear to be suitable for use for customer order driven engineering as described in the selected case situation, except for the fact that much of the data is too general and unreliable in this particular situation. This means that it would be more effective to invest in creating *slack* (see also Section 6.3) and *alertness* rather than spending time and effort on optimal planning. Alertness is needed in situations in which there is a large amount of uncertainty; if problems cannot be adequately anticipated, then the alternative is to react quickly when problems occur. A certain amount of slack needs to be arranged in advance in order to allow for effective reactions. A good decision support system can improve the alertness and speed of decision-making and communication. This means that the correct information must be provided to the decision-maker as quickly as possible. The decision support systems need to be designed with this in mind. The various decision support systems are included in the outermost layer of the information architecture diagrammed in figure 7.2. Examples of decision support systems for controlling customer order driven engineering are:

- network planning facilities for, among other things, generating the network structures for quotations and projects (see Sub-section 6.3.5);
- systems for preparing utilization profiles (see Sub-section 6.3.5);
- exception reporting systems based upon a periodic signalling of when the average number of quality problems which occurred during a production phase exceeds a predefined norm value (see Sub-section 6.2.7).

The fact that there are interrelationships between the control factors of quality, timeliness and cost as presented in Table 6.3 implies that the various decision support systems should be designed to provide control information in an integrated form with respect to the relevant control factors. In the subsequent sections, the details of the required state-independent and state-dependent data models are described which form the core of the management information system which supports the controlling system developed in Chapter 5 and 6.

7.4 The state-independent data model

The complete state-independent data model for controlling customer order driven engineering in the selected case can be split into product-oriented data sub-structures and process-oriented data sub-structures as follows:

- standard product data;
- standard aggregate networks and order structures (process data at the GFC level);
- standard process data (PUC level).

These sub-structures are presented and explained separately, here, for the purpose of clarity. The complete state-independent data structure is then presented as a whole.

7.4.1 State-independent product data

The state-independent product data (see Figure 7.3) represents the results of the customer order independent or innovative engineering. A number of *standard final products* are defined in a general sense or, in some instances, in detail for each *product family* based upon the expected market developments and requirements. These standard product descriptions are then used as reference models to support the product engineer and detail designer in their efforts to develop a customized product. The degree to which the standard final products are developed and documented independently from any specific customer order may vary from one or more *standard sub-functions* to complete *standard product modules* which are fully defined at the *item* level. The interrelationships between the entities illustrated in Figure 7.3 have already been described in Sub-section 4.4.1 (Figure 4.8).

The way in which the stored knowledge with respect to the standard products is made available for repeated use in developing new customer orders, is important. Product engineers will generally redevelop components and modules if they discover that an excessive amount of time or effort is required to find the specifications for a standard product. The *generic bill-of-materials* principle (Van Veen 1992, Hegge and Wortmann 1990, Muntslag and Van Veen 1993) can be seen as an important development with respect to the representation of product structures and could provide valuable support in this context. The way in which this type of principle could be used effectively within customer order driven engineering is not included within the scope of this book, however.

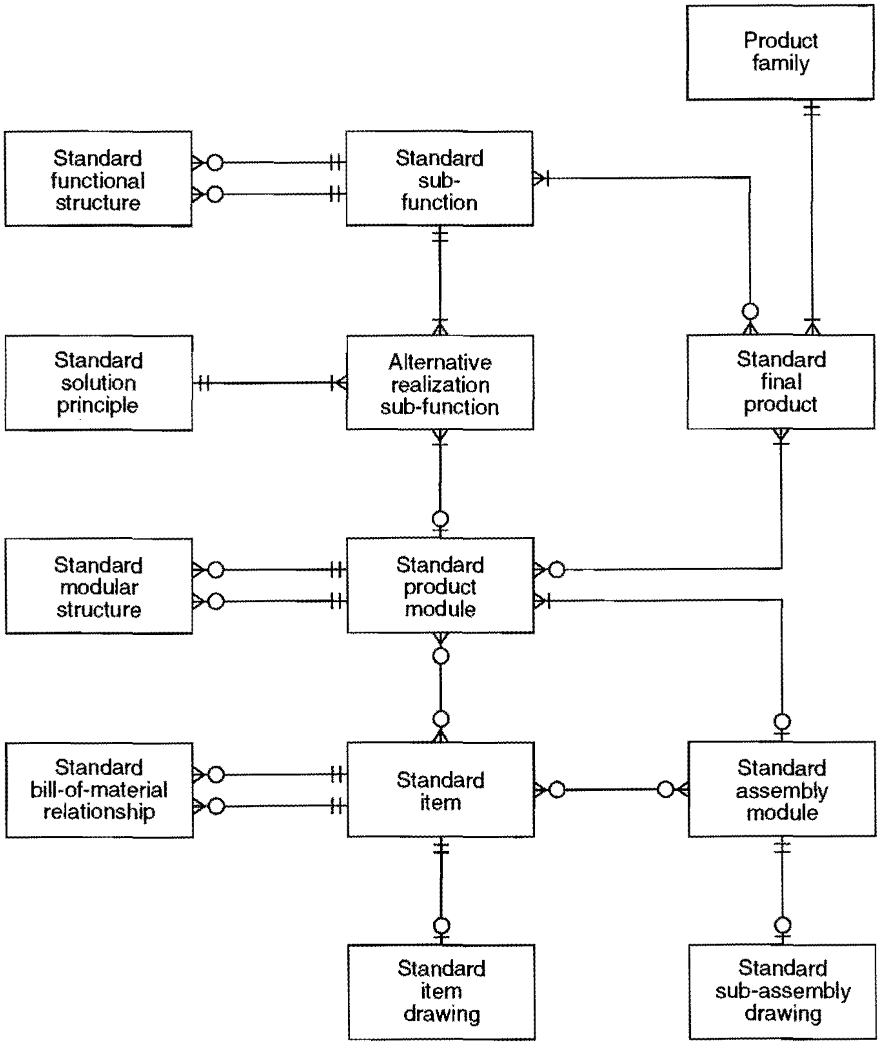


Figure 7.3 State-independent product data

7.4.2 State-independent networks and order structures

A quotation network structure consisting of a number of aggregate activities is defined for the purpose of calculating an expected throughput time for a potential order during the quotation phase. In connection with this, *standard project network structures* which have

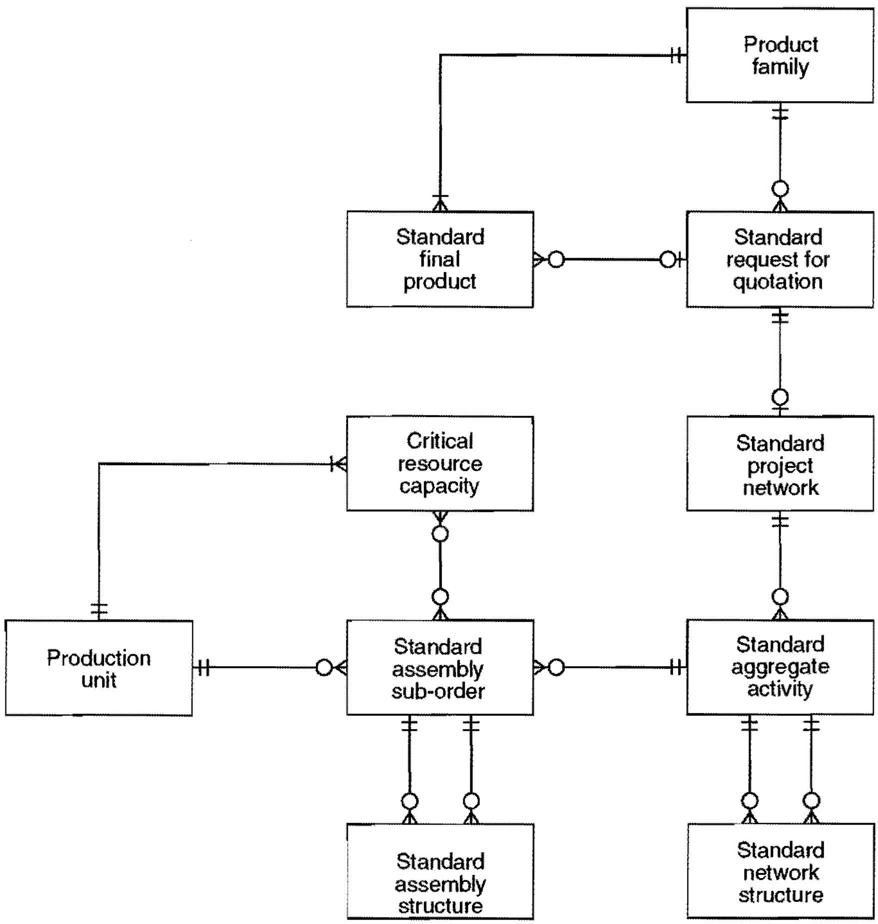


Figure 7.4 State-independent networks and order structures

been documented based upon experience with previous customer orders, are used as much as possible (see Sub-section 6.3.5). These standard project network structures are based upon customer order independent *process* data which supports the control at the GFC level (see Figure 7.4). A standard project network structure belongs to a *standard request for quotation*. In view of the emphasis on various resource capacity requirements, standard requests for quotation and standard project network structures are related to a specific product family. When a standard final product is (almost) fully developed and specified, a standard assembly structure may also be defined in the form of a network of *standard assembly sub-orders*. The state-independent structure of the assembly process is documented in this type of standard assembly network. The *production unit* to be used and the critical resource capacities which may be relevant are specified for each assembly sub-order.

