Cranfield University

School of Industrial and Manufacturing Science

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Network Master Planning
for a global manufacturing company

Ph.D. Thesis

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Department of Enterprise Integration

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Abstract

Production in global, intra-organisational networks is becoming more common. In this context, the allocation of production quantities to constrained manufacturing capacity is a challenging process. Due to a volatile environment it is argued to be impossible to achieve a ‘clean’ system design with dedicated resources which exactly meets future demand. Thus, recursive ‘Network Master Planning’ (NMP) becomes necessary.

The aim of this research is to generate an understanding of the unusual situation of Network Master Planning and enable improvement of NMP practice. The author introduces a specification of requirements that was derived from observation of the real-life NMP planning activity. The relevant literature is presented to focus and position NMP in the field of tactical production planning in the literature and business context. Solution principles, design rules, and an architecture are proposed and combined to a planning methodology.

The research is problem-solving in nature and based in management research. The author seeks to develop new understanding by testing hypotheses in practice. Thus, knowledge originates in real world situations. The thesis describes how NMP concepts have been derived in a single-case-study and validated by implementing and testing tool modules incorporating these concepts.

The understanding of fundamentals and requirements for NMP, proposed concepts to tackle NMP, and generic findings represent the major contribution to knowledge of this thesis. The core findings of this work are that:

- NMP is a series of steps not an isolated task.
- Aggregation does not solve the problems of NMP.
- Dynamic, multi-objective planning needs human decision makers.
- Tool support in NMP means complementing human actions; not replacing them by ‘automatic optimisation’.
- It is possible to implement the proposed NMP concepts in a practical procedure.

Additionally to building the basis for further work, the findings of this research work are transformed into recommendations particularly for practitioners who are in a similar situation to the case company. The individual points may serve as guidelines to support practitioners working in the field of NMP or restructuring an existing planning system.

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Notation

ADR	Additional Demand Request
AME	America
APA	Asia Pacific
APICS	American Production and Inventory Control Society
APP	Aggregated Production Planning
AR	Action Research
BP	Business Planning
CP	Common Rail Pump
CRI	Common Rail Injector
CRS	Common Rail System
CTM	Capable To Match
EUR	Europe
GA	Genetic Algorithms
HCL	High cost location
HPP	Hierarchical Production Planning
IT	Information technology
LCL	Low cost location
LP	Linear Programming
MB	Megabyte
MDS	Master Data Server
MPS	Master Production Scheduling
MSP	Market and Sales Planning
NCU	Network Coordination Unit
NMP	Network Master Planning
PPC	Production Planning and Control
PV	Product variety
SC	Supply Chain
SCM	Supply Chain Management
SNP	Supply Network Planning (SAP-module)
TEC	Technical capacity
TPZ	Technical planning data (German: Technische Planzahlen)
VBA	Visual Basic
VPZ	Sales planning data (German: Verkaufsplanzahlen)

1 Introduction

This chapter gives an overview of the research focus, the researcher's industrial background, and the proposed contribution to knowledge by this work. The focus of the thesis is on the unusual situation of mid- to long-term capacity planning in a heavily constrained environment and the sources of complexity that occur in practice. To enable the reader to understand more fully the characteristics of NMP, background information on global manufacturing in intra-organisational production networks as well as capacity planning in such an environment will be presented. The chapter ends with an overview of the thesis structure to help the reader understand the logic and sequence of the document.

1.1 Problem statement

Industrial companies have to give their core competencies a global footprint if they want to stay competitive in the long term (MacCarthy and Atthirawong 2003; Thuermer 2002). Because of the rapid developments in the globalisation of markets and international trade, not only worldwide inter-business relationships have developed but also the scope of individual companies has evolved beyond single-location manufacturing. Production in global, intra-organisational networks is getting more and more common, especially for manufacturers of high-volume, multi-variant products (Roland Berger 2004; Handelsblatt 2004). Thus, these companies turn away from locally concentrated, linear-chain constructs to more complex, spread networks (Lee and Billington 1993). According to Koulikoff-Souviron (2002), internal relationships between manufacturing units of large multinational firms are as complex as relationships between independent organisations and sometimes even more complex. In particular, allocating constrained manufacturing capacity is a challenging process (Waddington 2003).

Tactical, i.e. mid- to long-term capacity planning in a network is a crucial task for a large company. The allocation of production quantities to resources contributes to both its long-term success and the short-term capacity to act. In this context, *Aggregate Production Planning* (APP) and *Master Production Scheduling* (MPS) are well known approaches. A detailed analysis and classification of the former was presented by Nam and Logendran (1992), the latter was, in turn, examined e.g. by Higgins and Browne (1992). However, these approaches do not cover the requirements of every industrial environment. Furthermore, unlike capacity planning on the strategic level, which is seen as key in competitiveness (Hammesfahr et al. 1993), the importance of planning on the tactical level does not seem to be recognised. This research work is seeking to close this gap by introducing Network Master Planning (NMP) – as the author names the corresponding planning task for heavily constrained planning environments in intra-organisational production networks.

