MARKET-ORIENTED ORDER PLANNING
IN THE AUTOMOTIVE INDUSTRY

A BUILDING BLOCK FOR SUPPORT OF EFFICIENT ORDER PROCESSING

DISSERTATION

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Market-oriented Order Planning in the Automotive Industry.
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Ph.D. Thesis

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To my parents

“You can never plan the future by the past." Edmund Burke (1729-1797)

Preface

This thesis represents the result of my post-graduate research work as a Ph.D. student in the Research and Technology Division of the DaimlerChrysler Group. The dissertation topic is related to several research projects undertaken by the department *Product, Process, Resource Integration (RIC/EP)* within the laboratory *IT for Engineering (RIC/E)*. In particular, two research projects were closely coupled with the developed planning methodology for customer-neutral orders: preventive order control and ProDEMO (Product Development Meets Order Process). The former aims at optimization of order processing, the latter at further developing the product documentation with connection information. Both projects helped me to refine my ideas and to validate some of the results.

Particular gratitude owes Prof. Dr. Ir. Fred van Houten, who supervised my work on the part of the University of Twente with a great amount of interest. He was most helpful in offering his constructive criticism and experiences during our discussions. His expertise and analytical way of thinking have always helped me to question the things I have elaborated. Despite the distance between Ulm and Enschede, the discussions he was kind enough to grant me were sufficiently frequent to find their way into my research. Furthermore, I would like to express my gratitude and appreciation to the members of the committee: Prof. Dr. Ir. Grootenboer, Prof. Dr. van Harten, Prof. Dr. Ir. Akkerman, Prof. Lauwers, Prof. Dr. Ir. Gaalman, Prof. Ir. de Deugd, and Dr. Ir. Pels.

I would also like to thank Dr.-Ing. Siegmar Haasis for putting his confidence in me and for providing me the opportunity to accomplish this research work at DaimlerChrysler. He established the environment and the necessary degree of freedom for me to push the dissertation project within the projected trajectory. Many thanks to the colleagues in my department and in the projects and to the researchers of the *Laboratory of Design, Production, and Management* at the University of Twente for the prosperous discussions and good collaborative working we enjoyed.

I would also like to mention Juergen Lentschig for supporting me in developing the software demonstrator, the students doing practical internships and diploma theses related to the order planning research work, and additionally Larissa Glaser for proof-reading my thesis.

Finally, I owe more than my gratitude to my parents, Walter and Erika Sailer, for supporting me on my path in life and in all the phases of the research work beyond what I expected or could ever have hoped for.

Voehringen, November 2004

Bernd Sailer

Summary

To realize efficient order processing in manufacturing companies and to achieve fair profit in an increasingly dynamic environment is a demanding goal. And this is, in particular, true when companies offer their - nowadays typically customized - products in buyers' markets and if they are faced with an unforeseen slack in customer demand. In such a case, if additional marketing efforts do not boost customer demand and measures for capacity reduction are not sufficient or applicable, customer-neutral orders have to be planned to balance difficult-to-forecast market demands. This is especially true for capital-intensive enterprises, which are forced to ensure an almost steady, uniform utilization of cost-intensive capacities to achieve the desired economy of scale. Since the achievable profit is contingent not only on the economy of scale but also on the sales and marketing costs of the customer-neutral products to be planned, it is insufficient to carry out the planning only with respect to capacity considerations: instead, there is a need to integrate further planning perspectives. As appropriate tools for market-oriented planning of customer-neutral orders simply do not exist, an adequate methodology is needed to sufficiently support the sales planner in making a well-balanced decision in terms of improving the quality of decisions.

This thesis proposes a planning methodology for customer-neutral orders in manufacturing companies with a huge product portfolio diversity. This methodology serves as a building block to realize efficient order processing. The thesis is divided into three parts:

- Framework.
- Conception.
- Application.

In the first part, the order processing environment of manufacturing companies is elaborated and important aspects of planning and control of order processing are analyzed. Also, manufacturing, a classification of manufacturing companies, competitive strategies, and the order processing chain are sketched. The impact of complexity and variety on order processing is described with a special focus on the challenging need to manage the conflict between external and internal product variety. The currently prevailing concepts of product design and sales-specific methods for variety management are outlined. Furthermore, an overview of different levels of product documentation is given; the aims of product structuring and the methods for describing complex products are discussed. The section concludes with an introduction to product configuration which encompasses remarks on the relation between product structuring and the need for product configuration, configurable products, and configuration tools. The first part of the thesis is completed with a literature review on planning and control of order processing. The influence of humans on planning and control is outlined and terms from the field of production planning and control (PPC) are explained. Finally, relevant facets of program planning - a core task of PPC - conclude the framework of the thesis.

The second part presents the rough concept as well as the detail design of the planning methodology for customer-neutral orders. First, the need for customer-neutral order planning is described with respect to both different principles to organize order processing in manufacturing companies and distinctive market situations. In addition, the function of stock orders as a balancing instrument of fluctuating market demands to ensure a practically steady, uniform utilization of capital-intensive capacities and to increase the economy of scale is depicted. Subsequently, the requirements placed on the market-oriented planning methodology for customer-neutral orders are refined. The planning methodology is based on a special kind of product and process documentation: the product documentation with connection information. For this reason, this information backbone is elaborated with special focus on the integration of planning parameters and order-specific requirements planning, which is an important element of the planning methodology. The planning of customer-neutral orders necessitates a well-balanced support for decision-making. Hence, the integration of quantitative and qualitative planning perspectives is the challenge this thesis deals with. Especially the calculation of the number of producible orders of different product configurations, the computation of achievable contribution margins, and the calculation of the expected marketability of customer-neutral orders are described in detail. Thus, the second part of the thesis brings together the individual planning aspects.

The third parts sets out the implementation and application of the software demonstrator developed, finally drawing concluding remarks on the research work presented in this thesis. A use case diagram is developed and the use cases of this diagram are expanded to describe the functions that have been prototypically implemented. The application of the planning methodology for customer-neutral orders is illustrated by means of an exemplary scenario. Furthermore, experiences gained in the application of the demonstrator are presented and the necessary extent of process reengineering, which is a consequence of a planning system for customer-neutral orders in any real order processing environment, is depicted. The third part of the thesis ends with some concluding remarks on the planning methodology of customer-neutral orders and with a look at future research work.

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Chapter 1

Motivation

1.1 Introduction

During the last decade there has been a significant structural change in economics, policy, society, and in the worldwide distributed markets. Examples are the application of new information and communication technologies, the globalization of markets and industrial companies, and the increasing demand for individualized products. What this means for the manufacturing companies is that they must more and more align their process flows and performance with the requirements of different cultural regions and marketing areas and thus regard the customers as the pivotal driving force for order processing. From this perspective, the fulfillment of heterogeneous customer demands and the offering of products with a high level of functionality and quality within short delivery times have become core success factors in industry: yet they alone are not sufficient. The role of an efficient order processing chain as a crucial factor to achieve a fair profit has grown. Order processing is of the utmost importance, since there are many direct interfaces to the customers and it is in this process chain that the company performance in terms of products and services is generated (Baumgarten and Walter, 2000). Manufacturing companies can no longer regard themselves as limited entities, isolated from the outside world. Quite to the contrary, companies have to understand themselves as extremely complex, open, social systems connected by manifold relations with their environments (Lohse, 2001; Zäpfel, 2000). In summary, the networking of a large number of organizational units involved in the order workflow and the offering of a diversified product portfolio in combination with the early involvement of customers in the order processing chain increase the variety and complexity which have to be managed in manufacturing companies (Baumgarten et al., 2004).

The growing complexity in manufacturing companies in combination with the dynamics of the world markets leads to the time paradox, as illustrated in figure 1.1. With increasing complexity the reaction time required to adjust to changed basic conditions or market situations rises. In contrast to this stands the growing dynamic in the markets, which is reflected in the quickly-changing variability and ambiguity of the customer's demands, so that too little time is available to react to the changes called for due to the prevailing complexity.

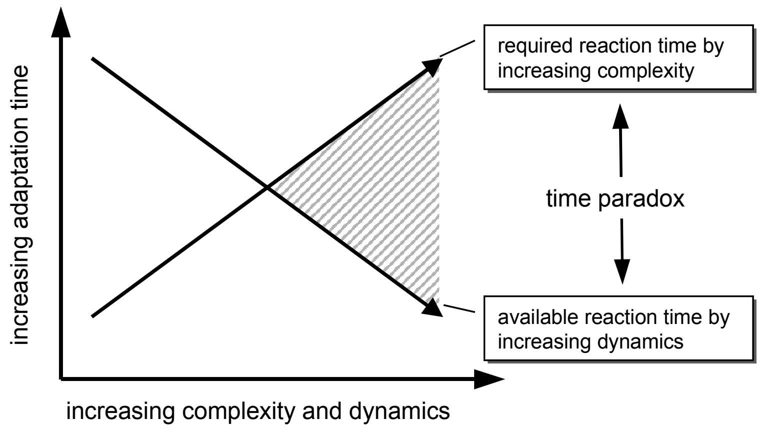


Figure 1.1: Time Paradox (Bleicher, 1995).

The significance for capital-intensive manufacturing companies such as European automobile producers is that the production capacities implemented cannot be adapted permanently to the often unforeseeable fluctuations of the market demand to the required extent in the time available. As a consequence, if unexpected slacks in demand occur, a steady utilization of cost-intensive capacities at a high level cannot be achieved. Yet this is a key prerequisite to achieve the desired economy of scale and to enable an efficient order processing. To balance unforeseen fluctuations in market demand, planning of customer-neutral orders, also called stock orders, is an important instrument in capital-intensive companies.

It is self-evident that decisions made during order planning gravely impact the productivity of the order processing chain. Traditionally, stock orders were planned on the basis of subjective estimations, and decisions were thus not well-balanced. However, the way sales planners make order planning decisions has to be supported and controlled, otherwise this will lead to costly mistakes in order processing.

1.2 Objective and Scope

Program planning is paramount in order processing to achieve the long-term aims of a company. However, keeping these goals has become more and more difficult. The dynamics in the markets together with the highly diversified product portfolios hamper the making of reliable sales forecasts. In addition, the manifold company-internal and -external relations as well as the different product strategies and marketing measures of the competitors hinder the making of high-quality plans in mid- and long-term program planning. Hence there is a need for an adequate methodology and IT tool in short-term program planning: a tool which can support the sales planner in balancing unforeseen fluctuations in market demand and in reaching the aims of order processing. Presently, however, sales planners in capital-intensive companies are insufficiently supported due to the lack of such a methodology and IT tool. Taking into account the great influence of program planning and order processing on the companies' profits, this is an entirely unsatisfactory situation.

This thesis reports on the planning of customer-neutral orders in manufacturing companies to overcome the drawbacks of insufficient support of the sales planner. As the name customer-neutral denotes, these orders have to be planned without the later end consumer being known. As a rule, if customer-neutral orders do not meet the current customer demands, they are typically difficult to market and may lead to a cost increase in order processing. Thus, in the approach described in this thesis, stock orders are only planned if not enough customer orders are available to utilize the part and manufacturing capacities which cannot be adapted to the decline in customer demand to the required extent at short notice. Three sub-objectives are derived from the topic:

- Identification of part and manufacturing capacities which are to be balanced through the planning of customer-neutral orders.
- Calculation of configuration-specific variable costs and contribution margins.
- Estimation of the market attractiveness in terms of the marketability of the planned customer-neutral orders.

The focus is placed primarily on the integration of different planning perspectives in terms of the competitive dimensions ‘time’, ‘cost’, and ‘quality’ to support a well-balanced decision-making process for the sales planner (figure 1.2). In the developed planning methodology, the ‘time’ aspect refers to the identification of the available capacities which are to be utilized in the planning period at the highest possible level. Thus, these capacities determine the number of producible stock orders with respect to the underlying planning dates in the order processing chain. The second competitive dimension ‘costs’ considers the calculation of variable costs of the different order configurations and aims at assuring a contribution margin-optimized production program. The estimation of the market attractiveness is related to the competitive dimension ‘quality’ in terms of the immaterial value of the planned customer-neutral orders. This qualitative aspect takes into account that the marketability of stock orders is a crucial factor for the profitability of the production program. However, not all competitive dimensions can usually be equally considered in the decision-making process in parallel. This is well-known as the dilemma of achievement of aims (Vahrenkamp et al., 2004; Gutenberg, 1994). In order planning, the results of the different planning perspectives may differ. In the end, the decision as to which customer-neutral orders have to be planned is generally determined in line with the corporate strategy and with the related long- and mid-term aims. However, the awareness of the consequences of a decision taken by the sales planner is a key prerequisite for a well-balanced planning of customer-neutral orders, thus necessitating the integration of different planning perspectives.

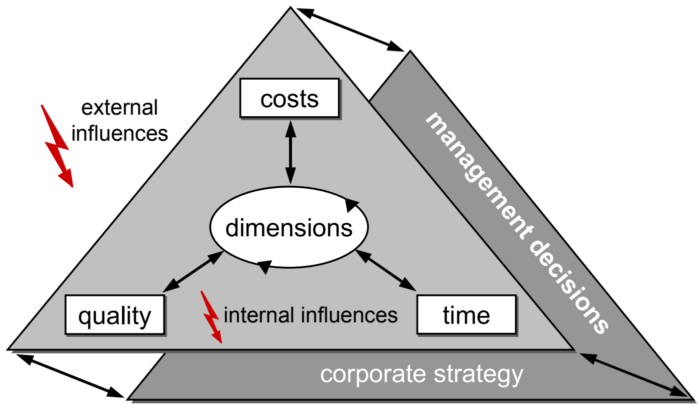


Figure 1.2: Dimensions of Competition.

The planning methodology is based on the product documentation with connection information in order to cope with the enormous product variety and complexity in manufacturing companies. This kind of product and process documentation serves as the information backbone.

Three major benefits are expected from the planning methodology:

- Balancing of fluctuating or difficult-to-forecast market demands.
- Support of well-balanced decision-making in order planning.
- Contribution to a cost-minimized order processing chain.

Since a concept or a methodology is only applicable inside the model space it is designed for (Stachowiak, 1973), the following paragraphs further define what lies within and outside the scope of the thesis.

There are three main premises:

- The cross-brand product documentation with connection information is available.
- The part and manufacturing capacities are given.
- The sales prices and cost information are known.

The research reported in this thesis has been performed in the framework of order planning and processing at a major European automobile manufacturer. The intention for this investigation is to develop a solution for a real, existing research gap, whose realization can lead to a lasting competitive advantage in an important industrial sector. Thus, the examples applied to explain the planning methodology are largely from the automobile sector. However, this is not done because the approach is confined to this industrial sector, but instead because this area offers a sound overview of the requirements and challenges in customer-oriented manufacturing companies with a huge product portfolio diversity.

The research will not deal with situations where there is incorrect, invalid or incomplete product and process documentation: instead, the cross-brand product documentation with connection information is assumed to be complete and up-to-date. Of course, relevant aspects are elaborated. The planning methodology will be evaluated on the basis of an abridged but true part of the product documentation with connection information, which is exemplarily implemented in the software demonstrator as information backbone. The determination of the part and manufacturing capacities in the long- and mid-term program planning which are available for the order planning is neglected. In addition, sales prices of products and the variable material and manufacturing costs needed to calculate the order configuration-specific contribution margins are presupposed to be given from the experts responsible for product calculation, cost accounting, and controlling in a manufacturing company. Downstream processes of short-term program planning such as order scheduling and shop floor line balancing are not part of this thesis.

1.3 Research Conception

According to Hill (1995), this thesis addresses a research work of applied sciences. Thus, in the focus of interest lie the description, explanation, and modeling of empirically discernable sections of the real world, the model space. In this context, this work is a building block to optimize order planning in the order processing chain of customer-oriented manufacturing companies with a wide product portfolio.

This thesis is composed of three parts: framework, conception, and application (figure 1.3). In the first part, problems in the practice of order processing in manufacturing companies with a high degree of customer-orientation are elaborated and classified using an (empirical) analysis of literature and practice (step 1). On this basis, problem-relevant theories of the empirical basic sciences are analyzed and evaluated (step 2). Here, the state of the art in the fields of order processing, product documentation and configuration, and production planning and control is outlined. By deriving requirements for the concept to be developed based on the previously carried out studies and the evaluated knowledge, the application context can be established (step 3). Industrial projects at a major automobile manufacturer in which the author was involved intensify the application-oriented practical value once more.

Subsequently, the designing rules and models for the considered application context are developed in the second part, the ‘conception’ (step 4). The development of the planning methodology for customer-neutral orders is based both on literature as well as on practical analysis concerning the current problems and desired working methods of experts responsible for order processing and order planning.

In the third part of the thesis, the generated methodology is elaborated in the application context (step 5). The prototypical implementation of the developed algorithms and graphical user interfaces is set out using an exemplary scenario of a major automobile manufacturer. Finally, a recommendation for industrial application is provided, together with a summary of the results of the thesis and a description of future research work (step 6).

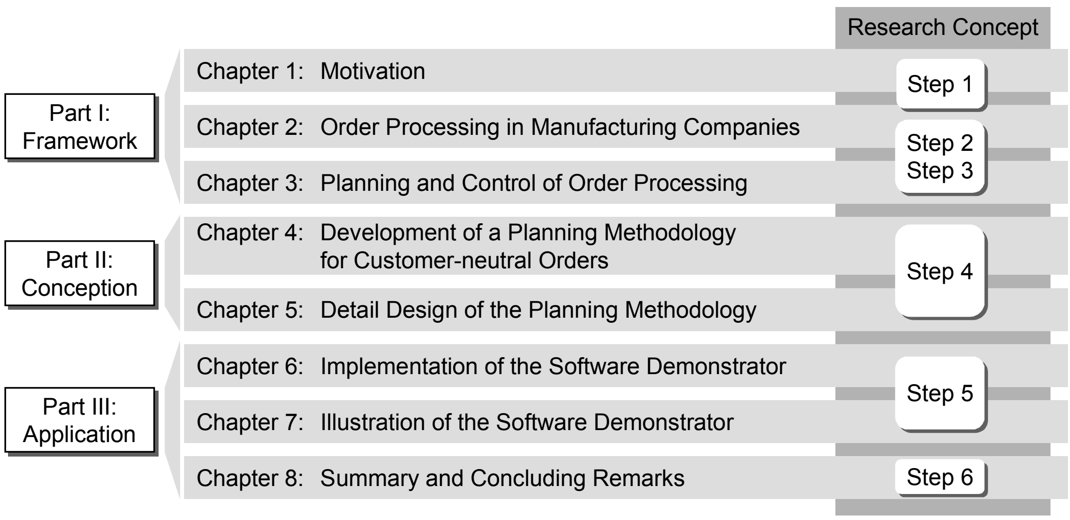


Figure 1.3: Research Conception and Outline of the Thesis.

Chapter 2

Order Processing in Manufacturing Companies

2.1 Manufacturing

Manufacturing is the backbone of any industrialized country due to its important influence on its economy and on the standard of living of the population (Kalpakjiian, 2001). Historically the word manufacturing is derived from the Latin *manu factus*, meaning made by hand. In the modern sense, manufacturing can be defined as a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management, and marketing of the products of manufacturing industries (Chisholm, 1990).

The main task of manufacturing is to make products from raw materials using various processes, machinery, and operations, with a well-organized plan for each activity required. Products can either be discrete products, meaning individual parts (e.g. gears, engine block) or continuous products (e.g. chemicals, sheets of metal or plastic), or they can be services (e.g. maintenance). The term product originates from the Latin *productum*, meaning something is manufactured. Each manufactured product has undergone a number of processes in which pieces of raw materials have been turned into a useful product, and it is then given a value: this is defined as the product's monetary worth or marketable price (Westkämper and Warnecke, 2001). Thus manufacturing has the important function of adding value in a transformation process (figure 2.1).

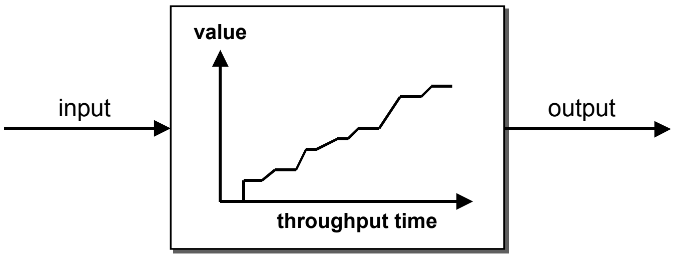


Figure 2.1: Transformation Process.

In the above, manufacturing is described as the process leading to the creation of products. In any manufacturing industry such as mechanical engineering, car manufacturing, or aircraft construction, this process is embedded in an organization, the so-called manufacturing system. In the mechanical and electrical engineering industries, a manufacturing system manifests an integrated group of functions. Thus, a manufacturing system is a collection of manufacturing functions that is intended to operate and be controlled as a whole. In this context, Porter (2004a) differentiates between primary functions and supporting functions. Primary functions include sales, design, production, and delivery, for example. Supporting functions (e.g. human resources management, procurement, administration, and research functions) provide a service to the primary functions of the manufacturing system.

2.1.1 Manufacturing Companies and Their Environments

A manufacturing company is a legal (commercial) organization that encompasses one or more manufacturing systems. A manufacturing company may consist of several (independent) manufacturing companies. This is also the case if different companies work together on a temporary basis, sharing responsibilities and coordination (Wijnker, 2003). Manufacturing companies differentiate three core processes in their operations: product creation, order processing, and enterprise management (Layer, 2003). The product creation process covers the entirety of operations from the initial conceptual idea to the completion of the product; order processing deals with the area from the very first product idea to delivery and after-sales services. Enterprise management is concerned with strategic and operational orientation, enterprise organization, and workflow optimization.

The environment in which a manufacturing company acts, comprising customers, partners, subcontractors, institutes, etc., is referred to as the enterprise environment. These environments provide both the opportunities and constraints for an industrial company. Developments in enterprise environments affect the realization and the operation of the manufacturing systems. Some key trends and demands in such environments are summarized in figure 2.2. A company is influenced by its environment in terms of unpredictable events, but does not have a direct influence on (control of) this environment.

REFA defines an event as '... the occurrence of a defined state' (REFA, 1991). A trigger of a change in state can be deliberately and consciously caused and is thus a planned event. Also the trigger for the change in status may be non deliberate. This is then an unplanned event (Heiderich, 2001). Causes and effects can be assigned to an (unplanned) event (Heil, 1995). Effects occur for systems: some of them are negligible and others require intervention. As a result of unplanned or unpredictable events, original plans, e.g. sales plans, are often no longer realizable, leading to a commensurate drop in planning stability. Unpredictable events, for instance, are a slack in demand, a request for changes to an order in terms of the product configuration or the occurrence of a capacity bottleneck on the part of a supplier. Khandwalla (1977) characterizes a turbulent enterprise environment with the terms dynamics, unpredictability, expansion, and fluctuations. In a multifaceted environment where trends and demands change increasingly rapidly, a manufacturing company is a complex system whose fundamental task is to deal successfully with complex interdependencies of the environment (Schuh and Schwenk, 2001).

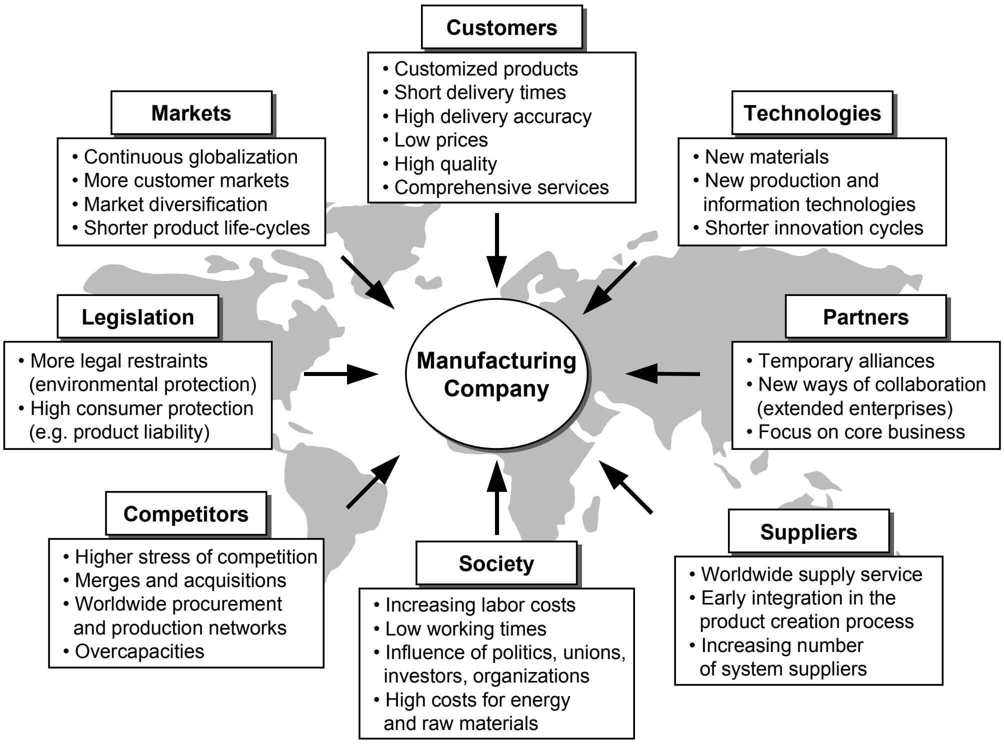


Figure 2.2: Trends and Demands in Enterprise Environments.

2.1.2 Classification of Manufacturing Companies

For the manufacturing company as a whole, its strategy should be predicated on matching its distinctive competence with its primary tasks (Chase and Aquilano, 1992). This reaction to competitive conditions is realized through a set of plans and policies by which the company aims to gain advantages over its competitors (Lutters, 2001). In literature, manufacturing companies are classified according to various criteria and from different perspectives.

One of the foremost constraints on applicable strategies is the type of manufacturing performed by the company. This describes the frequency at which the performance is repeated in the manufacturing process (Much and Nicolai, 1995). Manufacturing, i.e. manufacturing of parts and assemblies, can be differentiated according to the following basically types of manufacturing (Woodward et al., 1980; Corsten and Reiß, 1999):

- Batch production.
- Series production.
- Mass production.

Batch production concerns the unique production of individual products, which is only repeated at a later, non-defined time. Universally applicable machines and facilities are typically employed as manufacturing equipment. In series production, a product is successively manufactured several times. For reasons of economy, a series is divided into economically efficient lot sizes. Depending upon the number of items at hand, small, medium, and large-scale production are differentiated. Mass production is an almost continuous manufacturing of the same or very similar products or parts during a longer period with a fixed and as far as possible automated, standardized workflow.

The applied manufacturing type of a company is closely associated with its competitive strategy: for instance, a pervasive standardization of products and processes is predominantly realizable in connection with mass production, whereas batch production is most notably if customers ask for individualized products (Holthöfer and Szilágyi, 2001).

2.1.3 Competitive Strategies of Manufacturing Companies

Individualization and standardization represent two extreme forms for organizing the value adding chain to gain and ensure a competitive edge (Meffert, 2000; Mayer, 1993). The choice of a competitive strategy meshes with the strategic enterprise decision as to the extent to which individual customer needs are to be met (Porter, 2004b; Schneeweiß, 2002). Many companies have seen almost unlimited possibilities in individualization. However, for a long time industrial enterprises were unable to find adequate solutions that would combine mass production with individualization in order to exploit the advantages of both strategies (Jorgensen, 2001). Either the enterprises decided in favor of low costs and thus for standardization or for a high level of individualization and more complex workflows (Womack et al., 1992).

As a consequence, a hybrid competitive strategy, called mass customization, has emerged. The aim of mass customization is to reap the benefits from both single unit production and mass production with respect to customization and production volume (Piller, 1998; Davis, 1997; Pine, 1994). This means aspiring not only to increase stability and control of the processes but also to meet customer-specific desires at the same time (Schuh and Schwenk, 2001). The primary task of mass customization is to identify the individual wishes and needs of customers and to fulfill them in the best way possible. Subsequently, mass customization is a competitive strategy which aims at the highest possible individualization of products and services. This is independent of whether the products are manufactured singly or in modules or if they only represent a later variation of a standard product (Pine, 1994). Thus each product differs from the others while exactly corresponding to the needs of a customer (Piller, 1998). As a result of such close customer orientation, the product variety in manufacturing companies has soared. Faltings and Freuder (1998) in turn argue that the need for product configuration concepts emerges as a consequence of the diversified product portfolios (see chapter 2.5.1).

In the newer literature on business management, mass customization is often differentiated from variant production. Many authors state that the central criterion for distinction is the degree of individualization of the products and that this degree is noticeably higher in mass customization than in variant production. For example, Holthöfer and Szilági (2001) as well as Gilmore and Pine (1997) are of the opinion that variant production is making a selection from an existing product assortment and/or components, thus in most cases only roughly corresponding to customer needs. Hence, the authors state that under no circumstances can variant production be equated with mass customization. In contrast, Maroni (2001) comes to the conclusion that, with this comparison, two fundamentally different aspects are mixed up: a type of production (variant production) and a competitive strategy (mass customization). Furthermore, Maroni argues that no concrete connection between variant production and the degree of individualization of the products exists. Applying the above-mentioned definitions, mass customization is always equivalent to variant production when applied to a limited product range.

2.2 Order Processing

2.2.1 The Order Processing Chain

Order processing is one of the three core processes in manufacturing companies. In the order processing of a manufacturing company - independent of the degree of customer-orientation and the time when the customer is involved in the company processes - an order is the main guideline. According to Schönsleben (2004), an order is a business object which can be determined by at least two business partners and a date. In addition, an order describes a number of order positions which refer to the actual product, its items or the work to be done. An order undergoes different life phases (order life-cycle), from planning over the acknowledgement of order contents to execution (production) and invoicing.

Orders are typically categorized as either customer specific or customer neutral (figure 2.3). The customer-specific order, also called customer order, is based on a concrete market demand, i.e. an end consumer is known (Wöhe, 2002). In contrast, the customer-neutral order is a company-internal order between the Sales and Manufacturing Departments (Heuser, 1996). These so-called stock orders are often based on market research and sales forecasts without the later end consumer being known (Schönsleben, 2004). The activities of each organizational unit responsible for order execution should be aligned with the orders, taking the business aims into account (Lohse, 2001).

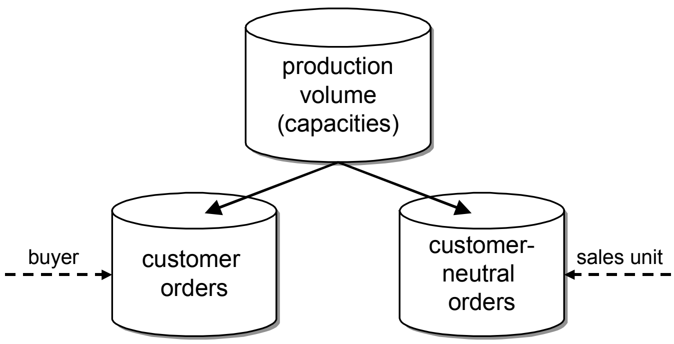


Figure 2.3: Differentiation of Orders.

In general, order processing involves offer management and order management (Much and Nicolai, 1995). From this perspective, order processing encompasses all the organizational units of a manufacturing system which are directly concerned with the value adding process or administrative functions. After a customer inquiry has been received, an offer is worked out and submitted by the Sales Department. Following the receipt of order and order acknowledgment (which may require clarification of technical details), the product is manufactured as per customer requirements and subsequently delivered to the customer.

Baumgarten and Walter (2000) describe order processing as a core function of logistics which represents the actual value adding process in a manufacturing company. Thus, realization of the general company aims such as growth, profitability, flexibility, and quality depends to a large extent on efficient company-internal order processing and logistics management along the entire supply chain (Pfohl, 2004). Primary aims of order processing are the reduction of throughput times and high delivery accuracy, i.e. to keep the promised delivery dates of each order. Moreover, a steady and uniform utilization of capital-intensive manufacturing resources at a high level is a key objective as well as the minimization of inventory for parts, modules, and semi-finished and finished products.

Order processing can be split up into a commercial and a technical part (Eversheim, 1996). The commercial part of order processing comprises product cost calculation, purchasing, and finance. In contrast, technical order processing involves business units and departments which are directly responsible for the order workflow and the manufacturing of the ordered products. This definition addresses various business units: Product Creation, Production Planning, Logistics, Manufacturing, Sales, and Dispatch (Lohse, 2001; Tränckner, 1990). Due to existing process-related interdependencies between the departments, it has become crucial that experts make their decisions under consideration of the particular parameters and constraints of the other organizational units involved in any sub-processes of the processing chain (figure 2.4).

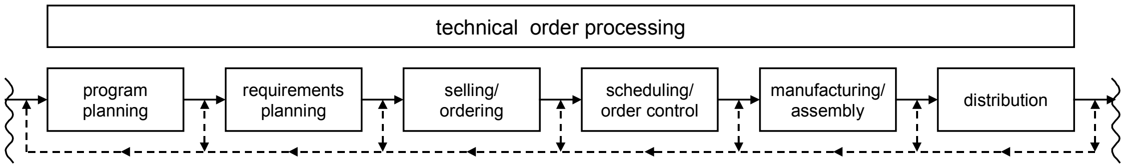


Figure 2.4: Technical Order Processing.

In this thesis the term technical order processing is defined more generally: order processing is the series of all interrelated activities and operations conjointly and directly aimed at planning, execution, and control of orders to fulfill customer requirements and to achieve a fair profit. Therefore companies have to meet the challenge to organize all the activities and processes in the order processing chain as efficiently as possible. However, to maintain competitiveness in a keen enterprise environment, it is not sufficient to focus solely on economical order processing also the competitive dimensions time and quality must be considered. This is because high delivery accuracy and high product quality have become more and more important customer requirements. Hence, successful order processing is characterized by the agreement of the dimensions ‘costs’, ‘time’, and ‘quality’ in all planning, coordinating, and executing activities.

2.2.2 Classification of Order Processing

The extent of customer orientation is an often used criterion for the classification of order processing in manufacturing companies. The market or customer influence is taken into account by analyzing the finished goods inventory policy of a company and the processes as contingent on a customer order. Employing this criterion for classification yields homogeneous and inhomogeneous types of order processing (Bloch and Ihde, 1997).

Homogeneous types of order processing have either pure customer-neutral or pure customer-specific manufacturing processes. Make-to-stock (MTS) is an example for a purely customer-neutral type of order processing. MTS is based on well-known and predictable market demand. A finished goods inventory acts as a buffer against uncertain demands and stock outs. The latter, pure customer-specific processes, are a typical characteristic of single item and small scale productions. In this context, engineer-to-order (ETO) has to be mentioned. ETO describes an order processing strategy with the engineering design of the product and the production itself based on customer requirements and specifications. The necessary intensive communication with the customer starts in an early phase of the product creation process and lasts until the technical and commercial order processing are finished.

In contrast to this, inhomogeneous types of order processing consist of both customer-neutral processes and customer-specific activities. The transition between these processes is determined through the decoupling point, which is also called the order penetration point. The decoupling point characterizes the entry of a customer order and its assignment to a product. From this moment on, all activities are directly related to this customer order (Corsten and Gössinger, 2001). As such, the decoupling point indicates the extent to which a customer order affects order processing. In this context, make-to-order (MTO) and assemble-to-order (ATO) may be mentioned. In both inhomogeneous types, it is in particular manufacturing of the product and all downstream processes in the order processing chain which depend - at least partly - on receipt of a customer order. MTO means that the order decoupling point is situated before any manufacturing activity starts. In contrast, assemble-to-order is typically subdivided into a customer-neutral product creation, manufacturing, and pre-assembly on the one hand and into a customer-specific final assembly and dispatch on the other hand. Therefore the order decoupling point, as the name assemble-to-order states, may be situated between manufacturing and assembly. Hence, many of the base components are standardized and manufactured customer-neutrally, while the manufacturing of the product as a whole is finished as per the specifications of the customer order. The types of order processing are described in detail in, among others, Schönsleben (2004), Mesihovic and Malmqvist (2000), McMahon and Browne (1998), and Melo (1996). In most manufacturing companies, many (changing) combinations of production situations - from MTS to ETO - occur. Figure 2.5 depicts an overview of the classification schema of order processing types.

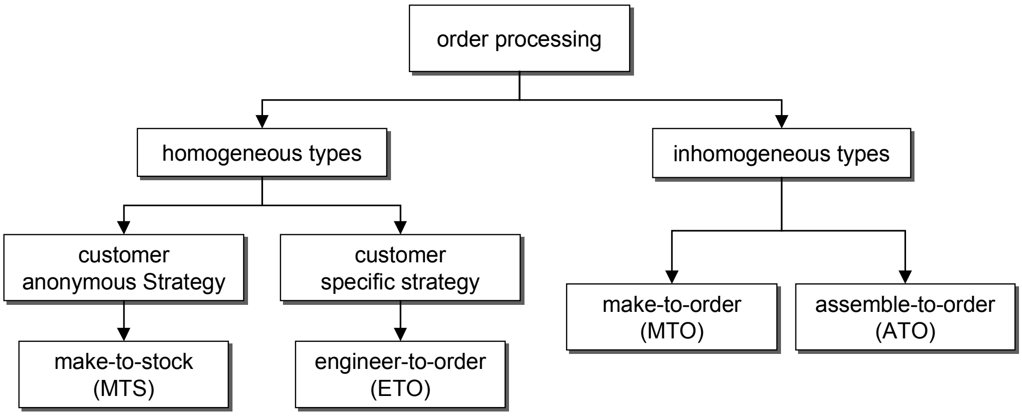


Figure 2.5: Order Processing Types.

2.3 Complexity and Variety in Order Processing

During the last decade, a change from a seller's market to a buyer's market has taken place in many industrial sectors. This switchover was accompanied by an increased customer orientation, which requires modified types of order processing (e.g. ATO) to, on the one hand fulfill the customer requirements and on the other hand to assure efficient company-internal processes. The growing customer influence leads to a commensurate increase in complexity and variety and affects the whole order processing chain. The following paragraphs provide some information on complexity and variety in general and also on the consequences of variability on assembly logistics in customer-oriented manufacturing systems such as assemble-to-order and make-to-order companies.

Complexity is an ambiguous and frequently applied term used in many different contexts. From the Latin *complexus* (together-knotted, interwoven, networked), the term denotes a whole that is closed in itself and whose parts are multifariously linked. Gerhard (1997) describes the measurement of complexity with the help of the characteristics of a number of elements and the cross-linking degrees of these elements. Wildemann (2000) and Adam and Freudenberg (1998) agree: they define complexity as a large number of different elements (variety) with a high degree of cross-linking (connectivity), all of which affect each other mutually and whose number and connections change almost unpredictably. A similar view is held by Schuh and Schwenk (2001), who describe complexity as a system in which not all of the elements can be allocated to each other and because of that shows indeterminable and unpredictable behavior. Figure 2.6 depicts the generally accepted characteristics of complexity.

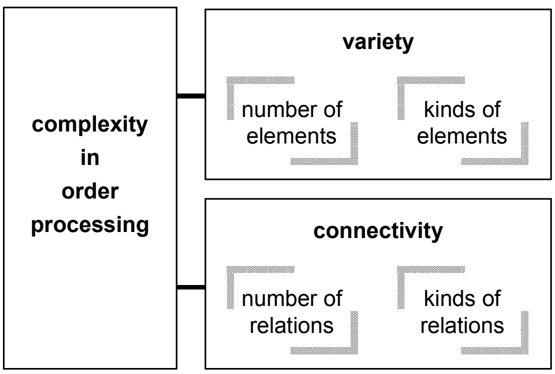


Figure 2.6: Characteristics of Complexity.

Complexity of products, processes, and subsystems is a substantial characteristic of customer-oriented order processing and variant production. Complexity arises in enterprises as a result of the combination of different objects with one another, whether these be different processes, characteristics, persons or other objects (Maucher, 2001; Franke and Firchau, 2001). Additional, unnecessary complexity originates when circumstances are not given clearly defined bounds or definitions are fuzzy due to the usage in different contexts, e.g. if Purchasing, Design and Sales apply different designations and classifications for what are basically the same objects and/or circumstances. Moreover, the rising requirements of the market and its customers accompanying the ongoing globalization and dynamics are considered as complexity drivers. On the one hand, this causes changes and fluctuations in demand and in the overall order processing chain. On the other hand, not only structural, informational, and communicative factors but also individual, company-internal factors lead to a significant increase of product, process, and production system complexity (Wildemann, 2004a). In this context, Schuh and Schwenk (2001) regard industrial companies as complex systems, which are under decision pressure and see the actual task of the management in handling this complexity. Steinbuch (2001) even describes manufacturing companies as extremely complex systems.

In the context of a technical system such as order processing in manufacturing companies, a variant can in general be defined as follows: a variant of a technical system is a different technical system with the same purpose, which differentiates in at least one relation or element (Franke et al., 2002). To carry this further, a relation or element differs from another in at least one characteristic. With reference to the terminology of the statistics, variance of a product, process or resource can be interpreted as a minor deviation from a standard (Bartuschat, 1995).

The fact that many industrial companies are trying to meet these market and customer demands with a nearly unlimited, uncontrolled variety of products and process has to be mentioned as a substantial cause for product- and process-related complexity, which often negatively impacts revenues (Wildemann, 2000). Products with many variants directly imply increasing complexity in the entirety of organizational structures and processes. This is because a wide variety of product alternatives, assemblies, parts, and documents in any permissible combinations have to be controlled and managed in the company (Franke and Firchau, 2001). Hence, variety can be regarded in companies as both a significant complexity driver and a key figure for complexity (Krumm et al., 2003).

2.3.1 Classification of Variety

Within a technical system, variants can be categorized into product, process, and resource variants (Menge, 2001). Figure 2.7 illustrates this schema for variant classification. Here, product variants can be divided into technical and structural variants. Technical product variants can differ in geometry, material, technology or service. Structural variants either can be chosen or have to be chosen, whereby the latter variants are indispensable for production, i.e. product assembly. The terms standard equipment and optional equipment, both of which are in widespread use in the automotive industry, were defined in this context, for example. Standard equipment encompasses the structural variants which have to be chosen because they are absolutely needed to build a product. In contrast, optional equipment corresponds to structural variants which can be added or, if desired, omitted according to the requirements of the customers. Schönsleben (2004) describes a product variant as a specific product of a product family.

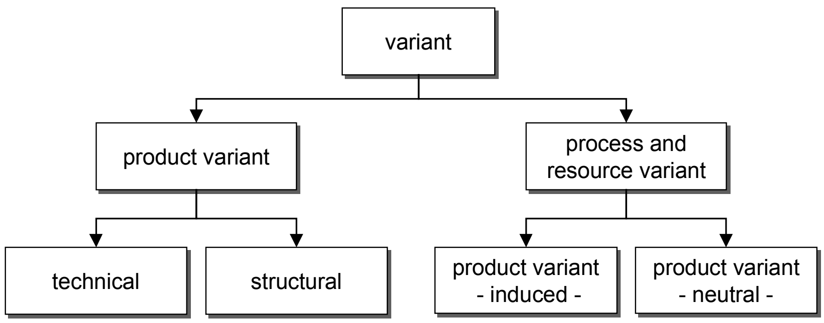


Figure 2.7: Classification of Variants.