7.4.3 State-independent process data

Detailed reference data concerning the customer order driven engineering process is maintained in addition to the required aggregate process data. This concerns process data which supports the control at the PUC level and should not need to be re-documented for each new customer order (see Figure 7.5). Various *production units* (PU's) can be identified (see Sub-section 4.6.4) within customer order driven engineering from a control point-of-view. The structure which combines these production units is state-independent. One or more *standard production phases* are carried out within each PU (see, for example, Sub-section 4.6.4). Each standard production phase is comprised of one or more *standard product engineering/detailed design operations*. For each standard operation, the required product engineering/detailed design resource capacity is specified. The output of a standard production phase is a *standard engineering document*. A standard engineering document represents the product description to the extent that it has been developed at a given stage of the customer order driven engineering process.

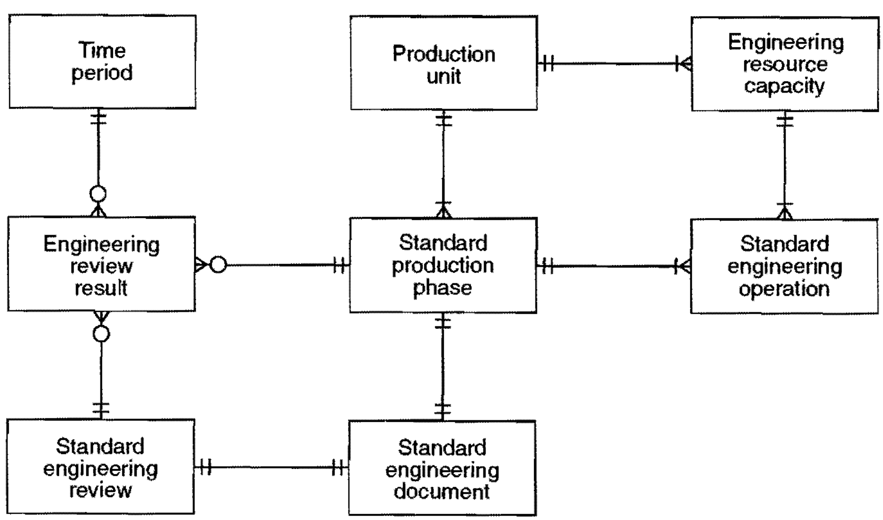


Figure 7.5 State-independent process data

In addition to data concerning the process, a number of state-independent reference data elements which deal with quality are also maintained. A *standard engineering review* is defined for each standard engineering document. A number of engineering reviews are performed at different points in time within each production phase for the purpose of quality assurance as an integral part of the processing of various customer orders. The results of these reviews (in terms of the total number of faults) are registered as state-independent values per production phase per period. A periodic analysis of the engineering process can be prepared (to control the quality of the process) based upon this data. As time progresses, the quality of the process can be evaluated based upon this quality data (see also Sub-section 6.2.7).

The combination of the three sub-structures described above results in the complete state-independent data structure diagram illustrated in Figure 7.6.

7.5 The state-dependent data model

The complete state-dependent data model for the control of customer order driven engineering in the selected case situation can be split into product-oriented data sub-structures and process-oriented data sub-structures (analogous to the state-independent data structure) as follows:

- state-dependent product data;
- state-dependent aggregate networks and order structures (GFC level);
- state-dependent process data (PUC level).

The state-dependent data structure diagram concerns the registration of all of the quotation-dependent and customer order dependent product data and process data. The *requests for quotation* in the quotation phase and the *customer orders* in the order phase are of primary importance here. In contrast with the way in which the state-independent data structure diagram was described, the state-dependent data structure diagram will not be split into sub-structures here. Many of the entities and relationships between these entities are analogous to the entities and relationships found in the state-independent data structure, with the major difference being that the data here is customer-dependent. The complete state-dependent data structure diagram is presented in Figure 7.7. The most important entities and their relationships are described chronologically according to the creation and the subsequent processing of a customer order.

The customer order driven engineering process starts with the arrival of a *request for quotation* from a *sales relation*. A significant part of the activities are closely related to

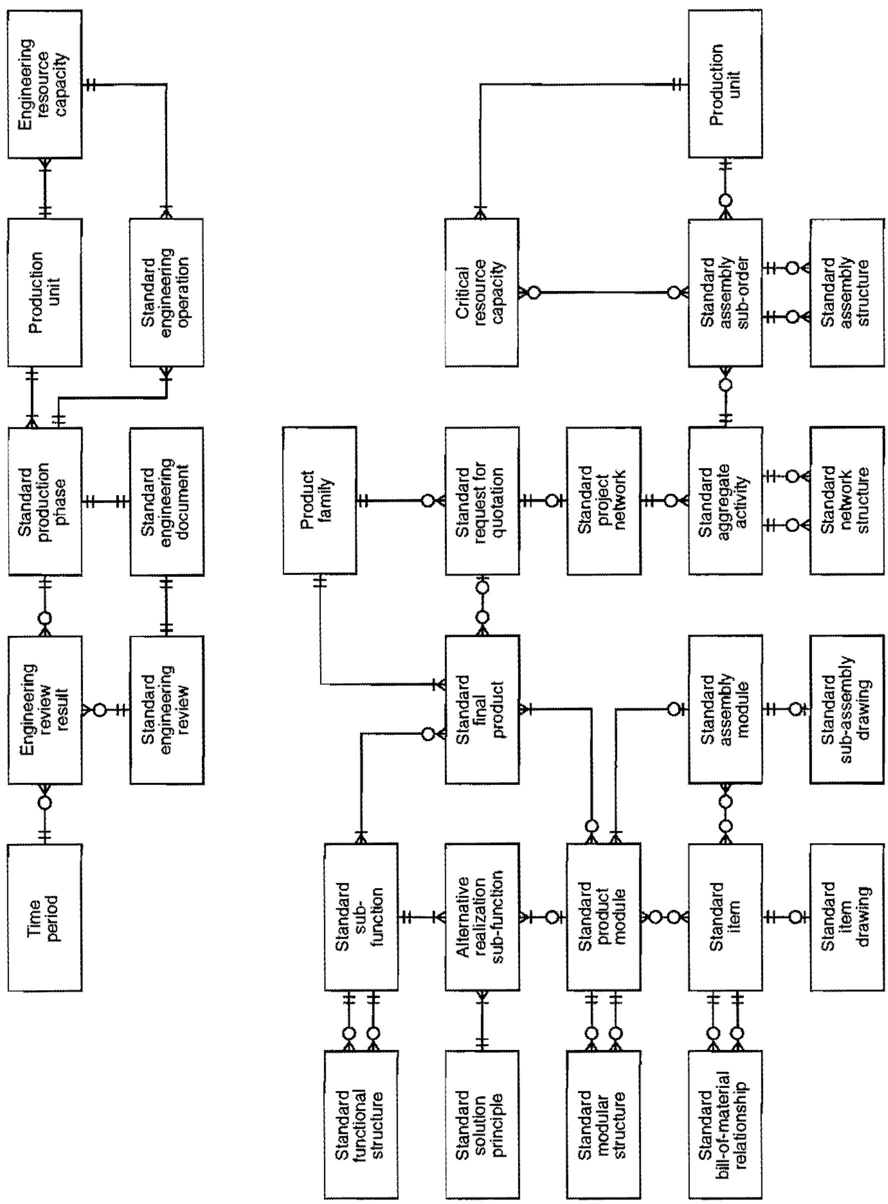
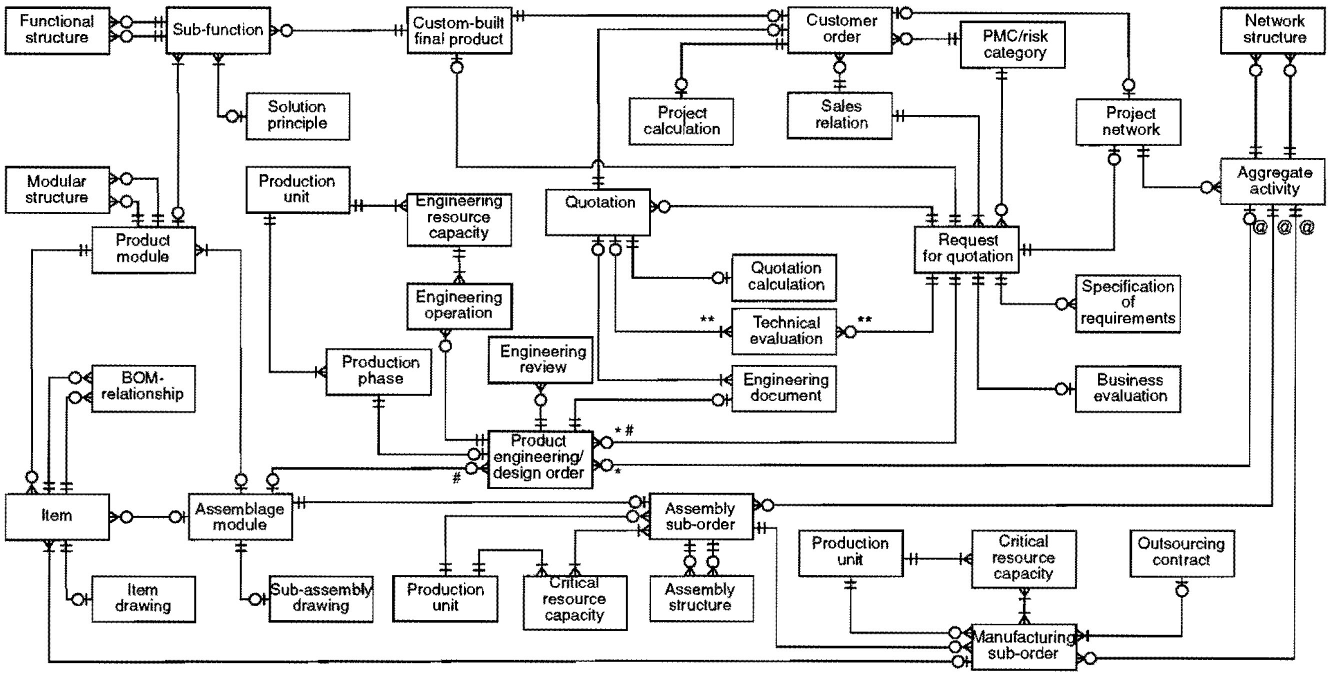