Process variants arise as a result of the different ways enterprise resources are utilized (Franke and Firchau, 2001). Menge (2001) differentiates process and resource variants as either product variant induced or product variant neutral. Product variant-induced process variants affect the process flow through the diversity of the products. As a result, additional process steps may occur, or the purchasing procedure may change due to a modification in the number of pieces. Depending on the product variant to be realized, different resources, e.g. machines, tools and fixtures, may be needed in production. In such a case, the resource variants are product variant induced. For example, the execution of a welding process and the necessary welding gun are determined by the geometry and further characteristics of a product. In contrast, if any differences in the process flow exist, product variant-neutral process and resource variants do not permit conclusions as to the concrete product variant. An example is the reengineering of a process by manufacturing on another machine as a consequence of problems in capacity utilization.

Moreover, variety can be classed as either external or internal. External variety is the diversity of products that are available for the customers. As this must be recognizable for the customer, it affects revenues (Franke et al., 2002). In principle, external variety is useful for an industrial company, as long as it does not exceed the variety which is actually demanded by the market. If this condition is fulfilled, variety enhances the attractiveness and usefulness of a product, thus supporting a virtually optimal fulfillment of customer wishes - also of extremely heterogeneous market demands in diversified, global markets - and contributes in the long run to assuring market shares (Wüpping, 1998). Thus, high external variety has become the guiding concept of many enterprises. However this form of differentiation from competing products leads to complex product structures with a multiplicity of product and process variants which have to be documented and controlled (Wildemann, 2000). The methods to document product structures are described in chapter 2.4 (state-of-the-art).

In the context of company-internal order processing, internal variety describes the growing variety of parts, assemblies, products, and processes. Reasons for this increase in internal variety are three-fold: a lack of knowledge about (negative) effects connected with an increase of variety, historically grown product structures, and non-availability of evaluation methods (Franke and Firchau, 2001). Internal variety causes high complexity and non-transparent workflows in departments which are involved in order processing, for example, product documentation. In addition, internal variety acts as an overhead cost driver as, due to the lack of suitable evaluation methods, costs cannot be assigned properly, i.e. according to the input involved. The consequence is that standard products or product variants which are frequently asked for become too expensive, while less frequently desired variants are offered too cheaply. Thus, a kind of cross-subsidization between the various product variants occurs. Compared with competitors offering a product range in which cost-intensive and low-demand product variants are eliminated, a significant competitive disadvantage is the result (Schuh and Schwenk, 2001).

2.3.2 Effects of Variety on Order Processing

An uncontrolled expansion of differentiated product structures with a multiplicity of product and process variants causes problems not only in costing and pricing and additional effort in product development and product documentation, but also in purchasing due to smaller quantities (smaller lot sizes), hampering volume bundling, or due to newly arranged procurement processes. Furthermore, additional effort occurs in other areas: in production planning and control because of special requirements brought to bear on the organization of the process flows (e.g. increased process flexibility), in production and distribution logistics owing to difficulties in controlling the flow of information and goods, and not least in after-sales due to the need to guarantee the spare part supply for many years. It hence becomes clear that the depth and width of the product program affects nearly all the processes comprised in technical order processing and, in the long run, almost all an enterprise's departments and areas of responsibility. The effects of variety on technical order processing according to Wildemann (2000), Lohse (2001), Franke and Firchau (2001) are summarized in table 2.8.

Product Design	Procurement / Logistics	Manufacturing	Accounting	Sales / Marketing	After-Sales Service
• Effort for design of new parts. • Creation and administration of additional technical documents. • Increasing effort for change management. • Care of additional part and master data. • ...	• More difficult requirements planning. • Higher purchase prices due to smaller batch sizes. • Increased ordering procedures. • Higher inventory to keep the service level. • Additional search and selection of suppliers. • ...	• Higher set-up costs due to smaller batch sizes. • More complex manufacturing control. • Unsteadily workload and resource utilization. • Less productivity. • Additional plans, tools, fixtures, equipment. • ...	• More demanding cost accounting. • Higher capital investment in stock. • Increased effort for value analysis and invoice-checking. • ...	• Reduced transparency of product portfolio. • Heterogeneous market segments. • More difficult market forecast. • Higher error rate in order planning. • Intense need for collaboration with manufacturing. • Difficult pricing. • Manifold sales documents, e.g. price list, brochures. • Higher effort for sales training. • ...	• Higher effort for training of customer support staff. • Additional documents. • Higher risk of complaints. • Increased stockpile for spare parts. • ...

Table 2.8: Effects of Variety on the Technical Order Processing.

Because of the globalization of the markets and individualized customer demand, product variety has soared in many industries. Additionally, many automobile producers are confronted with the challenge to expand their product offering commensurately with the increasing need for individual products in order to allow for the ongoing segmentation of the markets and to be able to fulfill demand in various niche markets. The following examples indicate the extent of product variety prevailing at some automobile manufacturers.

The Volkswagen Group cites the number of possible vehicle variants as over a billion (Deiler and Derenthal, 2003). For a single car model, not only are several types of the car body (e.g. coupé, sedan, convertible) available but also numerous different equipment lines and optional equipment are placed at the customer's disposal.

Also the following example of DaimlerChrysler clarifies the trend toward mass customization and individualization in the automobile industry: in a single passenger car production plant over 400,000 cars of the S-, E-, C- and CL-class are produced annually. Apart from the orders of bulk purchasers, e.g. of car rental services, only two vehicles in a year's production are one hundred percent identical; this is equivalent to a repeat rate of 0.0005 parts per thousand or $5*10^{-6}$. This figure results from the ratio of the number of identical product variants in a defined time period that was sold to the total of product variants marketed in the same time interval. The low repeat rate is explained by the immense number of possible product variants which can amount to an astronomical number over the product range due to the range of engine types, color, interior equipment and optional accessories available. For example, production plants at BMW are also confronted with similar low repeating rates (Ottomeyer, 2002). The car manufacturers mentioned belong to variant manufacturers, yet with low lot sizes as they are typical for build-to-order companies.

2.3.3 Variety Management versus Complexity Management

For the reasons described above, measures and concepts are necessary in order to make the complexity and variety in manufacturing companies manageable, thereby ensuring efficient, high-quality order processing.

Nowadays, the term management has become a firm constituent in the enterprise environment and is in the meantime frequently used for the re-evaluation of existing concepts, methods, procedures, and solutions. Colloquially, management is equated with running a company. As a rule, management designates the leading of institutions of any kind, whereas some understand it as people responsible for leading other people in performing tasks in an organization. At the same time, the word management is used for the entirety of sub-functions: definition of objectives, planning, decision-making, and control (Wöhe, 2002).

The term complexity management is frequently employed in close relationship with and/or even wrongly synonymously for variant management. A synonymous use of the terms complexity management and variety management should be avoided (Menge, 2001), since the former concerns - according to the system theory of business management - a super-ordinate management system. Also Franke and Firchau (2001) explicitly point out that variety is only one of numerous factors for complexity in an enterprise. However, complexity management determines the variety in the company (Wildemann, 2004b). Therefore Schuh and Schwenk (2001) define complexity management as organization, control, and development of the variety of the overall range of business activities in the company. In general, the range of business activities consists of the different products, processes, and resources. Reducing complexity targets the ability to control variety in the overall value adding process in such a manner that the greatest contribution to customer benefit can be achieved while simultaneously ensuring a high profitability of the value adding chain in manufacturing companies (Wildemann, 2000).

Meanwhile, many enterprises have recognized that the often prevalent variety and complexity of products is not always necessary in order to generate the individuality desired by the customer. However to which extent variety can be reduced or even avoided - as is again and again called for and sometimes often very controversially discussed in literature - should not be part of the further remarks in this thesis. Rather, variety must be accepted as a fundamental building block of the business activities in build-to-order and assemble-to-order companies and should be made controllable by appropriate organizational measures (Eversheim et al., 1998). Hence, variety management can be regarded as a control instrument to optimize variety and to master the effects of diversified product ranges (Menge, 2001). Substantial parts of variety management are, therefore, the development, design, and structuring of products and services in an enterprise (Schuh and Schwenk, 2001).

A general objective of variety management is the minimization of internal variety while simultaneously supplying the external variety demanded by the market and customers (Franke et al., 2002). During the identification of a compromise between standardization and differentiation, both cost-benefit analyses and strategic market decisions have to be taken into consideration. The solution must be situated between a too high variety which is too expensive as it does not permit volume bundling (economy of scale) and a too small variety which hinders companies in fulfilling the individual customer requirements and thus occupying favorable market positions (Krumm, 2003). Figure 2.9 shows the balancing act between external and internal variety as part of the variety management as presented by Bartuschat (2001) and Wüpping (1998). In principle it is most lucrative when the external variety called for can be offered to the market with the lowest possible company-internal product, process, and resource variety.

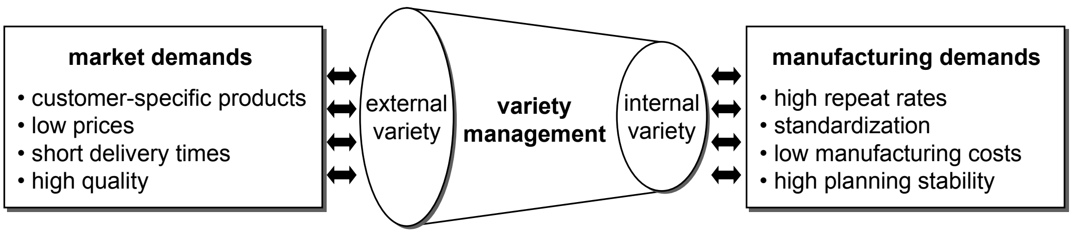


Figure 2.9: Variety Management.

2.3.4 Scope of Variety Management

From the perspective of the workflow and thus of the value adding chain, longitudinal and transverse measures of variety management can be distinguished (Franke and Firchau, 2001). Longitudinal measures pursue the goal of building variants at the end of the value adding chain as far as it is possible (e.g. positioning of decoupling points), thus minimizing the cost-intensive additional effort needed to supply resources and to control variants in the processes of the order processing chain (Wildemann, 2004b). Transverse measures, e.g. organization of product structures, aim at a grouping into classes so that different variants can be manufactured using the same processes, methods, and resources (see chapter 2.3.5).

Menge (2001) and Franke et al. (2002) assign currently taken approaches and measures to strategic or operational variety management. Strategic variety management is chiefly directed to the variant-aligned optimization of the product and production structure. Corresponding solutions refer to the avoidance of variety, the reduction of variety, the control of necessary variety (Wiendahl et al., 2004).

The results of strategic management directly affect operational management, which has the task to realize an efficient and smooth, trouble-free workflow of the variety given along the process chain. Measures for operational variety management are deployed in different areas and functions of a company, e.g. in sales, product creation, materials management, production planning, manufacturing or assembly. Examples of these measures are sales and marketing instruments designed to control market demand to a certain extent and approaches of product development for variety-optimized product design.

2.3.5 Methods for Variety Management

A great number of methods and measures are available to achieve efficient variety management. Some key concepts of product design and sales-specific instruments which are of interest for this research are subsequently outlined.

The concepts of product design pursue the aim of reducing customer-neutral product variety and thus realizing externally demanded variety efficiently through multiple reuse of parts, modules, and platforms that have been developed as customer-neutral (Wildemann, 2004b; Schuh and Schwenk, 2001; Rapp, 1999; Piller, 1998; Wüpping, 1993; Schuh, 1989). These concepts thus support the avoidance and control of variety without limiting the choice for the customer. Some main concepts of product design are set out below:

- Usage of standard parts.
- Model series.
- Unit assembly systems.
- Modularization.
- Platforms.

According to the competitive strategies described in chapter 2.1.3, modularization and the platform concept in particular should be highlighted. These approaches represent a compromise between the extreme forms of competitive strategies discussed: standardization and differentiation.

Modules and add-on parts with different functions but uniform interfaces enable a multiple compatibility of the components (Schuh, 1989). In contrast, Koller (1998) defines modules as building blocks with specific functions and interfaces, thus proceeding on the assumption of a restricted compatibility. The main advantage of modularization lies in the ability to realize a high variety of end products, thereby achieving strong customer orientation at comparably low company-internal variety. In the relevant literature, many forms of modularization are discussed: generic, quantitative, individual, and free modular design (figure 2.10). The various concepts are described in detail in, among others, Schuh and Schwenk (2001), Piller and Waringer (1999), Piller (1998), Göpfert (1998), and Pine (1994).

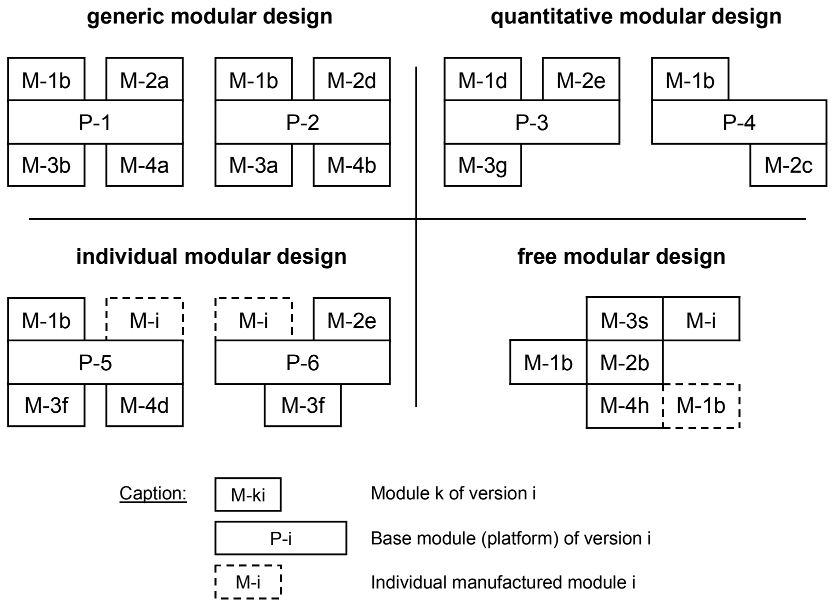


Figure 2.10: Modular Design (Piller, 1998).

Platform concepts are based on the philosophy of modularization and on the usage of standard parts but represent an evident extension of them. The idea is to use basic structures in the form of standard parts and modules over several product life-cycles and product lines. This applies to structures which are not perceptible for the customers or to those structures which have no influence on the design and character of a product. This necessitates not only that standard parts belonging to former products be identified if new products are be developed but also that these parts be preplanned for longer time frames (Rapp, 1999). This should thus effect a decoupling of the life-cycle of a product structure from the life-cycle of a product (Schuh and Schwenk, 2001). The major advantages are the realization of economy of scale which positively affect product costs, development times, and throughput times (Dudenhöffer, 2000; Wildemann, 2000). The platform concept is described in detail in Schmid and Anders (2001), Martin and Ishii (2000), Meyer and Lehnerd (1997), among others.

The automobile industry has taken on a pioneer role with regard to the application of platform concepts. Some automobile manufacturers (e.g. Volkswagen) employ a uniform platform consisting largely of the standardized floor structure, brake and steering system, drive and exhaust system, axles, and fuel system (Schmidt and Anders, 2001). On this basis, several product variants can be built up according to the different requirements of the customers: the platforms are combined with specific modules such as cockpits, seats, doors, and sunroofs. This allows a changeover from the classical sedan to a capacious and comfortable station wagon or a sporty convertible.

Apart from the instruments for product design, sales-specific measures which are of special interest in the automobile industry are at hand to avoid and reduce variety (Wildemann, 2000). The most interesting of these for the purposes of this work are set out below:

- Target group-specific equipment analysis.
- Price sensitivity studies.
- Functional indices calculations.

Target group-specific equipment analyses enable the identification of the market penetration of single equipment variants (e.g. air conditioning, diesel engine) for both the overall market and for the different market segments. Classification of the market offer into frequently- and seldom-requested product variants can be used as the starting point for a possible correction of the product range.

Price sensitivity analyses point out the relation between the customer value of a variant of an end product and the respective market coverage. The customer value refers to the maximum sales price which the customer is willing to pay for a new product variant. In concert with target group-specific equipment analysis, this allows a decision to be made as to whether a variant should be completely removed from the production program or if optional equipment should be integrated into the standard model. A further alternative is to offer the variant as a special model or equipment package. Offering equipment packages is an important method to optimize variety (Franke and Firchau, 2001). Attractive price offers are a strong incentive for the customer to buy product variants with additional performance characteristics, thereby increasing the lot sizes of single components and product configurations and thus displacing more product variants which are more cost-intensive in the production process. For quite some time now, in fact, special models have been incorporated regularly in the carmakers' product offerings. Often special models are offered as winter packages (e.g. winter tires, independent car heating, seat heating, heated mirrors, etc.), summer packages (standard tires, alloy wheels, air conditioning, tinted glass, etc.) or sport packages with sport seats, alloy wheels, sport exhaust, and sports suspension, for example.

The calculation of functional indices is a further complementary measure to elaborate the indispensability of the product variety offered to the customers. Here, the identification of products with similar functions lies in the foreground. In this context, the added value for both the customers and the manufacturing company is examined critically. The objective is to achieve a standardization of products with similar functions and avoid superfluity which is contrary to the realization of efficient variety management in the overall order processing chain.

2.3.6 Summary

The avoidance, control, and reduction of both complexity and variety are substantial challenges in customer-oriented manufacturing companies. This is because complexity and variety have immense effects on nearly every process and activity in the technical order processing.

Many approaches, measures, and tools are available for effective complexity and variety management. Yet these approaches and measures aim mainly at the definition of a strategy to cope with complexity and variety: they often take only product variety into account, not considering the variety of processes and resources prevalent in an industrial company. A crucial and indispensable success factor for efficient order processing is a trade-off between internal and external variety.

2.4 Documentation of Product Structures

Compared to former years, products in many industrial sectors have now undergone a rapid development regarding their structure, variety, and the way they are manufactured. The main reason for this is the individualization of customer requirements, while at the same time product life-cycles are reduced. The trend to increase the number of product variants in the various industrial branches not only raises the issue of structured representation and documentation of the multitude of products but also leads to additional, typically time-consuming and cost-intensive efforts to coordinate the different areas of responsibility in a company, for example between the departments of Manufacturing, Logistics, and Sales (Herlyn, 1990). One of the fundamental and indispensable prerequisites which enables efficient planning and control of the technical order processing in industrial companies is the documentation of products and of their structure. In general, the task of product documentation is to record activities concerning all the products of a company together with all the associated changes over the entire product life-cycle without any gaps, i.e. from product development, manufacturing and sales to after-sales service and recycling or disposal. Hence, if this is to be done correctly, all the information related to the products a company has developed, manufactured and sold is of relevance. This information is, in the end, also necessary for the communication between Development, Production, Bookkeeping, and Sales (Ohl, 2000).

2.4.1 Levels of Product Documentation

On the basis of the different manufacturing levels of a product, product documentation can be divided into several documentation levels. This is useful since different manufacturing functions are connected with the single manufacturing levels, i.e. product, aggregate, assembly, part, raw material, and semi-finished part. A further reason is that the quantitative and structural relations between the different manufacturing levels vary (Herlyn, 1990). In general, three documentation levels of a product can be differentiated: product level, technical level, and geometric level (figure 2.11).

Each of the documentation levels has a specific role, function, and type of task which distinguish this level from the others. At each level only a certain fragment of the product documentation is represented; that means that none of the levels documents the product as a whole. This kind of classification allows individual representation functions to be separated to some degree. Consequently, each documentation level comprises only the information which is of interest for the corresponding manufacturing level, e.g. part manufacturing or final assembly (Ohl, 2000).

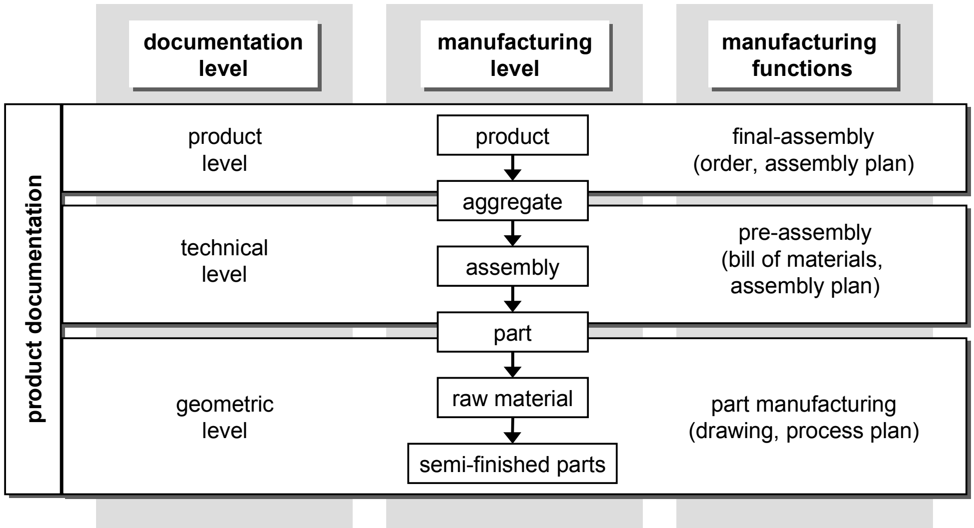


Figure 2.11: Levels of Product Documentation.

The product level represents only such information which concerns the product itself: it says nothing about the composition and structure of the product. At this level, both the product and all product variants are specified, while the product configuration and ordering by the customer takes place in the context of technical order processing (see chapter 2.5). At the product level, a description of an end product in the automobile industry which is configured by a customer may read as follows: Mercedes-Benz SL 55 AMG, roadster, design ‘AMG styling’, paint ‘metallic emerald-black’, upholstery ‘leather graphite’, and optional equipment ‘radar-assisted cruise control’, ‘sound system’, ‘luxury climate control’, ‘panoramic glass sunroof’.

The technical level of product documentation includes the actual product structure, for example in the form of a bill of materials (see chapter 2.4.4). At this level, information about the structural composition of the product is stored: the relation of the product to the assemblies and parts, on the one hand, and the structural relation of parts and assemblies to each other on the other hand. Finally, the technical level forms the connection between the product level and the geometric level.

The geometric level comprises information on the physical characteristics of a part (e.g. weight, volume, tensile strength, thermal and electrical conductivity), descriptive elements in the form of features and geometry data (e.g. shape, measures, tolerances). Due to the fact that especially the product configuration and the documentation of the product structures are of interest in this research, which aims at developing a methodology for customer-neutral order planning, the constructive-geometric level of the product documentation will not be further regarded. For additional information about the elements which describe the geometric and technological characteristics of a product, the so-called features, the application fields of features, and their benefits, see, for instance, Haasis et al. (2003), Layer (2003), Mbang et al. (2003), Katzenbach et al. (2001), Shah and Mäntylä (1995).

2.4.2 Relationship between Product Level and Technical Level

A product is specified by the characteristics which are desired by a customer. From the point of view of a customer, a product characteristic describes a functional feature of a product. However, the characteristics say nothing about the concrete technical content of a product in the form of assemblies or parts. In general the term product characteristic refers to a product type and/or product option(s). A product type bundles several products with a number of similar functional features and serves as a rough product description for a group of products. In contrast, a product option is an additional functional feature of a product which either must or may be selected by a person when configuring a product. Consequently, a product configuration, also called order configuration, consists of a product type and additional product features. To facilitate handling in manufacturing companies with huge product portfolio diversity - in the DP systems, in particular - the product characteristics are typically encoded. The documentation and encoding of the product characteristics allows a direct relation between the product level and the technical level of product documentation to be established (Ohl, 2000). That means that the specified product in terms of the primary requirements can be projected onto the technical level, thus allowing the identification of the materials, i.e. secondary requirements, needed to manufacture the product.

The encoding of the product characteristics can be implemented by means of so-called codes. A code does not describe a concrete part but instead a product function. Only with the assignment of a code to a specific product type, e.g. to a model series or to a concrete product, can the parts and assemblies required to manufacture the product be unambiguously identified.

In industrial practice, alphanumeric or numeric systematics are often employed for company-internal encoding of the product characteristics. Table 2.12 illustrates some product functions and the corresponding product characteristics with their codes, taking some examples from a price list of an automobile manufacturer. All the major automobile producers apply some kind of encoding to facilitate the handling of orders in data processing systems.

Product Function	**Product Characteristic**	**Code**
Paint, Trim, and Upholstery	• Leather-trimmed steering wheel and gearshift • ...	289 ...
Comfort	• Radar-assisted cruise control • Electric folding mirrors • Luxury climate control • Heated multi-function steering wheel • Infrared protective glass • ...	219 500 581 443 596 ...
Security and Safety	• Rear side-impact airbags • Bi-Xenon headlamps • Fire extinguisher • Tire pressure monitoring • ...	293 618 682 475 ...
Entertainment and Communications	• CD changer in center console • Sound system • ...	819 810 ...
...	• ...	...

Table 2.12: Product Functions and Encoded Product Characteristics.

Because of geometric and/or functional exclusionary conditions or interdependency relations between the product characteristics, they cannot be arbitrarily chosen and combined by the customer in an order without certain constraints. Thus, Herlyn (1990) suggests grouping product characteristics which are mutually exclusive in a single option class. Only one product option can be selected from each of the option classes when placing an order. Examples of mutually exclusive product options from the automobile industry which can be grouped to option classes without colliding with interdependency relations are the standard air conditioning system and the luxury climate control or the conventional and the sport seat.

Furthermore, not all product characteristics are of the same significance for an order and thus have to be systematized appropriately. Option classes may typically contain basic options or additional options - the so-called extras (Herlyn, 1990). From the option classes with the basic product characteristics, one variant has to be selected for each order compiled in order to obtain a fully described and saleable product. Examples for basic characteristics are the model series, car body (e.g. sedan, coupé), type of engine (e.g. diesel engine), transmission (e.g. automatic), paint job (e.g. metallic), and upholstery (e.g. leather).

Additional product options, the extras, complete the specification of the desired product to be manufactured. Extras, as they are listed in table 2.12 may be chosen by the customer additionally but without any coercive necessity, as omitting such product characteristics does not preclude specification of a manufacturable product.

2.4.3 Product Structures - Definition and Aims

As stated in chapter 2.4.1, the technical level of product documentation comprises the actual product structure. A product structure describes the structural build up of a product from its components and their set of requirements (Steinbuch, 2001). In so doing, assemblies and parts lead to structural steps in terms of classification levels by grouping the components of deeper levels in the product structure (Schönsleben, 2004). When developing a product structure, the following aims are pursued (Schuh and Schwenk, 2001):

- Structural classification of the parts of a product.
- Classification of the product creation and product development process.
- Uniform organization of drawings and bills of materials, i.e. usage of templates.
- Reuse of assemblies and single components.
- Reduction of production data and support of the information flow.
- Creation of a competitive edge by means of the appropriate choice of structuring.

In industrial practice, it is the criteria functional classification and assembly structure, in particular, that are applied to build a product structure. In this context, two fundamentally different concepts result: the functional-oriented and the assembly-oriented product structures (Grupp, 1995). These concepts are depicted in figure 2.13.

In the functional-oriented product structure, as is often used in product creation for example, materials and parts are assigned to assemblies only with respect to functional aspects. Thus, the assembly workflow and manufacturing sequence of parts is not visible. That means that this kind of product structuring is basically manufacturing and order neutral. The low classification depth leads to a large quantity of functional assemblies which, in general, contain huge and wholly different quantities of parts and materials.

In contrast, the assembly-oriented product structure groups parts to assemblies according to the physical structure. This way of product structuring results in a smaller classification width connected with an extended classification depth. This concept makes the assembly workflow of the products visible. Furthermore the assembly-oriented product structure establishes the relation between the order characteristics and the materials and parts needed in the assembly.

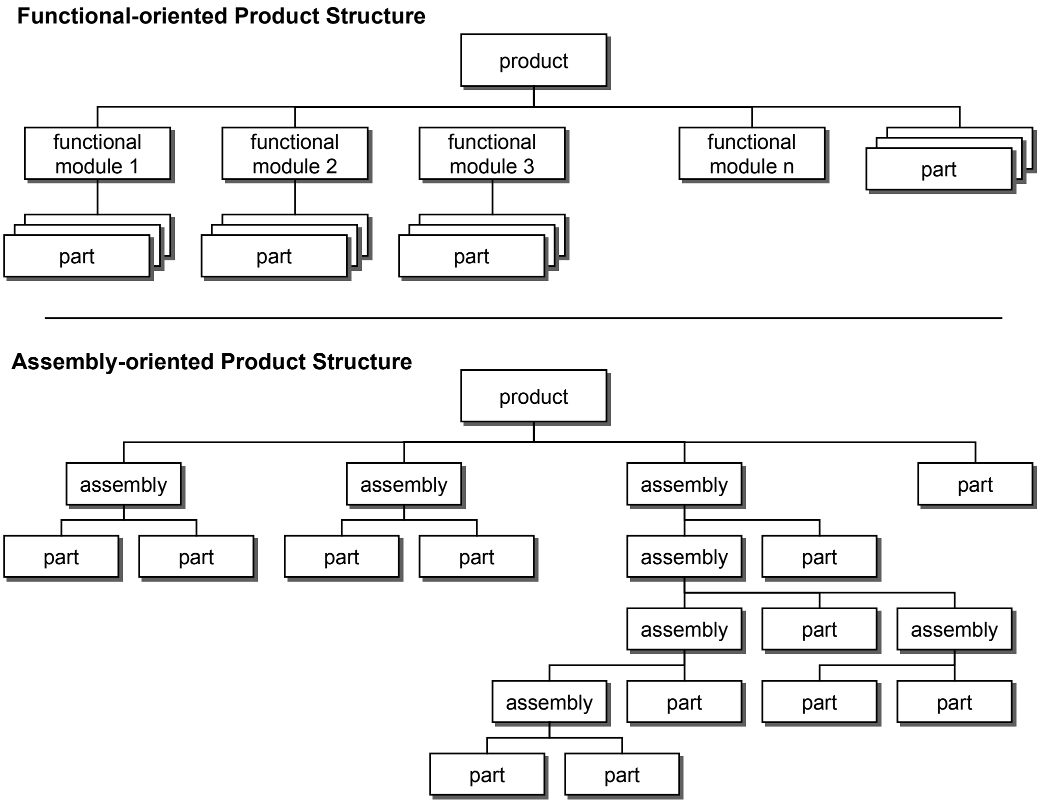


Figure 2.13: Functional-oriented Versus Assembly-oriented Product Structure.

2.4.4 Description of Product Structures

Various means can be employed to describe product structures: graphics, lists or formulas. Since formulas are rather unusual in industrial practice, this kind of product structure visualization will not be elaborated in this research.

The archetypical means to graphically illustrate product structures is the Gozinto graph (the part that 'goes into' it). The product at the highest structural level is, at the underlying structural levels, split up into assemblies and parts. Thus, the Gozinto graph represents a hierarchical kind of product structuring (figure 2.14). An arrow depicts the relationships between the components of different structural levels (e.g. parts and assemblies). Also, the exact quantity of a component integrated into the super-ordinate component can be indicated, in terms of a structural product level. For example, to produce one piece of the product, three pieces of assembly 'A1' and one piece of assembly 'A2' are required. Assembly 'A1' consists of four pieces of part 'P1' and two pieces of part 'P3'. Thus, passing the Gozinto graph from the highest level to the single parts and/or raw materials generates a bill of materials.

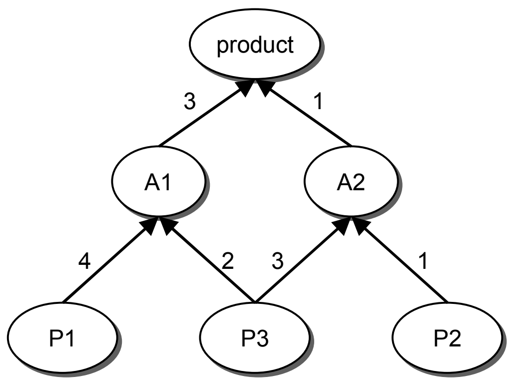


Figure 2.14: Gozinto Graph.

Various forms of bills of materials (BoM) which are of high relevance in industrial applications are based on the principle of the Gozinto graph. BoMs are a core element of the product documentation and establish the relation between the market, i.e. product functions demanded by the customers, and the product components (Ohl, 200). Bills of materials contain both the part-related and structural information of the whole product range of an industrial company.

In its simplest form the bill of materials describes how many parts, raw materials, etc. are required to manufacture one unit of the final product. For each respective purpose, a bill of materials is a complete, formally developed listing for an object which contains all the relevant elements with the specification of the description (name, part number), quantity and unit (DIN 199, 1977). Only those listings which refer to exactly one quantity unit of an object are called bill of materials.

Originally used internally within a company, the BoM served as a means of tracking product changes and maintaining an accurate list of the components required to build products. As manufacturing has become increasingly distributed, the BoM has taken on even greater importance, serving as the primary reference file for product data. Over the course of time, different forms of bill of materials have emerged (Eigner and Stelzer, 2001; Herlyn, 1990):

- Quantity structure bill of materials

  This kind of bill of materials refers to the quantitative composition of products, thus providing a quantity overview for a final product. In this description method of product structures, the constructive composition of the products remains unconsidered. Hence, this BoM is only a form of illustration, merely listing all the components of a product with their associated total quantities.

- Unit assembly bill of materials

  The unit assembly bill of materials contains all the parts and assemblies solely of the next deeper level of the product structure (DIN 199, 1977). Thus, if a product is manufactured in different manufacturing levels, subordinated assemblies are again split up into several unit assembly bill of materials. Consequently, if complex products with many manufacturing levels have to be represented, a large number of these bills of materials are required. To describe a passenger car, for example, several hundreds unit assembly BoM's are needed. Obviously, is extremely difficult to derive an overview of the end product with this kind of product description.

- Structural bill of materials

  In order to reduce the multitude of unit assembly bills of materials while still achieving a holistic illustration of the structure of a product, structural bills of materials are typically applied in industrial companies. In this form of bill of materials, the entire product structure with all assemblies and parts is dissected (DIN 199, 1977) with structural levels denoting the different classification levels which result from the hierarchical subdivision of a product into its assemblies and/or parts.

- Variant bill of materials

  Variant bills of materials are utilized to describe the structure of several products with a typically high proportion of identical parts and assemblies in a common document (DIN 199, 1977). A variant bill of materials documents not only the standard parts making up the product but also those parts which are contingent on the configuration of the end product. These types of bills of materials, however, do not contain information on the interdependencies of the parts, i.e. about parts which may not be interoperable or whose usage precludes incorporation of another element. Special forms of a variant bill of materials are the BoM for shared parts and the BoM for a basic product type (Steinbuch, 2001).

  In the BoM for shared parts, all those components are described which are identical for all variants of a product. The different components of the product variants (e.g. parts, materials, assemblies) are documented separately. A disadvantage of this kind of bill of materials is that any reference to the production is lost.

  Using the bill of materials for a basic product type, a product variant is defined as the basic product. Starting from the basic product as defined, the components added or deleted are listed and marked for each product variant (Scheer, 1997). Due to this marking of components, the BoM for basic types is also often called a plus-minus bill of materials.

Ohl (2000) classifies bills of materials with respect to their reference basis into 'open' and into 'closed' approaches. Closed approaches are characterized by separate bills of materials for each variant of an end product. This means that the number of necessary bills of materials corresponds to the number of manufacturable variants of the end product. In comparison, open approaches refer to all the theoretically possible variants of a product group, e.g. a model series, in a single BoM only. This kind of bill of material lists the entirety of possible choices which, in their multiple combinations, represent the different product variants. Such a kind of a BoM is the rule-based bill of materials for complex products, which finds general application in the automobile industry (Bracht and Holtze, 1999; Grupp, 1995). For each part a note is added, stating the prerequisites for integration of the part into the next higher structural level. These prerequisites for selection of relevant parts and part usage are represented using so-called code rules. Code rules are Boolean expressions which consist of codes and logical operations. Codes represent the encoded product characteristics of an order (see Chapter 2.4.2). If an order is placed either by a customer or by the Sales Department in the case of a customer-neutral order, the encoded product characteristics are compared with the code rules noted for each part or assembly in order to identify the components required to build the specific product (requirements planning).

In connection with open forms of the bill of materials, the process of requirements planning enables direct linking of specific order characteristics with the product description. Thus, this systematic is a key building block for customer-neutral order planning as targeted in this research. The universally valid order-part relation is shown in figure 2.15.

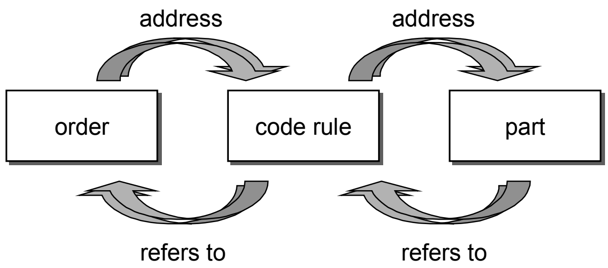


Figure 2.15: Order-Part Relation.

Usage lists represent a further form of a list employed to describe product structures. Usage lists point out the assemblies and/or final products a component, e.g. a part, is included in. Compared to the bill of materials, which refers to a specific product, usage lists consider the complete range of products in an industrial company (Steinbuch, 2001). A benefit of usage lists is that allow identification of all the impacts of a capacity bottleneck in the supply chain on technical order processing. Furthermore, the increased total material costs for the product portfolio which results from a rise in prices can be calculated. Also, when considering a specific order volume over a defined time period, the requirements of a part or assembly can be identified. Usage lists are hence a sensible supplement to the bill of materials.

2.4.5 Application Fields of Product Structures

Product structures are needed for various purposes and are, for example, applied for the execution of assembly activities, product calculation and spare part supply,. In combination with drawings, CAD data, and customized orders, bill of materials and usage lists serve as instruments for communication between Product Creation, Production Planning, Manufacturing, Assembly, Quality Assurance, Marketing, and Sales. As the documented information is utilized in a company in almost every field of order processing and is processed in very different data systems, the appropriate documentation of the product structures is one of the most important prerequisites in order to obtain the necessary transparency in order processing workflows. This is especially true for companies with a complex and huge product portfolio diversity.

The bills of materials and usage lists are of particular importance for the identification of the order-specific secondary requirement and for the subsequent in-time supply of the manufacturing materials and parts defined. Depending on the representation form of product structures applied, i.e. bill of materials or usage lists, the determination of requirements can be performed either analytically or synthetically. For analytical requirements planning, the product is split into its assemblies, which are again subdivided into parts and, often, again into the required raw materials (Steinbuch, 2001). This is carried out according to the product structures which are documented in the bill of materials.

In contrast, usage lists are applied for the synthetic determination of requirements. By means of the usage lists, the complete product structure can be analyzed; they set out how often each component (e.g. part) is needed for the manufacturing and assembly of a planned order volume. In this context, usage lists indicate for each component whether it is frequently or rarely demanded by the market. Within the framework of the available methods of variety management described in chapter 2.3.5, the thus achieved information transparency can be used to increase the efficiency of the product program. This is accomplished as unprofitable product characteristics, e.g. extras, are no longer offered in the markets.

Both the analytic and synthetic determination of requirements represent a combined quantity and time calculation: not only are the required quantities identified, the exact point of time is also computed when the components are needed in production. Of course, with the growing complexity of products in many industrial sectors, the need for best-possible accuracy of the documents has become more critical than ever in order to obtain reliable information for the downstream tasks in order planning and order processing.

2.4.6 Conclusions

Until only a few years ago, product documentation was often regarded as an unnecessary, additional effort which does not create any added value in helping to achieve the company goals more efficiently. However in the last few years, there has been a persistent change in that sense in many industrial companies. Nowadays, product documentation and, in particular, the methods for describing structures of complex products are no longer seen solely as additional expenditure but have instead come to take on an increasingly more important position in the operational information management in companies. These approaches are considered as indispensable tools to manage the growing complexity and variety of products in a transparent manner and to make them controllable. However many of the existing approaches almost fully neglect the connection and the equal significance of an appropriate method to document the manifold processes and resources which are necessary to produce the range of products.

The documentation of products and their structures is an essential communication tool to translate the order characteristics demanded by the customers into the components required to build the respective products and to guarantee the trouble-free, efficient coordination of the different functional areas of an industrial company. However, the manufacturing structure which is of importance for the production is only obvious in some conventional forms of bills of materials, for example in the structural BoM. In particular, what often becomes extremely difficult is the transparent and redundancy-free representation of products with a huge variety in a uniform bill of materials to enable an overview of the assembly structure of multi-level products.

In conventional approaches of product documentation, complete products are typically structured top-down, i.e. the product is hierarchically divided into assemblies, sub-assemblies, and parts. Yet, there are generally no accepted instructions for product structuring: products are usually structured under consideration of manufacturer-specific aspects. For example, a passenger car can be divided into chassis and body - but also into the left and right vehicle half. And it is this circumstance that makes the cross-functional, inter-disciplinary development of new products more difficult and, in individual cases, hinders distributed, cross-brand cooperation between organizational units.

The different methods used to document the products and their structures often lead to problems regarding the consistency and redundancy of information. Numerous pieces of information cannot be assigned directly to a concrete individual part or assembly since, in conventional BoM systematics, the production process is not clearly derived in terms of a process-oriented product documentation (Radow, 1999). Examples of typically non- representable information include process information, the manufacturing methods deployed, technological process data, as well as information about production resources such as the kind of manufacturing resources, operating and control information, and technical performance measures. Thus, process and resource variety, which in the past have often risen commensurately to product variety, remain non-transparent in the order processing chain and are thus not recognized by Management. As a consequence, an efficient organization of the business processes is only possible to a certain extent.

2.5 Product Configuration

2.5.1 Need for Product Configuration

In many companies which have in the last years initiated a customer-oriented competitive strategy such as mass customization, a demand for individual products is clearly obvious. These companies have become aware that their customers cannot be regarded as one homogeneous group, instead reflecting a market segment with a variety of needs. Thus, many companies find there are potentials in focusing more closely on the customers and use this as a strategic opportunity to establish a competitive edge (Jorgensen, 2001).

However, intensive customer orientation, such as prevalent today in the automobile industry, leads to tangled and non-transparent product structures (Radow, 1999). Also, the Sales Department as the direct interface of a company to the customer often encounters the problem that clarification of orders for complex products takes too long due to a high product variety, or that the configuration of manufacturable products is difficult because of numerous restrictions (rules) which have to be considered when combining several product characteristics.

With increasing variety on the part, module, and product levels, the number of configuration rules typically rises correspondingly. These rules are set up to ensure that only the actually manufacturable products can be configured by the customers, taking the relevant limitations of the Production and Sales Departments into account. However it is extremely difficult for the customer and the Sales Department to consider all the relevant combinations of rules solely by means of the underlying price lists and sales catalogs. Error-free order clarification is situated at the beginning of the order processing workflow: it therefore has a positive effect on all downstream processes (Holthöfer and Szilágyi, 2001).

Similarly, a further problem exists: systematic consideration of all the producible order configurations in the case of order clarification in order to be able to purposefully advise the potential buyers according to their needs and to find a suitable form to communicate the manifold configuration options to the customers. Each of the aforementioned reasons call for systematized processes and tools. These are needed to inform the prospective buyers about customization alternatives for a product and to guide and control the customer wishes within defined, company-internal rules for product configuration. In this research work, the terms product configuration and order configuration are used synonymously.

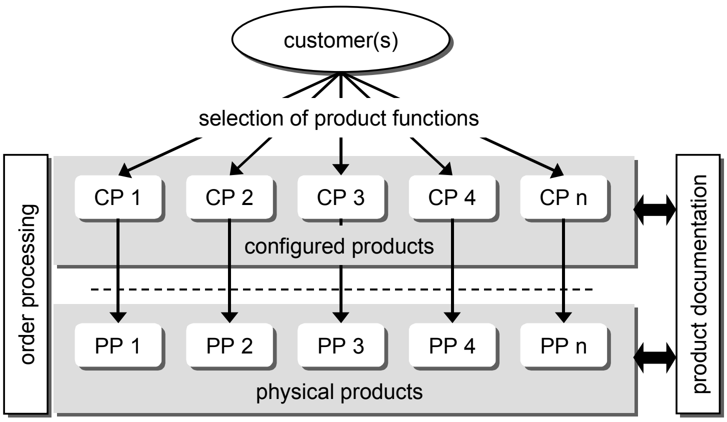


Figure 2.16: Product Documentation as Basis for Product Configuration.

In general, product configuration is the combination of products or system solutions according to customer specifications on the basis of standardized parts and employing a knowledge base which contains configuration rules, e.g. code rules (Schuh and Schwenk, 2001). In EN ISO 10007, configuration is defined as the functional and physical characteristics of a product as specified in technical documents and achieved in the product (European Committee, 1996). Thus, the product configuration is based on the product documentation. Here, the product level and the technical level are of utmost importance, i.e. the documented product characteristics and product structures, respectively. Figure 2.16 illustrates product documentation as the enabler for product customization: each configured product corresponds to a physical product in the order processing chain.

2.5.2 Configurable Products

Viewed from the customer's perspective, configurable products are products which are prepared to fulfill individual customer needs. Each customer can specify, i.e. configure, products from a given range of product characteristics so that every product delivered is individually manufactured or assembled in accordance with the specific requests of a customer (Soininen, 2000; Jorgensen, 2001). This applies to engineer-to-order, make-to-order, and assemble-to-order manufacturing companies (see chapter 2.2.2). In a simple form of product configuration, the composition of a product is based on a number of pre-defined modules, and every product is composed of a specified set of these modules. In more advanced forms, products can be configured by selecting values of certain properties, for instance by switch setting or by assigning values to parameters in embedded software. The customization of the product may sometimes be performed by the customers themselves but is frequently done with the assistance of a sales manager.

From the perspective of a company's Sales Department, a configurable product is more precisely a product variant which is selected from a product family (e.g. model series) through a configuration process. Usually a product family includes a large number of possible product variants with similar characteristics (e.g. shape, material), similar functionality, or similar product structure (Schönsleben, 2004). To a great extent, these product variants are made up of the same parts, modules and assemblies. It is hence not feasible and/or practicable to describe and document all the possible product variants of a family separately. Instead, one or more product families are described as a whole in a bill of materials, and a product variant is derived as a result of the configuration process. For this reason, configuration rules have to be decided in order to determine or configure an individual product variant from the product family in alignment with customer demand. An appropriate bill of material is, for example, the rule-based complexity bill of materials, as introduced in chapter 2.4.4.

2.5.3 Product Configuration Systems

Recently DP systems for structured product configuration and for the realization of a targeted selection process, so-called product configurators, have emerged throughout the industries (Hedin et al., 1998). Systems for product configuration enable the translation of customer language into the technically oriented language of product creation and production in a manufacturing company. A set of rules serves as the connecting piece between these languages. Determining technical incompatibilities between product characteristics on the one hand, such rules also identify necessary bill of materials contents (Forza and Salvador, 2001). A clear separation of these description levels appears sensible in view of both the relative stability of the product characteristics and the high change dynamics of the BoM contents (Männistö et al., 2001). In the mid-nineties, different methodical approaches were differentiated within the product configuration systems. These approaches have remained nearly unchanged or, at the least, are very similar to newer, slightly modified concepts. The following methodical approaches are discussed in Westkämper et al. (1995), for instance, and similarly in Holthöfer and Szilágyi, 2000):

- Rule-based configuration.
- Knowledge-based configuration.
- Interaction-based configuration.

As the name states, rule-based systems are founded on explicitly representable underlying rules. The configuration is predominantly determined by the customer. The systems employs a suitable user dialog to support and control navigating through the system; the presentation of options underlies specific constraints so that only those inputs logically resulting from previously made decisions may be executed. The defined rules are relations of interdependencies and mutually exclusive conditions between product characteristics and, hence, between parts, components or modules. These systems have the benefit that they may be utilized by the customers independently at any time, i.e. without direct support given by the Sales Department. Since customers do not have to come to terms with the product configuration during business hours, a high measure of flexibility is granted to them. This kind of product configuration is common, for example, in the automotive industry.

In direct contrast to rule-base product configurators, knowledge-based systems are founded on the company-internal knowledge of sales, production, and product creation. Such systems are employed, if the configuration options are extremely manifold and/or the planning of complex products (e.g. individual manufacturing of industrial plants and facilities) is concerned. In these cases the illustration of all possible variants and rules is not realizable at justifiable expenditures, and error-free configuration is not really viable without technical assistance, i.e. expert knowledge. Therefore, system-supported product configuration calls for a close cooperation and communication between the customer and the Product Management of the manufacturer.

Additionally, with interaction-based systems the detailed configuration of the product is typically made in collaboration with the manufacturer's sales staff. This kind of product configurators are helpful, in particular, if relatively complex products are concerned (e.g. machine tools), yet the variety of combination options is visible. Thanks to the direct integration of the customer, such systems offer in the bilateral sales talk the possibility to tailor the product to be manufactured as ideally as possible to the individual needs of the buyer.

2.5.4 Functions of Product Configuration Systems

According to the standard in the product configurators, four functions are implemented: information acquisition, plausibility check, information retrieval, and system integration. The first step in the configuration process is the specification of the customer requirements, which are asked for in the product. In this context, the product functions which are demanded by the customers are collected in the form of product characteristics to be selected. These have considerable influence on which parts and modules are required in the later assembly process and thus determine not only the delivery time but also the selling price of the product.

Standardized data input fields capture the required information, helping to document it in the appropriate form needed for preparation of an offer. To make the complexity for the user of the product configurator visible, graphical user interfaces (GUI) have become generally accepted. Often with the requirement specification, a plausibility check of the product configuration is carried out in parallel to assure the technical feasibility of the product. To do so, the configuration rules stored in the system are checked as to whether they have been observed or violated. If all is well, the realizability of product configured by the customer and/or salesperson is finally confirmed (Soininen, 2000; Männistö et al., 1996). Then, using the company-internal knowledge base, the user or potential customer is provided with further product information on unit prices, detail descriptions, delivery terms, dates of delivery, and multimedia applications. Multimedia applications, e.g. video clips, 360° views, enable the Sales Department to address, the customers emotionally to a certain degree within the sales process in direct contrast to the otherwise rather businesslike information retrieval by the configuration system.

To fully support the subsequent processes of order processing, the direct transfer of order data to relevant DP systems, e.g. enterprise resource planning systems (ERP), must be guaranteed. To be able to do so necessitates integration of an additional, standardized, implemented functionality of the product configurator in these systems (Schuh and Schwenk, 2001).

2.5.5 Conclusion

In connection with the documentation of complex product structures, instruments for product configuration contribute to added value for complexity management. In addition, product configurators build the basis for the trouble-free, smooth, and efficient processing of customer orders. If a product configurator in the form of a DP system is not in place, customers are confronted with a large product variety, manifold configuration possibilities, and numerous interdependencies, so that they are normally not in the position to determine the optimal solution for themselves manually. Even experienced sales employees cannot always ensure correct order clarification and are often not able to convey information to the customers in a transparent manner without the use of product configuration systems. This is especially true if the product range and/or the rules for producibility of the different product configurations are continuously changed. In industrial companies with complex product structures and a huge product portfolio diversity, product configuration tools are nowadays established building blocks in order planning and order configuration - key activities in the order processing chain.

2.6 Summary

The opening sections of this chapter discussed a number of terms related to manufacturing, competitive strategies, and order processing. Furthermore, the most relevant issues of the present manufacturing industry were surveyed. Then, some information about complexity and variety has been given and its effects on order processing in manufacturing companies have been explained. The conclusion is drawn that measures for variety management reduce the effort in the overall order processing chain, e.g. for documentation of the product structures and for order clarification.

Based on the literature study, it became obvious that complex product structures are typically documented with respect to the requirements of product design. Therefore most product structures are documented hierarchically, which is not suitable for the illustration of the assembly-relevant manufacturing sequence and interdependencies on the part level. Consequently, also process and resource information is not or only insufficiently considered in the approaches of product documentation applied today to meet the challenges in order processing resulting from the increasing product customization, product variety, and complexity of processes. Since the approaches of product documentation are only partly suitable to represent the soaring product variety, the documentation of producibility rules to be considered in the product configuration process is also hampered. But it is precisely this which is necessary to assure error-free order clarification and a customer service of high quality in spite of the multitude of possibilities for combining different product characteristics.

In brief, variety management and product documentation - especially on the product level and on the technical level - are closely linked with order configuration in the order processing chain of an industrial company.

Chapter 3

Planning and Control of Order Processing

3.1 Production Planning

3.1.1 General Characteristics of Planning and Control

The literature cites numerous definitions for the term planning, all of which aim at describing planning as accurately and comprehensively as possible. The Association for Work Design/Work Structure, Industrial Organization, and Corporate Development (REFA) provides a definition which is quite suitable for this research: planning is a systematic searching and definition of aims as well as the phrasing of tasks and resources which are required to achieve the aims (VDI-ADB, 1992; REFA, 1985). This definition contains typical characteristics of the term, which should be considered in order to point out the multiplicity and magnitude of planning aspects (Lohse, 2001):

- Planning is related to the future.
- Planning is purposive and systematic.
- Planning is formative.
- Planning takes place in several stages.
- Planning uses and generates information.

Potential risks are recognized at an early stage through the systematic search for and selection of alternatives. In addition, planning reduces the risk of erroneous decision-making and opens various possibilities for purposeful risk elimination. Thus, planning is a suitable instrument to analyze tasks and support the deviation of realistic aims and operational measures under consideration of the limiting basic conditions. Planning produces guidelines for Management which are directed to the preparation of decisions, so that a range of possible actions in the form of plans is created to avoid later time pressure (Zäpfel and Piekarz, 2002; Pfohl and Stölzle, 1997). Planning hence always includes decisions which are a result of a data processing process with several feedback loops. This decision-making process ends with a conscious, conclusive choice or resolution made by humans to realize the results of a more or less intensive, systematic planning process in the form of instructions for action.

Control is generally defined as a measure to systematically influence workflows and processes, i.e. according to a plan, to achieve a given aim. Consequently, control is described in the context of order control as arranging, monitoring, and ensuring the order workflow with respect to aspects of quantity, dates, quality, costs, and working conditions (VDI-ADB, 1992; REFA, 1985). Thus, control corresponds to the enforcement of a will by definition of guidelines for target values. The fulfillment, i.e. the degree of achievement of planned aims, is measured by means of a continuous comparison with the actual values. In the case of deviations from the aims which have their causes in an unrealistic planning and/or irregular realization, measures which either enable the achievement of the original plans or which require the adaptation of aims to changed basic conditions can be taken (Zäpfel and Piekarz, 2002).

To a large extent, this definition of control exceeds the meaning as it is applied in automatic control engineering. In this context, control is defined as an open sequence of actions with which initial values are influenced purposefully through given input values. According to this description, the aim-oriented monitoring and assurance of processes is not part of the approach in control engineering. In contrast to control, the regulation of a process represents a closed action sequence (automatic control loop). The variable to be controlled is continuously measured and compared with the given guideline. If a deviation is identified, the variable is adjusted to the guideline by changing the correcting variable (DIN 19226, 1994).

3.1.2 Planning and Control by Humans

As stated, planning and control processes always include decisions consciously made by humans. Examples are the definition of planning premises or the determination of proceedings for action in order to control the purposeful achievement of planning results. Within wide fields of psychology and for factual reasons, humans are not seen as individuals controlled and determined causally from the outside. Of course, there also exist learned stimulus-response behavior chains. Yet, in many cases human planning behavior is aim-oriented. In order to achieve a specific aim, someone selects from among oftentimes many possible actions those which subjectively appear most favorable. The success thus achieved, the necessary effort, and any unintended side effects possibly arising are reported back, are subjectively evaluated, and may lead to optimization of the behavior. This applies to both the continuous checking of the behavior and its results. This takes place with the possibility to immediately improve the problem solution and to subsequently evaluate the procedure of problem-solving. This cognition and awareness forms the foundation for a more favorable behavior in a comparable, later-arising situation. In this sense humans do not react in some situations, acting instead (Schönpflug, 2004; Wottawa and Thierau, 2003).

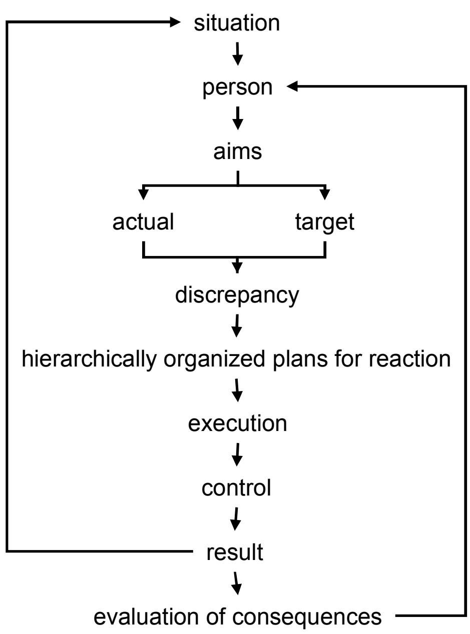


Figure 3.1: Structure of the Acting Process.

Figure 3.1 portrays the action model according to Heckhausen (2003) and Lantermann (1980). If a simple case is taken, then the optimization problem can be solved relatively easily. From the available behaviors, i.e. alternative ways of acting, the most favorable behavior is selected: that which enables the targeted aim to be reached in a particularly effective way at the lowest cost (among other things in the sense of side effects). Unfortunately the current situation in industrial companies is much more complicated. Simple models for action neglect many facets which determine the planning and acting of humans in real situations. On the one hand, the individual aims are embedded into super-ordinate hierarchies of objectives (figure 3.2). On the other hand, reaching an aim (and the ways chosen to do so) generate conditions which again influence the system.

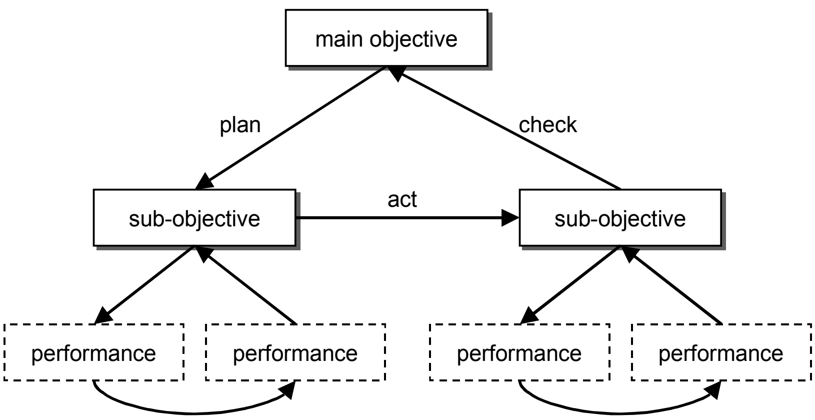


Figure 3.2: Hierarchical-Sequential Regulation of Actions (Volpert, 1980).

Each partial aim is imbedded within a cause-and-effect system. The consequence is that the evaluation of the achievement of aims and of measures used to do so cannot take place solely with regard to the respective partial aim, but must instead be done within the complete net of relations. The cross-linking of causal relations allows a final and comprehensive evaluation of a measure only then, when the system affected by this measure no longer exists (Wottawa and Thierau, 2003).

If an industrial company is regarded as an overall system, then it will only be possible after its closure to finally determine the consequences a certain measure had on the overall company existence. It is thus impossible to make a final empirical evaluation as to the actual effects of a measure. Furthermore, a sequential optimization of intermediate steps does not guarantee the achievement of an optimal overall result. This is because an industrial company is in principle an open system which not only is affected by numerous, unforeseeable influences but also reacts to the various, mutual connections to its environment (e.g. partners, competitors, customers). For example, the reaching of an intermediate target in the form of newly acquired market shares which results from additional investments in new products may be evaluated positively at a first glance. But in the event of an unforeseen slack in demand due to cyclical fluctuations or in case of certain reactions of competitors (e.g. marketing campaigns), the originally positively evaluated acquisition of the market shares must be viewed as negative overall, since the investments have become unprofitable. Due to these unavoidable and virtually unpredictable environmental influences, the plans of an industrial company can only be assessed temporarily using certain metrics; however such an assessment can in no way serve as a final prognosis for the later reaching of planned aims. Of course, this aspect is also true for the planning activities in order processing.

Nowadays, the increasing amount of planning information in an industrial company cannot be processed in an appropriate time frame and with a justifiable resource effort without the development and application of appropriate methods and data processing systems. The multiplicity of cross-linked planning activities becomes obvious in the context of production planning and control in the order processing chain, for example.

3.1.3 Production Planning and Control

Production planning is a substantial part of order processing in an industrial company. It supports the entire order processing chain in an integrated way, from quotation processing over order management to the distribution of products, including the planning and controlling of various activities in product development (Wildemann, 2002; Hackstein, 1989). Major tasks of production planning are to specify the production program in its quantitative and qualitative composition as well as to determine the execution and coordination of the relevant production processes with respect to super-ordinate company targets (Teich, 2002; Günther and Tempelmeier, 2002). By reason of the clearly close relationship between planning and control activities, the term production planning is often extended to production planning and control (PPC).

In this context, production planning and control can be defined as planning, control, and monitoring of the product development process with respect to quantity, time, and capacity aspects (Luczak and Eversheim, 2001). This results in PPS plans, which are realized in production among other things as orders in the context of technical order processing (e.g. design, manufacturing, procurement, or warehousing orders). The task of PPC is not limited to an individual organizational unit in a company. In contrast, each planning and control task which must be carried out by an organizational unit can be assigned to PPC (Onwubolu, 2002). Hence, a substantial cross function of production planning and control is order coordination (Much and Nicolai, 1995).

A fundamental task of order coordination is the harmonization of the activities undertaken in all the organizational units involved in order processing and the synchronization of the task fulfillment in the related planning. This takes place with the aim to increase transparency in order processing and to improve the flexibility to react appropriately to unpredictable events of the environment. At the same time, objective decision-making support is provided to solve conflicts of interests between different departments, i.e. organizational units. Thus, tasks of both sales planning and production program planning lie within the scope of order coordination (Heiderich, 2001).

With respect to the different areas of activities, production planning can be divided into the tasks production program planning, production requirements planning, in-house production planning and control, and external procurement planning and control (Domschke, 1997). Figure 3.3 wraps up the main tasks of production program planning. These tasks can be outlined as follows:

- Production program planning defines the kind of products, the respective quantities, and the dates to ensure the production of the planned quantity of products (see chapter 3.2).
- Production requirements planning determines the necessary factors of production (Recker, 2000).
- In-house production planning and control coordinates the in-time workflow of the product components to be manufactured with regard to quality and quantity aspects. Thus, it structures the flow of materials and times operational activities.
- External procurement planning and control manages the purchasing and administration of goods and services which are not manufactured in-house, instead being produced by external partners (Berning, 2001).

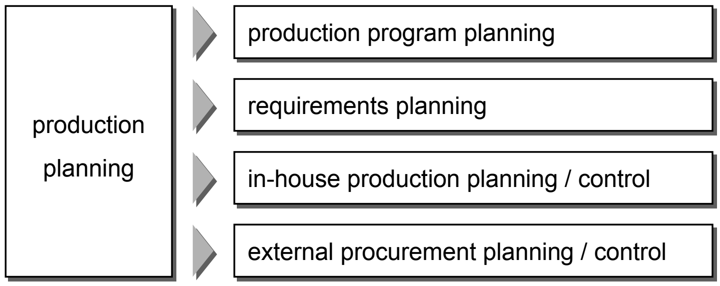


Figure 3.3: Main Tasks of Production Planning.

3.1.4 Production Planning and Control Systems

Computer-based PPC systems support the user in industrial companies in the execution of the various tasks of production planning and control (Hadeler and Winter, 2000). Through the automatic processing of data and the structured representation of information, these systems provide users with decision support regarding the definition of producible quantities and allocation of capacities, and the determination of dates and costs (Much and Nicolai, 1995). PPC systems are characterized by the integration of numerous functions which do not merely support the tasks of PPC but rather extend the scope (Holzer, 2000). More and more of the different functions of the following organizational units are incorporated in such systems (Dannhauser, 2000; Fandel, 1997; Paegert, 1997):

- Purchase and Sales (e.g. administration of suppliers and customers).
- Product design (e.g. administration of bills of materials and drawings).
- Scheduling (e.g. administration of production schedules).
- Inventory management (e.g. administration of storage location and stock ground).
- Cost accounting (e.g. cost type, cost center, and cost unit accounting).
- Bookkeeping (e.g. invoicing).
- Wage and salary administration.
- Production data acquisition.

Traditional PPC systems are based on successive planning with temporally increasing degree of detail. To do so, an overall task is fractionalized into several subtasks that are then each regarded temporally and organizationally as standalone and solved individually. An optimal solution is sought for each subtask. The relevant inputs into the subtasks are strongly contingent on the results of preliminary subtasks. However, at the same time, these results can be again affected by the inputs. Yet either no or only a very weak feedback occurs between the various subtasks. As a consequence, the interdependencies between program planning, quantity planning, and capacity planning, in particular, are regarded only insufficiently (Teich, 2002; Arnold, 2002). That means that if changes in plans occur, it is often unavoidable that the complete chain of subtasks has to be solved again from the very beginning.

The approach of simultaneous planning focuses on a parallel evaluation of all influencing factors and attempts to avoid the drawbacks of a successive planning. Here, comprehensive approaches of linear and nonlinear optimization are used. The development of such a planning model can be extremely complicated, which results in an immense effort for calculation (Wahl, 1995).

Hierarchical planning (e.g. MRP-II) aims at the avoidance of the disadvantages of the approaches described before and at combining their advantages. Similar to successive planning, the overall problem is fractionalized into partial modules. The modularization of the overall problem is aligned with the hierarchical structures of the manufacturing system, e.g. an industrial company. Then, the individual modules are solved with the same procedure as applied in simultaneous planning. A coordination mechanism ensures the trouble-free cooperation of the partial modules, so that a valid solution for the overall problem is found (Arnold, 2002). This procedure is described in detail in, for instance, Stadtler and Kilger (2002), Vahrenkamp (1996), and Lermen (1992).

The MRP concept (materials requirements planning), which emerged in the fifties, includes the change from consumption-oriented to requirements-oriented material disposition. Some decades later, the MRP II concept (manufacturing resources planning) was developed: apart from the production capacities, this approach also considers the economic and strategic aspects of production planning (Teich, 2002). In both MRP concepts, changes in the market demand occurring at short notice often remain unconsidered due to the fact that production planning employs the demand as the information basis to subsequently derive the primary and secondary requirements (Pieper and Sellmer, 2000). Thus, the conclusion can be drawn that MRP procedures offer good support for the planning of production processes if orders are placed regularly enabling close prediction of order forecasts (Klaus and Krieger, 2004), but that these procedures show their performance limitations in program planning of manifold products with short-term fluctuations in market demand.

With the further development of the MRP II concept to the ERP concept (enterprise resource planning), it is assumed that maximization of resource utilization will result in a commensurate increase in profit (Teich, 2002). Here, ERP systems are used to control, monitor, and coordinate all the processes and activities within the departments and business units (Norris et al., 2001). Hence a core aspect is the integration and consistency of an enterprise's database.

Based on ERP systems, a new generation of planning systems, the so-called advanced planning systems (APS), were developed. APSes are characterized by a comprehensive support in decision-making for the strategic, tactical, and operative planning of production and logistics activities (Corsten and Gössinger, 2002; Krüger and Steven, 2002). This is achieved by integrating all the activities within the value adding chain, from forecasts of customer requirements, offer and order management, over the logistical material flow and production, up to the purchase of raw materials and parts (Dudek et al., 2002; Pieper and Sellmer, 2000).

Consequently, the emphasis is placed on the integrated planning and control of the business processes along the entire supply chain of a manufacturing system. The basis for APS systems is founded on legacy PPC or ERP systems or any other systems which are used for data administration. Thus, APS can be regarded rather as a supplement to and not as a replacement for existing systems (Teich, 2002).

3.2 Program Planning

3.2.1 Scope of Program Planning

A main task of production planning is the planning of the production program (Much and Nicolai, 1995). In contrast to manufacturing process planning which schedules and establishes the chronological order of the necessary manufacturing activities, production program planning focuses on the quantitative definition of the products. This program depicts the end products to be manufactured, the respective quantities, and the projected dates (Kampker and Wienecke, 2002; Zäpfel, 2001). In this context, end products comprise both customized products and customer-anonymous pre-manufactured standard components. Usually, program planning without regarding any capacity limitations is the exception in industrial practice. 'Capacity' describes the performance of an economic or technical production unit of any type, size, and structure in a time period (Kern, 1962). Examples for a production unit are machines, robots, feed systems or any other manufacturing resources. The term capacity can be concretized through a differentiation in qualitative and quantitative capacities (Wöhe, 2002). Qualitative capacity includes both the type and the capability of a production unit (Corsten, 2003) with the technical characteristics and parameters such as the accuracy or life-time of the production units defined. In contrast, quantitative capacity describes the performance of a production unit such as a machine, with respect to the manufacturable product units in a limited time period, which is typically measured by the output per time unit. The capacity limitations in terms of material and manufacturing constraints have to be considered in the program planning, since they have a direct impact on the kind and quantity of manufacturable products.

The necessity of sales planning results from the discrepancy between the heterogeneous customer needs, which typically often change at short notice, and the comparably long lead and throughput times. Thus, all industrial companies have to make a sales plan, if they cannot plan entirely on the basis of concrete orders which are known long before the actual production, as they have to determine at an early stage in which way future customer requirements are to be fulfilled (Meininger, 1999). Sales planning specifies the kinds of products and quantities of a given product range that are to be produced and delivered within a certain time period (Kampker and Wienecke, 2001). Usually this time period is divided into several sub-periods. The resulting sales plan provides all the necessary data for the subsequent planning step by trying to determine future sales structures and thus anticipating future capacity and material requirements. On the basis of forecasts over this development in the sales markets and/or on the basis of existing customer orders within the product program, the different product types and respective quantities are then specified.

In addition, the scope of production program planning also encompasses inventory planning, primary requirements planning, and rough resource planning (Hadeler and Winter, 2002). The aim of inventory planning is to keep stocks at as optimal a level as possible and to prevent shortfalls. In principle, stocks on hand facilitate the realization of a smooth production process by bridging disturbances; however, stocks tend to conceal trouble-prone processes, the failure to harmonize capacities, lacks of flexibility, and a deficient on-schedule delivery (Schönsleben, 2004). Consequently, reducing stocks reveals shortcomings and weak points, thus putting increased pressure on problem-solving in the order processing chain (Wildemann, 2004b). To be able to keep the promised delivery dates within the time span available, it is necessary to determine the level of stock keeping for end products under consideration of the delivery times which are called for or tolerated by the market and with respect to the company-internal throughput times and/or lead times (Teich, 2002; Klaus and Krieger, 2004).

Primary requirements planning defines the demand for finished products for an upcoming planning period. The demand is calculated on the basis of sales forecasts and/or on customer orders received and acknowledged (Pfohl, 2003; Zäpfel, 2001; Scheer, 1997). The term primary requirements planning is often used synonymously with the actual production program (Wöhe, 2002; Tempelmeier, 2002). Apart from the most accurate calculation of the requirements as possible, the objective of primary requirements planning is minimization of the costs connected with the procurement and supply of product components (Corsten, 2003). In brief, primary requirements planning forms the interface between the business units Sales and Production in an industrial company.

Rough resource planning verifies the sales and production programs which have been determined in the preliminary planning steps. In this context, verification of whether or not the planned programs can be realized with the available resources is carried out (Kampker and Wienecke, 2001). Here, resources include the work force, manufacturing equipment, auxiliary equipment, and materials (Günther and Tempelmeier, 2002). Figure 3.4 summarizes the scope of production program planning.

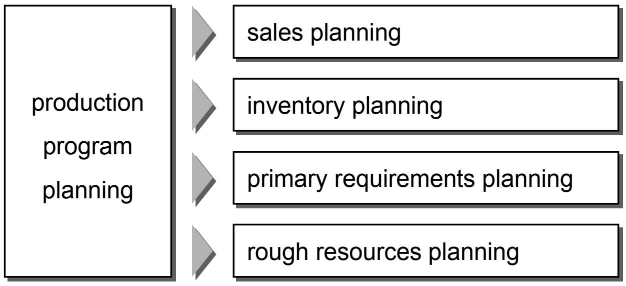


Figure 3.4: Scope of Production Program Planning.

3.2.2 Program Planning Horizon

With respect to various time horizons for decision-making, program planning can be divided into strategic, tactical, and operational program planning (Klaus and Krieger, 2004).

In strategic program planning, decisions are made concerning the business fields and the qualitative and quantitative objectives of a company. The products to be manufactured are derived from this basis and the possible product profile of a company is elaborated. Consequently, the annual production (structured into product types and product quantities) to be implemented within a longer planning time, e.g. five years, is defined on the strategic level. This long-term production plan is a guideline for the capacity provision of the necessary work force and manufacturing equipment (Wöhe, 2002).

In tactical program planning decisions are taken as to the product types to be manufactured on the basis of the product profile defined in strategic planning (Arnold, 2002). Thus, products which are planned in the long-term become further detailed. In order to master this task, the following basic conditions are defined within tactical planning (Schmitz, 1996):

- Width of the production program (number and types of basic products to be manufactured).
- Depth of the production program (number of the different production stages to be run through by the products).
- Required capacities (assignment of the product types to the available capacities).

Finally, operational planning defines the actual output of a company, i.e. the exact kind and quantity of the products to be manufactured in the coming time periods (Hadeler and Winter, 2000). To do so, the milestones and quantities of the two previous planning stages become concretized in operational program planning. In connection with the decisions made in strategic and tactical program planning and with regard to the given production infrastructure (e.g. buildings, plants), further tasks arise. For not only must this planning level ensure the optimal allocation of resources if a capacity bottleneck emerges, it must also guarantee a virtually steady, uniform utilization of production capacities at a high level (Wöhe, 2002).

3.2.3 Alignment of Planning Activities

Of special importance for the entire program planning with its different time horizons is the mutual coordination of the sales figures, which are planned by Sales (in terms of anticipated orders), and the available capacities and resources of Production. This is because the target sales figures will only be achieved if the products are, of course, manufacturable in time and in the required quantity using the available resources (Schmitz, 1996). Hence, these different planning parameters have to be harmonized between the Sales and Manufacturing Departments at regular intervals (figure 3.5).

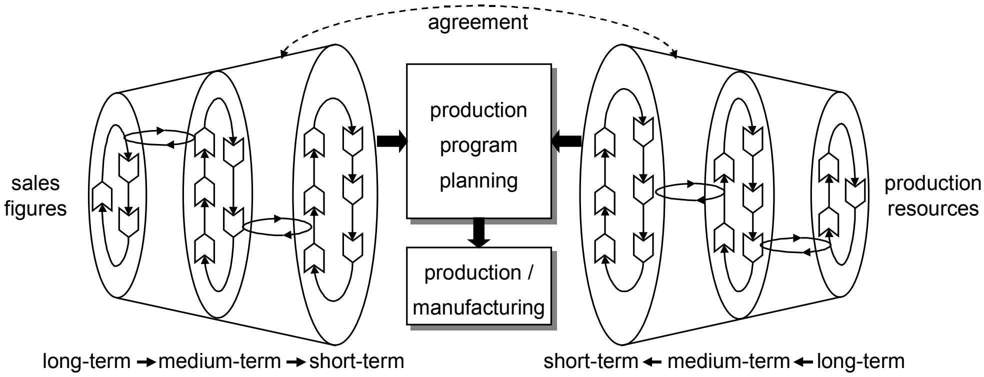


Figure 3.5: Synchronization of Planning Parameters.

The harmonization process undertaken by Sales and Manufacturing takes place successively and is aligned with the different planning horizons, with results from preliminary planning serving as input information for subsequent plans. With the decreasing time horizon, planning becomes more and more detailed for shorter planning periods (Kilger et al., 2002): both the capacities of production plants and the procurement possibilities (and limitations) for the raw materials and product components used in manufacturing are included (Schmitz, 1996). Due to the close cross-linking of sales planning and the actual production program planning these can be regarded as an integrated unit.

The result of the combination of sales and manufacturing program planning is a harmonized manufacturing program. This manufacturing program and the underlying harmonized material and manufacturing capacities are the input for the concrete planning of customer orders and customer-neutral orders. That means that each order planned and subsequently scheduled within the scope of short-term program planning strains the harmonized capacities.

However, both dynamic changes within a company (e.g. new product policies, modified marketing strategies) and difficult to predict or unforeseen developments in the environment of a company (e.g. cyclical fluctuations) may negatively affect the forecasted product life-cycles (i.e. market demand) and consequently the production program which was harmonized during the stepwise planning process. These negative impacts not only endanger the realization of the aspired to, steady utilization of the harmonized production resources and capacities but also hinder the reaching of the desired high planning accuracy and planning stability according to the subordinate tactical and operational targets derived from the main strategic targets (Sailer et al., 2004). For this reason, if a change in market demand occurs, appropriate measures have to be taken to adapt the production resources and capacities as well as the resource demand of the market. Two basic categories of balancing measures can be distinguished: short-term measures on the basis of given, unchangeable capacities and long-term measures through increasing or decreasing the available capacities (Wöhe, 2002).

Figure 3.6 illustrates several measures for balancing resource supply and sales demand. Utilization-oriented working time models and flexible production processes (e.g. model-mix-production) are excellent methods to react appropriately to different market situations at short notice. Many companies therefore set up different working time models, e.g. flexible working time and temporary employment, to be able to react more flexibly to changing market situations. The working time models can be arranged according to the current requirements and enable a personnel capacity offer which meets the present demands in changing market situations (Wildemann, 2004b).

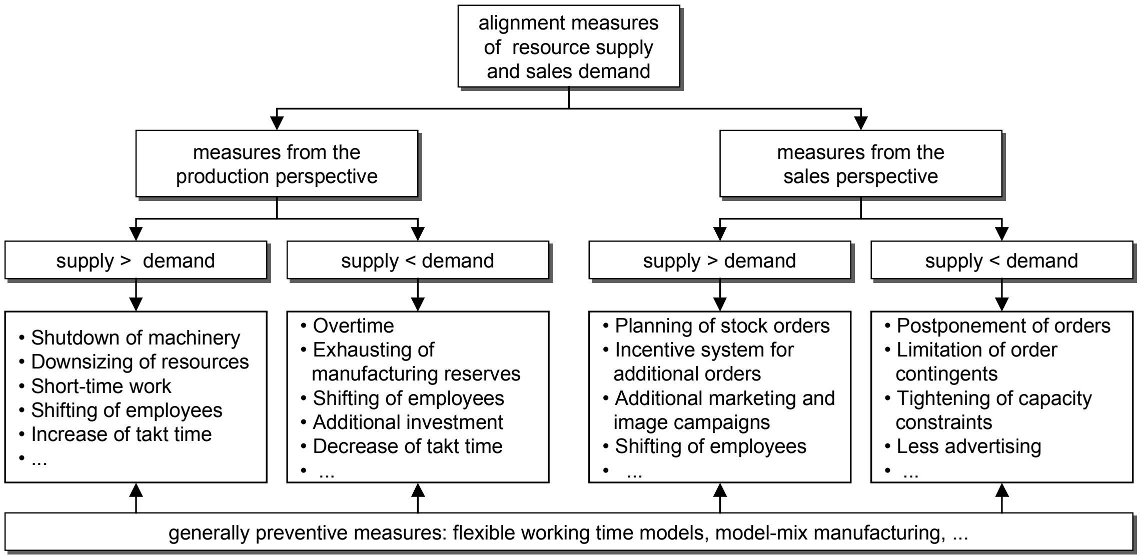


Figure 3.6: Alignment Measures of Resource Supply and Sales Demand.

3.2.4 Decision Guideline for Program Planning

From the monetary point of view, the principal aim of production program planning is to maximize the profit of the company. Profit is the difference between the sales revenues and the total costs. To calculate the sales revenues, the sales price per unit (p) has to be multiplied with the number of sold product units (x). The total costs consist of variable costs (c_v) and fixed costs (C_f). In brief, the equation of profit is defined as follows:

$$\begin{aligned} \text{profit} &= \text{sales revenue} - \text{total costs} \\ &= (p \cdot x) - (c_v \cdot x) - C_f \end{aligned} \qquad (1)$$

Variable costs (e.g. material costs) are quantity dependent, i.e. their amount is determined directly by the capacity utilization level. In contrast, fixed costs (e.g. interest for outside capital, leasing fees, salaries of the management staff) are not related to production quantities, so that fluctuations in the capacity utilization neither positively nor negatively affect the costs amount (Corsten and Reiß, 1999). Fixed costs result in any industrial company inevitably from establishing the ready status (e.g. purchase or rent of production resources, definition of the company organization structure). The ready status is the basic prerequisite for an industrial company before production can be started and output is generated. In industrial practice the classification of costs is often problematic, as there are no costs which can unambiguously be represented according to their character as variable or fixed costs - a slight doubt always remains. Rather, costs are only defined as fixed or variable costs by the kind of accounting and/or wording of the decision problem (Wöhe, 2002).

In short-term program planning, the fixed costs are not relevant for decision-making, since they represent a variable which is independent of the output. In addition, the available production capacities are regarded as a given constant in short-term program planning. Therefore, optimization models of short-term program planning are based on the maximization of the contribution margin under consideration of the given material and manufacturing capacities (Hadeler and Winter, 2000). The contribution margin is a key figure, which indicates, to which extent a product contributes to the recovery of fixed costs which are caused by establishing and maintaining ready status. The contribution margin per unit and the total product variant's contribution to profit are calculated as follows:

$$\begin{aligned} \text{contribution margin per unit} &= \text{sales price} - \text{variable costs} \\ cm &= p - c_v \end{aligned} \qquad (2)$$

$$\begin{aligned} \textit{total contribution margin} &= \textit{conribution margin per unit} \cdot \textit{quantity} \\ tcm &= (p \cdot c_V) \cdot x \end{aligned} \quad (3)$$

According to this definition, the computation of the contribution margin is unambiguously described. Using this equation in practice, the absolute values can only depend on the precision with which the input variables are determined and mapped. Using the contribution margin, the equation of profit can be described as follows:

$$\begin{aligned} \textit{profit} &= \textit{total contribution margin} - \textit{fixed costs} \\ &= (p - c_V) \cdot x - C_f \end{aligned} \quad (4)$$

The computation of the contribution margin, i.e. the consideration of variable costs, is better suited for the purposes of analysis, planning and disposition, than decision-making on the basis of full costs (Corsten and Reiß, 1999). The accounting of full costs often suggests removing products with a negative operating result from the production program. This is basically calculated as difference between the sales revenues and variable and fixed costs. However, such a conclusion is nearly always incorrect since, as a rule, fixed costs can be reduced only in the long term. Thus, fixed costs also accrue if production of what would appear to be a loss product is discontinued. Any discontinuance of a certain product must hence yields to the fact that the fixed costs must be covered by the products remaining in the production program, at least temporally.

The break-even point (BEP) has to be mentioned in this context; the basic model is portrayed in figure 3.7. The BEP is the quotient from fixed costs and the contribution margin per unit. It can be interpreted as a key figure which denotes the quantity (output) with the product-specific contribution margins that just covers the fixed costs (Horvath, 2003). Thus, smaller quantities result in a loss, whereas higher quantities yield profit. A product therefore has to be removed from the product portfolio in the context of short-term program planning only if the sales revenues are lower than the variable costs, so that the contribution margin of the product becomes negative (Wöhe, 2002). In this case, the product no longer contributes to covering the fixed costs. Vice versa, it is profitable to manufacture products with the highest possible contribution margin, which additionally utilize the production resources and capacities at as high a level and as steadily as possible (Corsten, 2003).

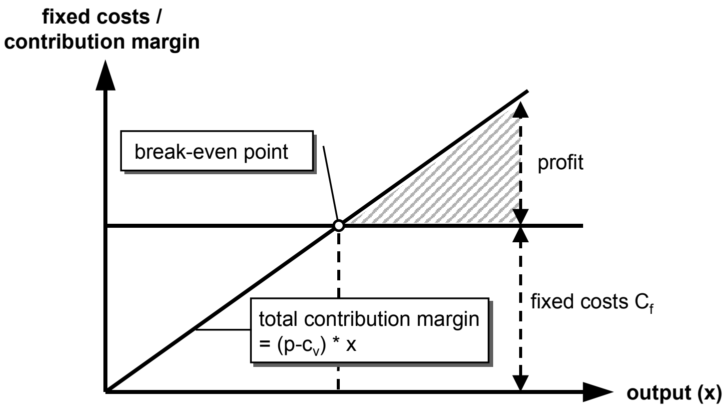


Figure 3.7: Contribution Margin.

3.3 Summary and Conclusions

This chapter has begun with some general remarks on planning and control in manufacturing companies and outlines the influence of humans in these activities. Then, information on production planning and control has been provided, since this is an integral part of order processing. PPC systems and the different planning concepts which are implemented in these systems are then compared with one another. One of the most essential tasks of production planning, program planning, has been described in more detail. The scope of program planning has been explained with respect to the underlying time horizons. In addition, the need to synchronize the planning activities between the Sales and Manufacturing Departments has been outlined. This coordination process results in harmonized material and manufacturing capacities which are summarized in the production program. The production program builds the framework for the planning of customer orders and customer-neutral orders.

Finally, the author has discussed the contribution margin as the key figure for decisions program planning and order planning. In the relevant literature, no further planning perspectives, e.g. the market attractiveness of different product variants, are described. Yet today, in planning processes also it is not sufficient to focus solely on one of the competitive dimensions ‘cost’, ‘time’ or ‘quality’. In terms of a well-balanced decision-making in short-term program planning and order planning, it is becoming more and more important to consider all of the dimensions mentioned, even if they could not be optimized to the same extent in parallel.

PART II: Conception

Chapter 4

Development of a Planning Methodology for Customer-neutral Orders

4.1 Need for Customer-neutral Order Planning

4.1.1 Order Processing Principles and Market Situations

The harmonized short-term production program is the guideline for the planning of orders which can be produced with the available resources and capacities in a certain time period. Orders represent the chief guideline within the order processing chain of a company, independent of the degree of customer-orientation and the time when the customer is involved in the company processes. For, in the long run, all activities in both technical and commercial order processing are related to the orders (see chapter 2.2.1). Consequently, orders have to be planned to reach the goals of short-term program planning and order processing.

The planning activities are contingent on the market situation and the implemented form of organization in the order processing chain. Basically, two different forms of organization may be distinguished: the push principle and the pull principle. The former means that orders are typically planned and produced based on market research and sales forecasts without knowing the later end consumer. Thus, the orders are initiated within the company by the Sales and Manufacturing Departments. In contrast, the theory of the pull principle denotes that order processing activities are initiated only by concrete customer demands, i.e. based on a customer order.