Figure 7.6 The state-independent data structure diagram



Datastructure relationships marked with * are mutually exclusive for one entity
Datastructure relationships marked with # are mutually exclusive for one entity
Datastructure relationships marked with @are mutually exclusive for one entity
Datastructure relationships marked with **are mutually exclusive for one entity

Figure 7.7 The state-dependent data structure diagram this request. A large amount of data is similarly linked to a request. The sales organization documents the customer's *specification of requirements* to support and clarify the request for quotation. A *business evaluation* and a *technical evaluation* are prepared for the purpose of Evaluation and Selection. More than one technical evaluation may be performed if multiple quotations are issued or if the specifications are changed during the quotation phase. If a request for quotation is accepted, an *product engineering order* is issued for preparing the quotation details. The product engineering order (which consists of a single *production phase*) is carried out within the *Product Engineering PU* in the form of a number of *engineering operations* and the use of a certain amount of *engineering resource capacity*. The product engineering order is comprised of instructions for the preparation of an *engineering document* which includes the preliminary draft of the future product. The engineering document, thus, represents an intermediate form of the final product. The *functional structure* and the *modular structure* which comprise the contents of this document are documented separately for each request for quotation (see Figure 7.7). As such, a distinction is made between the product which is required as the result of the product engineering order (the aforementioned engineering document) and the detailed preparation and documentation of the product description (the aforementioned functional structure, etc.). An engineering document can be seen as a description of a final product at a certain stage of development. The engineering document, as such, does not change, however; only the level of specification of the final product under development changes as the subsequent detailed design orders are completed during the order phase. The various steps in the engineering process can be review based upon the sequence of engineering documents which are prepared, registering the status of the product description at each stage. The data structure related to this has been excluded from Figure 7.7 in order to improve the clarity of this diagram.

It is possible that various successive quotations are issued during the quotation negotiations. This may also lead to successive versions of engineering documents and multiple engineering orders. A *quotation calculation* is prepared as the basis for the quotation price. A *project network* consisting of a number of *aggregate activities* with an associated *network structure* is defined in order to determine the throughput time for the quotation.

The quotation may lead to a *customer order* in some instances. Each request for quotation and each customer order is classified in a *PMC risk category*. The original project network is subsequently linked to the customer order. The quotation calculation is translated into a *project calculation*. In addition, the final product under development in the quotation phase is linked to the customer order and then developed in more detail. Performing the aggregate activity of Detail Design leads to various detailed design orders for the further development of the product description within the Detail Design PU. The total product is divided into *assembly modules* before the detailed design activities are initiated.

The aggregate activity of Assembly can be detailed further in the form of an *assembly structure* consisting of *assembly sub-orders* as soon as the assembly modules are defined. The various detailed design orders have an important relationship with the different assembly modules. Some of the detailed design orders are related to the general detailing of an assembly module while other detailed design orders are related to the detailed development of the different components within an assembly module. It may be decided to conduct one or more *engineering reviews* for each product engineering/detailed design order to evaluate the quality of the product description at certain points in time. The aggregate activity of Component Manufacturing is detailed further in the form of *manufacturing sub-orders* during the detailed design of the product. A manufacturing sub-order consists of instructions for producing a group of *items* related to a specific assembly module which is produced in the same *production unit* during approximately the same period of time. An estimate of the required amount of critical resource capacity is made for each manufacturing sub-order to be used as a basis for the evaluation of the capacity in connection with Sub-order Assignment and outsourcing decisions. One or more of the manufacturing sub-orders which are to be sub-contracted to the same supplier may be combined in a single *outsourcing contract*.

7.6 The relationships between the data models

The state-independent and state-dependent data models were discussed separately in the preceding sections. Nevertheless, these sub-structures should be seen as parts of a single, total data model in which important relationships between these two structures can be identified. The connections and relationships between the state-independent and state-dependent data models are described further in this section. For the sake of clarity, the complete data model will not be presented as one diagram since the large number of relationships between the state-independent and state-dependent data structures is rather overwhelming. The relationships between these data structures can be explained more adequately by presenting them separately in terms of the relationships between:

- standard product data and customer-dependent product data;
- standard aggregate network structures and standard order structures and customer-dependent network structures and customer-dependent order structures.

The standard product data such as standard sub-functions and standard product modules should be used by the product engineer and the detail designer as initial starting points for developing customized products. From the point-of-view of control, it is important that analyses can be made regarding how and how frequently that standard product data is used for the development of customized products. This means that the registration of the use of available standard product data for developing customized products should be included in the data model (see figure 7.8). The registration of which standard product data has been used and when it was used, is performed per engineering phase, starting with the *custom-built final product*, including the *functional structure* and ending with the *modular structure*.

A similar line of reasoning can be followed for the use of standard network structures and standard order structures (see also Sub-section 6.3.5). These relationships are illustrated in Figure 7.9.