Both organization forms are oriented toward the supply-demand situation of the seller's or buyer's market. In a seller's market, the sellers have greater market power than the buyers. The sellers can prescribe the conditions to a certain extent (e.g. sales price, contract conditions). The market power of a seller may result from various criteria such as excess demand or market regulations which largely restrict competition. In spite of a push principle, all products can be sold in the seller's market.

However, during the last decade more and more seller's markets have become buyer's markets. In such altered markets, the market power of buyers is stronger than that of the sellers. Typically, the market supply is higher than the customer demand. In connection with the push principle, overproduction occurs, i.e. not all made-to-stock products can be sold. With respect to the continuously changing customer requirements in buyer's markets, in particular, the fact that, within the push principle, production is based on market research and sales forecasts hampers the assurance of fast marketability of the customer-neutral products to be planned and manufactured. Stock products which do not meet the heterogeneous customer needs are difficult to market. These products often incur additional costs owing to warehousing, capital investment in stock, remedy of environmental damage, technical obsolescence, and artificial increase in demand (discounts), for example. These cost factors have a considerable impact on the contribution margin of made-to-stock products.

Empirical studies at automobile producers such as DaimlerChrysler or BMW have shown that a significant share of the annual production volume is based on customer-neutral orders. If the above cost drivers are calculated and added for the portion of the stock products, a considerable cost amount results. Consequently, carmakers try to avoid the production of customer-neutral orders in the face of consumer behavior in the European Economic Area (EEA). In contrast to other markets where consumer goods are typically sold from stock, e.g. in North America, within the EEA the opportunity to configure a product to individual needs is of great importance for the customer's decision to purchase. Thus, the pull principle, which allows for the customization of products, is a substantial element of the companies' business models in this marketing area.

Consequently, if a seller's market turns into a buyer's market it is sensible to switch from push to pull. If this is possible, the additional costs resulting from the push principle could be avoided, as the order processing activities are initiated and aligned with a customer order and the products comply with customer needs. Figure 4.1 summarizes the different market situations and order processing principles.

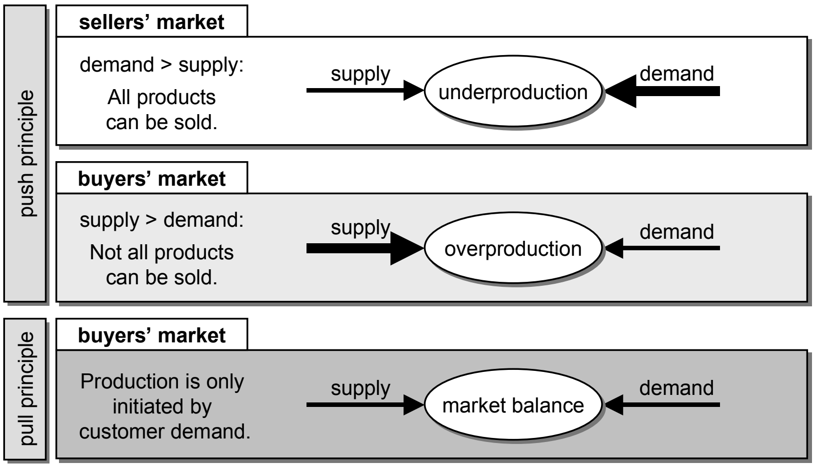


Figure 4.1: Order Processing Principles and Market Situations.

4.1.2 Customer-neutral Orders as a Balancing Instrument

Despite the addressed cost factors which are caused by the processing of customer-neutral orders, it is not always possible for customer-oriented industrial companies (e.g. MTO and ATO companies) which produce for the European market to accept only customer orders: to ensure a steady, uniform utilization of capital-intensive and available manufacturing capacities, customer-neutral orders have to be planned and manufactured, too (Sailer et al., 2003). This is because of many unpredictable events which may have a negative effect on the receipt of customer orders compared to the forecasted sales figures in long-and mid-term program planning.

A few examples of influencing factors are new market trends, cyclical fluctuations, rises in the cost of living, changes in legislation, and competitors' marketing campaigns. From the perspective of the Sales Department, ideal would be a transparent factory where processes and capacities are fully disclosed and adapted flexibly to accommodate the current customer order situation at all times.

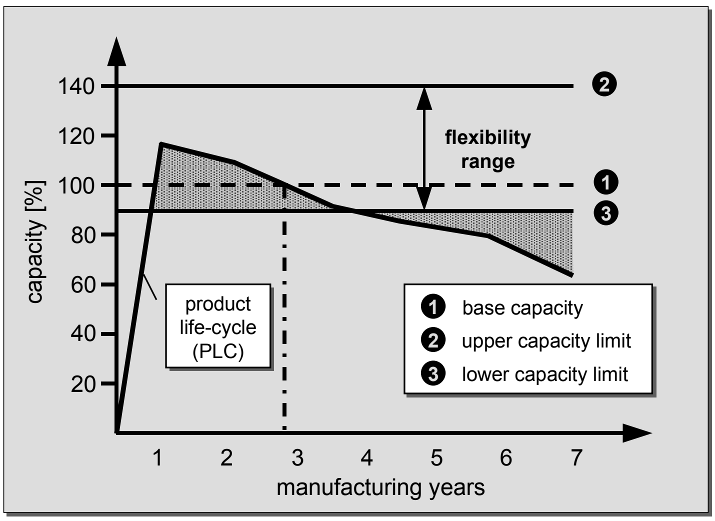


Figure 4.2: Flexibility Range Based on the Product Life-Cycle (PLC).

However, the resulting need for alignment of manufacturing performance (e.g. capacities, resources) with sales demand based on customer orders is only realizable to a certain extent within the available range (figure 4.2). The available flexibility range is planned by the Manufacturing Department within the scope of long- and/or mid-term program planning based on the product life-cycle forecast and the related sales figures (see chapter 3.2).

For the Manufacturing Department it is oftentimes difficult to reduce the existing manufacturing resources in the necessary proportion at short notice should demand decrease. A decline in customer orders results in a lower capacity utilization of production than originally intended in sales planning and production planning. This leads to expensive overcapacities and increases the cost portion of the state of readiness, which each individual product unit must bear. This is because long-term capital investments in buildings, equipment, machines, and manpower incur overheads even if no products at all are manufactured (see chapter 3.2.4). Fixed costs per piece which become lower with increasing production quantity are called economy of scale - a desirable manifestation.

If measures for capacity reduction (see chapter 3.2.3) are not sufficient or applicable and additional sales efforts such as incentives and advertising campaigns do not boost customer demand, stock orders are an instrument in short-term program planning to balance fluctuating or difficult-to-forecast market demands and to achieve economy of scale. Figure 4.3 shows the principle of stock orders as a balancing instrument under the premise that the target utilization of capital-intensive production capacities is reached as steadily as possible. The need for stock orders hence results chiefly from the limited manufacturing flexibility range and from the time delays until measures for capacity alignment in manufacturing and sales processes begin to take the desired effect. Of course, despite the acceptance of customer-neutral orders into the production program, the target capacity utilization cannot always be achieved as intended at the outset of mid- and short-term planning. Yet stock orders certainly contribute to more profitable capacity utilization.

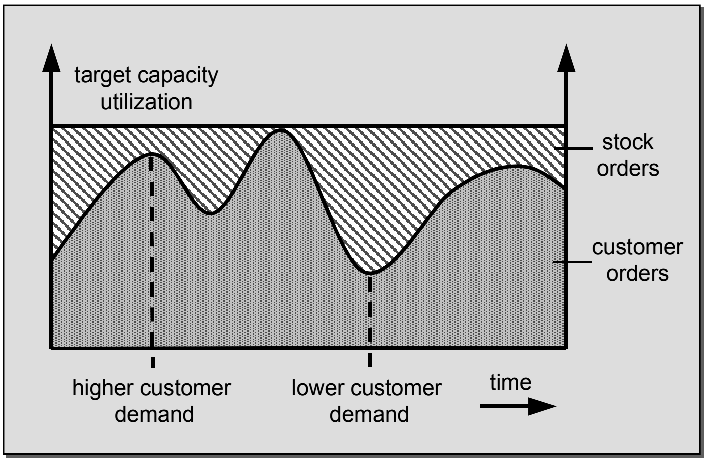


Figure 4.3: Stock Orders as a Balancing Instrument.

In the context of the market-oriented planning of customer-neutral orders, the following primary questions have to be answered:

- Which product variants can be produced based on the available resources and capacities?
- Which product variants should be produced, taking the product’s contribution margin to profit into account?
- Which product variants should be produced with respect to the highest possible market attractiveness and fast marketability?

4.2 Refining Requirements

The objective of this thesis is to elaborate a market-oriented planning methodology for customer-neutral orders based on the available part and manufacturing capacities, which cannot be adapted to the decline in customer demand to the required extent at short notice. The planning methodology is developed for application at car manufacturers having their key markets in European countries and offering a wide product variety in these markets. Furthermore these capital-intensive manufacturing companies, e.g. DaimlerChrysler and BMW, typically have a high degree of customer orientation and implemented continuous production - especially in the final assembly of the product. These companies are forced to meet customer needs in the best way possible while targeting the achievement of economy of scale in order processing. In addition, the manufacturing companies are called upon to keep the competitive dimensions (time, cost, quality) in balance. This is also true for the developed planning methodology for customer-neutral orders.

In summary, the refined requirements to be fulfilled in the planning methodology are as follows:

- Integration of different planning views.
- Support of a well-balanced decision-making, in terms of improving the quality of decisions.
- Computation of the market attractiveness.
- Detailed identification of the available part and manufacturing capacity.
- Detailed and differentiated quantification of variable costs of the different product variants.
- Calculation of the achievable contribution margins.
- Comparison between alternative customer-neutral orders.
- Ensuring that only permissible and manufacturable orders are planned.
- Actualization of the available capacity depending on the order backlog.
- Applicability to the company’s diversified product portfolio (variety on the product and part levels).
- Possibility to simulate different customer order situations and planning guidelines.

It is the first item in the list above, in particular, that is related to the hypothesis of this work: the planning methodology for customer-neutral orders must include both quantitative and qualitative planning aspects with the objective of considering several competitive dimensions to support well-balanced decision-making. The planning methodology is based on the product documentation with connection documentation, a special kind of product and process documentation, since it is the most suitable method to cope with the consequences of variability in order planning and order processing. Some of the most important requirements listed above are further explained in the following sub-sections.

4.2.1 Integration of Planning Views

The integration of different planning views means that not only quantitative aspects should be incorporated in planning considerations but also qualitative factors, which are at least as important. In the developed planning methodology for customer-neutral orders, quantitative factors refer to capacitive and monetary considerations. In contrast, qualitative planning aspects focus on the immaterial value of customer-neutral planned and manufactured products in terms of the market attractiveness. The higher this is, the better is the chance to find an end consumer at short notice. High market attractiveness ensures that the economy of scale which result from the acceptance of customer-neutral orders are not eliminated again by additional costs incurred due to warehousing, capital investment in stock, technical obsolescence, and additional discounts granted to facilitate unloading stock products.

Thus far, no suitable procedure or method exists to fulfill the multifaceted requirements satisfactorily and enable well-balanced decision-making for planning of customer-neutral orders. Instead, stock orders are typically planned by the various sales units (e.g. distributors, dealers), characterized by a lack of sufficient information transparency, for example about existing and unsold stock products. Furthermore, a coordination of the decentralized planning activities does not usually take place. A further insufficiency when planning customer-neutral orders is that the computation of the marketability and achievable contribution margins plays either no or only a subordinate role compared to the target capacity utilization. Consequently, in spite of the fact the desired economy of scale can be achieved with customer-neutral orders, poor marketability leads to the production of stock products which are difficult to market and incurs additional costs. Yet to avoid the costs of stock products (e.g. capital investment in stock), it is essential that customer-neutral orders also be planned with respect to a qualitative perspective: marketability.

In brief, the focus of interest is to ensure a manufacturing program for stock orders which meets market, cost, and manufacturability requirements. Figure 4.4 shows the perspectives in the developed planning methodology for customer-neutral orders. The integrated consideration of different planning perspectives within the planning methodology described in this research, contributes to more well-balanced decision-making and represents one of the most important distinction criterion for the planning concepts in use at present.

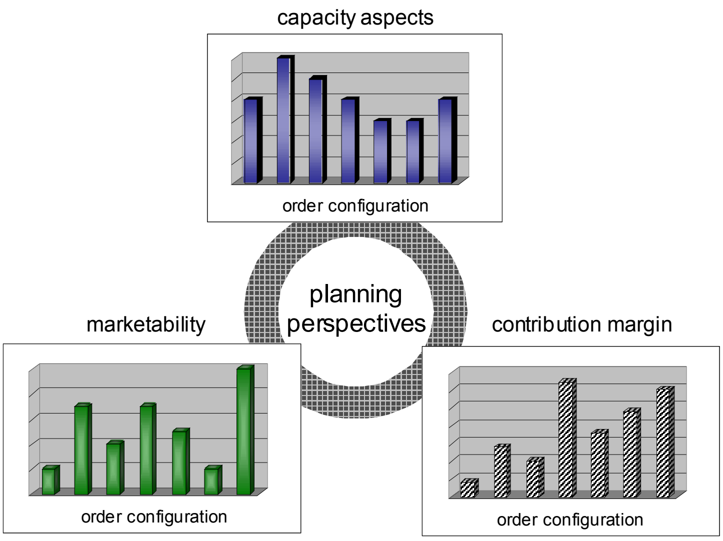


Figure 4.4: Views on Stock Order Planning.

4.2.2 Calculation of Contribution Margins

In the context of the short-term statements of income, the computation of the contribution margin on the basis of variable costs should direct short-term production and sales decisions. Thus, it is also an appropriate guideline (planning perspective) for decision-making when planning customer-neutral orders. Meaningful decisions as to the production program maximized to profit can be made only on the basis of the contribution margin. This is because the risk and difficulty of an inappropriate accounting of fixed cost to the cost object, e.g. a product unit, according to the cost-by-cause principle can be avoided.

The calculation of the order-specific contribution margin calls for three main components:

- Variable material costs.
- Variable manufacturing costs.
- Sales price of the end product.

In the underlying context, variable material costs and variable manufacturing costs vary with the production quantity either in the same proportion (proportional costs) or else faster (progressive costs) or slower (degressive costs) than the output. The sales price is the price to be paid by the customers for the end product. Both the variable costs and sales prices of the different materials, parts, and products are not calculated in this research. Instead, this information is taken over as known values from the company-internal Departments of Cost Accounting and Product Calculation. In order to be able to calculate in detail the order-specific contribution margins in connection with the given sales prices, the variable material and manufacturing costs are assigned directly to the respective information elements of the underlying product and process documentation. The subsequent transformation of primary requirements into secondary requirements by means of the product and process documentation (requirements planning) enables the computation of the order-specific contribution margins, which is integrated into the planning methodology in terms of a decision guideline (planning perspective).

For the computation of the total contribution margins of the product variants it is assumed - due to a weak customer demand which is the crucial reason for the planning and production of customer-neutral orders - that no bottlenecks of material and manufacturing capacities exist in one piece flow production. Instead, it can be assumed that over-capacities in all manufacturing sections exist in the underlying planning period. These result from the difference between the harmonized capacities, which are planned in long- and mid-term program planning (on the basis of anticipated sales figures and orders) and afterwards established in production, and the capacities needed to manufacture the products according to the customer orders which are taken in hand up to the planning date. The harmonized part and manufacturing capacities are integrated as upper limits in the form of constants in the product and process documentation which builds the basis for the planning methodology for customer-neutral orders.

Seen from the quantitative planning perspective and the capacity premises of the long- and/ or mid-term sales and program planning, the ranking of the contribution margins of the different product variants decides which customer-neutral orders are to be planned and manufactured in the underlying planning period. The ranking results from sorting of the product variants according to the amount of achievable contribution margins.

4.2.3 Applicability to the Diversified Product Portfolio

Because of the change from a seller’s market to a buyer’s market, which has taken place in many industrial sectors or which is still arising, many companies are reinforcing the alignment of their product and service portfolio with the actual requirements in the markets. In order to fulfill the divergent customer demands in the various market segments in the best way possible, companies offer a strongly diversified range of products. In connection with the ongoing saturation of the mass markets, companies are also trying to capture profitable market niches, which leads typically to a further enlargement of their already diversified product portfolios. Short product life-cycles result in high dynamics within the range of products, due to various product changes.

At today's European automobile manufacturers, for example, Henry Ford’s production philosophy and the associated way of thinking to produce only a very limited number of product variants would probably have no chance in today’s markets. Nowadays, the nearly unlimited variety on the buyers level is based on permutations, in the case of car manufacturers, created by the possibility to combine various body types, with several engine types, body colors, upholstery, and optional equipment to manifold order configurations. On the final product level a real ‘variant explosion’ has thus originated, whereby the repeating frequency of identical products is often insignificantly greater than one. Some car manufacturers in the meantime offer meanwhile a comprehensive variety that, measured by the annual production volume and average product life-cycles of from 5 to 6 years, only a small percentage of the total technically viable product variants can be produced at all. Statistical evaluations done at the car manufacturers' illustrate this trend of an increasing product diversification which has been observed for several years now. The variety on the final product level and the divergent order structures with respect to the various order configurations also boost variety on the part level. Undoubtedly, parts and assemblies which are independent of the customized order configuration and which are mounted in many vehicles do exist, but the predominant portion of the components are determined by the optional equipment selected by the customers. On the average, approx. 4,000 to 8,000 parts are installed in a vehicle.

Consequently, a key prerequisite for the development of a planning methodology for customer-neutral orders is the transparent representation of the existing variety. That means that an appropriate kind of product and process documentation has to be selected to enable both the efficient management of variety and also the order-specific requirements planning for the extensive product portfolio. If customer orders over the respective planning period are taken into account up to the date of planning the customer-neutral orders, the available capacities, i.e. those not utilized in production of the customer orders, can be identified by means of order-specific requirements planning. The opposite conclusion is thus derived: an incorrect product and process documentation makes it impossible to plan customer-neutral orders of high quality, i.e. to ensure a trouble-free order processing without any cost-intensive process interferences.

4.2.4 Simulation of Different Planning Situations

The planning of customer-neutral orders takes place in regular time intervals, whereby both the underlying customer demand (order situation) and the company-internal guidelines may have changed, compared to previous planning periods.

A change in the order situation influences not only the material and manufacturing capacities which are available for planning of customer-neutral orders and the achievable contribution margins (quantitative perspectives) but also the computation of the market attractiveness of the various order configurations (qualitative perspective). For example, the following situation may occur: in a previous planning period, a specific product variant was planned according to the available capacities and the assumed marketability at that time. However, these customer-neutral manufactured products could not yet be sold, because of an unpredicted market trend.

This new, unfavorable situation must be taken into consideration in the next planning period, as it is not beneficial to plan further orders with these product characteristics (configuration), since the probability of marketing these new vehicles as long as stock products from earlier planning periods remain unsold would be extremely low. Therefore it must be possible to regard the different order situations of the respective planning periods and to evaluate them within the planning methodology to be developed.

Moreover, the strategic priorities and planning guidelines of management may also have changed. It is conceivable that the achievable contribution margins can be decisive in the current planning period, whereby in the following planning period high market attractiveness is of particular importance, making a loss of contribution margins an acceptable trade-off. Quite conceivable is also the situation that marketing policy considerations might kill an order configuration, i.e. a product variant, which had thus far been regarded in the planning process. Consequently, this order configuration must not be available for the planning of customer-neutral orders in future. Changes in market demand, the priorities, and targets appear in manufacturing companies time and again, so that the planning methodology requires an appropriate flexible conception to be able to support different planning situations.

4.3 Summary

The principal guideline that cannot be influenced in the short-term planning of customer-neutral orders are the targets prescribed by the management as well as the material and production capacities which have been harmonized between Sales and Production within the scope of long- and mid-term program planning.

Within the planning methodology, the market-driven pull principle, and thus the customer orders, has top priority compared to the customer-neutral orders (push principle). This objective is considered in the methodology introduced by planning stock orders only for the material and manufacturing capacities which are not utilized with customer orders. The purpose of the planning of customer-neutral orders is to utilize capital-intensive resources and capacities of an automobile producer to realize economy of scale and to balance difficult-to-forecast market fluctuations. Stock orders are regarded as instruments to avoid a sub-optimal deviation from the primarily planned, capital-intensive capacities.

Figure 4.5 depicts an overview of the context and main aspects of the planning methodology. The product documentation with connection information enables the relevant components needed to build the customer-specific products as per the respective customer orders in the planning period to be identified. The comparison of the identified requirements with the harmonized material and manufacturing capacities, which are included as information in the product documentation with connection information, enables the identification of the available capacities, i.e. capacities not utilized with customer orders, in the planning period. This discrepancy, which may result from a decline in market demand, is balanced with customer-neutral orders.

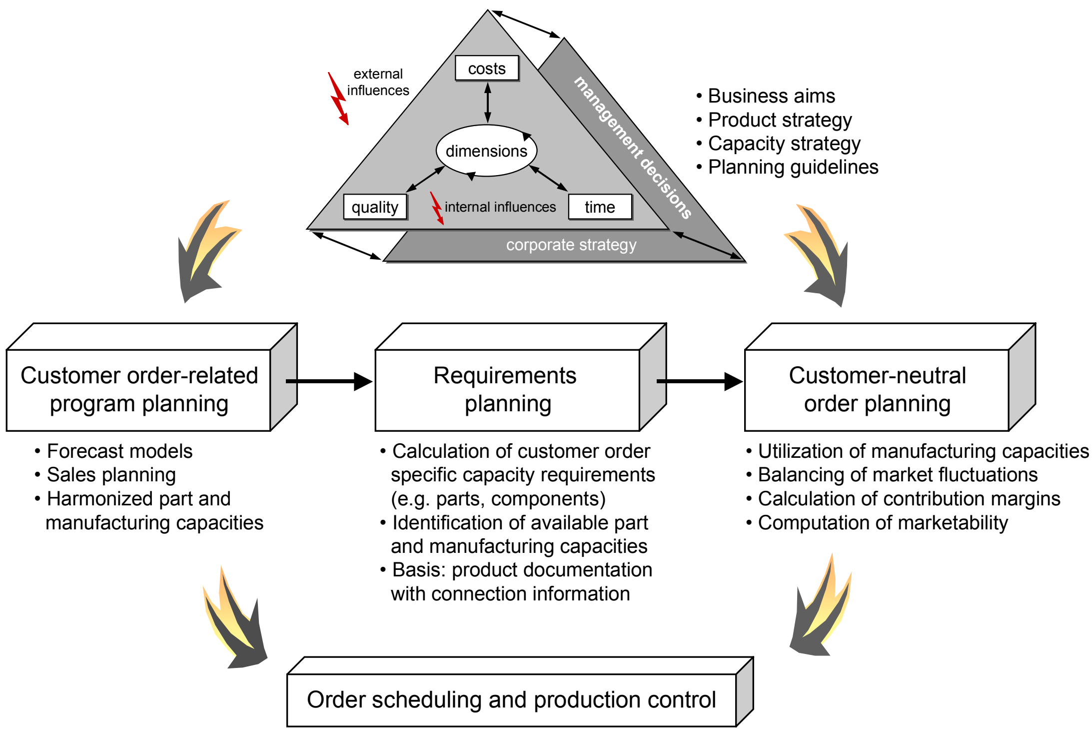


Figure 4.5: Context of the Planning Methodology for Customer-neutral Orders.

In order to support well-balanced decision-making and to avoid a rise in additional cost caused by stock products which are difficult to market, several planning perspectives are integrated in the methodology. Not only are quantitative planning aspects such as capacities or contribution margins considered but also a qualitative factor, the marketability of stock products, is calculated in parallel.

The conclusive decision as to which stock orders should be produced is actually made by the sales planner. This is because the Production Department has, of course, planned the resources and capacities within the scope of long- and mid-term program planning based on the product life-cycle forecast and the related sales figures. Consequently, the Sales Department has to assume any responsibility for a misinterpretation of the development of customer demand and to waive contribution margins if it should be necessary. After the planning of customer-neutral orders is finished, all orders of the planning period, i.e. customer orders and customer-neutral orders, are scheduled and automatically delivered for further processing to Order Control and Production.

This outlined rough concept of the planning methodology for customer-neutral orders is described in detail in the following chapter.

Chapter 5

Design of the Planning Methodology

5.1 Product Documentation with Connection Information

Due to increasing customer orientation, industrial companies and many European car manufacturers, in particular, offer a comprehensive product range to their customers. This allows customers to configure a product according to their individual requirements and wishes. Various product functions, i.e. product characteristics, can be selected and combined with other product characteristics from the wide product portfolio to build an individual product. This combination process is called product configuration (see chapter 2.5). The individual combination of various product characteristics results in customer-specific order configurations. Thus, an order configuration corresponds to a product variant. These terms are hence used synonymously in this research.

In order to be able to identify the differences in the various product variants (order configurations) on the part level and to consider them when planning customer-neutral orders, the applied product and process documentation method has to be elaborated in detail. In this research, the planning methodology is based on the product documentation with connection information. It describes not only the products and parts but also the relations between the parts. Furthermore, it contains the information about production processes and resources that is relevant to build the different product variants. By means of the documented relations on the part level, not only does it become possible to identify the order-specific secondary requirements, in terms of structural product information, but also information about the relevant production processes and resources is immediately available.

First, various aspects of product variety on the part level are introduced in order to illustrate the way in which the product documentation with connection information is established, since it serves as the information backbone for the planning methodology. Then, the documentation of planning parameters and order-specific requirements planning are discussed. Finally, the actual planning methodology for customer-neutral orders is elaborated in detail.

5.1.1 Documentation of Product Variants and Parts

In the context of product documentation with connection information, each final product, i.e. each product variant, is described as a net of parts. This part net results from the manufacturer-specific structuring of a product. Figure 5.1 shows a schematized representation of a product variant as net of parts which are connected with each other.

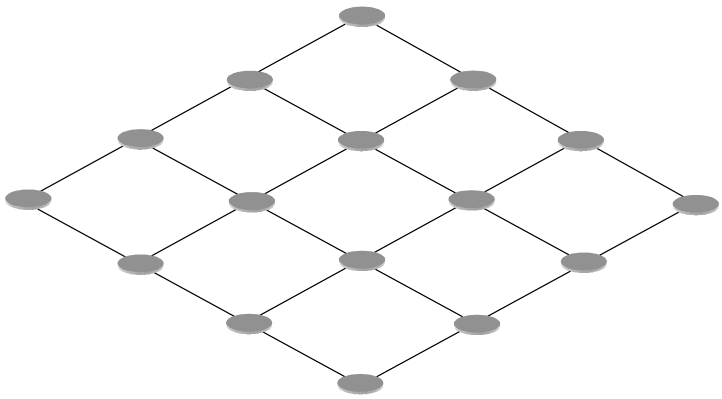


Figure 5.1: Product as a Net of Parts.

In contrast, figure 5.2 illustrates two different product variants. In this case, the product variety results from the fact that one part is substituted by another part, so that both product variants differ solely in one position in the product and in one part. Which part is to be mounted in the product depends on the specific order configuration. This, of course, has nothing to do with the applied method of product and process documentation. The darker illustrated alternative part is only mounted in the respective product according to the specific order configuration, i.e. the product characteristics which have been selected either by the customer or by the sales planner.

While it is more meaningful to represent the alternative parts in a common documentation than to separately describe each producible product variant of a manufacturing company, e.g. an automobile producer, due to the multiplicity of product variants, it is certainly more advantageous to control the alternative parts merely via the influencing product characteristics, for example by means of codes, and not on the basis of the complete, separately documented product variant.

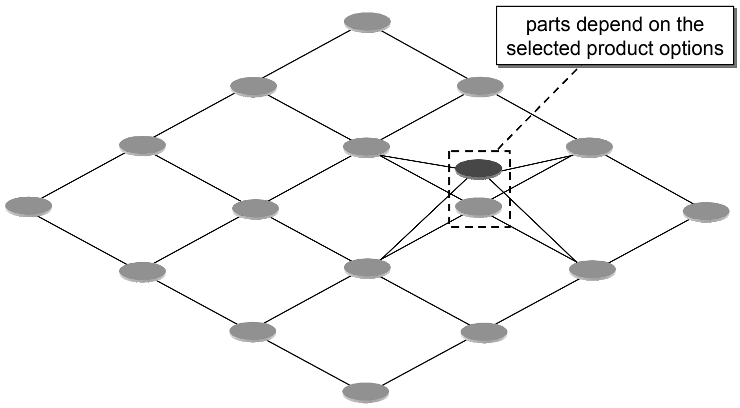


Figure 5.2: Product Variants.

If the product characteristics represent more complex product functions, then many more alternative parts are affected by these product features, which are selected in the context of product configuration. Figure 5.3 depicts two product variants with several different alternative parts. In this case, it is not only one part that has to be substituted by another part, but rather several alternative parts have to be mounted at different locations in the later final product according to the order configuration. Yet in this case also it is more beneficial to control only the affected parts by means of the corresponding product characteristics, instead of being forced to represent the whole product variant in a separate documentation.

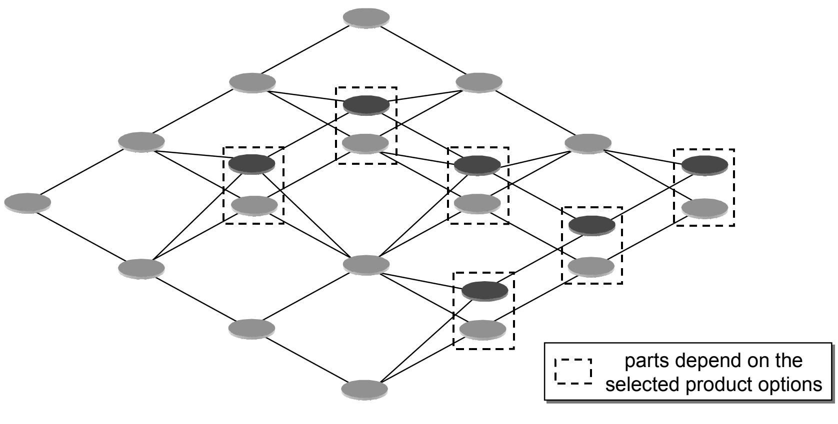


Figure 5.3: Order-specific Parts.

Within the product documentation with connection information, the end product is subdivided into part positions and is represented by them without overlapping (figure 5.4). In this context, each part position has a unique position ID which clearly refers to an actual geometric or functional position, i.e. where the part is to be mounted or installed in the later product. Thus, alternative parts mounted at the same position are bundled in the same part position.

A specific part which is to be placed in the product at the location corresponding to the part position is called a part position variant. As the examples above have shown, the selection of a part position variant is contingent on the order configuration. For each product, only exactly one variant, and therefore only one part, can be selected from each part position. Of course, more than one part cannot be installed at the same position in the product. Underlying the terminology of object-oriented modeling, part positions represent classes, whereas variants of the positions can be regarded as instances of these classes.

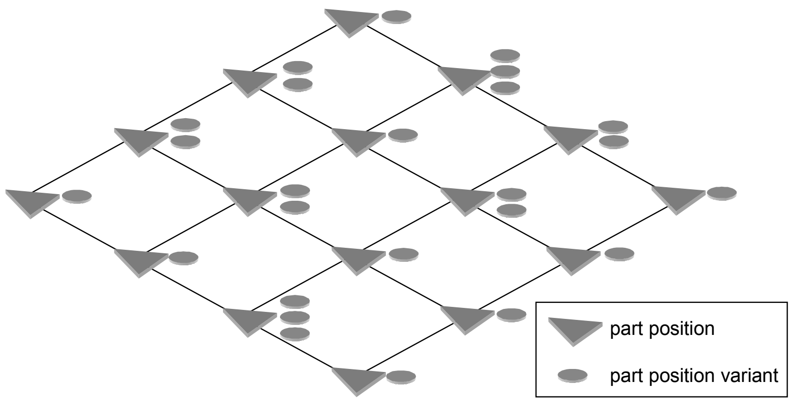


Figure 5.4: Net of Part Positions and Part Position Variants.

5.1.2 Creation of the Part Net

The development of the part net starts with the introduced structuring of the product into part positions, i.e. in geometric and functional locations at which a specific part is installed according to the selected product options and configured product.

After the product has been completely and non-redundantly structured into part positions, the design engineers responsible for the different part positions identify the product characteristics which cause variety on the part level. Then, they begin with the development of the first part position variant. The part position variant which is developed first is independent of the product characteristics and thus represents the standard part of the part position. However, in industrial practice, further part position variants often exist in a part position, depending on product characteristics, and are thus affected by the order-specific product configuration. For example, for the product options ‘comfort suspension’ and ‘sports suspension’, different physical parts, in this case, different shock absorbers have to be mounted in the products (which might influence the involved assembly processes), because the manufactured product needs to correspond to the desired order characteristics.

relevant options for part position

product option	code
X1	C1
X2	C2
X3	C3

position-specific code rules

C1	C2	C3	code rule
0	0	0	;
0	0	1	C3
0	1	0	C2
0	1	1	C2+C3
1	0	0	C1
1	0	1	C1+C3
1	1	0	C1+C2
1	1	1	C1+C2+C3

Figure 5.5: Possible Position-specific Code Rules.

At each part position variant within a part position, a respective manufacturing condition is documented. The part position-specific manufacturing conditions, the so-called code rules, result from the combination of the product characteristics determined as variety drivers for each part position. Figure 5.5 illustrates possible code rules which result from the various combination possibilities of three product options and which are used to document the specific producibility condition at each part position variant. If all product options can be combined with each other, 2^3 combinations and thus, of course, also 2^3 different code rules result for this part position. The binary representation of combinations of the product options in the rows are transferred into code rules such that each digit '1' is replaced by the specific code, whereas the digit '0' is omitted. Basically, the code rule of the standard part is represented as ';'.

Before further details about the permissible code rules in a part position are described, the different structures of a code rule are elaborated.

In its simplest form, a code rule consists of a single code (e.g. 'C1') which corresponds to a product characteristic (e.g. comfort suspension). Figure 5.6 illustrates a part position with three part position variants in total and the different code rules which each consist of a single code. The second part position variant is used for an order which contains the product option 'X1' (code 'C1'); in contrast, the third variant is mounted in a product, if the order configuration comprises the product option 'X2' in the form of code 'C2'. Consequently, the first part position variant is always of relevance, if both other part position variants may not be installed in a product due to the specified product configuration.

part position		
variant	part number	code rule
position variant 1	A 114 548 01 12	;
position variant 2	A 114 210 02 04	C1
position variant 3	A 114 422 05 23	C2

Figure 5.6: Single Codes as Code Rules.

A code rule may also consist of several single codes which are connected by means of logical operations. In this context, the Boolean algebra '+' (AND) and '/' (OR) are used to link the codes with each other. Figure 5.7 shows a part position with three part position variants. The second part position variant is mounted in a product if the order configuration contains the product options with both codes 'C3' and 'C4'. The third part position variant is selected if an order either contains the product option with the code 'C5' or the product option encoded as 'C6'. The linking of codes by means of the logical operation 'OR' is always referred to as an exclusive, ensuring that the code rule is unique and unambiguous. For all other order configurations, the first part position variant will automatically be identified in the context of requirements planning.

part position		
variant	part number	code rule
position variant 1	A 134 184 11 26	;
position variant 2	A 134 345 03 14	C3+C4
position variant 3	A 134 422 14 02	C5 / C6

Figure 5.7: Combination of Single Codes to a Code Rule.

A code rule may also consist of single codes and code combinations. An example is depicted in figure 5.8. In the part position, two part position variants are documented. The second position variant, and thus part 'A 341 214 12 02', is mounted in a product if one of the following three conditions is fulfilled:

- The order configuration contains only the product option with code 'C3'.
- The order configuration contains only the product option with code 'C5'.
- The order configuration contains both product options with the codes 'C3' and 'C5'.

If none of these conditions is met, then the first part position variant in terms of the standard part with the code rule ';' is used for manufacturing.

part position		
variant	part number	code rule
position variant 1	A 341 210 34 12	;
position variant 2	A 341 214 12 02	C3 / C5 / C3+C5

Figure 5.8: Example of a Combined Code Rule.

In the following sections, the requirements to be fulfilled by the code rules which are used within a part position and thus documented at the position variants are analyzed. Moreover, this answers the question of how combined code rules are developed at the part position variants.

To ensure that requirements planning is unambiguous, it is essential that only one part position variant be selected in each part position and thus only one part mounted at each location of the later end product. For this reason, the responsible design engineer has to specify, for each part position variant, the applicable condition(s) for selection of the variant, in terms of a part. Otherwise a biunique selection of the parts needed to build a product is not assured. Therefore, the part position variants documented within a part position must be mutually exclusive. In order to guarantee this, an exclusive 'or'-relation exists between the part position variants. This is realized and controlled by means of the documented code rules for each part position variant. Consequently, the position-specific code rules, which result from the specification and combination of product characteristics, may be used only once for one part position variant within a part position. In practice this prerequisite can be fulfilled by means of a supporting DP system. Automatic updating of the position-specific code rules, such that only codes rules which have not yet been used within a part position can be selected, may prevent the design engineers and documentation specialists from making serious mistakes in product documentation.

Combined code rules at a part position variant occur if more than one product characteristic or if even several different combinations of product characteristics serve as variety drivers in a part position. If the usage of a part position variant, i.e. of a part, depends on at least two product characteristics, then their codes will be joined to the position-specific code rule by means of the Boolean AND-operator ('+'). This code rule is then documented at the corresponding part position variant. In contrast, if different combinations of product characteristics are mutually independent, but relevant for the later selection of a part position variant, the encoded order characteristics are joined by means of the Boolean OR-operator ('/') to the respective code rule.

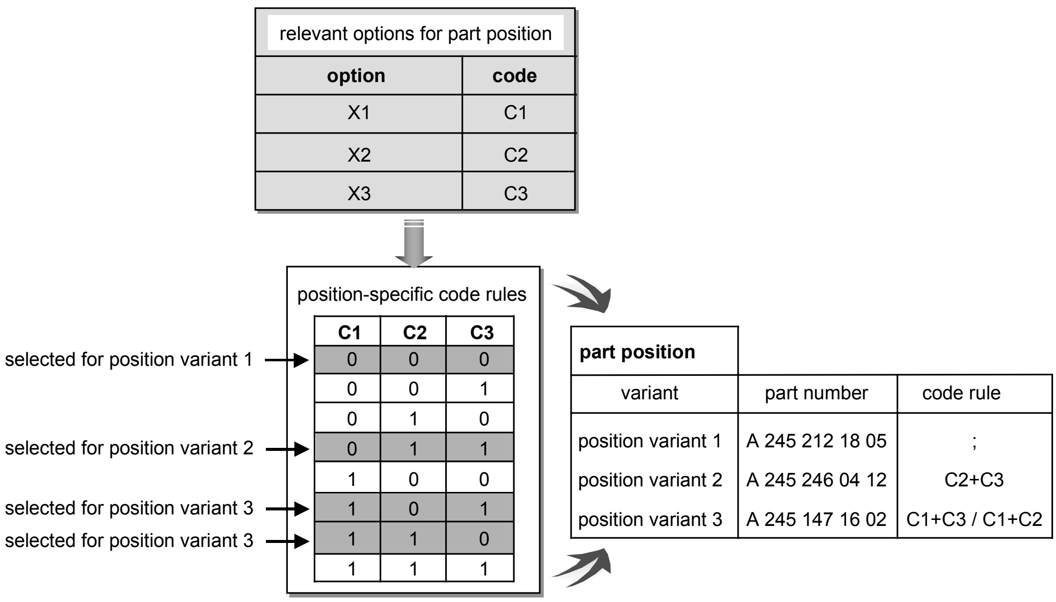


Figure 5.9: Mutually Exclusive Part Position Variants.

Figure 5.9 illustrates the aforementioned explanations by means of an exemplary part position. Based on the identified product options ‘X1’, ‘X2’, and ‘X3’, which cause the product variety on the part level within this part position, the permissible configurations of product characteristics are listed in the form of position-specific code rules. Also, the combined code rules are shown for the different part position variants.

The first part position variant represents the standard part. For the second part position variant, the code rule ‘C2+C3’ is documented: this means that this variant is selected if an order contains the product option ‘X2’ and the product option ‘X3’ within one order configuration. The usage of the third part position variant in production hinges on several, mutually independent combinations of product options. The code rule ‘C1+C3 / C1+C2’ indicates that this part position variant is needed to manufacture a product, if an order configuration either contains the encoded product options ‘C1’ and ‘C3’ or the product options with the codes ‘C1’ and ‘C2’.

5.1.3 Dimension of the Part Net

The part net should comprise each possible product variant of a manufacturer and, thus, all the part positions and part position variants which have been developed by the design engineers. In this case, a single comprehensive part net for all product brands of a manufacturer would exist.

Of course, also other criteria such as the product type or the model series could serve as the structuring level of a part net. However the choice of a deeper structuring level increases the number of part nets within an industrial company, increasing the effort required for preparation, administration, and maintenance of the part nets. Furthermore, with each additional part net the risk of data redundancy also grows significantly and, with it, the related effort for change management in product design and documentation. The identification of cross-model standard parts hence becomes more complicated due to a lack of or limited data transparency. In addition, the development of cross-brand platform concepts for new products and the reinforced use of common parts would become more difficult and unrealizable to the required extent. This is because of possibly different methods of product structuring and documentation of the part nets, in terms of the definition of the part positions, and due to the nonexistent common grounds regarding the product components and structures. In this case, the potential of cost reduction associated with a comprehensive part net at a manufacturing company will be only partly exploited or not at all. Thus, many automobile producers strive to standardize their documentation processes and DP system according to the slogan: be as uniform as required with as many degrees of freedom as possible.

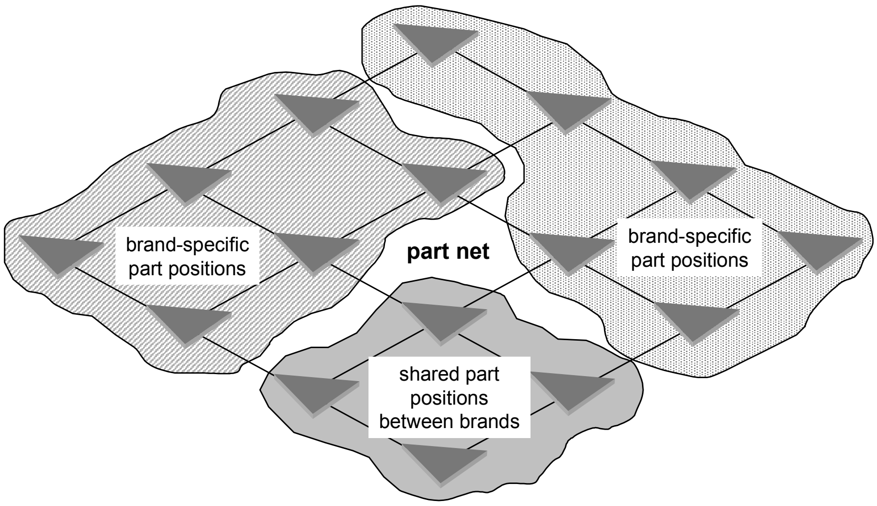


Figure 5.10: Cross-Brand Part Net.

Due to the reasons mentioned above, it would seem more beneficial to develop only one cross-brand and inter-model part net in the future (figure 5.10). Of course, this part net can be stored and managed in a decentralized way to promote clearness and ensure data security as long as the interdependencies, i.e. relations between the part positions, are kept and thus the integrity of the part net is guaranteed.

However, the fact should not be neglected that only one part net and the linked standardization of working methods and processes also reduces the existing and partly favored degree of freedom in product development and documentation. In addition, the responsibilities for the definition of part positions, the coordination of the development activities, and administration of the part net (e.g. geometric changes to parts) must be clearly defined. It is moreover necessary to reorganize the data exchange in cross-brand and inter-model series development cooperations.

5.1.4 Connection Positions

Considering that, in the sense of producing variants, the manufacturing process of end products is no different than a connecting of various parts, the introduction of so-called connection positions logically results. In principle, the connection positions are identically structured to the part positions. Connection positions link part positions which are in a physical or functional relationship with one another. A physical relation between parts exists, for example, if a vehicle seat is fitted using a mounting rail at the intended geometric location in the passenger compartment.

In contrast, a functional relation between part positions exists if no physical connection between the part positions and the assigned part position variants exists, but if the common consideration of them is useful according to the current use case. For example, a specific calculation task may serve as the basis for a functional relation between part positions. In such a case, the part positions, and of course their position variants (i.e. parts), are bundled by functional relations. The functional relations enable the consideration of all relevant part positions and the calculation of them as a whole. The calculation scheme for the connection positions can hence be reduced to a simple, automated addition of cost information which is documented at the variants within the part positions.

By inclusion of connection information, the part net as described in the previous sections is broadened. Thus, no conventional structure of a bill of materials which only comprises product-descriptive information arises; the product is rather represented as an information net of part positions and connection positions (figure. 5.11).

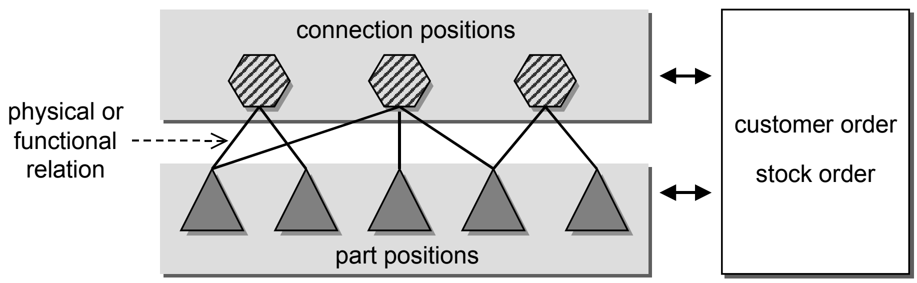


Figure 5.11: Connection and Part Positions.

The activities and processes which according to the order configuration are relevant for the manufacturing of the specific product are arranged around the relevant connection positions. This takes the fact into account that, after product design and/or procurement of components, all further activities of the production process visibly group themselves around the connection of parts (figure 5.12). By means of connection positions the subsequent process and resource information, among other things, can be represented: applied manufacturing methods, technological process data, information on the manufacturing resources, control information, and technical performance figures of machines.

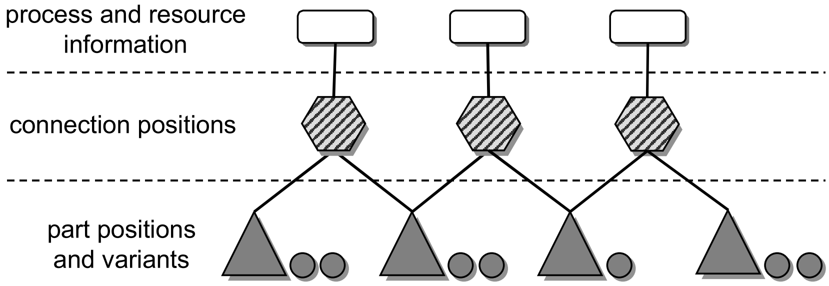


Figure 5.12: Connection Positions as Information Carriers.

A process-oriented view on the part and connection net arises as a result of additional documentation of the priority graph. The priority graph indicates the sequence in which the connection positions, i.e. the connections between the parts, are to be made in the production process due to logical reasons and/or facets of product design and manufacturing. The adjustment of the order of the connection positions to manufacturing-specific conditions (e.g. dimensions of production halls, technological defaults of machines) represents the actual manufacturing sequence of a product. Thus, the sequencing of the different connection positions corresponds to the direct documentation of the manufacturing process of a product (figure 5.13).#

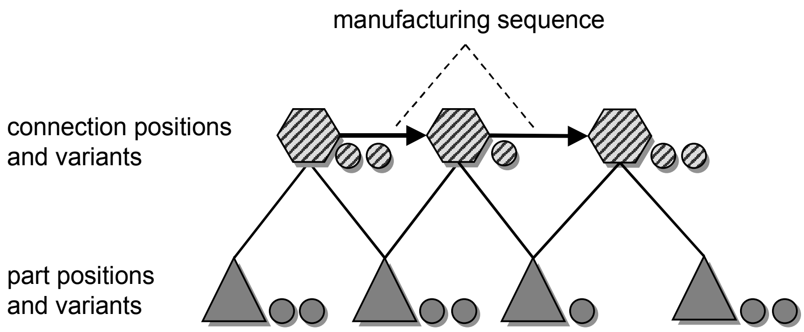


Figure 5.13: Manufacturing Sequence of a Product.

5.1.5 Connection Position Variants

Similarly to the part positions, it is possible to define variants within a connection position. A connection position variant represents a concrete value of a connection position and refers to part position variants either of different geometric locations in the end product or which are related to each other functionally.

Basically, a connection position variant in terms of a connection can be induced by a part, process or resource. A part-induced connection position variant exists if different part position variants are linked with each other. Often a connection position variant, i.e. connection, can be utilized for several combinations of part position variants. This is the case if different part position variants are linked with each other, but the connection itself is established using the same manufacturing methods and manufacturing resources. However, in this context, the prerequisite is that the part position variants can be unambiguously identified and controlled by their code rules. If this can be assured, the documentation of the activities and the related functions are reduced to a singular representation within the respective connection position.

In contrast, if part position variants (i.e. parts) are connected in the production process by means of different manufacturing methods and/or resources, several connection position variants which refer to same part position variants invariably exist within a connection position. For example, this is the case if a new manufacturing method such as the gluing of security-relevant parts is permissible in some markets, but prohibited by legislation in others. In this case, the same parts (i.e. part position variants) are mounted in the products in all markets, but this must be carried out using different manufacturing methods and resources. The resulting additional connection position variants within the corresponding connection position are thus caused by different manufacturing methods and/or resources.

Case 1 in figure 5.14 illustrates a connection position with one position variant, whereas case 2 shows the same connection position but with a second connection position variant. Furthermore, the connection position depicted refers in both cases to two part positions with one part position variant for each. The connection position variant in case 1 results from the connection of two parts (i.e. part position variants). In contrast, the second case shows a further connection position variant which is process and/or resource induced, since no additional part position variants exist in the linked part positions.

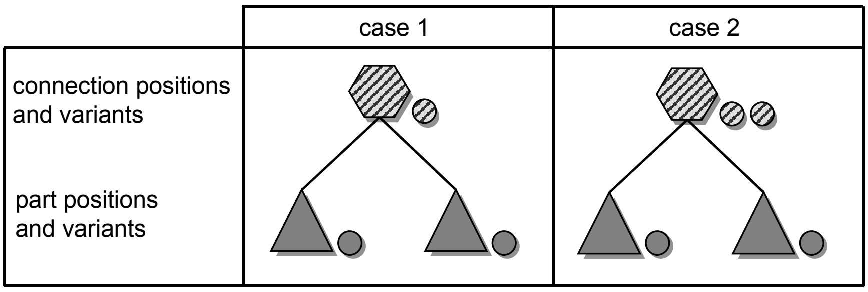


Figure 5.14: Connection Position Variants.

5.1.6 Classification and Documentation of Planning Parameters

Information which is needed for the planning of customer-neutral orders can basically be assigned to the positions and/or their documented variants in the form of attributes. This is true for both the part positions and connection positions. Figure 5.15 indicates the universal information structure within the product documentation with connection information.

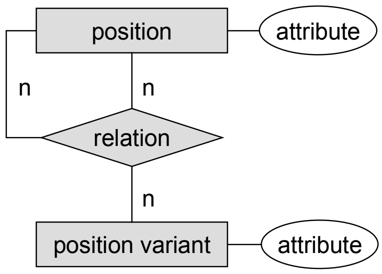


Figure 5.15: Universal Information Structure.

According to the universal information structure, it is possible to document the discussed manufacturing sequence of a product by means of an attribute at the connection positions. In addition, process and resource information which is useful for the production of the various part connections can also be assigned as attributes to the variants within the connection positions. Furthermore, at each connection and part position variant it is possible to document whether the variant is part, process, or resource induced. This information can be used to analyze and classify the existing product variety in a manufacturing company. This elaboration may contribute toward taking appropriate measures of variety management in order to reduce company-internal variety while simultaneously offering the external product variety demanded by the buyer's market.

Cost and capacity information which refers to materials or parts and which is, among other information, needed for the planning of customer-neutral orders is directly assigned to the corresponding part positions and position variants. Cost information comprises, for example, material costs and part costs, which either result from the procurement price to be paid to the suppliers or from the in-house manufacturing of the parts. Capacity information refers to the available quantity of materials and parts in the considered planning period.

The connection positions and connection position variants allow all information that does not directly refer to a part but instead to the connection of part positions and their variants to be classified and stored. For example, the manufacturing costs of a connection can be assigned to the relevant connection position variant. While the manufacturing costs result from the part-specific costs on the one hand, they also refer to the joining of parts and thus to their connection (figure 5.16). For the computation of total costs of a connection position variant, both the material and/or part costs assigned to the part position variants and the manufacturing costs documented at the connection position variants themselves have to be aggregated. The total material costs of a connection position variant result from the addition of the direct material costs and material overhead costs, which are stored in the form of attributes at the relevant part position variants. The total manufacturing costs of a connection position variant is the sum of the direct manufacturing costs and the manufacturing overhead costs.

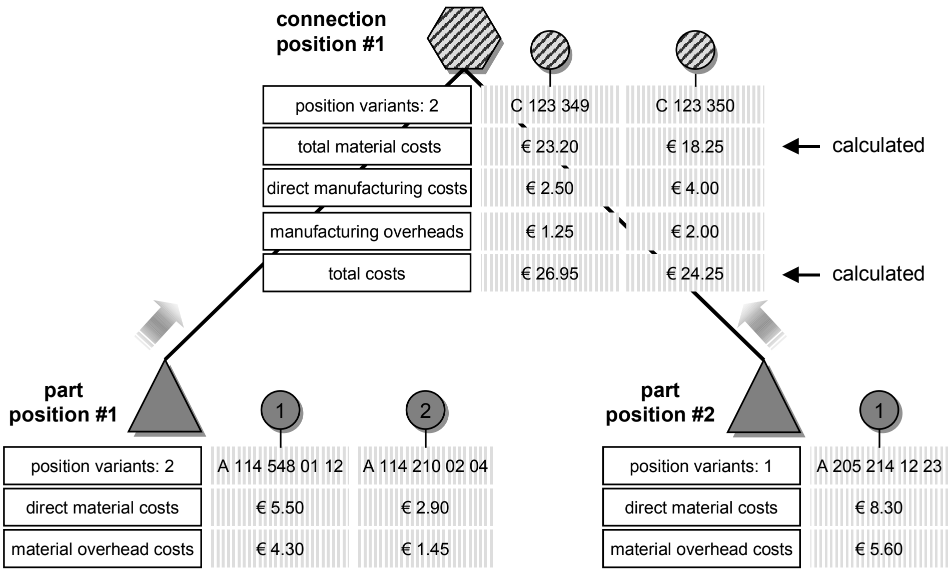


Figure 5.16: Example of Information Assignment.

A planning perspective for customer-neutral orders is the computation of the contribution margin for the order configurations selected by the sales planner. In order to calculate this, only the variable material and variable manufacturing costs which are documented at the part position variants and connection positions variants are considered. Consequently, overhead costs are not of interest in the context of stock order planning.

Attributes also allow restrictions to be documented at the connection positions and/or their variants. These restrictions represent limitations of the production process such as the maximum output of a manufacturing tool when balanced with the tact time specified for volume production. The information about the material and manufacturing capacities which is assigned to the part positions (variants) or connection positions (variants) is used for the planning of customer-neutral orders. Related to the available customer orders in a planning period, it is possible at each planning date of customer-neutral orders to identify the harmonized, free capacities which are to be balanced, since these capacities are not utilized by customer orders.

5.1.7 Order-specific Requirements Planning

Order-specific requirements planning means that for the primary requirement in terms of a product variant the secondary requirements are identified. The secondary requirements are the materials and parts needed to manufacture the product variant according to the order configuration. On the basis of product documentation with connection information, also information about manufacturing methods and resources is identified in requirements planning.

When a product variant is to be manufactured, a mapping algorithm is employed to identify the instances of the part and connection positions in terms of the right part position variants and connection position variants necessary to build the product. This algorithm compares the encoded product characteristics of the order, e.g. product type, upholstery, safety features, and in-car entertainment and communication devices, with the code rule of each documented part position variant. Aspects about the general specification and interpretation of code rules are set out in chapter 5.2.2. The mapping algorithm is used independently of the type of order, i.e. it is employed for both customer orders as well as for planning of customer-neutral orders.

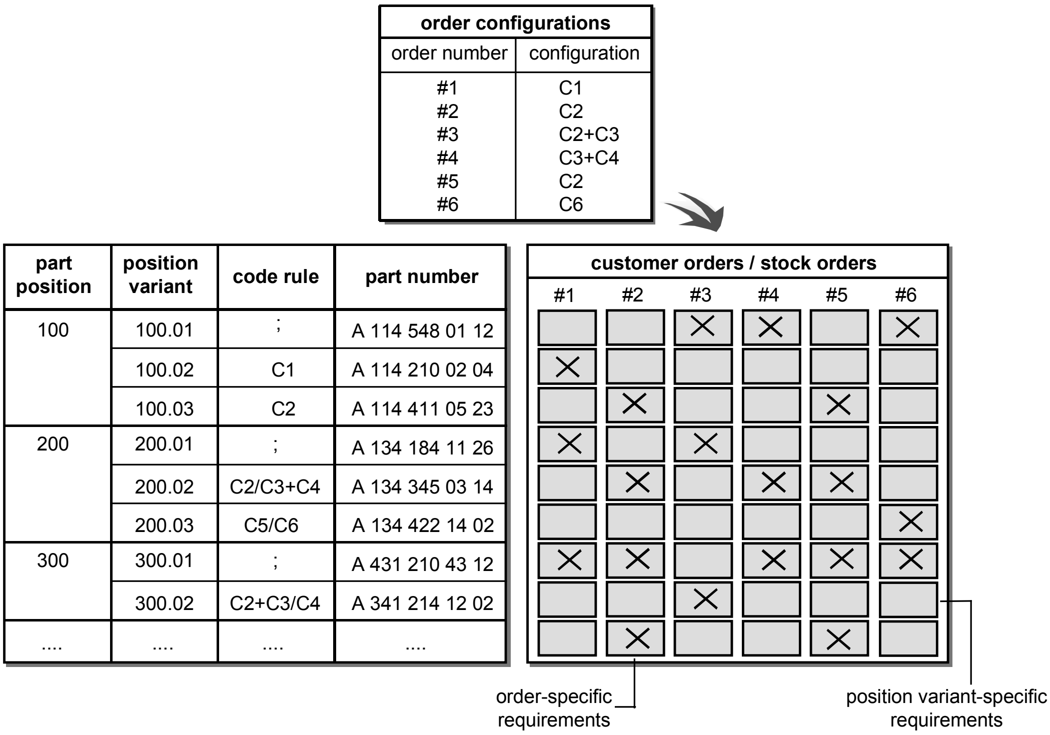


Figure 5.17: Requirements Planning.

The principle of requirements planning on the basis of the product documentation with connection information is clarified in figure 5.17. Shown are some orders with various configurations, a fragment of a bill of materials in terms of the part positions and their variants, and the order matrix, which contains the result of requirements planning. Within the order matrix, the part position variants and thus the parts needed to build the different orders and which are identified by the use of the mapping algorithm are marked with a cross. For reasons of unambiguousness as discussed, only one part position variant may be selected in each part position. Otherwise, if two or more parts were selected, they could, of course, not be mounted in the later product at the same position. For example, the comparison of the encoded order characteristics with the position-specific code rules of the part position ‘200’ leads to the result that various part position variants are required for the manufacturing of the following orders:

- The part position variant ‘200.01’ is required for orders ‘#1’ and ’#3’.
- The part position variant ‘200.02’ is required for orders ‘#2’, ‘#4’, and ‘#5’.
- The part position variant ‘200.03’ is required for order ‘#6’.

In order to identify the order-relevant connection position variants as well, two different possibilities basically exist. The first alternative applies a method similar to the above-described identification of the part position variants: the mapping algorithm compares the encoded order characteristics with the code rules of the part position variants and of the connection position variants. If a code rule corresponds to the order configuration, the respective position variant is marked. The second alternative is to identify the order-relevant connection position variants, i.e. connections needed to build the products, by means of relational knowledge which is documented at the part position variants. To do so, the individual part positions variants are assigned to the connection position variants when the part and connection net is developed. First, the part position variants are identified by the mapping algorithm of order-specific requirements planning. Then the related connection position variants can be identified via the defined relations to the part position variants.

On the basis of all part positions and connection positions, a specific set of requirements results for each order, representing the order-specific bill of materials with connection information. Furthermore, it is possible to calculate the required quantity of each position variant for all orders considered within a defined time period. This result can be utilized for company-internal process analysis or clustering into more or less frequently ordered variants, for example. In the context of customer-neutral order planning, the information on the position variant requirements is used to calculate the available, i.e. free, material and manufacturing capacities (see chapter 5.3.4). In brief, the product documentation with connection information contains functions from both a bill of materials and a usage list.

Hence requirements planning enables not only the determination of the parts and connections which are required to manufacture the various product variants but also the identification of relevant planning information which is assigned to the position variants in the form of attributes (see chapter 5.2.6). Consequently, information about material and manufacturing capacities and variable costs is available after the order-specific requirements planning has been completed. This information is used as input for the planning of customer-neutral orders. Requirements planning based on product documentation with connection information hence represents an integral part of the planning methodology in order to be able to realize the quantitative planning perspectives and thus support well-balanced decision making. Important prerequisites are that both the product documentation with connection information and the results of the requirements planning be not only correct but also up to date.

Similar to other methods of product and process documentation, the product documentation with connection information is also affected by manifold, frequently occurring changes. In particular, the diversified product portfolio is continuously subject to modification. For example, the design of new parts or the adaptation of existing parts affect the part position variants. This may result in the fact that either the validity of the part position variants used thus far will expire on a specific date, so that these position variants may not be deployed any longer in assembly or that new manufacturing conditions have to be defined by means of the code rules. Also, a modification of a part in product design, e.g. the geometry, may affect the number of valid, part-induced connection position variants. And, cost and capacity information which is stored by means of attributes may change from planning period to planning period. For all these reasons, ensuring a correct planning of customer-neutral orders necessitates that the requirements planning be carried out on the basis of up-to-date information and that it be integrated into the current planning process for customer-neutral orders.

5.2 Planning of Customer-neutral Orders

5.2.1 Possible Planning Procedures

Because of partly divergent business aims of the Sales and Production Departments, two different procedures for planning of customer-neutral orders are basically possible: production-initiated and sales-initiated planning.

The main objective of the production-initiated procedure is to automatically develop proposals for the planning and configuration of customer-neutral orders on the basis of the harmonized material and production capacities. In the first step, the part position variant and/or connection position variant that has the highest free capacity is identified. This position variant of the product documentation with connection information is the representative variant, i.e. clue for the next planning steps. Each documented position variant, and thus also the representative, is uniquely and unambiguously specified by means of a code rule. The code rule of the representative is employed to check the capacities of the other part position variants and connection position variants needed to build the product according to a specific order configuration. In so doing, special search techniques and algorithms can be applied to systematically evaluate the various code rules of the position variants in order to determine the number of manufacturable customer-neutral products of a specific order configuration. The top priority of the production-initiated approach is ensuring the steady utilization of the highest level-capacities which have been harmonized between the Sales and Production Departments the within the scope of long- and/or mid-term program planning and which cannot be adapted to a decline in customer demand to the required extent at short notice. However, the marketability of the different product variants is typically not considered as a planning criterion. Of course, this planning procedure can be applied to gain additional economy of scale, but because of the absent marketability of the stock products, these benefits would often be overshadowed by additional costs (e.g. capital investment in stock, discounts). Yet ensuring a high market attractiveness and fast marketability are two of the most important requirements placed on a planning methodology for customer-neutral orders to avoid additional costs in the order processing chain incurred due to technical obsolescence or additional discounts granted to unload stock products, for example. As a consequence, the production-initiated planning procedure is not further considered in this research.

Instead, the sales-initiated planning of customer-neutral orders is used in this research: in this procedure, the planning activities are strongly oriented toward the market demand (e.g. customer desires) in order to achieve the most favorable marketability of the customer-neutral planned products. Of course, the aim of assuring efficient capacity utilization is not neglected. However, further planning perspectives such as the marketability are integrated to promote well-balanced decision-making. The sales-initiated planning procedure is elaborated in the following sections.

5.2.2 Planning Dates

The planning of customer-neutral orders is part of short-term production program planning; yet, by no means may it be confused with the long- and/or mid-term market forecasts, i.e. of a prognosis method, or with job shop scheduling. The decisions made in long- and/or mid-term program planning serve as import input information for customer-neutral order planning: this input information defines the permissible and/or maximally existing degree of freedom for decision-making. Some examples of input information of preliminary planning processes are the prioritization of quantitative and qualitative planning perspectives and the material and manufacturing capacities which have been determined by means of fictive orders and prognosis methods within the scope of long- and/or mid-term program planning. The capacities which are afterwards harmonized by the Sales and Production Departments and the suppliers are installed in the production process in terms of manufacturing equipment and manpower, for example.

Based on the planned sales figures and installed capacities, an order quota is developed for each planning period. The order quota is a list which contains the number of orders which should be produced, i.e. target capacity utilization, and the actual number of available customer orders (figure 5.18). This information is grouped by the various product types. As a rule, most car manufacturers utilize a product type - an encoded, rough product description which contains information about the model series, body shape, type of engine, kind of steering system (LHD or RHD vehicle), and transmission. According to this definition, a product type does not contain details of the completely customized product (e.g. a passenger car), since it includes no further product information (e.g. about optional equipment).

product type	target capacity utilization	actual customer orders	need for customer-neutral orders
T 204 495 12	33	24	9
T 228 046 10	16	5	11
...	...	...	...

Table 5.18: Order Contingent.

The target capacity utilization, i.e. orders to be produced, can be adjusted to the current market demand to a certain extent within the flexibility thresholds. Therefore, the number of orders which are to be produced may differ from planning period to planning period.

Since the market-driven pull principle lies at the forefront of the planning methodology, customer orders have priority compared to customer-neutral orders. This is because customer-neutral orders are only planned for the capacities which are not utilized in handling customer orders in a planning period. The planning of customer-neutral orders hence takes place at the latest possible point in time: at the end of a planning period (figure 5.19). It is then that the number of customer-neutral orders of the various product types which are to be planned and produced is calculated. To do so, the number of customer orders is subtracted from the target capacity utilization, i.e. the target number of orders in the planning period. The resulting difference indicates the product type that the customer-neutral orders should correspond to. Consequently, this information is used as the starting point for the planning of customer-neutral orders. Requirements planning, however, must ensure that the demand determined for customer-neutral orders which is identified on the product type level is in fact producible in connection with the complete order specification.

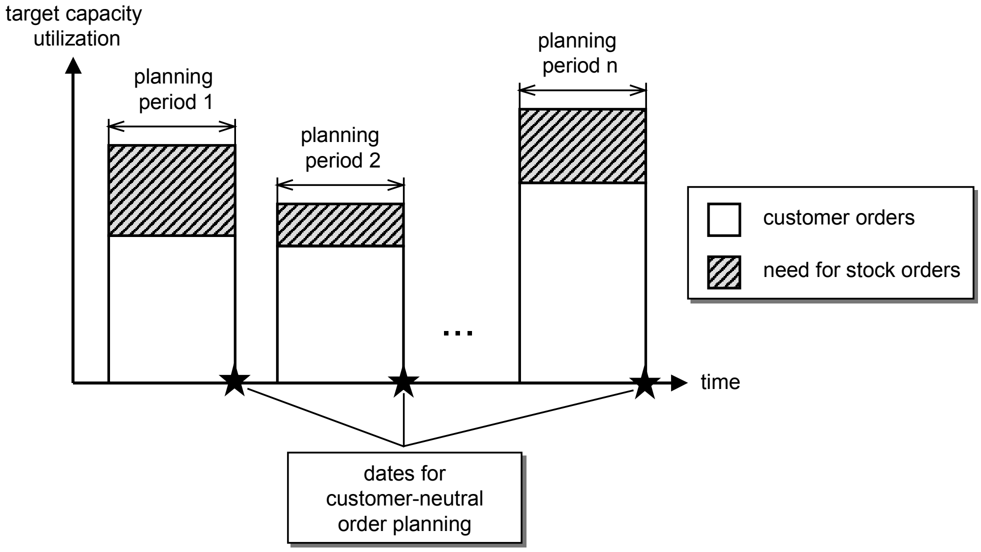


Figure 5.19: Planning Dates for Customer-neutral Orders.

5.2.3 Planning Process

The sales-initiated planning process for customer-neutral orders starts at the planning dates as set out in the previous section. Figure 5.20 presents a holistic view of the planning process to facilitate understanding of the following chapters. As background information, only the main process steps of the sales-initiated planning process are illustrated and explained briefly. The planning steps are described in detail in the chapters mentioned in the figure. In brief, the different planning steps comprise the tasks and activities set out below.

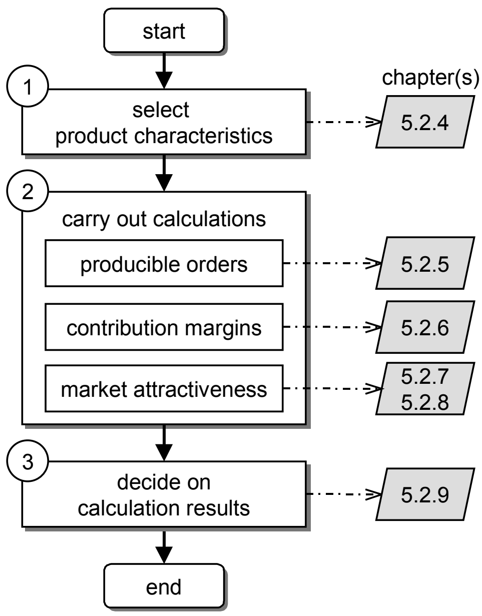


Figure 5.20: Flow Chart of the Planning Process.

In the initial planning step, the product characteristics, i.e. product type and product options, are selected by the sales planner for the customer-neutral orders. Then the sales planner selects the product variants of interest for subsequent planning steps from the set of the various order configurations. Focusing on the relevant order configurations has one advantage: the effort needed for calculation can be purposefully minimized in the planning methodology.

In the second planning step, the available part and manufacturing capacities and the number of producible stock orders of the previously selected order configurations are calculated. Then, the achievable contribution margins and anticipated market attractiveness of the various order configurations are computed.

On the basis of the automatically calculated results, the responsible sales planner of the market then decides which customer-neutral orders are to be scheduled and produced. This conclusive decision ends the planning process.

5.2.4 Selection of Order Characteristics

If customer-neutral orders are to be planned in order to balance fluctuations in customer demand, various order characteristics are also combined to an order configuration, similar to the ordering of a product by a customer. However, in this case it is the task of the sales planner to find the optimum configuration for the enterprise. This is because the later end consumer is not known at time when the planning of customer-neutral orders takes place.

At the planning date for customer-neutral orders, the sales planner first selects a product type. To do so, the sales planner utilizes the overview of the different product types which are listed in the order quota for this planning period and the demand for stock orders which is identified on the product type level as a clue for the planning of customer-neutral orders. With the selection of a product type, the customer-neutral orders to be planned are roughly specified, i.e. model series, body shape, type of engine, kind of steering system (LHD or RHD vehicle), and transmission. The encoded product type and the product options which are selected in the second planning step together form the product specification (order configuration).

Next, the product options are selected by the sales planner to complete the specification of the customer-neutral orders. Table 5.21 illustrates five product options of an automobile producer, which are encoded with the represented codes. Using these different product options for a product type, a comprehensible example of the number of the various manufacturable order configurations (product variants) can be derived. In combination with the exemplarily defined interdependencies between the several product options, the consequences for the number of manufacturable product variants, e.g. passenger cars, can also be clearly illustrated. This is done in the following three case studies.

Code	**Product option**
220	Tire pressure monitoring
401	Comfort ventilated front seats
485	Comfort suspension
486	Sport suspension
873	Heated front seats
...	...

Table 5.21: Example of a Product Option List.

In the first case it is assumed that no limiting manufacturing interdependencies exist and that all the listed product options can therefore be combined arbitrarily. This hypothesis results in 2^5 (= 32) manufacturable product configurations.

As stated in chapter 2.4.2, interdependencies between the various product options, i.e. product characteristics, frequently exist. If these relations are neglected in product configuration, conflicts regarding the manufacturability occur, so that orders, in the end, become not producible. Consequently, the case study described above with its premise of arbitrary configuration possibilities of the product options is, in industrial practice, the exception.

In the second case it is assumed that it is not permissible to combine all of the product options listed in table 5.21 with each other. Rather, the premise is taken that it is only permissible to select the product option 'comfort ventilated front seats' together with the option 'heated front seats' in an order. The coercive consideration of this producibility requirement limits not only the number of combination possibilities of the different product options but also the number of the producible order configurations, of course. Thus, in this case, only 2^4 (= 16) order configurations (product variants) are technically realizable – half the above quantity.

Additionally to the above-described manufacturing interdependency, in the third case a further coercive manufacturing conditions is assumed to be given: the product options 'comfort suspension' and 'sport suspension' are mutually exclusive in an order. That means it is only permissible to choose either one of these two product characteristics when configuring a product. Of course, this technical restriction again reduces the number of manufacturable product variants. That means in the concrete example, that only twelve variants are producible.

configuration list				
220	401	485	486	873
0	0	0	0	0
0	0	0	0	1
0	0	0	1	0
0	0	0	1	1
0	0	1	0	0
0	0	1	0	1
0	0	1	1	0
0	0	1	1	1
0	1	0	0	0
0	1	0	0	1
0	1	0	1	0
0	1	0	1	1
0	1	1	0	0
0	1	1	0	1
0	1	1	1	0
0	1	1	1	1
1	0	0	0	0
1	0	0	0	1
1	0	0	1	0
1	0	0	1	1
1	0	1	0	0
1	0	1	0	1
1	0	1	1	0
1	0	1	1	1
1	1	0	0	0
1	1	0	0	1
1	1	0	1	0
1	1	0	1	1
1	1	1	0	0
1	1	1	0	1
1	1	1	1	0
1	1	1	1	1

producible configurations				
220	401	485	486	873
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1

Figure 5.22: Producible Order Configurations.

Not only does figure 5.22 illustrate the various order configurations which are producible if no manufacturing interdependencies between the product options exist, it also gives the number of currently feasible product variants if the manufacturing interdependencies illustrated in figure 5.21 are observed. In the columns, the encoded, available product options are listed. Each row represents a specific order configuration. Order configurations which are not producible due to the assumed manufacturing interdependencies are gray shaded. The digit '1' means that the respective product option is selected for an order configuration; in contrast, the digit '0' indicates that the product characteristic is not part of the order configuration. The example depicted for a producible order configuration with the binary coding ‘1 1 0 1 1’ means the combination of the codes ‘220’, ‘401’, ‘486’ and ‘873’ is permissible from the point of production. It also means that use of the product option ‘comfort suspension’ with the code ‘485’ is prohibited, because in each passenger car, of course, only one type of suspension can be mounted.

Apart from the technical manufacturing interdependencies between product characteristics, other limitations which additionally reduce the number of order configurations actually offered to the customers also exist. These limitations include, among other things, country-specific legislation or modified marketing strategies in the various markets. For example, market-specific exhaust laws may result in the necessity to offer different combustion engines in the respective markets in order to observe the limiting values. Thus, the order configurations which can be selected by the customers may also vary according to the different laws, guidelines, and standards.

For the planning of customer-neutral orders, this means that the permissible order configurations for the market have to be identified with respect to the order characteristics chosen by the sales planner before further planning and calculation steps are initiated. This ensures that only currently valid order configurations are considered in succeeding planning steps. Moreover, it is useful if the sales planner selects from the set of identified, permissible order configurations exactly those configurations which are actually of interest for customer-neutral order planning, thus avoiding unnecessary calculation effort within the planning methodology. Otherwise, without the selection of order configurations by the sales planner, the entirety of the identified permissible and technical producible order configurations would have to be considered in the next planning steps.

Deviating from the above-described specification of customer-neutral orders by means of selecting the product type, product options, and relevant order configurations, it would also be thinkable to take all the manufacturable and permissible order configurations into account in the planning methodology. But this would mean in practice that the automobile manufacturer would have to consider several million possible order configurations within the planning methodology - a time-consuming and enormous planning and calculation effort.

5.2.5 Calculation of Configuration-specific Capacities

The material and manufacturing capacities which have been harmonized between the Sales and Production Departments within the scope of long- and/or mid-term production program planning are assigned to the part positions variants and connection positions variants by means of attributes. These given capacities which are to be utilized in the planning period serve as the foundation for the calculations to be carried out within the methodology for customer-neutral order planning (see chapter 4.2.2).

The available material capacity of a part position variant ($ac_{PPosV,t}$) is the difference between the target capacity ($tc_{PPosV,t}$) in the planning period (t) and the material requirements ($rc_{PPosV,t}$) needed to produce the customer orders which are available up to the planning date of customer-neutral orders:

$$ac_{PPosV,t} = tc_{PPosV,t} - rc_{PPosV,t} \tag{5}$$

A part (e.g. fastener) with the same item code can be used in several part positions. If this is the case, the total capacity of the relevant item code has to be allocated either fixed or variably to the relevant part position variants in the form of the target capacity ($tc_{PPosV,t}$). This can be done by means of a linear system of equations, for example.

The material requirements of a part position variant ($rc_{PPosV,t}$) results from the multiplication of the quantity coefficient of a part position variant (q_{PPosV}) with the number of times this part position variant occurs in building the customer orders in the planning period. The required part position variants are identified by means of the algorithm of order-specific requirements planning (see chapter 5.1.7). By definition, only one part position variant may be selected from each part position. The quantity coefficient indicates how many parts of a corresponding part position variant are required to manufacture a product.

However, the available capacity of a part position variant ($ac_{PPosV,t}$) which is calculated as stated above does not provide direct information about the number of producible customer-neutral orders ($cno_{PPosV,t}$) for the part position variant considered. The number of producible orders depends on the quantity coefficient of a part position variant:

$$cno_{PPosV,t} = \frac{ac_{PPosV,t}}{q_{PPosV}} \tag{6}$$

By comparing of the calculated numbers of producible orders for all part position variants required to build a product variant, the limiting material capacity ($pc_{lim,t}$) can be identified. This indicates the actual number of producible customer-neutral orders of this product variant (i.e. order configuration) from the point of view of the material capacity.

The computation of the manufacturing capacities of the connection position variants which are available for the customer-neutral order planning in the planning period is carried out similar to the calculation of the material capacities which are not utilized with customer orders up to the planning date. Of course, this requires that not only the part position variants needed to build the customer orders are identified but also the relevant connection position variants. These are identified by means of the order-specific requirements planning using the documented knowledge about the assigned part position variants (see chapter 5.1.7).

The available manufacturing capacity of a connection position variant ($ac_{CPosV,t}$) is the difference between the target capacity ($tc_{CPosV,t}$) in the planning period (t) and the manufacturing capacity ($rc_{CPosV,t}$) required to build the customer orders. Since the part position variants which are assigned to the connection position variants can only be connected with each other once in the manufacturing process, the quantity coefficient of a connection position variant is invariably one. Thus, from the manufacturing perspective, the available manufacturing capacity of a connection position variant ($ac_{CPosV,t}$) corresponds directly to the number of producible orders:

$$cno_{CPosV,t} = ac_{CPosV,t} = tc_{CPosV,t} - rc_{CPosV,t} \tag{7}$$

Comparing the calculated numbers of producible orders for all connection position variants required to build a product variant enables the limiting manufacturing capacity ($mc_{lim,t}$) to be identified. This indicates the actual number of producible customer-neutral orders of this product variant (i.e. order configuration) from the point of view of the manufacturing capacity.

The maximal number of customer-neutral orders ($n_{oc,t}$) which can be planned and produced with a specific order configuration in the planning period (t) is determined either by the limiting material capacity ($pc_{lim,t}$) or by the manufacturing capacity ($mc_{lim,t}$):

$$n_{oc,t} = Min\{ pc_{lim,t}, mc_{\lim,t} \} \tag{8}$$

with

$$pc_{lim,t} = \underset{PPosV,t}{Min}\left(cno_{PPosV,t}\right) \tag{9}$$

$$mc_{lim,t} = \underset{CPosV,t}{Min}\left(cno_{CPosV,t}\right) \tag{10}$$

Figure 5.23 illustrates the identification of the maximally producible customer-neutral orders for an exemplarily considered order configuration from both perspectives: the limiting material capacity and limiting manufacturing capacity. The exemplary order configuration contains only the encoded product characteristic ‘C2’. Using requirements planning, the necessary part position variants ‘100.03’, ‘200.01’, and ‘300.02’ as well as the connection position variants ‘C 100.02’ and ‘C 200.03’ are identified for this order. This position variants are marked with a cross in the figure. In this example, the lowest material capacity of twelve producible orders exists under the consideration of the quantity coefficients at the part position variant ‘300.02’. The lowest manufacturing capacity of eighteen producible customer-neutral orders is determined by the connection position variant ‘C 200.03’. By comparing of these numbers, it becomes obvious that at the maximum twelve customer-neutral orders with the product characteristic, e.g. a product option, ‘C2’ can be planned and produced in the planning period, since the capacity is limited by the part position variant ‘300.02’.

part position (PPos)	position variant (PPosV)	code rule	part number	quantity coefficient (qc)	available capacity ($ac_{,t}$)	producible orders	required for order
100	100.01	;	A 114 548 01 12	1	20	20	
	100.02	C1	A 114 210 02 04	1	25	25	
	100.03	C2	A 114 411 05 23	1	15	15	×
200	200.01	;	A 134 184 11 26	1	30	30	×
	200.02	C2+C3/C4	A 134 345 03 14	1	12	12	
	200.03	C5/C6	A 134 422 14 02	1	17	17	
300	300.01	;	A 431 210 43 12	2	20	10	
	300.02	C2/C3+C4	A 341 214 12 02	2	24	12	×
....	....	....	....	....	....	....	

lowest part capacity $pc_{lim,t}$

connection position (CPos)	position variant (CPosV)	code rule	connection number	producible orders	required for configuration
C 100	C 100.01	;	C 492 242	30	
	C 100.02	C1/C2	C 492 136	40	×
	C 100.03	C3+C4/C5/C6	C 492 675	20	
C 200	C 200.01	;	C 631 274	15	
	C 200.02	C3+C4	C 631 284	30	
	C 200.03	C2/C6	C 631 293	18	×
....	....	....	....	....	

lowest manufacturing capacity $mc_{lim,t}$

Figure 5.23: Calculation of the Number of Producible Customer-neutral Orders.

5.2.6 Computation of Contribution Margins

The calculation of the maximally producible number of customer-orders with respect to the limiting material and manufacturing capacities is the prerequisite for the computation of the total contribution margins for a specific configuration, i.e. product variant.

Within the product documentation with connection information, the variable material costs and variable manufacturing costs are assigned by means of attributes to the part position variants and connection position variants, respectively. This cost information already exists in the departments of an industrial company which are responsible for product calculation, cost accounting, and controlling. Thus, it is not necessary to calculate these costs within the planning methodology. Instead, this cost information is assumed to be given and is assigned to the relevant position variants. By means of the requirements planning, not only are the position variants identified but also the variable costs become known for the computation of the total variable cost of an order (i.e. product variant).

Figure 5.24 again refers to the example from figure 5.22 and illustrates the order-specific computation of the variable costs on the basis of the identified part position variants and connection position variants. The variable material costs of the part position variants can be added and assigned to the respective connection position variants. In this context, it has to be noted that a part position is assigned to at least two connection positions in different connection positions. Otherwise no complete part net would exist. For this reason, the variable material costs of a part position variant have to be distributed proportionately to the respective connection position variants.

This is clearly shown when considering the part position variant ‘200.01’. In the first manufacturing step, the part position variants ‘100.03’ and ‘200.01’ are joined to each other. This is illustrated by means of the connection position variant ‘C 100.02’. According to the manufacturing sequence, in the next step the part position variants ‘200.01’ and ‘300.02’ are mounted as illustrated by the connection position variant ‘C200.03’. Thus, the variable material costs of the part position ‘200.01’ are distributed proportionately to the connection position variant, in this example half each. The variable material costs can be added to the variable manufacturing costs which are assigned to the connection position variants, amounting in the total sum of variable costs of certain connection position variants.

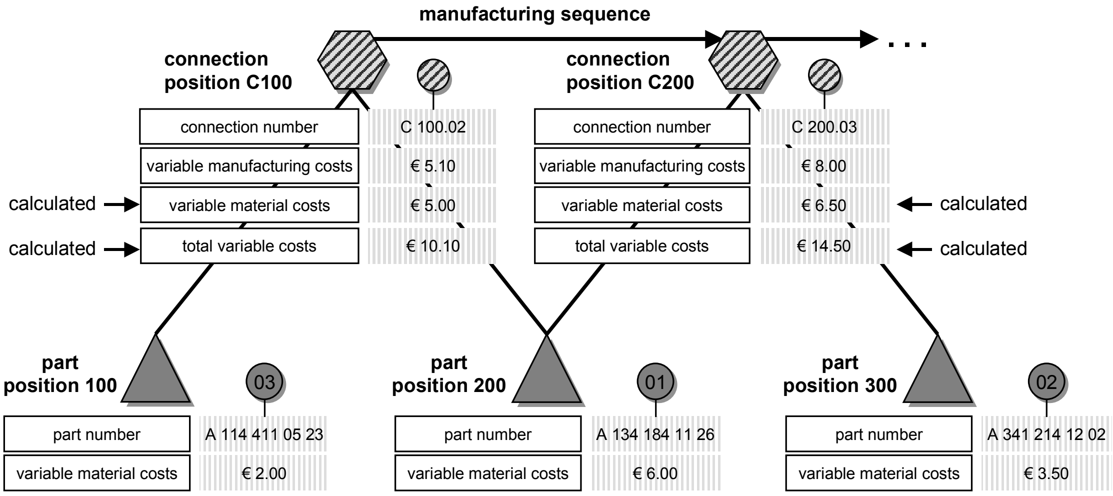


Figure 5.24: Order-specific Calculation of Variable Costs.