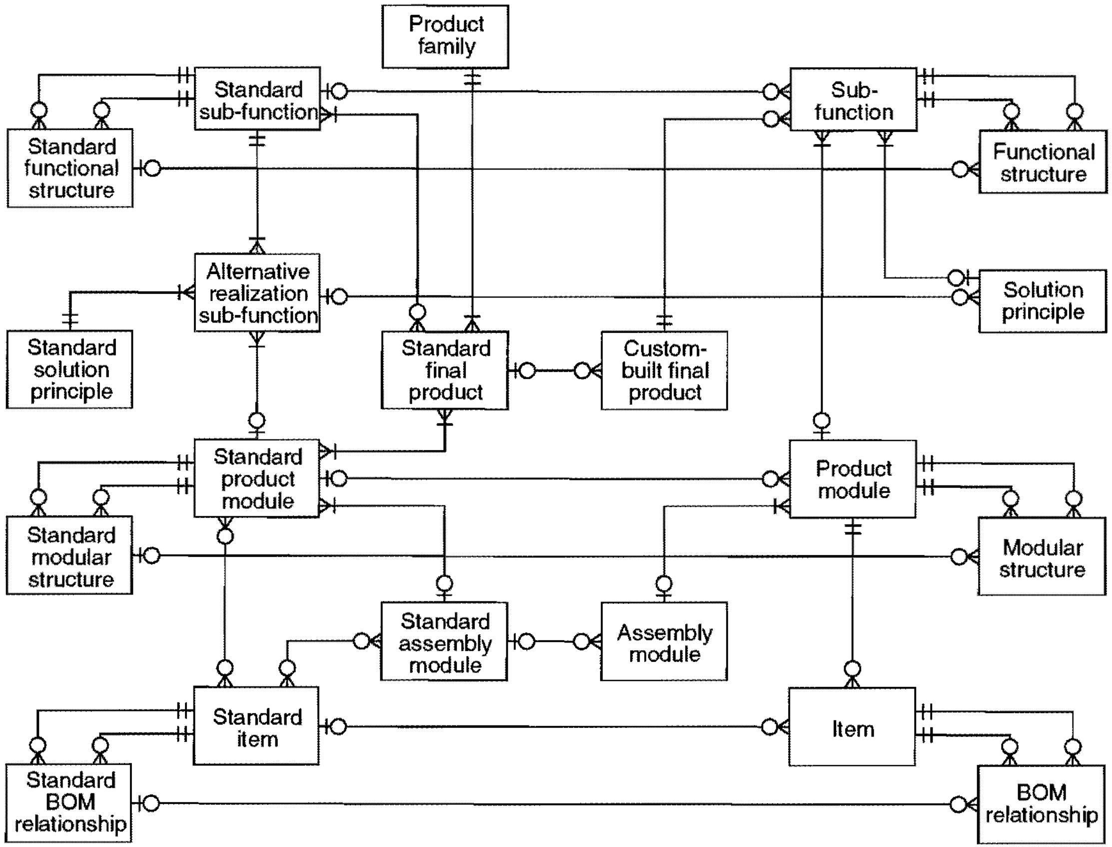


Figure 7.8 The relationships between the product data

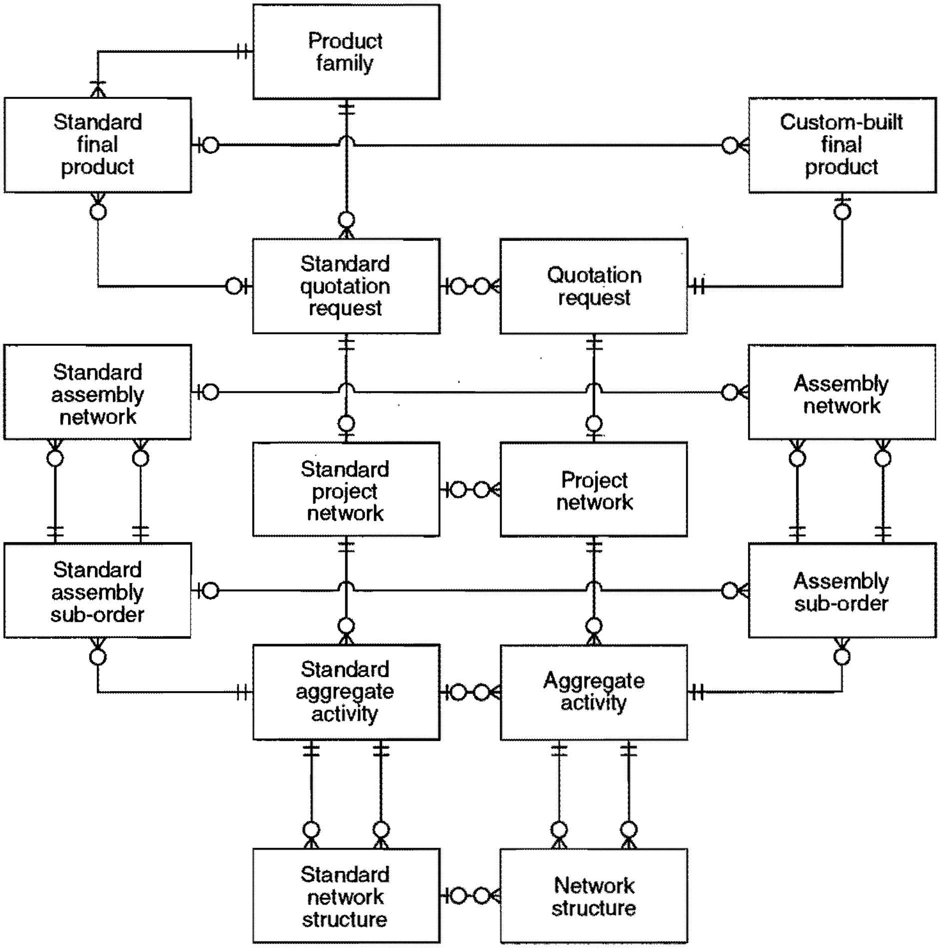


Figure 7.9 The relationships between the networks and order structures

7.7 The relationship with computer-aided development systems

In addition to the use of management information systems within customer order driven engineering, a second application of information technology can also be identified, namely, the use of computer-aided development systems. This refers to a set of automated tools for supporting various product development or engineering activities. In addition, product descriptions in various stages of development can be stored and maintained within this type of system. Only a limited, cautious start has been made with the introduction of computer-aided development systems in the selected case described in this book. The question of the extent to which these systems should actually be used in the selected case situation is thus also left unanswered in this research. Nevertheless, a further explanation of the nature and the area of application of computer-aided development systems is presented in this section due to the potential overlap with the management information system described in this chapter and the possible influence of this on the actual engineering process. The following topics are discussed in the following order:

- the different types of computer-aided development systems which can be identified and the various possibilities for applications with respect to the engineering process;
- the influence of the application of this type of system for the customer order driven engineering process and for the control of this process;
- the relationships with the management information system.

7.7.1 The distinction between different types of computer-aided development systems

Listed below in the order of increasing complexity and application possibilities, three types of computer-aided development systems can be identified (see, for example, Kaas and Stakenborg 1990):

- computer-aided drafting (2D-CAD) systems;
- computer-aided design (3D-CAD) systems;
- computer-aided engineering (CAE) systems.

The *2D-CAD systems* support the detail designer in creating two-dimensional (2D) drawings of the various components and sub-assemblies of the product. The drawing is prepared on a computer screen instead of on a drafting board. A large library of standard symbols, geometric functions and other designs is available for use by the detail designer. Through the use of standard elements in this way, standardization is encouraged, the throughput times for preparing drawings are reduced and changes to the drawings can be made more easily. The 2D-CAD systems can be used in the customer order driven engineering process in connection with the detailed design of the various assembly modules. With respect to the use of computer-aided development systems, only an initial start has been attempted with respect to 2D-CAD systems in the selected case situation described in this book.

The *3D-CAD systems* support the product engineer and detail designer in developing the product concept by providing the possibility for creating a three-dimensional (3D) (software-)prototype on the computer screen. This makes it possible for the developer to model the envisioned product concept (or part of this concept) without having to build a physical prototype. The *3D solid modelling* technique (Kaas and Stakenborg 1990) can be seen as an important development in this area which can be used to build a model of the future product starting from existing, basic 3D models. Solid modelling is also an important basis for the effective use of CAE systems (see below) and provides a much broader support than just a 3D visualization. It is possible to make use of 3D-CAD systems to support the customer order driven engineering process in selecting the solution principles for sub-functions, defining the modular structure, preparing the preliminary draft of the product and designing the components and sub-assemblies. In contrast to 2D-CAD, 3D-CAD can thus be used in an early stage of the engineering process and can provide a much broader support. It is possible to use 3D-CAD systems in combination with 2D-CAD systems. The geometric product specifications from a 3D-CAD system can be transferred to a 2D-CAD system for generating 2D drawings.

The *CAE systems* support the product engineer and detail designer in the analysis and optimization of 3D development alternatives in addition to modelling the product (3D-CAD). Various methods for analyzing and optimizing the mechanical, kinematic and dynamic behavior of development alternatives are available for this purpose, using a 3D-CAD model. The *Finid Element Method* is an example of this type of analysis method. The use of these types of computer-aided analysis methods for customer order driven engineering can have a great impact on the quality of the product description, the throughput time of the engineering process and, as a result, the control over the cost of a customer order.

7.7.2 Influence on customer order driven engineering

The part of the total engineering process in which the different computer-aided development systems can play an effective role was indicated in the description of these systems. The use of these types of development systems can have an important impact on carrying out the engineering process. The influence of information technology on the transformation process in this sense is an example of the effect that "I" can have on "P" as indicated in Figure 2.6b. These systems differ with respect to the degree to which they can influence the engineering process, in addition to the differences in the way they are used in this process. In particular, the 2D-CAD systems have a support function and they can contribute to the standardization (of drawing conventions), the efficiency and the improvement of the turnaround time for drafting work. In addition, the use of these types of systems encourages the routine use of standards. The 3D-CAD systems generally enhance the content of the engineering process by providing for the three-dimensional construction of an envisioned product concept together with a visual evaluation. Nevertheless, the most significant added value to the process of customer order driven engineering is afforded by CAE systems. In view of the fact that this involves the development of customized products, it is normally not feasible to build physical prototypes during the engineering process in order to evaluate the consequences of the envisioned product concept. In the selected case situation, for example, this leads to a large number of engineering changes after the product has already been released for production since the physical consequences of the chosen product concept first become visible at this point in time. If a CAE system were to be used in this situation (in combination, of course, with 3D-CAD), a significant improvement could be realized with respect to the quality assurance of the customer order driven engineering process in the selected case. This would mean that part of the product uncertainty could be eliminated and that the technical risk would be reduced accordingly, simplifying the control of the engineering process. Using information technology in this way to improve the control of the transformation process can be seen as an example of the influence of "I" on "C" as illustrated in Figure 2.6b.