By aggregation of the detailed cost information for all part position variants and connection position variants needed to manufacture a product, the total sum of variable costs of a specific order configuration can be computed. The order-specific contribution margin per unit ($cm_{oc,t}$) is the difference between the fixed selling price of a product ($p_{oc,t}$) and the total sum of variable costs ($tvc_{oc,t}$):

$$cm_{oc,t} = p_{oc,t} - tvc_{oc,t} \tag{11}$$

Multiplication of the contribution margin per unit with the maximal number of producible customer-neutral orders ($n_{oc,t}$) gives the achievable total contribution margin of an order configuration ($tcm_{oc,t}$) as follows:

$$tcm_{oc,t} = cm_{oc,t} \cdot n_{oc,t} \tag{12}$$

If several different order configurations are regarded in parallel in the planning of customer-neutral orders, then these can be ranked according to the height of the total contribution margin. Since production program planning aims at achieving a maximization of the company’s profit, it is favorable to plan customer-neutral orders which would gain the highest possible contribution margin while contributing to a nearly steady utilization of the capital-intensive capacities.

5.2.7 Definition of Market Attractiveness

The elucidation in the previous chapters of the developed planning methodology for customer-neutral orders focuses on integrating consideration of capacitive and monetary aspects (e.g. contribution margin accounting). However, it is also necessary to take the immaterial value of the customer-neutral orders into account in order to contribute to the realization of the desired well-balanced decision-making in stock order planning (see chapter 4.2.1).

The immaterial value in order planning refers to the expected market attractiveness, i.e. marketability of the customer-neutral products to be planned and manufactured, and corresponds to the qualitative planning perspective within the developed methodology. Typically, the market attractiveness of the various order configurations is differently high. Considering the entire product life-cycle it becomes clear that some of the multitude of order configurations are either produced only a few times or perhaps not at all, whereas other combinations of order characteristics are produced frequently. This is due to the fact that not each manufacturable product variant meets the heterogeneous, often changing market demands to the same extent. In order to avoid manufacturing customer-neutral products which are difficult to market, the qualitative perspective, i.e. the marketability, has to be considered in order planning. Of course, any nonexistent or insufficient marketability of the customer-neutral orders to be planned has a direct monetary impact on the sales and marketing costs, since additional expenditures in the order processing chain for unloading the product are inevitable. Apart from the product documentation with connection information, the computation of marketability is one of the most important innovations compared to the planning methods employed thus far in practice.

The market attractiveness of customer-neutral orders is determined by computing the marketability index. This index is a function of the following four indices:

- Stock vehicle index (SVI).
- Customer time index (CTI).
- Customer order index (COI).
- Assessment matrix index (AMI).

Each of the four indices takes a specific scope of reality into account in the modeling: the connections which exist in reality are reduced in line with the scope considered to those aspects which are relevant for the computation. The results are only then correct, if there is no overlapping of the scopes of reality considered by the four indices. Despite the reduction of the often very high complexity in reality, each index offers a purposeful assessment variable for the probable market attractiveness and marketability of the customer-neutral orders to be planned. With the inclusion of several aspects in the form of the above indices, a broad information basis is used to measure market attractiveness. This significantly decreases the risk of a one-sided or false misevaluation. However, a residual risk persists as is the case for any kind of modeling. This is because it cannot be guaranteed with absolute certainty that, in a dynamic and complex environment of an industrial company, no further, possibly not or even hardly quantifiable, influencing factors exist; and it cannot be precluded that, after the planning date, new, so far unknown aspects may arise. For example, a marketing offensive (e.g. advertising campaign, price discount) undertaken by a competitor may allow the current market attractiveness to be unfavorably compared to the market attractiveness computed at the planning date for customer-neutral orders. However, this uncertainty is a general drawback of all forecasting methods and planning approaches which exist in both theory and practice. In the following sections, the above indices, which are used to estimate the market attractiveness of the various order characteristics (product variants), are elucidated in detail.

The stock vehicle index (SVI) describes the market attractiveness of customer-neutral orders under consideration of the stock vehicles in the inventories at the sales units (e.g. dealerships) in terms of products which were produced in former planning periods and which so far remain unsold. In this context it is assumed that it is not favorable to plan further stock orders with a specific order configuration if vehicles with these order characteristics are in stock at the sales units, as this indicates a lack of market demand. The SVI is computed for 1...N order configurations which are selected by the sales planner before the calculation process of the planning methodology for customer-neutral orders is started. The SVI of a order configuration (oc_n) in a planning period (t) is computed as follows:

$$SVI_{oc_n,t} = \left\{ \begin{array}{ll} \dfrac{v_{oc,\max} - v_{oc_n}}{v_{oc,\max} - v_{oc,\min}} & \text{for } v_{oc,\max} \neq v_{oc,\min} \\ 1 & \text{for } v_{oc,\max} = v_{oc,\min} \end{array} \right\} \tag{13}$$

with

$$v_{oc,\max} = \underset{n=1}{\overset{N}{Max}} \left\{ v_{oc_n} \right\} \quad n \in \{1, \ldots, N\} \tag{14}$$

$$v_{oc,\min} = \underset{n=1}{\overset{N}{Min}} \left\{ v_{oc_n} \right\} \quad n \in \{1, \ldots, N\} \tag{15}$$

- v_{oc_n}...number of existing stock vehicles of the considered configuration oc_n.
- $v_{oc,max}$ ... the order configuration with the highest number of stock vehicles.

- $v_{oc,min}$ ... the order configuration with the lowest number of stock vehicles.
- $SVI_{oc_n t}$ ...stock vehicle index of the considered configuration oc_n.

According to the above function, the more vehicles of an order configuration which are as yet unsold, the lower the SVI is. Of course, the opposite is also true: the value rises if fewer unsold stock vehicles are in the dealerships' inventories. The co-domain of the computation function extends from zero to one, whereby these values correspond to the minimum and maximum $SVI_{oc_n t}$, respectively (figure 5.25).

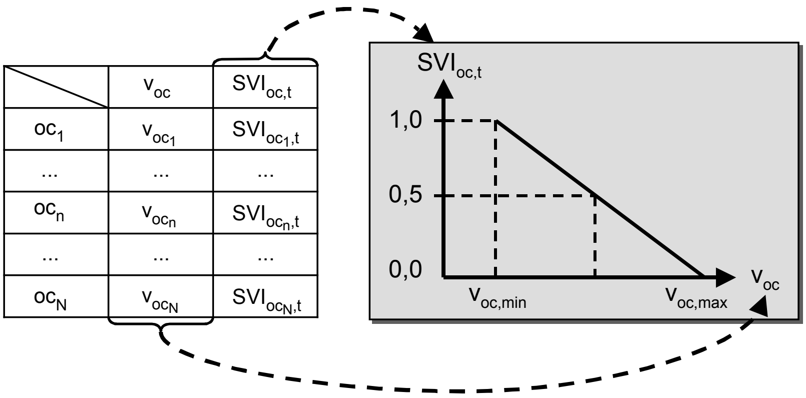


Figure 5.25: Stock Vehicle Index.

Closely related to the stock vehicle index is the customer time index (CTI). The CTI delineates the market attractiveness of 1...N order configurations (oc_n) in the planning period (t) as a function of the average length of time passing between the completion of production of stock vehicles and the conclusion of a sales contract with a customer. It is assumed that those customer-neutral manufactured products which were difficult to market in recent planning periods, will also in the future only be sold after a relatively long period of time. The longer this time period is, the higher are the costs for stock keeping and capital investment in stock, as, in the meantime, no payment is received from a customer, and there is consequently no return on investment (ROI). The CTI is computed for the 1...N order configurations which have been selected by the sales planner by comparing these configurations with each other as follows:

$$CTI_{oc_n,t} = \left\{ \begin{array}{ll} \dfrac{ct_{oc,\max} - ct_{oc_n}}{ct_{oc,\max} - ct_{oc,\min}} & \text{for } ct_{oc,\max} \neq ct_{oc,\min} \\ 1 & \text{for } ct_{oc,\max} = ct_{oc,\min} \end{array} \right\} \qquad (16)$$

with

$$ct_{oc,\max} = \underset{n=1}{\overset{N}{Max}} \left\{ ct_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \qquad (17)$$

$$ct_{oc,\min} = \underset{n=1}{\overset{N}{Min}} \left\{ ct_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \qquad (18)$$

- ct_{oc_n} ...average length of time of the considered order configuration oc_n.
- $ct_{oc,max}$... longest average length of time of one of the selected order configurations.
- $ct_{oc,min}$... shortest average length of time of one of the selected order configurations.
- $CTI_{oc_n,t}$...customer time index of the considered order configuration oc_n.

The average time span between the end of production of customer-neutral orders to be planned and the time of selling the corresponding stock products to a customer is, of course, computed on the basis of available information from the past. To do so, the time intervals of the customer-neutral orders with the same order configuration that have been planned and produced in former planning periods are totaled. This value is then divided by the number of orders considered. By comparing of the average length of time for the 1...N order configurations, the variables needed for the above formula used to calculate the customer time index (CTI) can be determined. The shorter the determined time interval of a respective order configuration, the higher the CTI. As a logical consequence, the longer the stock vehicles produced in former planning periods could not be sold, i.e. the longer these products have incurred additional costs for warehousing and capital investment in stock, for example, the lower the CTI. The co-domain for this computation function is between zero and one, whereby these values represent the lowest and highest CTIs of order configurations in the planning period, respectively (figure 5.26).

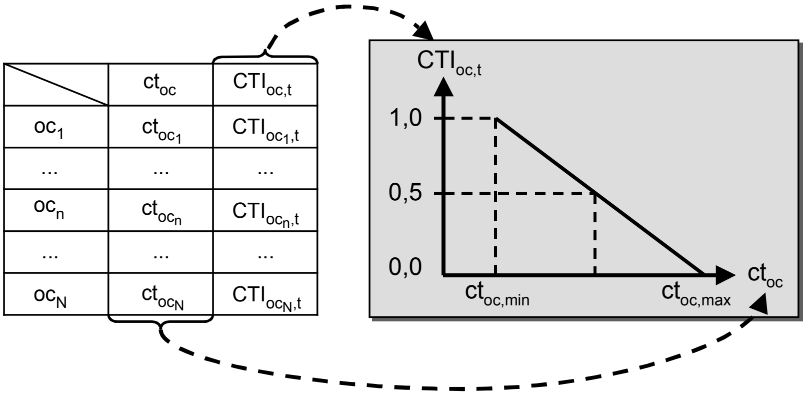


Figure 5.26: Customer Time Index.

The third index for measuring the expected marketability of customer-neutral orders is the customer order index (COI). The COI describes the market attractiveness of the 1...N order configurations (oc_n) in the planning period (t) with respect to the order characteristics of the current customer orders received. The order characteristics of both are considered: the customer orders of the current planning period as well as the incoming customer orders of future planning periods. It is assumed that, thanks to the similar characteristics as in the considered customer orders, the marketability of customer-neutral orders will increase, since these orders meet the current customer wishes. That means that the COI of an order configuration is higher, the more customer orders with these same order characteristics are received. The customer order index of the different order configurations is calculated as follows:

$$COI_{oc_n,t} = \begin{cases} \dfrac{x_{oc_n} - x_{oc,\min}}{x_{oc,\max} - x_{oc,\min}} & \text{for } x_{oc,\max} \neq x_{oc,\min} \\ 1 & \text{for } x_{oc,\max} = x_{oc,\min} \end{cases} \tag{19}$$

with

$$x_{oc,\max} = \underset{n=1}{\overset{N}{Max}} \left\{ x_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \tag{20}$$

$$x_{oc,\min} = \underset{n=1}{\overset{N}{Min}} \left\{ x_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \tag{21}$$

- x_{oc_n} ...number of customer orders of the considered order configuration oc_n.
- $x_{oc,max}$... the order configuration with the highest number of customer orders.
- $x_{oc,min}$... the order configuration with the lowest number of customer orders.
- $COI_{oc_n,t}$ ...customer order index of the considered order configuration oc_n.

The co-domain of the customer order index is between zero and one, whereby these values represent the lowest and highest COI of an order configuration, respectively. Figure 5.27 illustrates the comparison of the order configurations which have been selected by the sales planner and the co-domain of the function.

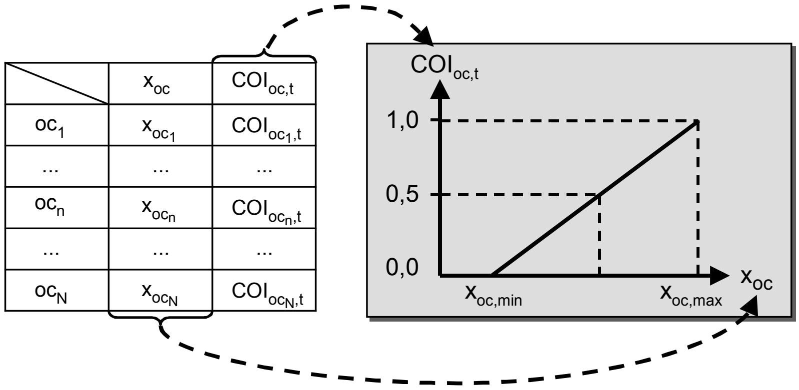


Figure 5.27: Customer Order Index.

All of the above indices have an objective character, as they are based on the statistical analysis of concrete figures. In contrast, the assessment matrix index (AMI) enables the sales planner responsible to evaluate the market attractiveness of possible order configurations for the customer-neutral orders according to subjective experiences and on the basis of forecasts of the market trends. This is useful because, as stated above, in the complex environment of a industrial company some soft facts which can either not or only insufficiently be quantified by means of objective data analysis may exist. For example, the effects of a marketing campaign or product launch either of the subject company or of its rivals are often difficult to measure. In order to be able to nevertheless consider these influences to a certain extent, the assessment matrix index can be calculated. The AMI describes the marketability of the 1...N order configurations (oc_n) for customer-neutral orders on the basis of the rating by sales experts. The AMI is calculated as follows:

$$AMI_{oc_n,t} = \begin{cases} \dfrac{s_{oc_n} - s_{oc,\min}}{s_{oc,\max} - s_{oc,\min}} & \text{for } s_{oc,\max} \neq s_{oc,\min} \\ 1 & \text{for } s_{oc,\max} = s_{oc,\min} \end{cases} \tag{22}$$

with

$$s_{oc,\max} = \underset{n=1}{\overset{N}{Max}} \left\{ s_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \tag{23}$$

$$s_{oc,\min} = \underset{n=1}{\overset{N}{Min}} \left\{ s_{oc_n} \right\} \quad ; \quad n \in \{1, \ldots, N\} \tag{24}$$

- s_{oc_n} ...assessment scores of the considered order configuration oc_n.
- $s_{oc,min}$... the order configuration with the lowest assessment scores.
- $s_{oc,max}$... the order configuration with the highest assessment scores.
- $AMI_{oc_n,t}$ ...assessment matrix index of the considered configuration oc_n.

Similar to the other functions, the co-domain of the linear function to calculate the assessment matrix index also lies between zero and one. These limiting values represent the lowest and highest AMI, respectively. The higher the number of assessment scores, the higher is the value of the assessment matrix index of the considered order configuration, and, of course, the opposite applies (figure 5.28).

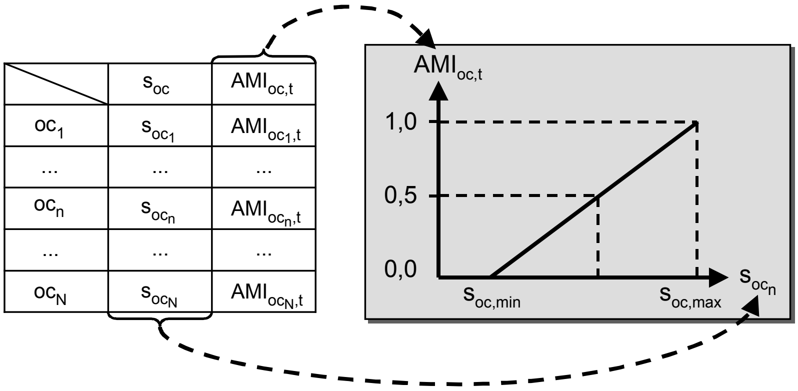


Figure 5.28: Assessment Matrix Index.

In order to calculate the assessment scores for the 1...N order configurations, the method of pairwise comparison is applied. The main principle of the method is that each order configuration which has been selected in the planning process for customer-neutral orders is compared with every other selected order configuration, whereby the value ratio of two order configurations is specified to each other by means of a score. Of course, the comparison of a configuration with itself is impossible, i.e. a comparative configuration - a benchmark - is invariably needed. Figure 5.29 illustrates the method of pairwise comparison.

configuration (rows) / configuration (columns)	oc_1	...	oc_n	...	oc_N	assessment scores s_{oc}	
oc_1		2	1	0	1	4	
...	0		2	0	0	2	← $s_{oc,min}$
oc_n	1	0		1	2	4	
...	2	2	1		2	7	← $s_{oc,max}$
oc_N	1	2	0	0		3	

Legend:
0 = Configuration is less marketable than the comparative configuration
1 = Both configurations are equally marketable
2 = Configuration is more marketable than the comparative configuration

Figure 5.29: Method of Pairwise Comparison.

In the initial step, the assessment matrix is developed: it itemizes the relevant order configurations in the rows and columns. To avoid superfluous effort, care must be taken to ensure that the configurations in the rows and columns are listed in the same order.

Then, each of the documented configurations in the rows is assessed to the comparative configurations in the columns one after another. Within the planning methodology elaborated in this research, the following possibilities exist:

- The configuration is better marketable than the comparative order configuration: the configuration receives two scores and the comparative configuration zero scores.
- Both configurations are equally marketable: both configurations gain one score.
- The configuration is worse marketable than the comparative order configuration: the configuration receives zero scores and the comparative configuration two scores.

The scale may also be extended, for example, by up to five assessment gradations with different scores. Then, the terms ‘better’ and ‘worse’ are differentiated in more detail with respect to the evaluation of the marketability of the order configurations. Then a phrasing could conclude as follows: the configuration is considerably better or worse marketable than the comparative configuration. However, with the increasing gradation of the terms, also the difficulty increases to find a definitive decision when assigning the assessment scores to the various order configurations. Here, it can be assumed that, in the case of an evaluation by several experts, the obtained results of the marketability will differ to a larger extent due to the extended assessment possibilities. For this reason, a three-step scale is favored for the pairwise comparison of the order configurations.

In the third step the assessment scores of each order configuration in the assessment matrix are added to a total sum. The resulting sum of assessment scores is then used to calculate the AMI as per the above function.

The main advantage of the applied method of pairwise comparison lies in the systematic proceeding employed to evaluate the various order configurations. However, the evaluation of the order configurations is based on subjective value assessments which have to be determined in a decision-making process. Thus, the method can limit serious mistakes, but it can by no means replace the value judgments of the experts (e.g. sales planners).

5.2.8 Calculation of the Marketability Index

The marketability index (MAI) which is used to describe the market attractiveness of the various order configurations (oc_n) in the planning period (t) consists of the four indices introduced above (figure 5.30). The higher the calculated value of the configuration-specific MAI, the better are the sales opportunities for the customer-neutral orders to be planned and produced. Consequently, when planning customer-neutral orders, those order configurations that have an MAI which is as high as possible should be preferred. The marketability index hence serves as a guideline to avoid difficult-to-market stock products in upstream stages of order processing, i.e. in the order planning process.

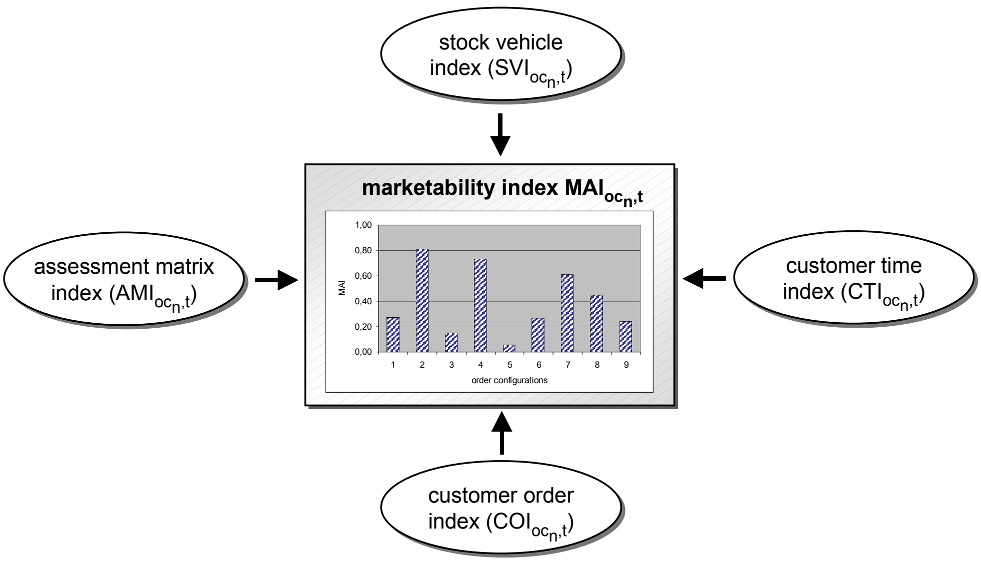


Figure 5.30: Marketability Index of Customer-neutral Orders.

The uniform co-domains of the different functions enable the joining of the indices to the marketability index ($MAI_{oc,t}$) by means of weighting coefficients without any further additional transformations:

$$MAI_{oc_n,t} = SVI_{oc_n,t} \times w_{SVI} + CTI_{oc_n,t} \times w_{CTI} + COI_{oc_n,t} \times w_{COI} + AMI_{oc_n,t} \times w_{AMI} \quad (25)$$

with

- $SVI_{oc_n,t}$...stock vehicle index of a order configuration.
- w_{SVI}...weighting coefficient for stock vehicle index.
- $CTI_{oc_n,t}$...customer time index of a order configuration.

- w_{CTI}...weighting coefficient for customer time index.
- $COI_{oc_n,t}$...customer order index of a order configuration.
- w_{AMI}...weighting coefficient for customer order index.
- $AMI_{oc_n,t}$...assessment matrix index of a order configuration.
- w_{AMI}...weighting coefficient of assessment matrix index.

The influence of the different indices on the marketability index can be adjusted by modifying the relevant weighting coefficients. The weighting coefficients represent the significance of the indices which are utilized to assess the market attractiveness of the various order configurations. The significance of the indices, and thus the numerical values of the weighting coefficients, can be determined and represented either by a binary, ordinal or cardinal scaling. Scaling is a method to objectify and measure subjective, qualitative estimations and valuations. So-called rating scales combine assessment terms (semantics) with numerical values.

Binary scaling allows for a very simple classification of the indices by declaring a predicate. For example, the binary predicates ‘unimportant’ and ‘important’ can be employed to differentiate the indices. However, the predicates may also be represented by means of the numerical values zero and one, respectively. In ordinal scaling, the indices are assessed and ordered on the basis of their similarity to each other, resulting in a ranking of the indices. However, in this context it is not the absolute value of the similarity that is crucial, but merely the rank of an index compared to the rank of the other indices. Using ordinal scaling to assess the indices, the detailed grading of similarity into a more or less of a similarity is of paramount. For example, the customer time index (CTI) can be rated more similar to the customer order index (COI) than the assessment matrix index (AMI) to the customer order index (COI). In general, the semantics employed for the assessment are contingent on the concrete aims pursued with the underlying assessment process. This means for the semantics applied in this research that the indices are regarded as more or less important to assess the various order configurations of the future customer-neutral orders.

The cardinal rating scale is an extension of the afore-described ordinal scaling, since not only is the order (i.e. ranking) of the different indices known, but also the difference of the similarity is quantified by numerical values. Consequently, this kind of rating provides additional information about the significance of each index in relation to the other indices used to assess the market attractiveness of order configurations. In order to accomplish this, a suitable semantics needs to be specified for the cardinal scale, and corresponding numerical values must be defined. The concrete semantic classification of the indices can be based either on the opinion of only one expert (e.g. sales planner) or on the assessment of several experts. In the latter case it is conceivable that the board of experts be interdisciplinary in nature.

Figure 5.31 shows the procedure applied in this research to determine the weighting coefficients on the basis of a five-step cardinal rating scale. Compared to a scale with fewer gradations, the five-step cardinal rating scale allows the differences in the significance of the various indices to be identified on a more detailed level. First, the significance of an index is assessed by means of the semantic differential. Then, the corresponding numerical value of the rating scale is determined. This is also done for the other indices. The number of assessments (n) of the four indices (i) depends on the size of the board of experts. Thus, the co-domain ranges from 1 to N assessments. After the assessment is finished by the experts, the assigned rating scores are conglomerated to a total sum for each index (rs_i).

$$rs_i = \sum_{n=1}^{N} r_i \quad ; \quad i \in \{SVI, CTI, COI, AMI\} \quad ; \quad n \in \{1, \ldots, N\} \tag{26}$$

The weighting coefficients of the indices (w_i) are calculated as follows:

$$w_i = \frac{rs_i}{rs_{SVI} + rs_{CTI} + rs_{COI} + rs_{AMI}} \quad ; \quad \sum w_i = 1 \quad ; \quad i \in \{SVI, CTI, COI, AMI\} \tag{27}$$

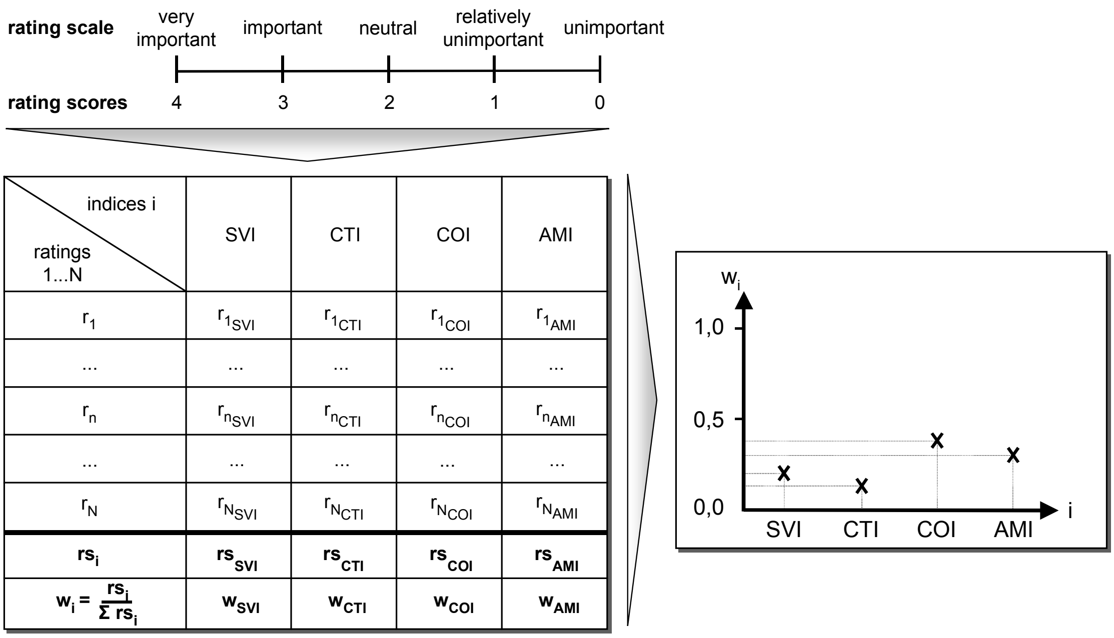


Figure 5.31: Determination of Weighting Coefficients.

The higher the value of a weighting coefficient, the higher is the significance of the index to assess marketability, and of course vice versa. An index can be completely neutralized when calculating the expected market attractiveness of the different order configurations if it is categorized as unimportant in the overall rating process. This means that, for this index, the sum of the rating scores is zero. As a logical consequence, the corresponding weighting coefficient also takes on the value zero. The neutralization of an index can be useful if only some of the developed indices are to be considered when calculating marketability. For example, it is conceivable that the assessment matrix index should be neglected, since this index is of a subjective nature compared to the other indices (SVI, COI, CTI). However, at least one of the weighting coefficients should have a value greater than zero, since otherwise the calculation of the marketability index is mathematically not possible in its present form and the consideration of the market attractiveness would subsequently be baseless.

The calculation of the marketability index for the various order configurations is summarized in figure 5.32 by means of a numerical example. For each of the listed order configurations which have been selected by the sales planner at the beginning of the planning process, the calculated values of the indices are multiplied with the relevant weighting coefficients and added to a total sum. This sum represents the order configuration-specific marketability index. Finally, the rank of an order configuration can be identified by comparing the MAI with those of the other configurations. In this example, the order configuration oc_3 has the highest MAI. Thus, viewed from the perspective of marketability, top priority should be given to this order configuration when planning customer-neutral orders.

order configurations \ indices / weighting coefficients	$SVI_{oc_n,t}$	$CTI_{oc_n,t}$	$COI_{oc_n,t}$	$AMI_{oc_n,t}$	marketability index $MAI_{oc_n,t}$	ranking
	$w_{SVI} = 0.43$	$w_{CTI} = 0.19$	$w_{COI} = 0.22$	$w_{AMI} = 0.16$		
oc_1	0.82	0.00	0.42	0.39	0.507	3
oc_2	1.00	0.24	0.65	0.00	0.619	2
oc_3	0.75	0.35	1.00	1.00	0.769	1
oc_n	0.00	1.00	0.12	0.41	0.282	5
...	...	...	...	...	...	...
oc_N	0.41	0.12	0.00	0.68	0.308	4

Figure 5.32: Decision-Making in View of Multiple Goals.

5.2.9 Conclusive Planning Decision

In customer-neutral order planning, the conclusive decision as to which stock orders (i.e. product variants) are to be produced can be based on the identified capacities which are not utilized with customer orders, on the achievable contribution margins, or on the qualitative planning perspective - the expected marketability. However, it is to be assumed that in the conclusive decision-making process not all of the elaborated planning aspects can be considered with equal standing. Only in the rarest cases will an order configuration be the best from all of the planning perspectives: the results may differ. Therefore, the question arises as to whether the conclusive decision should be founded on quantitative or qualitative aspects.

Based on the sales figures and capacities which have been planned and harmonized within the scope of long- and/or mid-term program planning, it would be sensible to manufacture those order configurations with the highest total contribution margins, thus using the quantitative key figures for decision-making. However, in this connection the fact may not be neglected that a customer-neutral planned product should be saleable. Hence, in the ideal case, i.e. before production is finished, this product is sold to an end consumer. Otherwise, the customer-neutral planned and manufactured products will inevitably incur additional cost-intensive expenditures, e.g. due to technical obsolescence or discounts granted to unload the stock products. The consequence would be that the calculated contribution margins may be reduced or even undercut by these neglected cost factors. In such a case, the appropriateness of the planning decision seems doubtful.

Therefore, the sales planner may choose to deviate from the monetary calculation result should the following situation arise: based on the calculated total contribution margins, it would be reasonable to manufacture customer-neutral orders of the order configuration with the highest contribution margin, yet the marketing chances have to be categorized as low due to the calculated marketability index (MAI). Here, it might be advisable for the sales planner to select another product variant, i.e. order configuration, with a lower contribution margin in favor of a higher marketability. However, it is the responsibility of the Sales Department to waive contribution margins because the Manufacturing Department has, of course, planned and installed the resources and capacities on the basis of the forecasted product life-cycle and the related sales figures.

It can be assumed that, in industrial practice, the planning decision is, of course, not made independent of the corporate goals and planning guidelines of the management. Most likely the conclusive planning decision as to which order configurations are to be produced will be oriented toward the aims and priorities given for the respective planning periods. In this context it is conceivable that, in one of the former planning periods, this decision is made according to the height of the achievable contribution margins, whereas, in the current period, the market attractiveness of the customer-neutral orders is the chief planning guideline.

5.3 Summary

This chapter intends to recapitulate the design of the method for customer-neutral order planning and how the product documentation with connection information enables the integration of both quantitative and qualitative planning factors for well-balanced decision-making. The planning methodology has been primarily developed for the application at European car manufacturers offering a huge product variety in customer markets which are forced to utilize capital-intensive manufacturing capacities at a high level. Yet the methodology is not limited solely to these companies. In contrast, companies with similar characteristics and facing the challenges of other industrial sectors can implement the planning methodology - if necessary also only parts of the methodology such as the calculation of the market attractiveness.

Figure 5.33 depicts the planning model, distinguishing between the preparation and the application sides. The latter is concerned with the actual order planning for a diversified product variety and the developed planning views whereas the former stores and provides the necessary information.

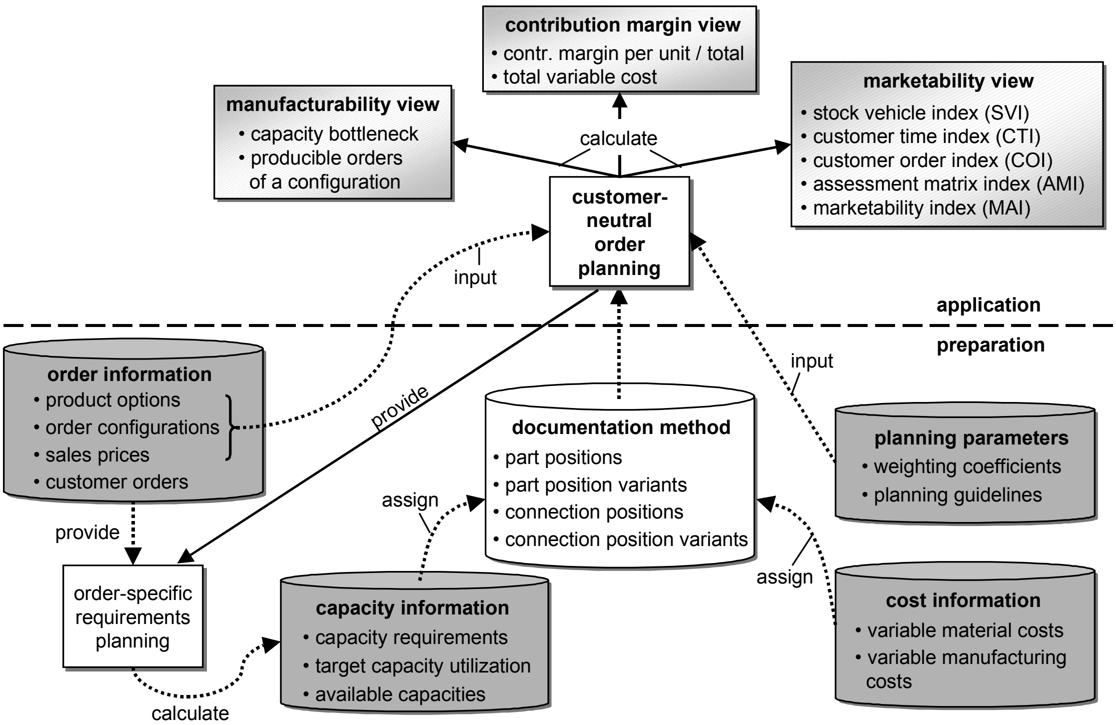


Figure 5.33: Planning Model for Customer-neutral Orders.

Information on customer orders, selectable product characteristics, permissible order configurations, and their sales prices are stored in an order database. This information is utilized as input for the customer-neutral order planning. The capacities required to build the customer orders in the current planning period are identified by the order-specific requirements planning. The result, i.e. part and manufacturing requirements, as well as the target capacity utilization are directly assigned to the part and connection position variants by means of attributes. This information is necessary to calculate the available capacities for planning of customer-neutral orders. Furthermore, cost information such as variable material and manufacturing costs needed to calculate the achievable contribution margins for the different order configurations is also an integral part of the product documentation with connection information. Cost information is available from the departments responsible for product calculation and controlling. Additional planning parameters, e.g. weighting coefficients and the planning guidelines relevant for the conclusive decision-making, are represented in a further database. Solely for reasons of clearness, the databases are separated. Implementing the planning methodology in a DP system does not necessitate physically independent databases.

For customer-neutral order planning, first relevant product characteristics in terms of the product type and product options are selected. Then the resulting permissible product configurations are visualized to the planner. After the relevant order configurations have been selected, the material and manufacturing requirements are planned for the order configurations in the same way as is done for customer orders. Through the requirements planning algorithm used to identify the configuration-specific part position variants and the connection position variants, the available capacities can also be calculated and updated in order to determine the number of producible orders of a specific configuration. Together with the documented sales prices and calculated variable costs, this information enables the computation of the achievable, order-specific contribution margin. To prevent the targeted benefits resulting from the customer-neutral planned orders and the hereby increased economy of scale from being superposed by additional costs (e.g. capital investment in stock, discounts to market the stock vehicles), a further planning perspective - the market attractiveness of order configurations - is included in the planning methodology after production has been finished. This qualitative planning aspect complements and extends the focus of customer-neutral order planning and supports a well-balanced decision-making in the planning process. Thus, the integration of different planning perspectives meets the need to consider several dimensions, i.e. cost, quality, and time aspects, in parallel in order to ensure that the planning decisions are of high quality.

The necessary information backbone for the developed planning methodology is the product documentation with connection information. Through this special kind of product and process documentation, the variety on the part level resulting from the diversified product portfolio and also from the variety of manufacturing processes can be made transparent and manageable. Furthermore, in connection with the implemented algorithm for requirements planning, detail information necessary for the planning methodology is at hand without time-consuming searching. Thus, product documentation with connection information contributes significantly to the third above-mentioned planning dimension ‘time’.

PART III: Application

Chapter 6

Implementation of the Software Demonstrator

6.1 Objectives and Scope of the Demonstrator

During the research project, a demonstrator software application has been developed to validate the market-oriented planning methodology for customer-neutral orders at a major automobile producer. The purpose of the demonstrator is to test the practical applicability of the planning methodology and to illustrate the planning process. The former aspect includes the calculation of the number of producible orders, the achievable contribution margins, and the market attractiveness as explained in chapters 5.2.5, 5.2.6, 5.2.7, and 5.2.8. The illustration of the planning process comprises the developed graphical user interface (GUI) and the corresponding user guidance.

The planning methodology is fully implemented in the demonstrator as described in this thesis for an exemplary case. The associated simplification of the reality and reduction of complexity has nothing to do with the general validity of the planning methodology for customer-neutral orders but is driven by the fact that an adequate test environment is not yet available. For example, the related research projects which target establishing the actual information backbone of the planning methodology - the cross-brand product documentation with connection information - are not yet finished to the required extent. Apart from this circumstance, the following bill of material information list could be exported to the software demonstrator from the currently deployed data system for reuse:

- Part position.
- Part position variant.
- Part number.
- Item.
- Quantity coefficient.
- Code rule.

But since it could not be ruled out that no documentation errors in the form of data inconsistency, data redundancy or incomplete and/or obsolete data which might falsify the planning results have been made in the past, these data from the existing DP system are not used for processing in the software demonstrator. However, to be able to illustrate the actual planning methodology for customer-neutral orders in an appropriate form, an exemplary product documentation with connection information was developed for the demonstrator, allowing part positions, part position variants, connection positions, and connection position variants to be defined.

The flexible structure of the demonstrator enables the illustration of various exemplary planning situations, since not only the algorithm to identify the order-specific part and manufacturing requirements is completely realized but also the algorithms to calculate the results of the quantitative and qualitative planning perspectives. Furthermore, the product documentation with connection information can be modified at any time (e.g. the code rules) in order to be able to consider different product structures and manufacturing workflows.

At the moment, no real customer orders of the automobile producer are included in the software demonstrator, as these orders contain sensitive data and must be treated confidentially for reasons of data protection. But, of course, it is possible to define as many exemplary customer orders with respect to the maximal available part and manufacturing capacities in a planning period as desired in order to simulate various market situations when planning customer-neutral orders. In addition, further planning guidelines can be modified, e.g. the weighting coefficients used to calculate the market attractiveness, the number of stock vehicles manufactured and remaining unsold, the sales prices of order configurations, and the amount of variable material and manufacturing costs.

In brief, human resource implementing capacity has focused on the following main functions of the demonstrator:

- Definition of exemplary customer orders and selectable order characteristics.
- Definition and modification of an exemplary product documentation with connection information.
- Simulation of different initial situations for customer-neutral order planning, e.g. through modification of the customer orders, the target capacity utilization, and the sales prices.
- Requirements planning for customer orders and customer-neutral orders.
- Customer-neutral order planning.

These key functions are further detailed by means of a use case diagram and the related use cases in chapter 6.2.4, after some important remarks about the prototypical implementation are given.

6.2 Prototypical Implementation

The demonstrator was developed using the database management system (DBMS) Microsoft Access. A DBMS is a utility program which provides the basic functions for data administration, storage, and analysis. The designing of a database management system, also called in brief database system, requires a formal description of the section of the real world to be modeled, whereby a structure-oriented point of view dominates. In this context, the structure of data and the relations between the data are considered among other things. These data structures, which are described on abstract level, have to be transformed into the formal scheme of the database model. The database model most commonly used today is the relational model. Within the relational model the data are represented by means of two-dimensional tables which are related with each other. Microsoft Access, which is used for the development of the software demonstrator, also belongs to the class of relational database systems.

In contrast to programming languages and other database systems, Microsoft Access is a complete development system with manifold additional functions. Apart from the actual programming language Visual Basic Applications (VBA), it consists of further components such as tables, queries, forms, and reports. To ensure that these various components work together trouble-free, the database system offers the possibility to access the objects which are created within the components by means of the programming language. The main advantages of Microsoft Access are as follows:

- Graphical user interface (GUI).
- Integration of other applications (interface for data import and export).
- Enhanced possibilities for extensions and utility programs.
- Comfortable user guidance through built-in help, advice, and assistant functions.

Thanks to the ongoing development of the processor performance, the loss of processing speed typical for relational DBMS when handling large amounts of data is not as critical as in the past. The planning methodology for customer-neutral orders and the functions mentioned in chapter 6.1 could be fully implemented in Microsoft Access, so that an application of other systems, databases, and programming languages was not necessary for the development of the demonstrator.

6.2.1 Development Process of the Demonstrator

The software demonstrator was developed by means of a systematic process. The purpose of the applied development process was to identify, structure, and classify the various development activities systematically, so that superfluous activities and/or a time-consuming redesign of the demonstrator can be excluded from the very beginning. The development process is illustrated in figure 6.1 and will be explained in the following sections.

In the first development step, a description of the initial situation, the problem, and the aims pursued with the software demonstrator were worked out. For the successful conception and development of the demonstrator it was crucial that the application description be detailed as exactly as possible, yet that no needless aspects and parameters be included. Since reality is far too complex, the challenge was to create a suitable model of the reality: a model which comprises only the facets that are important for the software development, i.e. a model including all necessary information but which neglects all useless data.