7.7.3 The relationship with the management information system

In view of the possibilities for using the aforementioned computer-aided development systems, important relationships with the management information system can be identified. The registration of standard product descriptions and customized product descriptions in various stages of development are found in both types of information systems. Nevertheless, the registration of product descriptions within 3D-CAD and CAE systems is not done from the point-of-view of control. As a result, this does not conform completely to the way in which the registration of product descriptions is performed within the context of the management information system designed in this chapter. Various production phases can be identified from a control point-of-view within the customer order driven engineering process (see Chapter 4) with associated output in the form of a product description. If 3D-CAD systems and CAE systems, in particular, were to be used in the selected case for storing and maintaining the product descriptions, then this should be implemented in such as way that the output of the separate production phases can be recognized and identified in the desired form. In this way an automated interface between the systems and control over the consistency of product data can be realized.

Chapter
8 CONCLUSIONS

8.1 Introduction

An organizational design is described in this book for customer order driven engineering in an engineer-to-order production environment. Within this context, the design of the customer order driven engineering process, the controlling system and the management information system were discussed, in that order. To complete the discussion of our research in this book, a number of conclusions about the results of this research are presented in this chapter. The specific topics here are:

- the major conclusions from this research;
- generalizing the organizational design to other situations;
- recommendations for further research.

8.2 The major conclusions from this research

8.2.1 Conclusions regarding the contribution of this research

The presupposed objective of this research (see Chapter 1) was to provide a specific contribution to the industrial engineering theory with respect to:

- filling the gap in the literature published on the subject of controlling customer order driven engineering in engineer-to-order production environments in the form of a design of a controlling system and an information system for a selected case situation (see Chapter 2). The intention of this design is to provide an initial basis for further research in comparable situations;
- exploring the possibilities for applying industrial engineering principles and concepts, which were originally designed to control physical production processes, to the non-

physical production processes after incorporating some adaptations. In this case the non-physical production process refers to customer order driven engineering;
- integrating the factors of quality, time and cost within a single controlling system and management information system;
- contributing to the research methods which are used for design-oriented research in the field of industrial engineering.

♦ *Controlling customer order driven engineering*

As indicated in Chapter 1, very little or no research has been published to the knowledge of the author dealing with the control of customer order driven engineering in engineer-to-order production plants. Subsequently, a detailed analysis of the consequences of not having this type of control was presented in Chapters 1 and 3. It can be concluded that a lack of this type of control can affect the total performance of the company. The results of this research can serve as an initial contribution to fill the gap in the literature on the control of customer order driven engineering in engineer-to-order production situations. A controlling system and a management information system which adequately address the specific control issues found in customer order driven engineering are designed in this book for a selected case situation. This design could serve as the basis for further research in this area. Generalizing the specific results derived from this research to other situations is discussed in Section 8.3

♦ *Applying existing industrial engineering principles*

A large number of industrial engineering principles have been used in developing the organizational design for the *non-physical* process of customer order driven engineering. Several examples of the principles used are described below.

In Chapter 2, the PCI Model (Bemelmans 1986) was used as the basis for structuring the initial design. This structure and the implied relationships can be recognized in the structure of the organizational design which is developed further in Chapters 4 through 7. In addition to the relationships between "P", "C" and "I" which are identified in this model, reciprocal relationships are also defined between the controlling system ("C") and the transformation process ("P") in connection with a more detailed design of the engineering process in Chapter 4. Design requirements are included from the point-of-view of production control and cost control as well as from the point-of-view of quality assurance in connection with designing the customer order driven engineering process. It is shown that the design requirements which were originally formulated for the purpose of production control of the physical production processes (see Section 4.6) also appear to be relevant and applicable to non-physical production processes.

The design principles used in connection with the production control of physical production processes are also used in Chapter 5 for designing the controlling system for customer order driven engineering. A wide range of existing methods and techniques are used deliberately in Chapter 6 for designing the quality assurance processes and the production control and cost control aspects within the controlling system. These design aspects are then integrated within a single controlling system.

♦ *Integrating the control factors within a single control system*

As indicated in Chapter 1, most of the published studies about control systems do not approach the factors of quality, timeliness and cost in an integrated manner. Evidence is then provided to support the premise that quality, timeliness and cost factors need to be integrated into a single controlling system to enable an effective control of customer order driven engineering processes. This is one of the important objectives of the research presented in this book. In Chapter 5 it is demonstrated that the design principles used in designing a production control system can also be used for designing a control system in which the cost and quality factors are included along with the timeliness factor. Chapter 6 then presents a more detailed explanation of the three control factors, independently, and an explanation of the interrelationships between these factors within a single controlling system. It is apparent from the design of this controlling system in Chapter 6 that the integration of the three control factors within a single controlling system is not only feasible, but is also a necessity. It is clear that these control factors often need to be evaluated in combination with each other in order to provide for an optimal control (see Section 6.5). Subsequently, an information architecture is developed in Chapter 7 in which the (decision support) information related to the three control factors is included in an integrated fashion.

♦ *A contribution to the research methods in industrial engineering*

The research described in this book can be characterized as being design-oriented. A great deal of attention has been focused on following a proper scientific approach for completing the design-oriented research presented in this book. The structure and scope of this design-oriented research (see Chapter 2) and the further development of the various topics in Chapters 3 through 7 could serve as an example for future design-oriented industrial engineering research. The approach used for structuring and developing the topics of this research can be seen as a contribution to the design-oriented research methodology in the field of industrial engineering.

8.2.2 Other conclusions

The results of this research have provided the basis for deriving several other conclusions in addition to the aforementioned aspects. These other conclusions from the research results are related to:

- the development of a classification scheme for customer order driven engineering;
- the use of standard product data;
- the integrated design of the transformation process ("P"), the controlling system ("C") and the management information system ("I") as a single, total system.

♦ *A classification scheme for customer order driven engineering*

It is apparent from the analysis of various engineer-to-order situations in this research that the nature and complexity of customer order driven engineering varies radically from one situation to the next. A classification scheme has been developed for customer order driven engineering as part of the research here in order to be able to classify the various types of situations. The various types of customer order driven engineering (see Chapter 1) can be distinguished in terms of the order-independent specification level (OSL). The OSL indicates the degree to which standard product structures can be used within the customer order driven engineering process. Another aspect which is significant in connection with classifying the customer order driven engineering process is the specification freedom provided to the customer. If the customer's specification freedom with respect to the formulation of specific product requirements is increased, then the technical risk and the complexity of the control problem also increase. The choice of OSL as well as the specification freedom provided to the customer have an important impact on the design and the control of the engineering process.

The classification scheme for customer order driven engineering which has been developed as part of this research could be useful in future studies to make a distinction between different types of control situations.

♦ *The use of standard product data*

It has become apparent from this research that the definition of standard product data and maintaining the accessibility of this data can have an important impact on the quality of the customer order driven engineering (Chapter 4). An increased use of standard product data reduces the technical risk. In addition, the use of standard product data reduces the complexity of the control problem since reliable normative data is available for the standard product definitions which can then be used within the controlling system. Storing and maintaining the standard product data in such a way that it remains readily accessible poses specific requirements with respect to the data model associated with the management information system. The way in which the standard product structures can be maintained in a management information system is explained in Chapter 7.

♦ *The integrated PCI design*

The PCI Model (Bemelmans 1986) has been used as a basis for structuring this organizational design. One of the assumptions in connection with this approach is that there is a certain interdependency between "P", "C" and "I". The interdependencies in this model are often identified in the scientific research carried out in the field of industrial engineering (see, for example, Van Rijn 1986, Heemstra 1989, Greveling 1990 and Van Genuchten 1991). These research studies have dealt primarily with the relationships between only two of the three subsystems of "P", "C" and "I", however. The research described in this book is based upon an *integrated* design in which the transformation process (P), the controlling system (C) and the management information system (I) are treated as a single, total system.

In addition to the interrelationships defined in the PCI Model, the reciprocal relationships which have an effect in the opposite direction are identified and described in this research. These relationships are concerned with the effect of:

- the controlling system on the transformation process;
- information technology on the transformation process;
- information technology on the controlling system.

8.3 Generalizing the organizational design to other situations

Much has been published in the literature about the limitations of generalizing the results of case studies due to the limited number of situations which are considered (see, for example, Yin 1989 and Ryan et al. 1992). The design-oriented research described in this book should not be seen in the same light as the research method known in the literature as *case study research*, however (see, for example, Yin 1989 and Van der Zwaan 1990). The objective of this type of research is oriented toward the formulation of hypotheses or theories (explorative research) or testing hypotheses (experimental research). The type of research described in this book is primarily oriented toward the guidelines and procedures required for influencing and actually changing a case situation (see also Chapter 2), however. Nevertheless, working hypotheses for future research could be derived from this research.

The industrial engineering organizational design described in this book is based upon a single case situation. As part of the explanation of the organizational design, the reasons are also presented which support the conclusion that this design provides an adequate solution for the problem described in the selected case situation. A question of scientific interest, however, is the extent to which the organizational design described in this book can be generalized and used in comparable production situations. Kennedy (1979) forwarded an important proposition concerning the applicability of this type of organizational design to other situations. We agree with his opinion within this context:

> ...judgment should *not* be made by the evaluator. Instead, it should be made by those individuals who wish to apply the evaluation findings to their own situation. That is, the evaluator should produce and share the information, but the receivers of the information must determine whether it applies to their own situation. Because the evaluator cannot know who his receivers are, he must, of course, be quite specific in his description of the attributes of his case...
> (Kennedy 1979, p. 672).

Kennedy (1979) suggests in this way that the general applicability of the design must be determined by those persons who wish to apply the results in a comparable situation. Nevertheless, an important condition in connection with this is that the researcher provides good documentation of the results of his research and the characteristics of the case situation upon which these results have been based. This type of stipulation has been a major reason for providing an extensive description and definition of the selected case situation in Chapters 2 and 3 and an detailed description of the actual design in Chapters 4 through 7. Researchers are not used to leaving the proof of generalization of their results to the users, even though this approach is normal within other disciplines. With respect to this, Kennedy (1979) refers to the example of using "jurisprudence" within the legal system. Kennedy (1979):

> The term "case law" refers to that portion of the law that is built up from specific cases rather than from statutes. These specific cases are resolved on the basis of statutes, but the interpretations of statutes that are made in each case set precedents for future cases. Thus the decision reached regarding a single case may be generalized to future cases. ...Though these decisions may be stated with the intention that they be generalized, it is the later court which must decide whether in fact a particular decision generalizes to its own case. Thus it is the receiver of the information who determines the applicability of a finding to a new situation. (Kennedy 1979, p. 672).

The degree to which the organizational design described in this book can be generalized to similar case situations should be determined in this way by carrying out a specific evaluation in these similar situations.

8.4 Recommendations for further research

The design of the customer order driven engineering process, the control of this process and the management information system for a single, selected case situation has been the central theme in this book. The results of this research represent an initial contribution to the industrial engineering theory on this subject. A brief summary of the supplementary research which would be useful, based upon the results of the research here, is outlined in this section. The relevant areas for further research are:

- an empirical test of the applicability of the results of this design-oriented research in comparable situations;
- the use of information technology to enhance the accessibility of standard product descriptions;
- the interface between management information systems and computer-aided development systems.

As indicated in section 8.3, the general applicability of the results of this research should be determined by evaluating the applicability in comparable situations. Further research is required with respect to controlling customer order driven engineering in other production situations in addition to determining the applicability of the results in similar situations. The classification scheme for customer order driven engineering processes as used in this research could provide a useful basis for subsequent studies.

As previously mentioned in numerous places in this book, the use of standard product structures can play an important role with respect to the quality of customized product descriptions and the control of customer order driven engineering. The degree to which such standard structures are used in practice will depend upon their accessibility. Information technology can play an important role in this area; further research into these possibilities is desirable.

In Chapter 7, a differentiation was made between information systems for supporting the control of the engineering process and information systems for supporting the engineering process, itself. Important conclusions in this respect were that:

- a significant overlap between these two types of systems exists with respect to the registration of product descriptions;
- the ways in which the product descriptions are registered in these two types of systems is clearly different.

Further research into the coordination and interfacing between these two types of systems would be useful.

Appendix
A IMPLEMENTATION EXPERIENCE IN THE SELECTED CASE

A.1 Introduction

A description of the selected case situation was presented in Chapter 3 which included an analysis of the major issues which customer order driven engineering needs to address. The customer order driven engineering process in the selected case is redesigned in Chapters 4 through 7 using a proper research approach as outlined in Chapter 2, based upon this description in Chapter 3. Portions of the organizational design have actually been implemented in the selected case. Relevant details concerning the implementation experiences are described in this appendix.

The research significance and scientific contribution provided by the implementation of the organizational design are discussed in Section A.2. The project structure and resourcing aspects are then covered briefly in Section A.3. Relevant implementation experiences are subsequently described in Sections A.4 and A.5. Conclusions are presented in the last section of this appendix.

A.2 Scientific contribution provided by the implementation

The chosen research approach has been described in detail in Section 2.2. In connection with this, particular attention has been paid to the evaluation criteria used for determining the scientific value of the organizational design. The results of the actual implementation have not played a significant role with respect to this. The example of laying out a garden was used in Section 2.2 to illustrate the point that it is not possible to determine the scientific value of an organizational design by simply implementing this in the relevant organization since an important portion of the variables which affect the performance of the organization cannot be influenced by the designer. In addition to the scientific relevance and the innovative value, the most important evaluation criterion is the plausibility of the reasoning followed during the development of the design.

Nevertheless, the implementation experiences in the selected case situation have been able to add significant value to the design. In the first place, the implementation of the organizational design has had a strong influence on working out the details of this design, and vice versa. It has been possible to define specific aspects of the design in more detail as a result of the implementation experience. In the second place, the implementation experience *supports* the scientific evaluation of certain parts of the design. In any case, the practical feasibility of the design has been proven for those parts of the design which have actually been implemented in the selected case situation.

A.3 Project structure, phasing and resourcing

♦ *The project structure*

A project structure incorporating two levels, a steering committee level and a task group level, was chosen for the operational realization and implementation of parts of the design. Two separate task groups were formed. The steering committee consisted of the complete Management Team together with the leaders of the two task groups and this author. The composition of this steering committee is illustrative of the shared responsibility and direct involvement of company management. The steering committees task was to monitor the progress of the project, to review the content of the (intermediate) results and to make the necessary "go/no-go" decisions. The two task groups within this project organization were formed to cover the "Primary Process" and the "Control Process", respectively. This author played an active role in both of these task groups. Analogous with the structure of the design, the Primary Process Task Group was responsible for the operational realization and implementation of the parts of the design concerned with the customer order driven engineering process (see Chapter 4). The Control Process Task Group was responsible for the parts of the design dealing with controlling the customer order driven engineering (see Chapters 5 and 6). Very few of the aspects dealing with the management information system (see Chapter 7) were implemented in the selected case in view of the dependency relationships between (re)designing the transformation process ("P"), the controlling system ("C") and the management information system ("I") (see Section 2.5).

♦ *The project phases*

The project activities were carried out by the task groups according to the following sequential project phases:

- project initiation phase;
- concept development phase;
- concept translation phase;
- implementation phase;
- evaluation and follow-up phase.

The required project activities were worked out in more detail in each of the task groups during the *project initiation* phase. The tasks and objectives were defined along with a project schedule and project resourcing plan to allocate the tasks to the task group members. Various aspects of the design as described in this book were conceived and developed during the *concept development* phase. This author's involvement in both of the task groups was primarily during this phase. The further development of the concepts identified during this phase and the translation of these concepts into practical terms was accomplished during the *concept translation* phase. These last two phases overlapped to the extent that there was a cyclical process whereby the concept translation lead to a certain amount of concept redevelopment. The practical application lead to changes in the initial concepts in some instances. It was, thus, difficult to maintain a sharp distinction between these two phases in practice. A significant amount of time was additionally spent preparing for the implementations and developing an implementation plan during the concept translation phase. The respective parts of the design were implemented in the selected case situation and responsibility was transferred to the line organization during the *implementation* phase. The results of the project were reviewed and evaluated during the *evaluation* phase and active support was provided by both of the task groups to ensure that the newly implemented methods and procedures were followed. In view of the fact that the design was not implemented as an integrated whole in a single step, the Control Process Task Group was obligated to carry out these phases several times, each time for a specific part of the design. At the time of writing this book, the Primary Process Task Group had not progressed further than the implementation phase due to the widespread implications of the redesigned process for the organization.

♦ *The project team*

Representatives of the various functional areas within customer order driven engineering were included in both of the task groups. These functional areas were Sales, Product Engineering and Detail Design. The line management of these functional areas was included in the Control Process Task Group, in addition to several key members of the Management Team. This degree of heavy involvement in the task group was essential, considering the focus on developing the controlling system of the engineering process. In view of the attention paid to adapting the operational activities, employees at the shop floor level were specifically represented in the Primary Process Task Group.