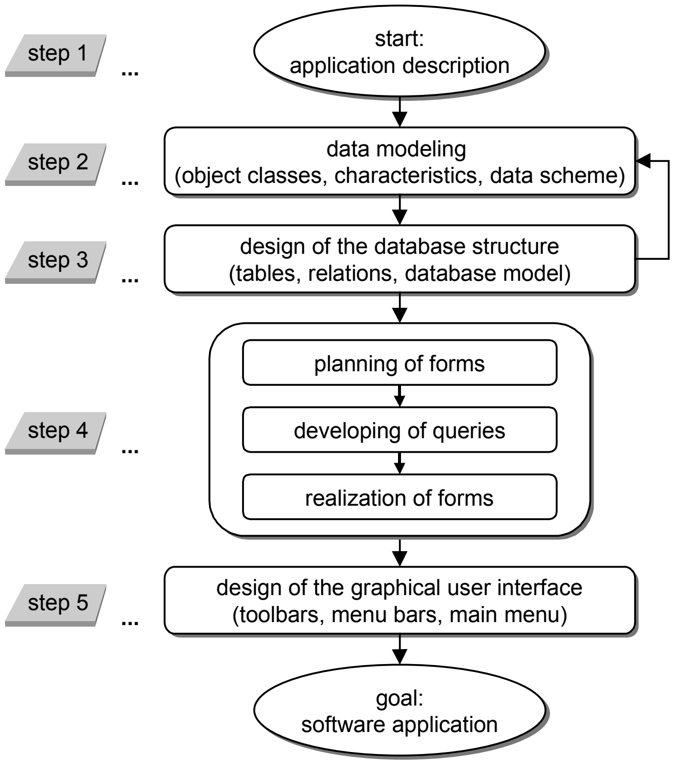


Figure 6.1: Development Process of the Software Application.

The second development step was of special importance within the application development process: the design of the data model and the related correct design of the database structure. These activities represented the fundamental prerequisites for the further application development, thus building the keystone of the implemented database. For the success of the software application and to avoid later, time-consuming modifications in the further development steps, it was necessary to ensure that the concepts of both the data model and the database structure have been carefully designed. To do this, the transformation of the application description into the data model was carried out in several sub-steps.

First, the existing model of the reality relevant for the application was limited. Then the objects of the section of the real world and their relationships were defined. For example, the object classes part positions and connection positions have been implemented. The relationships between these both object classes have been unambiguously specified according to the method of product documentation with connection information. That means that each connection position must be assigned at least two part positions in order to be able to represent the assembly process of parts. Then, the most important characteristics of the objects within the object classes were determined. For example, a part position variant is characterized by the descriptive name, code rule, available material capacity, variable material costs, and quantity coefficient. When applying the software demonstrator, typically different object classes are of interest depending on the current functionality to be executed. On the basis of the developed model of the reality, only those characteristics which are useful for decision-making when planning customer-neutral orders are stored within the data model. The data modeling resulted in a conceptual data scheme which comprises all the object classes in the form of tables, their relevant characteristics, and the relationships between them.

In the third step of the development process, the data scheme was transformed into the database structure underlying the software demonstrator. In this connection, the most important feature of a relational database has to be mentioned: the storing of data in tabular form. Based on the conceptual data scheme, each object class corresponds to a table. The characteristics of each object within an object class are stored in data fields of the table. The existence of a so-called primary key in each table enables the unambiguous identification of the data records contained. Furthermore, the database structure is characterized by the relational links between the object classes, i.e. by the relationships between the several tables. A relationship can be defined by reference fields, which must be included in the object classes to be linked with each other. If the values of these fields are correspond to each other, Microsoft Access joins the corresponding data records of the tables. This ensures that the required data records for customer-neutral order planning are available. Figure 6.2 depicts an extract from the database structure with the implemented tables and relationships which form the basis for the developed software demonstrator.

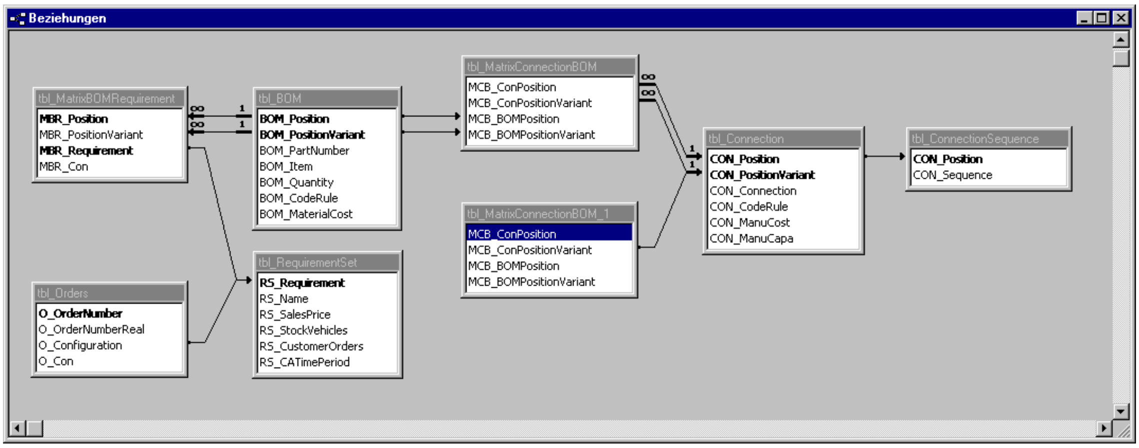


Figure 6.2: Database Structure.

In the fourth development step, the later user guidance and the demonstrator forms required to visualize the planning information were planned. However the task of forms is not limited to this. For example, forms are the main interface between the database application and the stored data. This means that not only are forms utilized for data input and data visualization, they also serve for simplification of the user guidance. Thus, an extensive program code often exists behind a form, promoting comfortable usage of the software demonstrator. In order that the data which is required for the planned forms is available, corresponding data queries have to be generated. Queries allow data to be visualized, changed or analyzed in different ways. Microsoft Access offers various types of queries according to the use cases at hand. The most often needed query type for the software demonstrator is the selection query: data fields of one or several tables can be selected with respect to the defined selection criteria. In addition, the data records can be sorted, grouped, or filtered. After the development of the queries was completed, the planned forms were generated with several control elements such as text fields, check boxes, and command buttons used. Control elements serve to enable the data access to the user and to simplify the execution of actions, e.g. to change data or to start and carry out the planning process for customer-neutral orders. The most important control elements when developing a software application are text fields. They are utilized to represent a text or a numerical value of the data source which serves as the basis for the respective form. In fact, text fields are paramount in making the calculation results of the planning methodology visible for the user.

In the fifth development step, the graphical user interface (GUI) of the demonstrator was implemented: the main menu, tool bars, and menu bars were designed according to the requirements of the users and the forms were linked with each other by means of command buttons. The developed and implemented GUI facilitates navigation through the complete planning process for customer-neutral orders. The development process of the software demonstrator was finished with the implementation of the GUI.

6.2.2 Programming Language

Microsoft Access provides two possibilities for programming: macros and Visual Basic programs. Macros have the advantage that uncomplicated tasks can be executed extremely quickly and trouble-free. Yet if the tasks are more complicated, macros rapidly reach their performance limits. The programming language Visual Basic Applications (VBA) enables the development of more challenging software applications. And it is for this reason that the software demonstrator was mainly programmed by means of VBA. Macros have only been used occasionally to generate simple procedures, e.g. to open a form by means of a command button. Basically, VBA is a procedural programming language with a substantial similarity to the well-known programming language ‘Basic’ that is extended by a number of functions known from other languages, e.g. ‘C/C++’ or ‘Pascal’.

The programming language VBA consists of three components:

- General Visual Basic language elements.
- Microsoft Access-specific language elements.
- Data access objects.

The Visual Basic language elements underlie the VBA. Examples for these elements are the ‘If...Then...Else’ construct or general functions such as the ‘Date’ function to identify the current date.

The second component provides functions which are adapted to the specific requirements of the database management system. This component contains, among others, the ‘DoCmd’ object used to execute the diverse macro actions (e.g. the opening of forms) or the listing ‘Forms’ which is employed to access to the currently opened forms of a database.

The third component enables and controls the data access. This component allows the access to tables or queries, for example. All these components are integrated within VBA, so that the segmentation is not noticed in the programming and application of the database.

A benefit of VBA is that it promotes a very clear program structure. This is of particular interest for longer programs, which otherwise may very soon become complex and non-transparent. The most important VBA concept for structuring comprises the so-called procedures. Within the procedures, manageable partial problems are solved, i.e. a more complex problem is divided into several partial problems. An individual procedure may contain an almost unlimited number of instructions. The segmentation of a complete program into several procedures offers the advantage that these can be programmed and tested separately from each other. Thus, the main procedure by which the several sub-procedures are called becomes substantially clearer. Of particular importance is the separation of a problem into procedures, if these elements are to be deployed in several positions of the program. For example, a procedure which is used to visualize a message on the screen can be activated from different forms of a database. If, in such a case, a different text of the message is to be visualized, it is sufficient to modify only the procedure employed to activate the message, instead of changing each of the program locations. A program code structured by means of procedures is simpler to maintain and redundancies can be avoided. The universally valid syntax of a procedure is represented in figure 6.3:

```
[Private] Sub <procedure name> ([<parameter list>])

[<instructions>]

End Sub
```

Figure 6.3: VBA Command Syntax.

Each text which is enclosed by angle brackets <...> must be replaced when developing a procedure. An example is the text *<procedure name>*, which must be exchanged by the name of the respective procedure. In contrast, the specification of a *<parameter list>* is not mandatory. This is therefore represented within square brackets. The same applies for the keyword *Private*. All other texts including the blanks and line changes must be taken over without modifications. The notation is not case sensitive. Between the head of a procedure and its end, which is marked by *End Sub,* several instructions can be included. Figure 6.4 depicts an example of some selected VBA program code from the developed software demonstrator.

Form_frm_StockOrderPlanning1 : Klassenmodul

(Allgemein) | Accept_Click

```
Option Compare Database
Option Explicit

Private Sub Delete_Click()
    Dim intAktuelleZeile As Integer

    For intAktuelleZeile = 0 To Me.ListCode.ListCount - 1
        Me.ListCode.Selected(intAktuelleZeile) = False
    Next intAktuelleZeile
        Me.ListMatrixCode.RowSource = ""
End Sub


Private Sub Accept_Click()
    Dim intAktuelleZeile As Integer
    Dim txtsql As String
    Dim i As Integer


    txtsql = "SELECT RS_Requirement, RS_Name FROM qry_StockOrderPlanning2 WHERE ("
    i = 1

    If Me.ListCode.ItemsSelected.Count = Me.ListCode.ListCount Then
        txtsql = txtsql & "(RS_Requirement<>'')"
    Else
        For intAktuelleZeile = 0 To Me.ListCode.ListCount - 1
        If Me.ListCode.Selected(intAktuelleZeile) = False Then
            If i > 1 Then
                txtsql = txtsql & " AND "
            End If
            txtsql = txtsql & "(RS_Requirement Not Like '*" & Me.ListCode.ItemData(intAktuelleZeile) & "*')"
            i = i + 1
        End If
        Next intAktuelleZeile
    End If

    txtsql = txtsql & ");"
    Me.ListMatrixCode.RowSource = txtsql

End Sub
```

Figure 6.4: VBA Program Code.

6.2.3 Structured Query Language (SQL)

The Structured Query Language (SQL) has been developed for relational databases such as Microsoft Access in order to create, read, change or delete data. SQL is a non-proprietary (open) language, established by the American National Standards Institute (ANSI). SQL has, over the last decade, become the standard language for programmers to interact with databases through database management systems (DBMS). SQL is not to be confused with a programming language, since it, in general, does not provide procedural functions and serves only for manipulation of stored data. This is true except for a few functions such as querying of data, execution of calculations, and grouping and sorting of data.

An SQL query selects information from specific columns of certain tables in the database. The results of an SQL query is a (possibly empty) set of data records in a tabular form. SQL is applied to query all the information necessary for realization of the developed methodology for customer-neutral order planning in the demonstrator.

Typically, SQL queries include Select, From, and Where statements. The formulation of a query can be summarized as follows:

- The Select statement relates to those columns from which content needs to be copied to the attributes of elements or relations.
- The From statement relates to the tables in which these columns can be found.
- The Where statement relates to the filters in the request.

In the resulting tabular list of data records, each data record includes all the values that need to be copied into attributes of associated elements and relations. In order to be able to interpret these data records, the sequence in the 'Select' statement needs to be recorded. This is implemented by maintaining an ordered list of attributes to which the columns in the data records apply. This list is kept with the result.

6.2.4 Use Cases

To describe the functionality of the developed software application, a use case diagram has been developed: the use cases of this diagram are subsequently presented in detail. A use case describes, from the views of its actors, a quantity of activities of a system which lead to a perceptible result for the actors. A use case is always initiated by an actor. An actor acts exterior to the system and is involved in the interaction with the system that is described in the use case. An actor is either a user or a system. As a rule, use case diagrams are applied to determine user requirements; here they are applied to describe the scope of functions. Use case diagrams depict actors, use cases, and their relations. The use cases in a diagram are not listed in any chronological order.

Figure 6.5 portrays the use case diagram of the software demonstrator and depicts five actors: the sales planner, the design engineer, the manufacturing engineer, the program planner, and the controller. Microsoft Access is not considered as external to the Demonstrator and is therefore not depicted as an actor in the use case diagram.

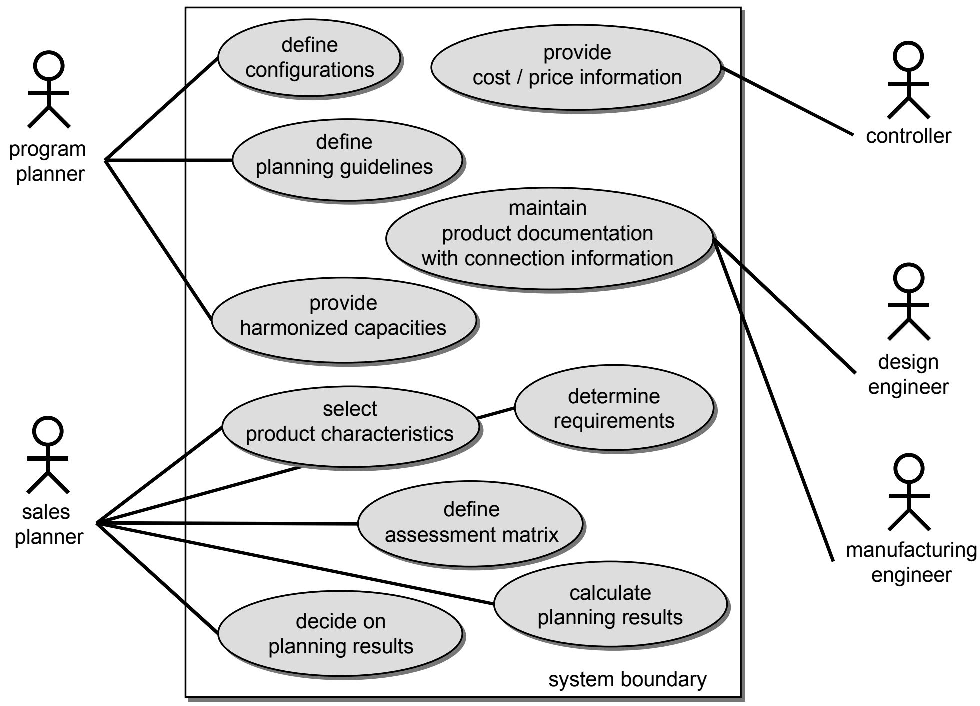


Figure 6.5: Use Case Diagram.

The use case 'define configurations' adds permissible and/or manufacturable configurations for both customer orders and customer-neutral orders to the database. This is done by the program planner who is also responsible for the use case 'define planning guidelines', setting the strategic aims for the customer-neutral order planning and the weighting coefficients employed to calculate market attractiveness. The weighting coefficients are determined using cardinal scaling of the importance of the indices as described in chapter 5.2.8. The strategic aims, which of course also have to be considered in short-term customer-neutral order planning, determine the later decision-making of the sales planner.

The use case 'maintain product documentation with connection information' is concerned with the definition of the part positions, part position variants, connection positions, and the connection position variants, but also with keeping this information up-to-date. The actors of this use case are the design engineer and the manufacturing engineer. The design engineer is responsible mainly for the correct product structuring whereas the manufacturing engineer defines the connections between the part positions dependent on the manufacturing process in the assembly plant. Figure 6.6 shows the dialog called when an existing part position (variant) is to be created or modified.

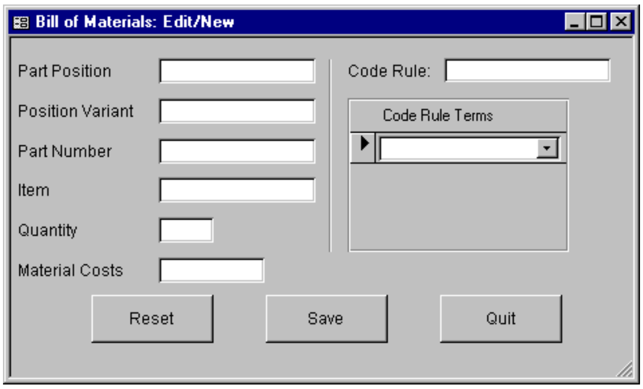


Figure 6.6: Definition of Part Position Variants.

The use case ‘provide harmonized capacities’ uses attributes to assign the available part capacities and manufacturing capacities of the underlying planning period to the defined variants of the part positions and connection positions. These capacities are harmonized between the Sales and Production Departments in long- and mid-term program planning. The documented part and manufacturing capacities are input information to calculate the planning results for the sales planner.

The use case ‘provide cost / price information’ assigns variable material costs and variable manufacturing costs to the part positions variants and connection position variants, respectively. Furthermore, the sales price of a product variant is associated with the order configurations documented in a table of the database. This information is necessary to calculate the achievable contribution margins in the order planning process. The controller performs this use case. Of course, future implementation work targeting a productive system must focus on integrating an enterprise resource planning (ERP) system, e.g. SAP R/3, in order to avoid redundancy and to ensure consistency.

The actor for the use case ‘select product characteristics’ is the sales planner. In line with the combination possibilities of the selected product characteristics, the permissible and manufacturable order configurations are identified. The selection of relevant order configurations by the sales planner represents important input information for the use cases ‘determine requirements’ and ‘calculate planning results’. Furthermore, the sales planner is responsible for the definition of the assessment matrix. Within this matrix the selected order configurations are compared pairwise and valued with regard to market attractiveness. This information is required to calculate the assessment matrix index (AMI).

The use case ‘determine requirements’ is concerned with the identification of the part and manufacturing requirements needed to build both the customer orders and the planned stock orders depending on the selected order configurations. Here, the mapping algorithm as described in chapter 5.1.7 is employed to identify the order-specific part position variants and the connection position variants. The sales planner starts this function; further human interaction is not required in this use case.

The use case ‘calculate planning results’ provides the results according to the different planning perspectives of customer-neutral order planning. The sales planner, as the actor of this use case, merely starts the calculation process; apart from that, this process is also run through without any further human interaction. It comprises the following steps:

- Retrieval of the selected order configurations.
- Identification of the lowest part and manufacturing capacity.
- Determination of the producible orders.

- Aggregation of the variable material and manufacturing costs of an order configuration.
- Computation of the achievable contribution margins.
- Estimation of the market attractiveness.
- Storage and visualization of the calculation results.

It is the responsibility of the sales planner to perform the use case ‘decide on planning results’. This actor decides on the basis of the calculation results and on the defined planning guidelines which customer-neutral orders are actually planned. These stock orders are then scheduled and produced.

6.3 Summary

In this chapter the objectives and the implemented functions of the software demonstrator were described. The purpose of the demonstrator is to gain an initial impression of the applicability of the developed planning methodology and to enable further insight into the requirements to be met for a productive planning system for deployment in an automobile producing enterprise.

In addition, the applied development cycle of the software demonstrator has been elaborated. The necessary functions for validation of the planning methodology have been fully implemented. The scope of the functions is illustrated by means of a use case diagram. The relevant use cases are subsequently further detailed. The implementation of the functions and the graphical user interfaces were realized with the database management system Microsoft Access. Furthermore, VBA and SQL were applied as programming language and querying language, respectively.

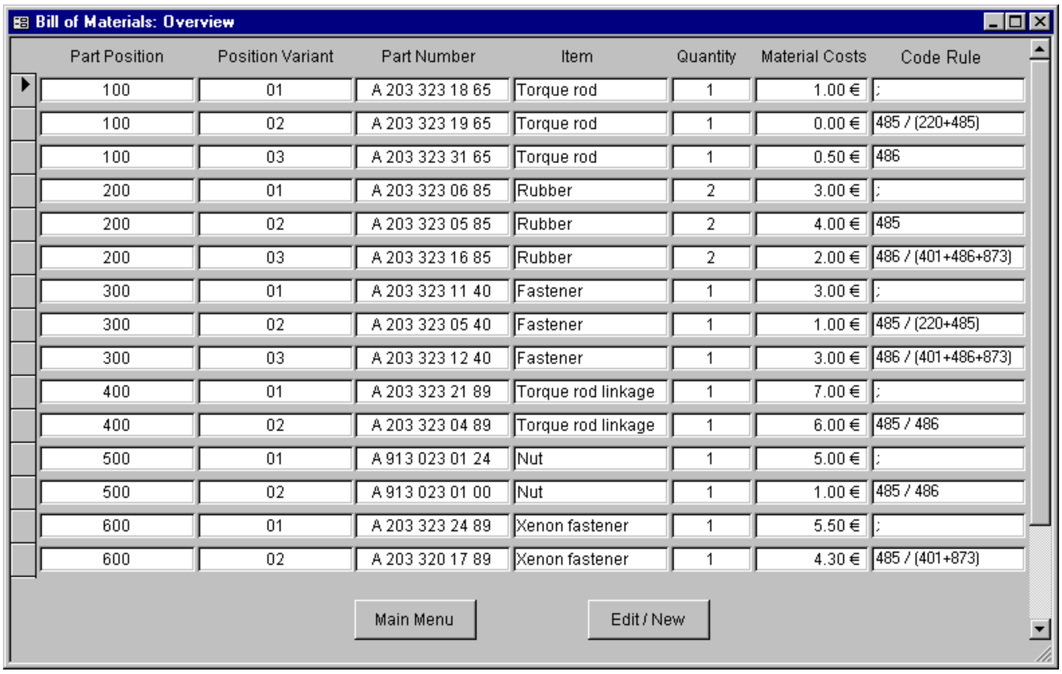
Chapter 7

Illustration of the Software Demonstrator

7.1 Application

The application of the software demonstrator focuses on the illustration of the implemented process flow of the planning methodology for customer-neutral orders at a major car manufacturer, DaimlerChrylser AG. This is done by means of the developed user interfaces and the implemented user guidance through the single planning steps. The purpose is to present, in an adequate form and based on a realistic, exemplary scenario, the different facets of the planning methodology to the sales planners in their role as the future users of a productive system. The illustration of the demonstrator yields a number of benefits: experiences are made regarding the user comfort, user bias can be detected and examined, helpful suggestions for extensions gained, and the necessary extent of process reengineering identified.

As cited in chapter 6.1, the implemented planning scenario is based on an exemplarily defined product documentation with connection information, as such documentation is not yet available in practice. Figure 7.1 shows a part of the bill of materials in terms of the defined part positions and part position variants. Each part position variant is specified by the attribute's part number, item designation, quantity coefficient, variable material costs, and the code rule. These attributes only are relevant to illustrate the planning methodology; further attributes which may exist in practice are neglected in this context.



Part Position	Position Variant	Part Number	Item	Quantity	Material Costs	Code Rule
100	01	A 203 323 18 65	Torque rod	1	1.00 €	;
100	02	A 203 323 19 65	Torque rod	1	0.00 €	485 / (220+485)
100	03	A 203 323 31 65	Torque rod	1	0.50 €	486
200	01	A 203 323 06 85	Rubber	2	3.00 €	;
200	02	A 203 323 05 85	Rubber	2	4.00 €	485
200	03	A 203 323 16 85	Rubber	2	2.00 €	486 / (401+486+873)
300	01	A 203 323 11 40	Fastener	1	3.00 €	;
300	02	A 203 323 05 40	Fastener	1	1.00 €	485 / (220+485)
300	03	A 203 323 12 40	Fastener	1	3.00 €	486 / (401+486+873)
400	01	A 203 323 21 89	Torque rod linkage	1	7.00 €	;
400	02	A 203 323 04 89	Torque rod linkage	1	6.00 €	485 / 486
500	01	A 913 023 01 24	Nut	1	5.00 €	;
500	02	A 913 023 01 00	Nut	1	1.00 €	485 / 486
600	01	A 203 323 24 89	Xenon fastener	1	5.50 €	;
600	02	A 203 320 17 89	Xenon fastener	1	4.30 €	485 / (401+873)

Figure 7.1: Bill of Materials.

Again, for reasons of the requisite unambiguousness, each code rule may only occur once in a part position. Otherwise, the algorithm for requirements planning would identify more than one part position variant in a part position and the orders would thus not be producible (see chapter 5.1.2). To ensure unambiguousness of the code rules, the data input made by the user is compared with the acceptance rules which are defined in the database. If an input rule is violated, the code rule will not be accepted and the user is asked to correct it. If this occurs, the user is supported by the output of a corresponding error message with the input instruction to be followed.

To complete the product documentation with connection information, the connection positions and connection position variants are also defined. Figure 7.2 depicts one of the generated connection position variants and the related part position variants. To specify the connection position variants in more detail, also process information (e.g. machining time), resource information (e.g. type and specification), and factory information (e.g. production line, work station) is added. The variable costs of a connection position variant result from automatic aggregation of the documented variable manufacturing costs and the variable material costs. The attribute ‘sequence number’ depicts the position of the connection position variant in the manufacturing sequence. The sequence number is an example for an implemented class-instance relation: the attribute is defined only once at the corresponding object class ‘connection position’ because the sequence number is identical for all assigned instances, the connection position variants. Class-instance relations reduce the risk of data redundancy and data inconsistency.

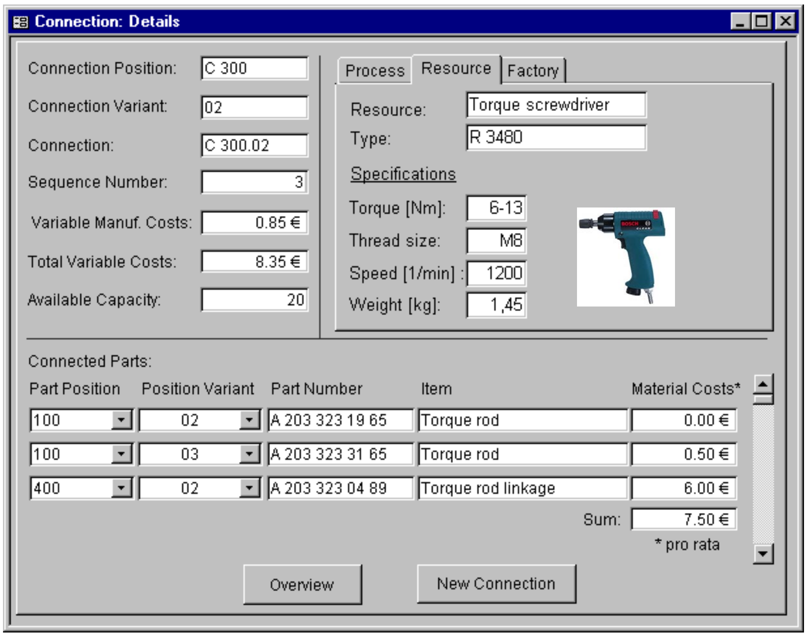


Figure 7.2: Definition of Connection Position Variants.

The first step of the actual planning process for customer-neutral orders is to specify the order characteristics by selecting a product type and the product options. To do so, the sales planner uses the order quota as a clue to select a product type. The order quota contains the rough information on the quantity of stock orders of a certain product type that are to be produced as determined on the basis of the forecasted customer orders received and the actual available customer orders in the planning period. The sales planner selects the order characteristics from two lists which contain the permissible product types and product options for each model series and market. These lists are stored in the database in tables.

Second, the permissible, i.e. the producible order configurations, are automatically identified and visualized. These configurations result from the permissible combinations of the previously selected order characteristics (product type, product options) with one another. This visualization enhances transparency of the selectable configurations for the sales planner. Furthermore, the user is not required to know all the manifold permissible combination possibilities of the product characteristics, which typically vary from model series to model series and from market to market. Thus, the risk of forgetting an order configuration is minimized and faulty data inputs can be avoided. This planning step ends with the selection of the order configurations which are of interest for customer-neutral order planning. This significantly reduces the time required to calculate the planning results in the subsequent planning steps. Figure 7.3 portrays the described planning steps.

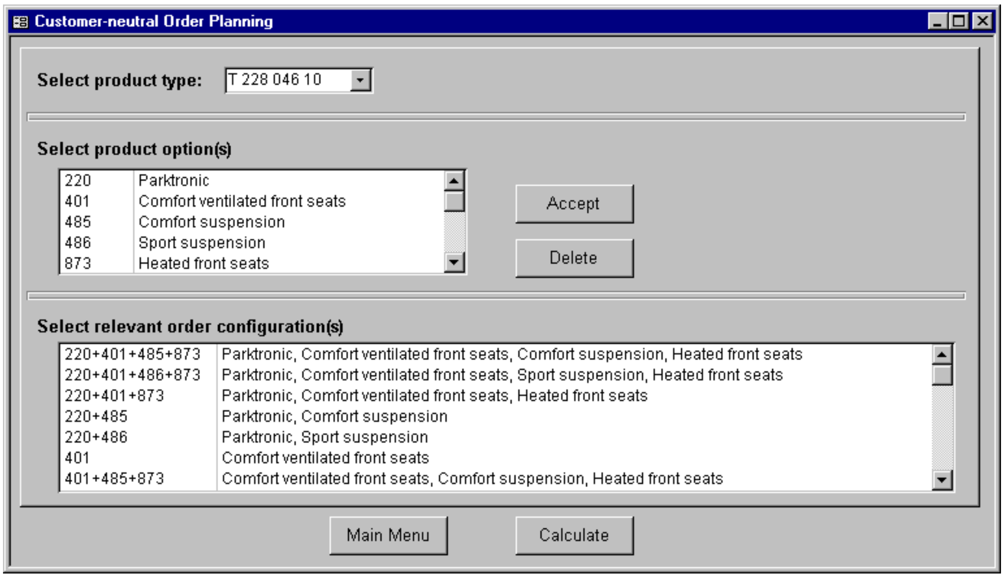
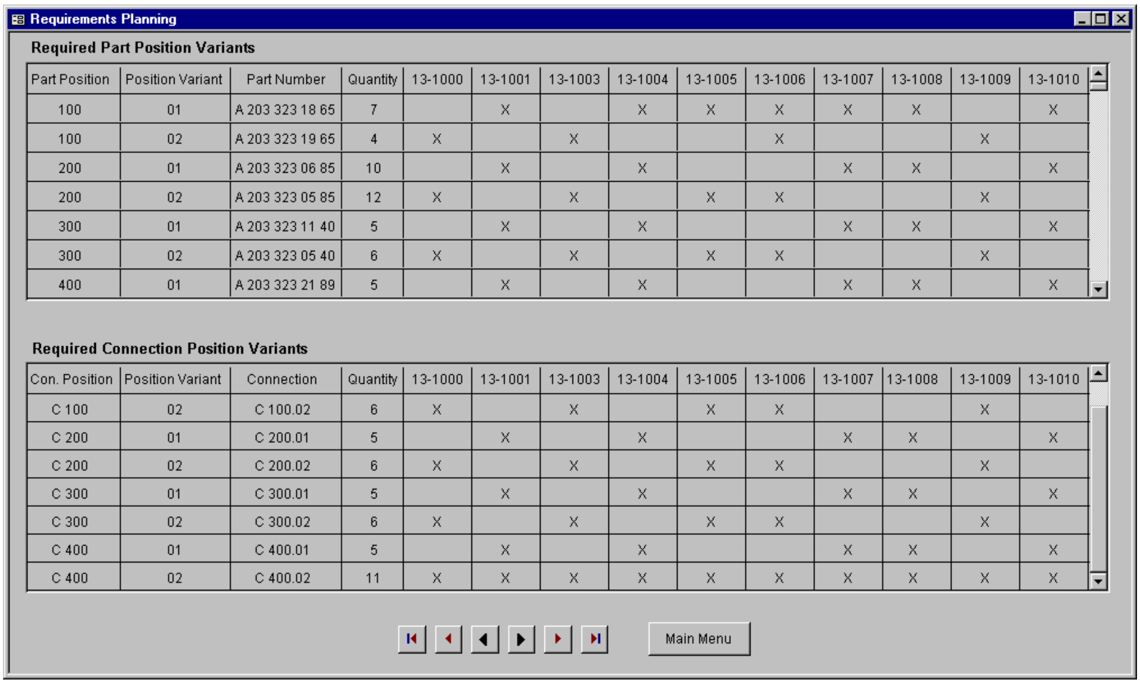


Figure 7.3: Selection of Order Characteristics.

In the next planning step, the calculation process for the selected order configurations is carried out. This planning step includes the following activities:

- Requirements planning.
- Identification of the available part and manufacturing capacities.
- Calculation of the number of producible orders.
- Computation of the contribution margin per unit and of the total contribution margin.
- Calculation of the market attractiveness in terms of the marketability index.

These activities are carried out for each selected order configuration as described in detail in the second part of this thesis. The entire calculation procedure is done automatically; the sales planner merely triggers the process.



Required Part Position Variants

Part Position	Position Variant	Part Number	Quantity	13-1000	13-1001	13-1003	13-1004	13-1005	13-1006	13-1007	13-1008	13-1009	13-1010
100	01	A 203 323 18 65	7		X		X	X	X	X	X		X
100	02	A 203 323 19 65	4	X		X			X			X	
200	01	A 203 323 06 85	10		X		X			X	X		X
200	02	A 203 323 05 85	12	X		X		X	X			X	
300	01	A 203 323 11 40	5		X		X			X	X		X
300	02	A 203 323 05 40	6	X		X		X	X			X	
400	01	A 203 323 21 89	5		X		X			X	X		X

Required Connection Position Variants

Con. Position	Position Variant	Connection	Quantity	13-1000	13-1001	13-1003	13-1004	13-1005	13-1006	13-1007	13-1008	13-1009	13-1010
C 100	02	C 100.02	6	X		X		X	X			X	
C 200	01	C 200.01	5		X		X			X	X		X
C 200	02	C 200.02	6	X		X		X	X			X	
C 300	01	C 300.01	5		X		X			X	X		X
C 300	02	C 300.02	6	X		X		X	X			X	
C 400	01	C 400.01	5		X		X			X	X		X
C 400	02	C 400.02	11	X	X	X	X	X	X	X	X	X	X

Figure 7.4: Order-specific Requirements Planning.

Figure 7.4 shows the result of a requirements planning for some orders which have been exemplarily defined in the database. The list boxes indicate for each variant of a part position and connection position whether a variant is required to manufacture an order. This is illustrated in the figure by a cross behind each variant and for each order. Furthermore, the quantity of each part position variant and connection position variant required to build the considered customer orders is calculated: each cross is counted and the resulting sum multiplied with the quantity coefficient. The procedure of requirements planning is identical for both the actual customer orders and for planning of customer-neutral orders.

Thus the requirements planning is also executed for the different order configurations which have been selected by the sales planner in a previous planning step, allowing not only the relevant part position variants and connection position variants but also the planning parameters documented at the respective position variants that are available for the following calculation steps to be identified. Examples for the planning parameters are the part and manufacturing capacities and the variable material and manufacturing costs. This information is stored in the form of attributes in the database. In requirements planning, this information enables the computation of the number of producible orders and of the achievable contribution margins with respect to the selected order configurations, making the results of the quantitative planning perspectives available for the decision-making process.

For the computation of the market attractiveness of the order configurations (qualitative planning perspective), the weighting coefficients first have to be determined by means of the described cardinal rating scale. The different weighting coefficients refer to the stock vehicle index, the customer order index, the customer time index, and the assessment matrix index. These indices are multiplied with the respective weighting coefficients. The results are then added to a total value: the marketability index. Of course, the user may, if desire, neutralize an index for the computation of the order configuration-specific marketability by defining the numerical value zero for the associated weighting coefficient.

Figure 7.5 depicts the graphical user interface which visualizes the defined weighting coefficients and the calculated values of the above indices for the selected order configurations. The configurations are listed in chronological order according to the calculated value of the marketability index.

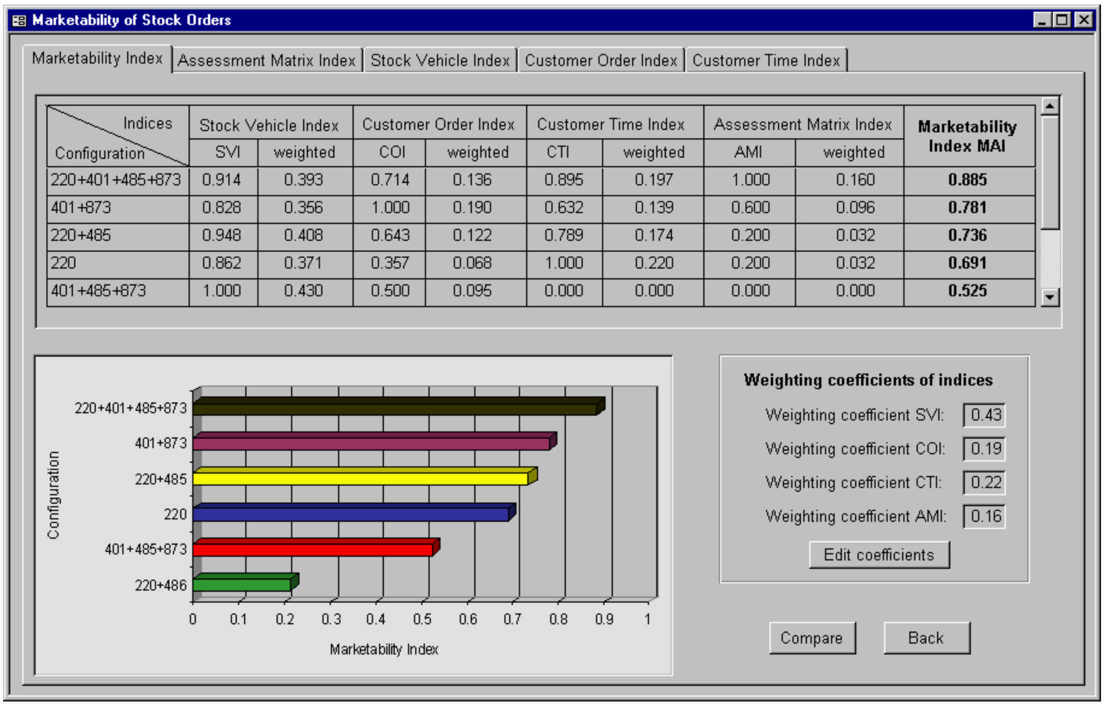


Figure 7.5: Market Attractiveness of Order Configurations.

Additionally, the software demonstrator allows the calculated market attractiveness of two order configurations to be compared graphically. As figure 7.6 shows, the differences between the configurations are highlighted.

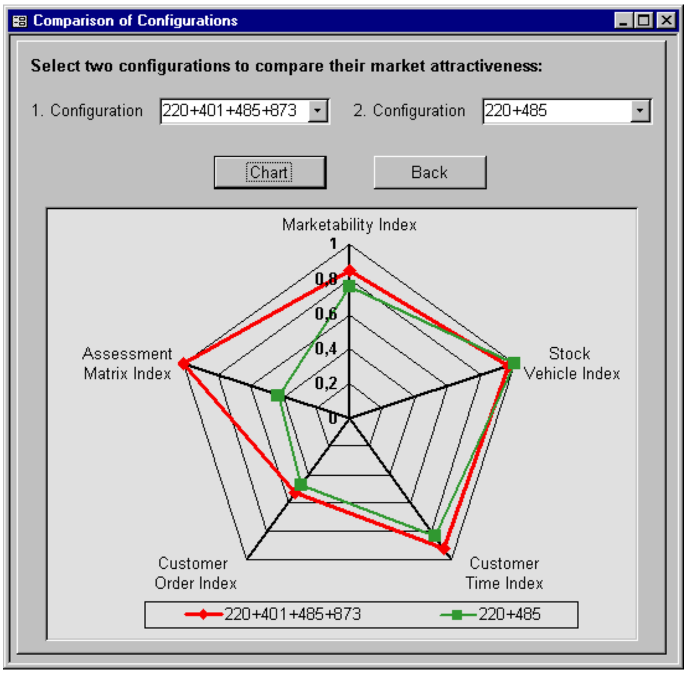


Figure 7.6: Comparison of the Market Attractiveness.

The assessment matrix index as part of the marketability index is determined by means of a pairwise comparison of the order configurations considered. Figure 7.7 shows the implemented assessment matrix and the user interface employed to define and edit the assessment scores of the selected order configurations. Here, the numerical value one means that an order configuration is equally marketable compared to another order configuration. The assessment score zero denotes that the configuration is less marketable, whereas the value two indicates better marketability. The assessment scores are stored in the database. Thus, the scores for the order configurations only need to be defined once and are also available in the future planning periods.

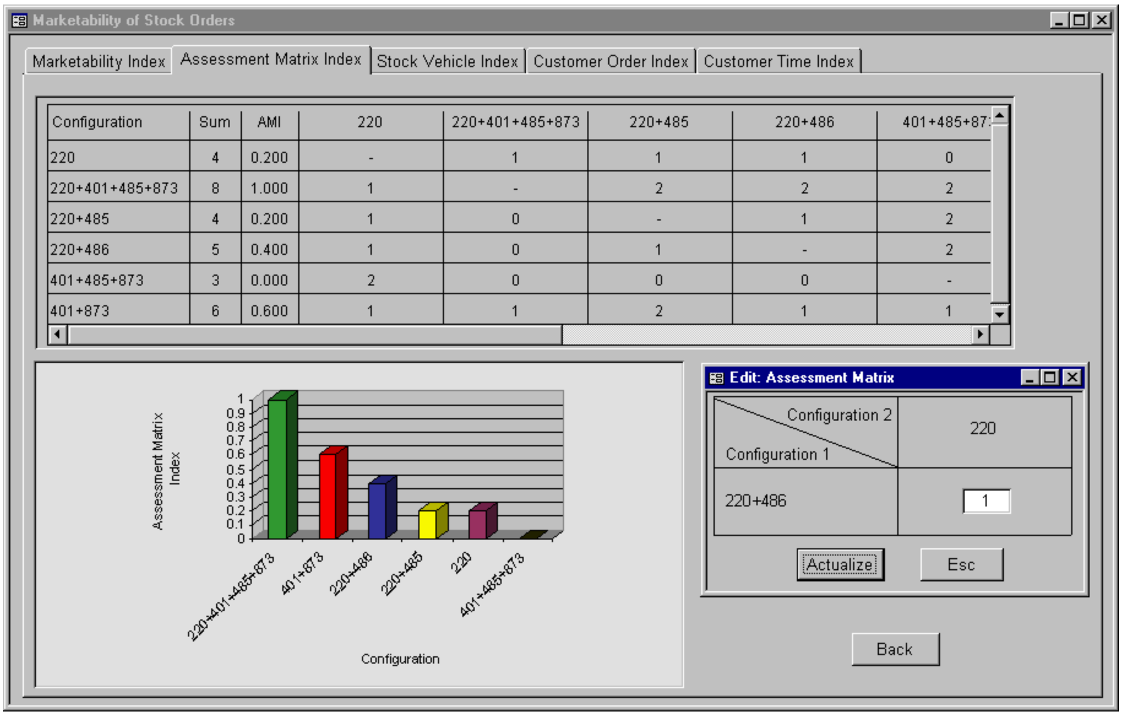


Figure 7.7: Implemented Assessment Matrix.