A.4 Experiences implementing the redesigned process

A redesigned customer order driven engineering process is described in Chapter 4. Key aspects of this redesign are a clear phasing of the process, the definition of distinct engineering steps and defining the output of each of the engineering steps in terms of specific engineering products. The use of a number of pre-defined engineering steps and, in this way, following a logical development sequence from "function to form" can be seen as the essence of this approach to redesigning the engineering process. A detailed explanation of the shortcomings of the engineering process in the selected case is presented in Sub-section 3.8.2. These shortcomings can be seen as the original reasons for redesigning the process. The implementation of the redesigned process in the selected case situation implies significant changes for all of the persons involved in the process, however, since a totally different approach is followed to engineering and maintaining product descriptions. This type of implementation can only be successful with thorough preparation and the use of a phased approach. The primary objective of the task group was not to directly implement this new approach to engineering, but rather to make the necessary preparations to ensure a successful implementation by:

- evaluating the basic principles of the new engineering approach with respect to the existing standard product descriptions;
- creating initial versions of new standard product descriptions based upon the future engineering approach;
- increasing the awareness of the reasons for changing the engineering approach by all of the parties involved in the engineering process and training various employees in using the new method;
- preparing a proposed form for documenting the product descriptions in the successive stages of the engineering process. In connection with this, significant attention has been paid to ensuring that the documentation is consistent and coordinated across the various disciplines and that information is communicated effectively during the transfer of work between disciplines.

A further description of the implementation experiences is presented below for the first two project activities identified.

♦ *Evaluating the new engineering approach*

The new engineering approach was evaluated based upon a single, specific reference machine. An attempt was made to translate the details of the existing product description into the future product structures (see also Figure 4.9). The most important conclusion from this effort was that it is certainly feasible to translate the existing product structures into the future structures, but with one exception. The exception occurred in some instances where it was not possible to assign a product module uniquely to only one assembly module (see 't Hart 1992). The consequences of this are that when the standard structures are used for a given product module, a customer-dependent modification of that product module may lead to changes in multiple assembly modules. This means that the current assembly modules cannot be treated as being completely independent of each other in the detailed design phase, in contrast with the ideal situation (see Figure A.1).

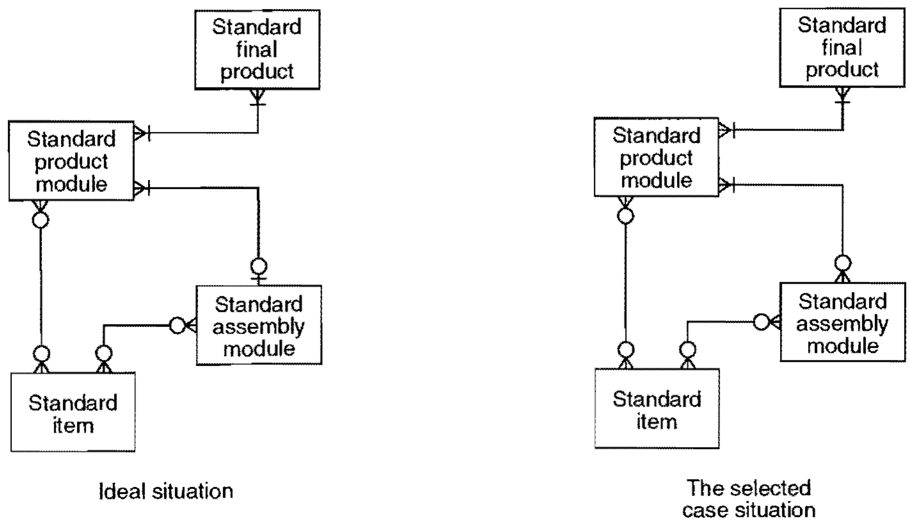


Figure A.1 Shortcomings of the current standard product structure

♦ *Creating standard product descriptions within a pilot implementation*

It became apparent from carrying out the evaluation as described above that the current standard product descriptions had not been adequately defined and were certainly not specified and documented sufficiently to be able to support the future engineering approach. A necessary condition for implementing a new engineering approach is that the existing product knowledge is documented and is readily accessible in the form of standard product descriptions. A start was made with respect to defining the necessary standard reference structures as part of the initial pilot project (see 't Hart 1992). Within the "Packaging" product family, various types of supply lines can be distinguished which have been used in conjunction with different customized packaging machines in the past. Each supply line can be seen as a separate assembly module. The following activities were carried out as part of the pilot project:

- organizing the available knowledge about supply lines;
- selecting which information about the supply lines should and should not be used in defining the standard reference structures;
- defining the required standard reference structures and maintaining this data in a form which can be used by the new engineering approach.

The result of this pilot project was the documentation of the standard product structures for the packaging machine supply lines in terms of (see also Figure 4.9) standard sub-functions, alternative solution principles and standard product modules. A number of positive effects also resulted from this pilot project in connection with the subsequent engineering of customized supply lines in the selected case situation:

- the standard reference structures defined for the supply lines were found to be useful as direct input and support for the product engineers and detail designers;
- it became apparent from a thorough analysis of the existing knowledge that the applicability of certain solution principles was dependent upon the value of certain sizes or other variables. This fact had not been documented, however, and it was not generally known. By explicitly documenting the scope and applicability of certain solution principles, technical problems which have occurred in the past can be prevented in the future;
- by fully reviewing all of the existing knowledge, a number of solution principles which have been used in the past but have proven to be unsatisfactory could be eliminated from the standard reference structures.

A.5 Experiences implementing the redesigned control aspects

A redesigned controlling system for customer order driven engineering was described in Chapters 5 and 6. The essence of the changes can be found in the explicit decision structure which incorporates the factors of quality, cost and timeliness. The shortcomings found in connection with the current control approach used in the selected case situation were discussed in detail in Sub-section 3.8.2. The most important conclusion was that there was virtually no formal controlling system. Analogous to the plan followed by the Primary Process Task Group, the choice was made to follow a phased approach for the project initiation and implementation activities in view of the expected impact of the controlling system as described in Chapters 5 and 6. The Control Process Task Group started with the implementation of the first integral "Request for Quotation Evaluation" decision in view of the added value of this decision and the lack of a formal decision structure. At the same time, the task group also started with the creation and implementation of engineering reviews in a number of pilot projects since a structured approach to quality assurance was missing. These activities had been completed at the time of writing this book. The implementation experiences in connection with these activities will therefore be discussed in more detail here.

♦ *Implementing the "Request for Quotation Evaluation" decision*

The received requests for quotation did not go through a selection process in the selected case situation due to the lack of an integral decision structure as described in Chapter 5. Attention and scarce product engineering resource capacity was spent on any request for quotation which appeared to be interesting based upon an individual evaluation. As a result, resource capacity was sometimes spent on requests which were not really worthwhile and other, more favorable, requests were not given consideration due to a lack of resource capacity. Therefore, in view of the importance of this for the company as a whole, the Control Process Task Group initiated several activities to establish a request for quotation evaluation and selection procedure.

In the first place, the PMC strategy was defined and translated into operational terms in collaboration with the Management Team. This was essentially a statement about the degree of attractiveness to be assigned to each combination of product group and geographical marketing area (the PMC) and the sales and profit margin targets for each PMC. Note that the definition of risk categories as described in Chapter 6 had not yet been used here. The received requests could be sorted into the important categories for further consideration based upon the clarification of the PMC strategy and communicating this to the organization. Each PMC was also divided into market sectors (in addition to geographical areas and product groups) primarily for the purpose of setting targets for the Sales organization. Examples of market sectors for bottling machines include the distilled beverage industry (e.g. whisky), the dairy industry and the soft-drink industry. Each combination of PMC and market sector was assigned to one of the following categories:

- an important PMC for which new orders should be actively solicited (Category A);
- a lesser important PMC for which no special marketing efforts are warranted (Category B);

- an unimportant PMC for which requests for quotation generally will not be accepted (Category C).

The adherence to this PMC strategy is an extremely important business criterion. If a request for quotation does not fall into Category A, then the salesperson will need to provide convincing arguments in order to get the request selected and accepted. The annual sales budget is translated into a sales target and a target profit margin per PMC. This and other information can be used to set priorities for the requests for quotation within the Sales organization.

In the second place, a procedure was developed for a *business evaluation* and a *technical evaluation* for the requests for quotation and subsequently implemented in the selected case situation. The business evaluation is carried out within the Sales organization. The respective salesperson evaluates a request based upon four main criteria, namely:

- the product/market strategy which dictates whether this request falls into a PMC which is important to the business;
- the chance of winning the order, based upon information about which competitors are also preparing quotations and whether this is an existing customer;
- an estimate of the potential revenue from this sale (the price level);
- the follow-on potential of this request for quotation, based upon information about whether this is an important opportunity in an important market segment, whether the customer is the market leader and whether there are possibilities for additional orders.

The business evaluation is carried out by completing a standard business evaluation questionnaire. The salesperson provides a final opinion regarding the business attractiveness of the request based partially upon a subjective evaluation of the scores which are assigned to the various main criteria using this questionnaire. The requests are discussed once each week within the Sales organization and a decision is made regarding which requests are sufficiently attractive from a business point-of-view. The Sales organization may also decide to select and accept a request for quotation even when it has a low score for one or more of the main evaluation criteria. In this situation, a supplementary argumentation should be included to support this decision. In addition, a normative internal throughput time is assigned to each request to indicate the deadline for completing the quotation. The assignment of a due date in this way is useful for planning the work to be released to the Product Engineering PU. The technical evaluation is carried out within the Product Engineering PU by filling out a standard technical questionnaire. The purpose of this questionnaire is to provide support in estimating the technical risk associated with the request for quotation based upon the functional requirements specification. As the number of customized requirements included in the request increases, there is a greater likelihood that more than the originally estimated product engineering and detailed design hours will be needed, thus increasing the technical risk.

The "Request for Quotation Evaluation" decision is made once each week during the Quotation Team Meeting in the selected case situation. In attendance at this meeting are the members of the Management Team, the managers of the Packaging Technology and Bottling Technology sections and the Materials Manager. A number of requests for quotation are selected at this meeting, based upon the selection of requests for quotation made by the Sales organization and the results of the business and technical evaluations.

The implementation of the "Request for Quotation Evaluation" decision and the formalization of the PMC strategy lead to a number of important positive developments, namely:

- the sales effort could be focused more strongly on the more attractive market segments as identified in the PMC strategy;
- due to the implementation of an integral coordination of the activities in response to the received requests for quotation via the Quotation Team Meeting, an initial, structured purpose was given to the communications and coordination between Sales and Production which had not previously existed;
- the scarce product engineering resource capacity was utilized more efficiently and effectively since time was now spent on only the attractive requests for quotation;
- a quotation could be prepared and issued more quickly since the availability of product engineering resource capacity was taken into account at an early stage at the time of selection;
- the pressure and stress associated with meeting deadlines was reduced by eliminating the over-utilization of the product engineering capacity, leading to a reduction in needless errors caused by stress and carelessness.

♦ *Quality assurance through the implementation of engineering reviews*

In addition to the initiation and implementation of the "Request for Quotation Evaluation" decision, the Control Process Task Group initiated the implementation of engineering reviews within a number of pilot projects at the same time (see Van Alphen 1992). The initial focus was on reviewing the preliminary draft of the product which is used as the starting point for the detailed design activities. Two support documents, the Standards Specification and the Checklist (see Sub-section 6.2.7) were defined for use in reviewing the preliminary draft. The Checklist was enhanced further based upon the practical experience gained during the pilot projects.

The following categories were defined for classifying the faults which were found during the engineering reviews in the selected case situation:

- an extremely serious fault, requiring 60 hours or more to rectify;
- a major fault, requiring 20 to 60 hours (i.e., an average of 40 hours) to rectify;
- a minor fault, requiring less than 20 hours to rectify.

The number of hours mentioned here to correct a fault includes all of the hours which would be required within the organization to make the necessary corrections throughout the remainder of the process in the event that such a fault is not found during the engineering review. This includes the hours for the engineering organization as well as for sales, manufacturing and assembly. Each of the faults discovered by the individual reviewers was classified under one of the fault categories as part of the initiation and preparation activities. Using this information, an estimate could be made of the number of hours potentially saved by performing each of the pilot reviews. This type of measurement in terms of potentially saved hours provides an indication of the added value of the engineering review conducted. This savings also provides a justification for the investment of (scarce) resource capacity, particularly from the engineering organization, in the review process. The total capacity requirements per engineering review amounted to 35 hours, comprised of 7 hours for each of the 5 reviewers involved. The preliminary drafts of the products for three different customer orders was chosen as the subject for the first trial review. The review process which was followed is illustrated in Figure 6.4. The results in terms of the average number of faults found and the average potential savings in hours are presented in Table A.1.

Fault category	Average number of faults	Potential savings (hours)
Extremely serious faults	4.7	282
Major fault	4.7	188
Minor fault	22.3	223
		693

Table A.1 Results of three pilot implementations of engineering reviews

It appears from these results that, in addition to a large number of minor faults, an average of five major faults and five extremely serious faults were discovered in each of the preliminary drafts of the products. The conclusion was the same for all three of the customer orders. Especially the faults in the last two categories can lead to significant negative consequences (in terms of time and cost) for the organization, particularly when such faults are not discovered until one of the final stages of the physical production. When this is translated into a total potential savings in hours, an average of almost 700 hours can be saved (see Table A.1). When the total effort of 35 hours invested in the review activities is taken into account, the net (potential) reduction of the number of hours is still significant.

Based upon the evaluation of the three pilot projects and the faults found in these instances, it was determined that the engineering reviews can provide a significant contribution to the quality assurance in connection with customer order driven engineering in the selected case. Discovering the extremely serious and major faults, in particular, at an early stage means that:

- a reduction can be achieved in the number of engineering changes after the product has been technically released;
- significantly fewer "last minute" problems will occur during the assembly phase due to detailed design problems;
- significantly reduced time pressure and reduced backlogs result with respect to the physical production of the machines.

A large number of faults such as found in the selected case situation is, of course, partially the result of not following a formal engineering approach. The implementation of the engineering process as described in Chapter 4 will serve to eliminate an important portion of the quality assurance problems which have been identified. An engineering review should also be considered in order to improve the control of the customer order. In connection with this, estimates of the technical risk and the average number of faults expected in the future situation will play an important role (see also Chapter 6).

A.6 Conclusion

The experiences in connection with the implementation of parts of the organizational design described in this book have been described briefly in this chapter. Only a limited start has been made with respect to the total actual implementation in view of the extent of the redesign and the implications for the organization in the selected case situation. Nevertheless, based upon the results of the implementations which have been carried out so far, it is possible to conclude that the implemented parts of the organizational design (can) function as anticipated and (can) represent a significant added value in practical situations.

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STELLINGEN

behorende bij het proefschrift

MANAGING CUSTOMER ORDER DRIVEN ENGINEERING

An interdisciplinary and design oriented approach

van

DENNIS RICHARD MUNTSLAG

I

Voor het ontwerpen van besturingssystemen voor klantordergedreven produktontwikkeling is het zinvol om gebruik te maken van een typologie die bedrijfssituaties ordent naar de mate waarin de specificatievrijheden voor de produktontwikkeling verschillen (dit proefschrift, hoofdstuk 1).

II

Het onderscheiden, toegankelijk vastleggen en gebruiken van referentie produktgegevens heeft een belangrijke verbetering van de kwaliteit en bestuurbaarheid van klantordergedreven produktontwikkeling tot gevolg (dit proefschrift, hoofdstuk 4).

III

De bredere toepasbaarheid van resultaten van bedrijfskundig ontwerpgericht onderzoek moet worden vastgesteld door diegenen, die de resultaten in een vergelijkbare situatie willen gebruiken. Een belangrijke voorwaarde hierbij is echter dat de onderzoeker de totstandkoming van zijn ontwerp en de karakteristieken van de aan het ontwerp ten grondslag liggende case-situatie goed documenteert (Kennedy 1979; dit proefschrift, hoofdstuk 8).

IV

De toegevoegde waarde van een geïntegreerde besturing van de aspecten kwaliteit, tijd en geld bij klantordergedreven produktontwikkeling wordt bepaald door een optimale afstemming van deze aspecten en niet door het voortdurend kunnen maken van trade-off's tussen deze aspecten (dit proefschrift, hoofdstuk 6).

V

Er kan in menig opzicht een parallel worden getrokken tussen klantordergedreven produktontwikkeling en het doen van promotie-onderzoek. De in dit proefschrift ontwikkelde concepten kunnen dan ook analoog worden toegepast bij de aansturing van promotie-onderzoek.

VI

De kwaliteit van een wetenschappelijke bewering wordt niet afgemeten aan het feit of deze wel of niet wordt achterhaald. Het is veel meer een kwestie van de tijdsduur waarbinnen deze wordt achterhaald.

VII

De relativerende wijze waarop een zojuist gepromoveerde terugziet op het eigen promotie-onderzoek, kan worden vergeleken met die van een beklimmer van een zeer steile en hoge berg. Pas wanneer deze na veel ontberingen de top heeft bereikt en uitkijkt over het dal, ziet hij welke route het best genomen had kunnen worden. Die route zal voortaan iedereen volgen die na hem komt.
(Naar: Hermann Helmholtz, een negentiende-eeuwse fysicus)

VIII

Bedrijven die actief participeren in bedrijfskundig wetenschappelijk onderzoek kunnen een belangrijk concurrentieel voordeel behalen.

IX

De kwaliteit van een minister moet met name worden afgemeten aan het succes van zijn opvolger, gezien het lange termijn effect van genomen maatregelen.

X

Een reclamecampagne van de 'Bond tegen het Vloeken' langs de snelwegen zal, gezien het toenemend aantal verkeersopstoppingen, inmiddels een groter bereik hebben dan de bestaande campagnes op treinstations en in bushokjes.