The calculation result of the order configurations selected in the second planning step is summarized in figure 7.8. Since the planning perspective ‘total contribution margin’ is activated, the configurations are listed in chronological order according to the calculated value. In addition, the sales price, the calculated variable material and manufacturing costs, and the number of producible orders in the current planning period are visualized. The user may switch between the various quantitative and qualitative planning perspectives. The relevant calculation results are immediately available, since this information is stored in the database.

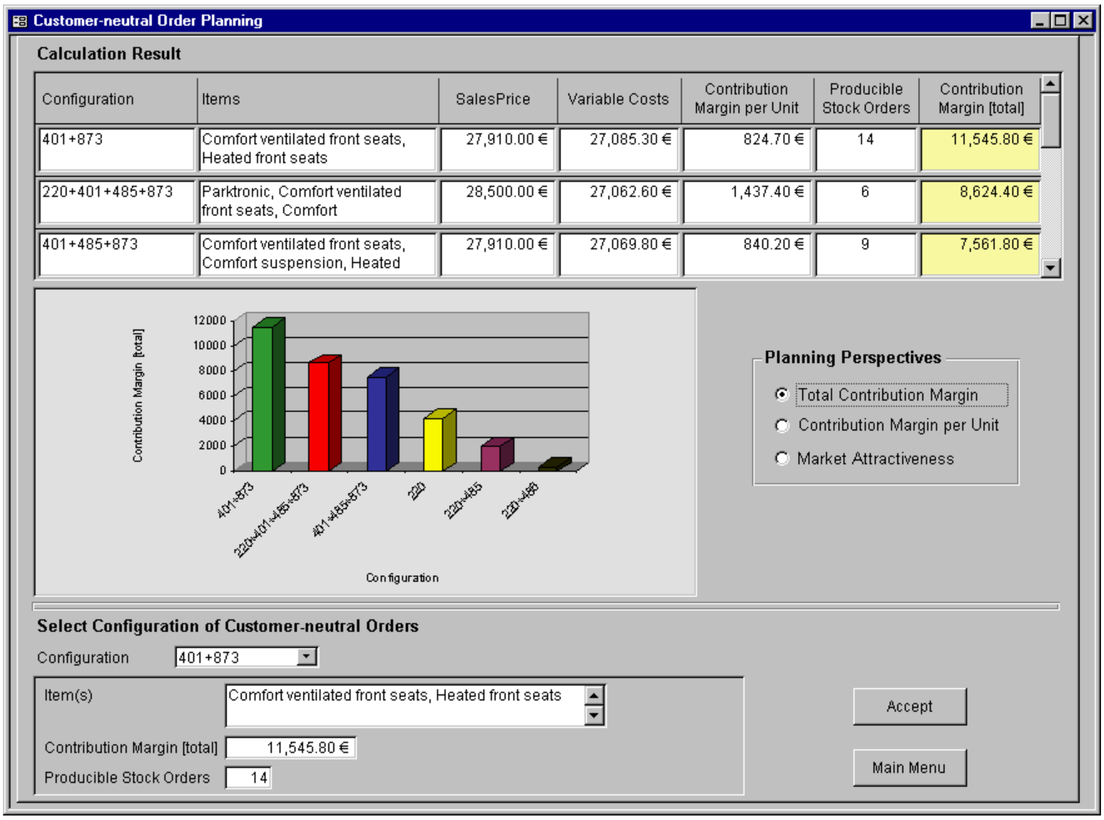


Figure 7.8: Calculation Result of Customer-neutral Order Planning.

The planning process ends with the selection of an order configuration for the stock orders to be planned first. The selection has to be confirmed by the sales planner before the calculated number of producible orders is scheduled for the present planning period. After confirmation, the calculation process is started once again for the remaining order configurations which have also been selected by the sales planner at the beginning of the planning process. This is done so because the scheduling of the customer-neutral orders reduces the available part and manufacturing capacities, thus making it necessary to update the number of producible orders and achievable contribution margins of the other configurations before recomputation. In this context, only the results of the qualitative planning perspective remain unaltered. Of course, the recalculation process is started automatically and carried out.

The sales planner is not forced to utilize all the available capacities in the planning period by means of planning customer-neutral orders, yet it is the responsibility of the Sales Department to waive contribution margins, since the capital-intensive capacities have been planned on the basis of the forecasted sales figures.

7.2 Experiences with the Demonstrator

With the application of the software demonstrator and the discussion with potential users at DaimlerChrysler, experiences were gained concerning the applicability of the planning methodology, user acceptance, and the resulting scope of process reengineering. The most significant lessons learned are described in this section.

Sales planners, as the main users of the software demonstrator, were able to realize integrated overviews of information for a well balanced decision-making - which is particularly relevant for their role in the order planning process. Typically, the users consult a number of different information sources to acquire all the information they need. This is especially true if several planning perspectives exist. In the demonstrator, the users were able to easily switch between the calculated results of the integrated planning perspectives via a single interface. In the software demonstrator, relevant planning information is stored in different tables of the database. In contrast, in a productive planning system, information may also be linked from several existing sources (e.g. ERP systems) instead of storing them in a single database. If this is done, no changes are needed according to the process flow of the planning methodology.

During the discussions it appeared that the two most appreciated advantages of the user interface were its convenient input function and easy modification of information as well as its transparent user guidance through the individual process steps of the planning methodology. Moreover, all user inputs could be checked automatically for correctness, e.g. definition of a code rule. In brief, the implemented user interface has emerged to be of valuable use for the sales planner who is responsible for the planning of customer-neutral orders. In addition, the demonstrator seems to be a useful tool to illustrate the developed planning methodology in a transparent manner and to increase the users' readiness to rethink the decision-making process: there is now a viable alternative to the way thus far employed in the order planning process.

The developed methodology for customer-neutral order planning, as illustrated by the software demonstrator, does not significantly change the workflow of the sales planner. Rather this actor's task is made easier, since consistent planning information is always at hand. Sales planners can base their decisions on the different information integrated in the planning methodology by means of several planning perspectives. Thus, time-consuming information searching has become a thing of the past. In addition, the risk of neglecting relevant planning information can be avoided. The sales planner is now able to carry out comparisons between alternative configurations of the stock orders to be planned with respect to quantitative (e.g. contribution margin) and qualitative (e.g. market attractiveness) criteria. Thus, a planning system for customer-neutral orders supports the sales planner in the overall decision-making process.

The planning results are based on the detailed calculation of the configuration-specific part and manufacturing requirements. The backbone for this calculation process is the introduction of the product documentation with connection information. While this changes the workflow of the design and manufacturing engineers most significantly, this is a task not primarily driven by order planning: rather, the increasing need for new methodologies of product and process variety management in the product development and product creation process calls for this. Of course, with the introduction of a new methodology of product and process documentation benefits in order processing, e.g. for order planning and order change management, were also expected (see chapter 7.3).

The introduction of the product documentation with connection information expands the current scope of the design engineer and the manufacturing engineer. The design engineer is responsible for determination of the product structure which underlies the application, i.e. by defining part positions, developing new or modifying existing part position variants, and assigning the code rules to the position variants after grouping them to the part positions. In addition, the design engineer has to make sure that the product structure is up-to-date and must, if necessary, modify it. The manufacturing engineer has to define the connection positions, the connection position variants, and the relations to the part position variants according to the manufacturing sequence of the products. These activities are completely new, since the product documentation currently in use does not take the manufacturing sequence on the part level into account. Furthermore, the connection information must be adapted to the changes in the manufacturing process by the manufacturing engineer from time to time. The cited tasks of the design and manufacturing engineers might also be affected independent of whether a planning system for customer-neutral orders is introduced or not.

As the product structure and the manufacturing sequence are subject to ongoing changes, e.g. added or deleted part position variants and connection position variants initiated by either the design engineer or manufacturing engineer, it has to be warranted that the product documentation with connection information is always up-to-date. Otherwise, planning results may become incorrect. And this may lead to tremendous and expensive disturbances in the order processing chain, e.g. in Procurement or Assembly. The management of these changes might lie within the area of responsibility of documentation specialists whose job description has thus far not been fully specified. Since the background of a documentation specialist is typically not predominantly technical and the changes might be manifold, further communication and coordination with the design and manufacturing engineers is necessary to ensure the correctness of the product documentation with connection information.

The program planner is, in addition, only occupied with defining the planning guidelines for customer-neutral order planning, i.e. which planning perspective (e.g. market attractiveness) is to determine the later decision of the sales planner. Furthermore, this actor is responsible for defining the permissible order configurations in the market and for maintaining the part and manufacturing capacities which have been harmonized between the Sales and Production Departments in the long- and mid-term program planning process. These tasks have to be carried out independently of the developed planning methodology. The controller, in turn, is not burdened with additional work since such an application relies on data in an ERP system in order to avoid redundant and inconsistent data. Relevant cost and price information can be imported from the ERP system via interfaces to the order planning system.

Since innovations are typically accompanied by process changes in the daily work of the people concerned, new approaches are often not fully accepted at first. This is even true if only minor process changes are required. The objective must target developing the attitude that the planning system for customer-neutral orders is a useful tool in supporting sales planners in their activities and that it is not to be regarded as superfluous. If the planning system lacks acceptance due to user bias, the potentials of such a system cannot be exploited. Therefore, preparatory work is a must.

7.3 Summary and Conclusions

This chapter illustrated the application of the market-oriented planning methodology for customer-neutral orders in the form of the implemented software demonstrator. With the construction of an example and the discussion with sales planners at DaimlerChrysler AG, an order planning system was simulated on a small scale. The limitation to a small scale was necessary as the product documentation with connection information, which forms the foundation for the developed planning methodology, is still in the pipeline and currently not at hand. Thus, an exemplary fragment of such a kind of product and process documentation was defined for the application of the demonstrator. Since the order-specific requirements planning is based on the product documentation with connection information (which is not yet available to the required extent), it was also necessary to limit the number of selectable product characteristics and permissible order configurations in the demonstrator. Apart from this, the planning methodology was illustrated by real, existing examples from the company. Although the scope of the current software application does not allow the results of the example applied in the demonstrator to be interpreted into a generic empirical validation of the planning methodology as a whole, a number of initial conclusions which indicate the applicability and user acceptance of the methodology can be drawn.

It appeared that, for example, the extent of process reengineering and additional work for the people involved is relatively low. Even now, the activities connected with applying the planning methodology are a predominant part of their daily work. The most far-reaching changes are expected for the design and manufacturing engineers. Together, they are responsible for establishing the product documentation with connection information. Yet this is a task which is independent from the application of the planning methodology for customer-neutral orders.

The availability of such a tool in a real industrial environment at an automobile producer's would certainly support the sales planners making decisions as to which customer-neutral orders are to be planned. The initial feedback was that the planning methodology implemented in a productive system would save the users a lot of time otherwise required to search for the various information. Furthermore, the integration of qualitative and quantitative criteria promotes well-balanced decision-making. Additionally, the integration of the different planning perspectives reduces the risk that any relevant information might be overlooked. The implemented user interfaces ensure transparent user guidance through the individual planning steps and comfortable information input and visualization of the automatically calculated planning results. For repetitive tasks, the user is able to store planning guidelines (e.g. weighting coefficients, assessment matrix) and to re-apply them. Finally, the demonstrator has shown that it is a helpful tool to achieve the desired attitude and acceptance of the people using it: and it is this aspect which is necessary to exploit the potentials of the planning methodology in the best way possible.

One of the next steps to be done is to accompany the development of the product documentation with connection information and to implement it for an improved usability of the demonstrator. Additionally, interfaces for the data import and export with other data systems (e.g. ERP system) should be implemented. With the further development of the demonstrator, the planning methodology can be evaluated more generally. But also the product documentation with connection information, which is the most important information backbone in the market-oriented planning methodology for customer-neutral orders, for example, can be validated in the context of this application and, if necessary, modified.

Chapter 8

Concluding Remarks

8.1 Conclusion

Manufacturing companies today are faced with ongoing globalization, increasingly severe competition, higher price pressure, and overcapacity. In addition, they are forced to meet growing market demands such as customized products, shorter lead times and delivery dates, high product functionality, and high product quality to avoid loss of market shares. Furthermore, order processing can be characterized by an increased customer influence and growing product and process complexity. These aspects come together with the need for efficient order processing to achieve a fair profit. The activities in the overall order processing chain have also become more and more interrelated. Thus, they have to be carried out in close collaboration with the several organizational units involved. A further complication factor for realization of efficient order processing and planning of orders is that the environment in which manufacturing companies operate is highly dynamic and continuously influenced by developments in markets, technology, society, legislation, competitors, supply chain, and partnerships.

Each of the internal or external relationships may impact order processing through various unpredictable events such as a slack in customer demand. As a result, original plans, e.g. sales plans, are often no longer realizable, leading to a commensurate drop in planning stability. Thus, there is a need to react appropriately in order planning to ensure the steadiest possible utilization of capital-intensive capacities which cannot be adapted to the decline in customer demand to the required extent at short notice. However, there is neither an appropriate tool nor an adequate methodology for customer-neutral order planning which supports the sales planner sufficiently in making a well-balanced decision. Subsequently, the objective of this thesis has been to develop an adequate methodology that includes not only capacity and/or cost aspects but also marketability considerations and which thus contributes to the realization of an efficient order processing chain. In order to cope with the requirements resulting from growing product variety and complexity, the planning methodology has to be based on an adequate product and process documentation. However, in a dynamic environment it is also the product and process documentation that is affected by ongoing changes. As this documentation is an important information backbone for the planning of customer-neutral orders, the planning quality achieved is contingent on up-to-date information.

The requirements for an order planning methodology have been derived from the current situation as described above. They have been further refined based on the results of the state-of-the-art literature review. Thus, an issue of practical interest has been captured and elaborated. To avoid any rush decision-making that would have precluded promising solutions or proper methodologies, all those areas that are in any way related to order processing and order planning have been examined, of course including the state of the art in these fields. Extensive research has also been performed in the areas of variety and complexity management, product structuring, product configuration, production planning and control, and program planning. The analysis resulted in the awareness that thus far no explicit planning methodology for customer-neutral orders which meets the identified requirements exists. Furthermore, it became obvious that the identified concepts for variety management may result in a reduction of internal product variety, which facilitates the planning of stock orders. This is because the number of product characteristics and permissible order configurations to be considered in the planning methodology can be limited, and the calculation effort in the planning methodology can be minimized. Since variety is a cost-intensive complexity driver in manufacturing companies, a reduction of product variety decreases the internal complexity in favor of enhanced transparency in product structuring and documentation.

As the planning of customer-neutral orders is contingent on the product and process documentation, methods for describing product structures have been identified and evaluated on the basis of the requirements to be met. The identified concepts show considerable shortcomings with respect to the objective of this thesis and to the challenges which arise from and in a dynamic environment. They are, in particular, not able to manage the variety from the product to part levels in a transparent manner. In many concepts, a diversified product portfolio has to be documented in separated documents (bill of materials). In addition, the integration of product information and manufacturing information is not solved satisfactorily. Order-specific manufacturing information such as the relations between the parts which are to be mounted in the end product is either not considered in the concepts or cannot be assigned to the product information. Furthermore, the identified concepts contain solely descriptive information in terms of a bill of materials, with no additional variable data included. Thus, order-specific requirements planning using these concepts is limited to aiming at identification of the parts and materials needed to build the different products. And, information about the assembly processes and the variable data such as available part and manufacturing capacities is simply not at hand for order planning. In the absence of a complete and applicable product and process documentation as required for this research work, the most promising approach has been to apply and extend the methodology of product documentation with connection information to the needs of customer-neutral order planning.

The characteristics of the product documentation with connection information have been described in detail. Various key questions have been answered: how the product variants and parts are documented, how the part net is created, and how the manufacturing relations between parts can be established. The facets of the object classes ‘part positions’ and ‘connection positions’ and their respective instances ‘part position variants’ and ‘connection position variants’ have been explained. Through the universal information structure applied within the product documentation with connection information, it is possible to assign relevant planning parameters and additional data by means of attributes to the object classes and objects. Class-instance relations reduce the risk of data inconsistency and the effort for data administration. It has been demonstrated that product documentation with connection information builds the basis for order-specific requirements planning, which enables the identification of information (e.g. part capacities, variable material and manufacturing costs) needed for the planning of customer-neutral orders. Thus, requirements planning has been elaborated as a pillar of the developed planning methodology.

Both the quantitative planning perspectives and the qualitative aspects of the developed planning methodology have been explained in detail. The focus of the quantitative perspectives has been to consider the identification of the available part and manufacturing capacities with respect to the customer order situation and the target capacity utilization in the current planning period. The number of producible stock orders and the achievable contribution margins for the different order configurations have been calculated with respect to the lowest identified capacity. To ensure that the economy of scale which results from the additional customer-neutral orders in the planning period will not be exceeded by cost-intensive investments in marketing campaigns to unload difficult-to-market stock vehicles after production is finished, the market attractiveness has been introduced. This qualitative perspective of the planning methodology contains neither capacity aspects nor monetary considerations, instead focusing on determination of the marketability of customer-neutral orders. The influencing factors that are of interest for the calculation of the market attractiveness have been represented as single indices. These indices are the stock vehicle index, the customer time index, the customer order index, and the assessment matrix index. These indices have been combined to the marketability index, which enables the interpretation of the market attractiveness of different order configurations. The marketability index has been represented as a function of the afore-mentioned indices and of weighting coefficients. The weighting coefficients are employed to simulate different planning guidelines according to various market situations. In order to be able to objectify and to measure subjective and qualitative estimations of the importance of the weighting coefficients, a cardinal rating scale has been developed and applied. The comparison of the applied rating scale with both a binary and a ordinal scale has shown that not only the ranking of the indices is known but also the difference in importance of the indices.

The refined requirements as described in chapter 4.2 have largely been fulfilled. An evaluation of the applicability of the developed planning methodology for the complete cross-brand product portfolio must be left open, since the related research project to establish the product documentation with connection information has not yet been finished. The applicability has been elaborated using an exemplarily defined product documentation with connection information in the context of a large industrial manufacturing company. On the basis of this information backbone, a software demonstrator has been constructed to validate the planning methodology. All the functions and algorithms of the planning methodology were implemented. The demonstrator has indicated the feasibility and the added value of integrating several planning perspectives. It became evident that the opportunity to provide the sales planner with an integrated information overview leads to obvious improvements for the efficiency and effectiveness of the planning activities. Both the time required for the search for information and the risk that relevant information will be overlooked decrease substantially. The graphical user interfaces enable ease of navigation through the planning process and support transparent user guidance. It also appears that the extent of process reengineering needed to realize the developed planning methodology is relatively low and requires only a moderate amount of effort. The greatest changes and additional effort are expected from the introduction of the product documentation with connection information, as it affects a multitude of processes in a manufacturing company. Yet the efforts required to establish and maintain this kind of product and process documentation are independent from the application of the developed planning methodology for customer-neutral orders.

In brief, it has been shown how market-oriented planning of customer-neutral orders can take place with respect to several competitive dimensions. The considered competitive dimensions ‘time’, ‘cost’, and ‘quality’ support a well-balanced planning of customer-neutral orders. As the term customer neutral denotes, stock orders have to be planned without the later end consumer being known. Thus, the developed planning methodology cannot guarantee that absolutely no stock orders which will afterwards be difficult to market are planned and produced. However, this risk can be minimized through the qualitative planning perspective integrated in the developed planning methodology. Thus, additional costs for stock orders owing to warehousing, capital-investment in stock, technical obsolescence, and an artificial increase of customer demand (e.g. discounts) can be reduced significantly. Of course, customer orders have top priority compared to stock orders. Only if an insufficient number of customer orders are available to utilize the part and manufacturing capacities to the required extent in the planning period are customer-neutral orders planned. Thus, customer-neutral orders will be only planned by the responsible sales planner at the end of each planning period. The conclusive decision as to which stock orders are to be planned lies within the responsibility of the Sales Department as Production has, of course, planned the capacities within the scope of long- and/or mid-term production planning based on the product life-cycle forecast and the related sales figures. It can be concluded that the presented methodology for market-oriented planning of customer-neutral orders can boost the realization of an efficient order processing chain.

8.2 Outlook

Future work must evaluate the planning methodology for customer-neutral orders in empirical studies in the real order processing environment. In this context, especially interesting are the applicability of the methodology for companies with a huge product portfolio diversity, the transferability of the planning methodology from laboratory conditions of an exemplary sales market to the real, typically heterogeneous market requirements, and finally the quality of the planning results. The latter should include a continuous monitoring of the calculated market attractiveness of the several order configurations under consideration of the actual market situation. In this respect, practical experience will be crucial in addition to the experiences gained under laboratory conditions.

Furthermore, in the context of the decision-making process to determine which customer-neutral orders are to be planned with respect to the computed results of the different planning perspectives, the introduction of threshold values should be taken into consideration. Threshold values would allow the freedom of decision-making of the responsible sales planners to be limited purposefully. Threshold values could be defined for both the contribution margin and market attractiveness, e.g. in the form of minimum values. For example, the introduction of a minimum value for the marketability index would then have the consequence that the sales planner can and may choose only such order configurations for the customer-neutral orders at the end of the planning process whose computed market attractiveness lies over the defined threshold value. Of course, the same is conceivable for the contribution margins of the order configurations. The definition of threshold values which have to be kept in any case ensures that planning results are not neglected, and one-sided decision-making can thus be avoided. However, before reasonable threshold values can be defined, the developed planning methodology and the decision-making process of the responsible sales planners, which has most probably been changed by the new methodology, must be evaluated on an appropriate information basis.

In this context, future test-cases and scenarios must be performed on an increasing scale in industrial manufacturing companies. Therefore, the functionality of the software demonstrator needs to be extended. The extension of the demonstrator will increase the potentials and quality and offer the opportunity to develop the planning methodology into a full-scale (productive) software application. Future work must also be concerned with the most convenient way of presenting the calculation result of the market-oriented order planning to the sales planner. This may include the design of the graphical user interfaces and the implementation of the user guidance with respect to psychological aspects to guarantee best user comfort and acceptance of such a planning system.

A broader evaluation of the planning methodology for customer-neutral orders and of the software demonstrator, of course, necessitates the accessibility of the cross-brand product documentation with connection information. In general, renowned universities, research institutes, and many software developers ascribe an increasing importance to the integration of product, process, and resource information and to the related data management. In addition, many industrial companies - especially in the automobile sector - invest enormous effort to standardize their documentation methods and processes and their data processing systems, following the motto: be as uniform as required with as many degrees of freedom as possible. In line with this thesis, these endeavors underline the importance of an effective and efficient documentation method to manage the increasing variety and complexity in a transparent way.

An industrial application of the product documentation with connection information would contribute to the common interest of information integration and to the standardization of (cross-brand) product and process documentation. In this context, it is important to exploit the potentials of this approach in the broad domain of the product creation process and order processing in manufacturing companies. The application of the product documentation with connection information is not limited merely to the planning of customer-neutral orders as described in this thesis. On the contrary, it is also applicable for further application fields in the order processing chain, e.g. for order control and order change management. Relevant planning parameters and constraints for order control (e.g. minimum distance of a product option between two orders) can be stored as attributes of the object classes and objects in the product documentation with connection information as illustrated for customer-neutral order planning. When a disruption of order processing occurs, any and all affected orders can be easily identified, since information is available which parts and connections are needed to build the scheduled orders. For example, if a capacity bottleneck for a product option should arise; all orders which contain this product option in their order configuration can be blocked and re-scheduled with respect to the relevant assembly constraints. Additionally, order change management benefits from the application of the product documentation with connection information: if an order is to be modified, e.g. a product option has to be exchanged with another product option, all the relevant parts and documented constraints could be identified and checked. Of course, the same is true if a specific part is changed geometrically by a design engineer and the adjacent parts are to be identified and adjusted to the new geometry. In both cases, the application of the documentation method avoids cost-intensive interferences in the domains of order processing and the product creation process. To exploit the cited potentials, the further development and exploration of the product documentation with connection information is an important step in this direction.

To realize a seamless integration of product documentation in manufacturing companies, it is essential that not only parts and their manufacturing relations be considered in parallel but also that geometric information of product creation be integrated. In the product creation process, feature technology is gaining more and more importance. Not only do feature-based CAD applications provide geometric and technological descriptions but also a large variety of supplementary information can be linked to the features of the parts, e.g. experience on using the feature. In future, the part net with the manufacturing relations will not be the lowest documentation level of the product documentation with connection information, but the features of the parts which are described in CAD models.

To conclude, the market-oriented planning of customer-neutral orders is an important step towards an effective and efficient utilization of cost-intensive capacities which cannot be adapted to the decline in customer demand to the required extent at short notice. It is thus a crucial building block for support of efficient order processing in manufacturing companies.

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Abbreviations

AMI................................. assessment matrix index
APS................................ advanced planning system
ATO................................ assemble-to-order
BEP................................ break-even point
BoM................................ bill of materials
CAD................................ computer-aided design
COI................................. customer order index
CPos.............................. connection position
CPosV............................ connection position variant
CTI.................................. customer time index
DP.................................. data processing
EEA................................ European Economic Area
ERP................................ enterprise resource planning
ETO................................ engineer-to-order
GUI................................. graphical user interface
LHD................................ left-hand drive vehicle
MAI................................. marketability index
MRP I............................. material requirement planning
MRP II............................ manufacturing resource planning
MTO............................... make-to-order
MTS................................ make-to-stock
OC.................................. order configuration
OEM............................... original equipment manufacturer
PLC................................ product life-cycle
PPC................................ production planning and control
PPos............................... part position
PPosV............................ part position variant
RHD............................... right-hand drive vehicle
ROI................................. return on investments
SAP................................ systems, applications, products
SQL................................ structured query language
SVI.................................. stock vehicle index
VBA................................ visual basic applications

Glossary of Terms

This glossary contains a list of terms applied in this thesis and their definitions. The words in brackets behind a term indicate the context of the term. Terms within a definition that are explained elsewhere in the glossary are set in italics.

Actor (software development)
An actor acts exterior to the system and is involved in the interaction with the system that is described in the *use case*.

Assemble-to-order (order processing)
Production is carried out to convert raw materials into basic components and subassemblies. Customer orders are supplied by assembling these stock components, allowing for customized configurations.

Assembly (product)
An assembly is a group of subassemblies and/or parts that are put together (**I**). The act of assembly is the fitting together of fabricated parts into a complete *product* or unit of the product (**II**).

Bill of materials (product structure)
A bill of materials contains part-related and structure-related information of the whole product portfolio of a company. It is a complete, formal listing of raw materials and parts which are needed to build exactly one piece of an end product.

Buyer's market (order processing)
In a buyer's market, the market power of buyers is stronger than that of the sellers. Typically, market supply is higher than customer demand.

Capacity (program planning)
The qualitative capacity describes the type and the capability of a production unit, whereas the quantitative capacity denotes the performance (output) of a production unit in a limited time period.

Characteristic *(product)*
A product characteristic corresponds to a functional feature of a product, but it states nothing about the concrete technical content of a product in terms of parts or assemblies.

Code (product documentation)
A code is used to encode a *product characteristic* in terms of a product function.

Code rule (product documentation)
Code rules are Boolean expressions which consists of codes and logical operations. Code rules describe the conditions for part usage and are needed for *requirements planning*.

Complexity (order processing)
Complexity is a large number of different elements with a high degree of cross-linking, influencing each other in a mutual way, and whose number and connections change almost unpredictably.

Contribution margin (program planning)
The contribution margin is the difference between the sales price and the variable costs of a product and describes the extent to which a product contributes to covering the fixed costs.

Control (production)
Control is the power of directing processes towards a predetermined objective.

Customer-neutral order (order planning)
A customer-neutral order is a company-internal order between the Sales and Manufacturing Departments. So-called stock orders are often built on market research and sales forecasts without the later end consumer being known.

Customer order (order planning)
A customer order, also called customer-specific order, is based on a concrete market demand, i.e. an end consumer is known.

Data (information management)
Data is the representation of facts, concepts or instructions in a formalized manner; suitable for communication, interpretation or processing.

Documentation (product)
The task of product documentation is to describe all the products of a manufacturing company and to denote all the related modifications during the overall *life-cycle*.

Economy of scale (production)
Economy of scale refers to a situation where the cost of producing one unit of a good or service decreases as the volume of production increases. Economy of scale tends to occur in industries with high capital costs in which such costs can be distributed across a large number of units.

Engineer-to-order (order processing)
Engineer-to-order describes an order processing strategy with the engineering design of the *product* and the *production* itself based on customer requirements and specifications.

Enterprise environment (order processing)
The environment in which a manufacturing company acts, comprising customers, partners, subcontractors, institutes, and other lobbies etc., is referred to as an enterprise environment.

Feature (product)
A feature is a generic shape that carries some engineering meaning.

Information (information management)
Information is the meaning that a human assigns to data by means of the known conventions (context information) used in its representations.

Life-cycle (product)
The product life-cycle is the period of time from the very first product creation idea to manufacturing and product usage and on to recycling/disposal.

Make-to-order (order processing)
Production is carried out to respond directly to customer orders, and no finished product inventory is held. Production is based on existing product definitions.

Make-to-stock (order processing)
Production is carried out to convert raw materials into finished products which are held in stock in anticipation of customer needs.

Manufacturing (production)
Manufacturing is the series of all interrelated activities and operations conjointly and directly aimed at the engendering of products and accompanying resources, methods, and procedures.

Manufacturing company (production)
A manufacturing company is a legal (commercial) entity that encompasses one or more manufacturing systems. Manufacturing companies differentiate three core processes in their operations: product creation, *order processing*, and enterprise management.

Material (product)
Material is any commodity used directly or indirectly in producing a *product*, e.g. raw materials, purchased components, sub-assemblies, and supplies.

Order (order processing)
An order is a business object which can be determined by at least two business partners and a date. Orders are typically categorized as either *customer orders* or *stock orders*.

Order configuration (product)
An order configuration, also called product configuration, describes the functional and physical characteristics of a product as defined in technical documents and achieved in the product.

Order processing (manufacturing company)
Order processing can be split up into a commercial and a technical part. The commercial part comprises product calculation, purchasing, and finance, whereas technical order processing involves business units and departments which are directly responsible for the order workflow and the manufacturing of the ordered products.

Organizational unit (manufacturing company)
At this, organizational units are groups of persons or single persons who are responsible in the companies' organizational structure for a specific spectrum of tasks.

Planning (order planning)
Planning is the systematic searching and determination of aims and the phrasing of tasks and resources which are necessary to achieve the aims.

Process (production)
A process is the course of action or a procedure, particularly a systematized series of distinct operations in *production*.

Product (production)
The term product originates from the Latin productum, meaning something is manufactured and offered on a market. Products can be discrete products, meaning individual parts, continuous products, or services.

Production (product)
Production is the process in which pieces of raw materials are turned into a *product*. During this process the product is given a value which is defined as its monetary worth or marketable price.

Production planning and control (order processing)
Production planning and control involves the planning, control, and monitoring of activities in the order processing chain with special focus on quantity, time, and capacity aspects.

Product option (product configuration)
A product option is an additional functional feature of a *product* which either must or can be selected by a person when configuring a product.

Product structure (product description)
A product structure is a systematic way to describe the components and the quantities in a *product* to be built.

Product type (order processing)
A product type bundles *products* with similar functional characteristics, serving as a rough description for a group of products.

Program planning (production)
Program planning is a main task of *production planning* which focuses on the definition of the *products* to be manufactured, the respective quantities, and the projected dates.

Pull principle (order processing)
Pull principle means that *order processing* activities are only initiated by a concrete customer demand, i.e. based on a *customer order*.

Push principle (order processing)
Push principle means that orders are typically planned and produced based on market research and sales forecasts without knowledge of the later end consumer.

Relation (manufacturing)
A manufacturing relation describes the interdependencies of parts to be mounted or installed at the later *product*.

Requirements planning (product)
Requirements planning is the identification of the secondary requirement in terms of materials and parts which is needed to build the *products* (primary requirements).

Seller's market (order processing)
In a seller's market, the sellers have greater market power than the buyers. The sellers can prescribe the conditions to a certain extent.

Stock order (order planning)
see: customer-neutral orders

Stock product (order processing)
Stock products are produced on the basis of *customer-neutral orders*. Stock products are difficult to market if they do not meet the current customer needs.

Use case (software development)
A use case describes a number of activities of a system from the actors' perspective which lead to a noticeable result for the *actors*.

Variety (order processing)
Variety is the plentitude of different kinds, forms, or similar things, in which a certain object exists. A variant differentiates in at least one relation or element.

Variety management (order processing)
The aim of variety management is to minimize the company-internal *variety* while at the same time offering the external variety demanded by the customers.

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Appendix

Brands in the Automobile Industry

Within the automobile industry, the brands of a company are of utmost importance when securing market shares in highly diversified markets and acquiring new customers in the face of ever increasingly keen competition. A brand plays a crucial role for the image and prestige of the products and of the company itself. In the automobile sector, the brands and/or products are typically divided into volume brands and premium brands, whereby the premium brands can be further differentiated into luxury brands (Diez, 2001).

A brand is a distinctive mental image of a product or a service which is stored in the mind of a consumer. Hence, a brand fulfills the following four key functions (Meffert, 2000):

- It facilitates the identification of products for the customers.
- It serves as an orientation guide for product selection.
- It generates trust in the products and a company.
- It attempts to develop a sense of competence and product quality.

A brand may appear in the markets in the form of a name, description, sign, design/layout, symbol, or a combination of these elements. It serves for identification of a product or a service of a company and for differentiation from the competitors (Hadeler and Winter, 2000).

A1. Classification of Premium Brands

A premium brand can be defined as a brand which achieves higher sales prices for their products in the markets compared to other brands with products which have similar tangible functions (Kapferer, 2000). In contrast to volume brands, which only achieve the average prices at the best with their products in the markets or market segments, premium brands can be characterized by the price premium. Therefore, the price premium can be related either to the positive price difference of the premium brand to the average price in the overall market or to the average price in the various market segments.

However the term ‘premium’ is not an objective, innate characteristic of products: instead, it is assigned by the consumers. This is because it is, in the end, the consumers who decide which products they are willing to pay a higher price for, thus making a brand into a premium brand (Diez, 2001). The theory of consumer behavior mentions three elements which influence the subjective feeling of a product value:

- Prime value.
- Labor value.
- Symbolic value.

The prime value is the value of a product which is determined by the technology and material used to manufacture the product. Innovative technologies which significantly improve the product characteristics for a customer (e.g. safety, comfort, or reliability) and the materials used together increase the product value. Thus, the readiness of customer to pay a higher sales price rises.

The labor value describes the value of a product; this results on the one hand from the manufacturing process and, on the other hand, from the production location. In this context, a product which is fully handmade or consists of many handmade parts and components is often regarded as more valuable by consumers than machine-made products in large scales. Furthermore, consumers frequently connect a specific manufacturing location (e.g. a country where a product is manufactured) with extremely high product quality. The significance of the so-called ‘country-of-origin’ effect as a selling point should not be underestimated by the companies. This is especially true if consumers regard products as relatively complex and the manufacturing process as complicated, e.g. the manufacturing of a passenger car (Hausruckinger and Helm, 1996).

The symbolic value originates from the significance which is assigned to a brand in the mind of the customers. The symbolic value of a brand is often connected with a trademark or a company logo such as the ‘Emily’ of Rolls-Royce, the ‘star’ of Mercedes-Benz, and the ‘rotating aircraft propeller in front of the colors of the sky - blue and white clouds’ of the BMW group. Of course, logos and symbols are also widespread in other industries, e.g. in the fast food industry (the ‘golden arches’).

A2. Premium Brands and Luxury Brands

In the automobile industry, a classification of brands is based not only on economic criteria but also on the measure of value which is generally accepted in society. Of course, from the economic view it is acceptable to classify brands solely with respect to the price premium, which is typically higher for luxury brands than for premium brands; however, the price threshold where the luxury brand begins and the premium brand ends is defined arbitrarily.

A more transparent classification of premium and luxury brands will be achieved by considering psychographic criteria. The basic prerequisite to be accepted by the consumers for a premium producer is that all tangible functions and characteristics of products have been perfected. According to this premise, a premium car is manufactured in volume production which meets the highest quality requirements and which is also functional to a high degree. Thus, if a premium car is to be developed, an enormous amount of effort is needed to achieve the optimum in technical and qualitative perfection.

In contrast, the characteristics of a luxury brand or product are wasteful abundance, refinement and excess (Kapferer, 2000). Hence, the additional effort needed to manufacture a luxury product does not increase primarily the perfection of a product, instead improving the product characteristics which are outside the product logic in terms of technical and ergonomic functions. For example, the interior of a Rolls Royce does not correspond to the principles of technical or ergonomic perfection. Various aspects could be criticized, e.g. the confusing placement of the control elements or the seats which have too little side stability. Yet, the wasteful usage of high-quality materials, on the other hand, or also the luxurious size of the passenger compartment is impressing for anyone who has ever sat in a Rolls Royce (Diez, 2001).

A3. Customer Types

Automobile producers which market chiefly volume brands are so-called volume manufacturers or generalists. These companies try to gain economy of scale by means of high sales figures and platform and module strategies in product development. In contrast, producers of premium brands try to achieve relatively high sales prices by offering individualized products in purposefully selected market segments. In general, recently the trend has been that more and more volume producers are interested in switching over to premium markets or at least in placing their products there, since companies assume that the margins in these markets are higher. Companies which produce for the various premium market segments are so-called premium producers or specialists.

Basically, two completely different types of customers can be distinguished in the automotive industry (figure A.1). Both of these customer types differ substantially in their purchase behavior, their purchase preferences, and their expectations toward the companies (Sailer et al., 2002).

Typically, customers of type ‘A’ have less need for differentiation and individualization, since these buyers prefer standardized cars with only a few additional product characteristics. As a rule, they demand almost no optional equipment which does not belong to the standard scope of supply of the product. This is because functionality lies at the forefront and not unneeded luxury. However, this customer type will accept only relatively short delivery times; as such customers wish to obtain their cars at short notice. Usually this customer group can be identified as populating the North American market and purchasing from the generalists.

In contrast, customer type ‘B’ can be characterized by its high degree of customization: these customers wish to buy a car which meets their individual requirements in the best way possible.

In return, they are typically willing to accept longer delivery times in favor of their individualized car. This customer type is chiefly identifiable in European markets and at the specialists.

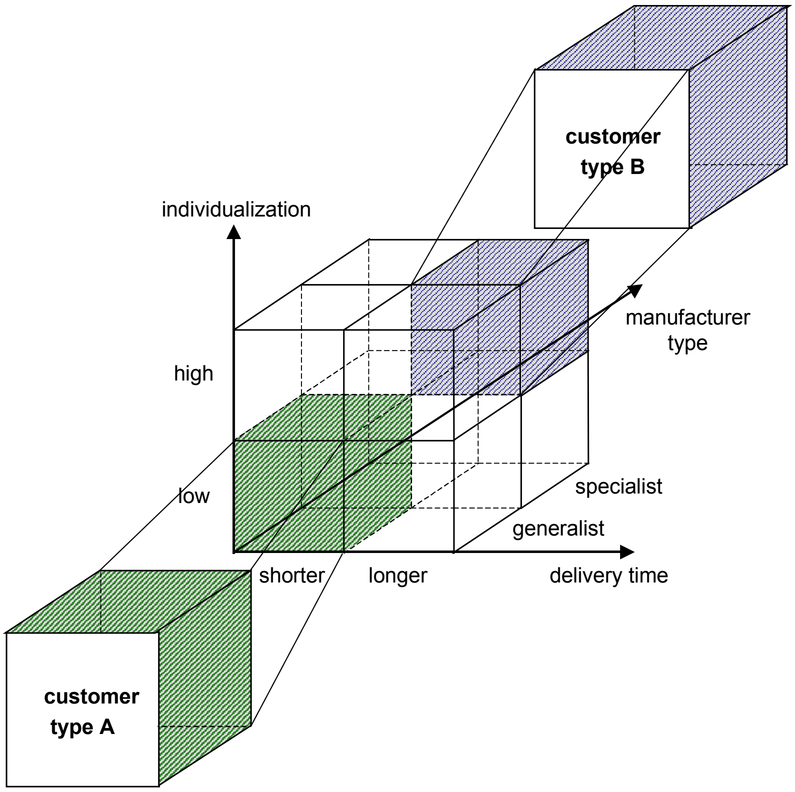

Figure A.1: Classification of Customer Types.

To conclude, observations have indicated that it is not exclusively the above-discussed extreme forms of customer types that are found in industrial practice. Instead, several other customer types most likely exist, making it more complicated to unambiguously differentiate the various types from each other. In addition, different criteria can be employed for classification, so that other groups of customers may be identified. Furthermore, car producers usually identify more than one customer type. This is independent of whether the producer in question is a volume or a premium producer. Typically, the prevailing customer type at a company differs from product type to product type and from model series to model series.

Research at the OPM Laboratory

Research carried out within the Laboratory of Design, Production, and Management embraces the manufacturing of industrial products and focuses on developments in computer-aided manufacturing, covering the overall range from design to the integral control of the activities on the shop floor. Over the last decade, the integrated approach towards the product realization process has become a necessity as - for various reasons - industry has increasingly been experiencing problems with the implementation of part-solutions. Reports of the research projects are distributed in a limited edition by the Laboratory of Design, Production and Management. The series is published with the ISSN number 1386-5307. Dissertations that have been released previously are listed below:

A.H. van 't Erve	Generative computer aided process planning for part manufacturing, an integrated approach (1988).
J.R. Boerma	The design of fixtures for prismatic parts (1990).
F.J.A.M. van Houten	PART: a computer aided process planning system (1991).
J.J. Tiemersma	Shop floor control in small batch part manufacturing (1991).
F.J.C.M. Jonkers	A software architecture for CAPP systems (1992).
H.J.W. Vliegen	Classification systems manufacturing; managerial control of process knowledge (1993).
A. Lenderik	The integration of process and production planning in small batch part manufacturing (1994).
L.J. de Vin	Computer aided process planning for the bending of sheet metal components (1994).
R.M. Boogert	Tool management in computer aided process planning (1994).
O.W. Salomons	Computer support in the design of mechanical products (1995).
A.L. Arentsen	A generic architecture for factory activity control (1995).
R. Geelink	Flexible definition of form features (1996).
J. de Vries metal	Integrated process planning for small batch manufacturing of sheet components (1996).
J.H. Kappert	Integration of component design, process planning and die design in rubber pad forming (1997).
A. Liebers	An architecture for cost control in manufacturing (1998).
R.E. Begelinger	Computer support in the design of product families (1998).
P.A. Wollf	Conceptual Design of Warships (2000).
M.M.T. Giebels	EtoPlan; A concept for concurrent manufacturing planning and control (2000).
D. Lutters	Manufacturing integration based on information management (2001).
T.H.J. Vaneker	Development of an integrated design tool for aluminum extrusion dies (2001).
S. Finke	Solid freeform fabrication of metal components by extrusion and deposition of semi-solid metals (2002).
E. Ten Brinke	Costing support and cost control in manufacturing (2002).
D. Wijnker	Integration of information in manufacturing systems (2003).
A. Layer	Case-based cost estimation. A building block for product cost management and design-for-X (2003).
R. Mentink	Process management in design and engineering. Applying dynamic process modeling based on evolving information content (2004).

"The impossible is often just the other possibility." Erhard Horst Bellermann (*1937)