In this context, the objective of Business Planning is to design an efficient intra-organisational production network. A usual approach is to create a 'clean' system design with dedicated resources (Vos 1991). However, the problem with dedicated resources is the accurate choice of dimension. Due to a volatile environment, it is impossible to design a system that exactly meets future demand. In effect, capacity mismatches will occur at individual operations in the production network – leading to a need for re-planning of the system (Luecke and Luczak 2003) and, consequently, to inter-plant transfers of work. In order to generate feasible plans, the clean network design of business planning has to be given up.

1.2 Research focus

The fundamentals for NMP in intra-organisational production networks can be summarised as:

- Work is shared between the network resources.
- A vertical integrated company is caring for utilisation throughout the network.
- Some work is interchangeable in the network through resource duplication.

The consequences for the planning process that follow these fundamentals will be elaborated in this work. As this thesis is principle-based, the focus is on describing the situation, presenting what makes NMP complicated, and proposing concepts to overcome some obstacles and improve NMP. At the same time, these concepts will allow the reader to access the subject.

The reader will be led to an understanding of the unusual situation of a planning task that is a reality for global manufacturing, vertically-integrated companies. Further, he or she can expect solution concepts. What the reader cannot expect is NMP software as panacea or an all-integrating tool that solves all problems of NMP.

The focus of this research mainly originated from the researcher's industrial background. He is working with the *Robert Bosch GmbH* (BOSCH), an automotive supplier that is an example for the aforementioned type of organisations with high-volume, multi-variant products. Problem-solving, real-world action research was conducted in one of BOSCH's business divisions. The planning environment under analysis spans more than 15,000 part numbers. The corresponding production network consists of nine sites with, in total, 27 production lines. Analysis of the planning process – which is of core interest for this work – was conducted over a period of 18 months.

1.3 Research objectives and research outcome

The aim of this research is to propose Network Master Planning concepts that generate an understanding of the unusual situation of NMP and that allow the improvement of NMP in practice. To achieve this industrial aim, this research project has the following key research objectives:

- Position the subject of research in the field of related planning tasks.
- Derive a specification of requirements from as-is analysis.
- Formulate principles and design rules from requirements analysis.
- Combine principles to a solution architecture.
- Develop a planning methodology that covers the whole process from raw input data to an agreed network master plan.
- Specify integrated supporting tool modules.

A well-designed planning methodology is to ensure a constant quality of the process and comprehensible planning steps. To free the planner from routine work and to empower him to focus on the parts of the process that need human decisions, supporting tool modules are needed. The aforementioned objectives are reached through active observation of the real-life NMP planning and the specification of 'rocks' in the NMP process, i.e. those activities or situations that often block smooth progress in the planning process. Subsequently, it is possible to derive and propose:

- How the planning process can be simplified.
- How a NMP methodology has to be designed.
- To what degree the process can be supported by tool modules.

1.4 Research question

The current research project is based on the following hypotheses:

- Global manufacturing is a reality.
- Intra-organisational production networks provide similar complexity as external ones.
- Volatile demand can generate bottle-necks in a production network, which has cost implications.
- There is a need of constant re-planning of the production networks over time.
- To allocate constrained manufacturing capacity is a challenging process.
- Fast reactions in planning are necessary to satisfy customer requests.
- Little is known about the characteristics of capacity planning under conditions of a heavily constrained environment; a task here referred to as ‘Network Master Planning’.
- No holistic NMP methodology could be found but potential for improvement is expected to lie in improvement of the planning task itself.

Based on these hypotheses, a research question has been developed for further exploration. The research question can be used as a means to validate contribution to knowledge, and it gives an indication of the nature of the research itself. According to New and Payne (1995), environment determines practice and only appropriate practices survive. The research question therefore not only focuses on theoretical contribution to knowledge, but also on understanding the dynamics of how practices fit with the actual environmental situation. The research question is:

Can Network Master Planning concepts be found that contribute to an understanding of NMP and improve NMP practice?

1.5 Thesis overview and navigator

To enable the reader to follow the structure of this document, in Figure 1.1 a graphical overview in form of a thesis navigator is given. Chapter 2 presents the research approach, the applied tools, and the research process design. Chapters 3 and 4 build the basis for understanding the complex situation of NMP. In chapter 3, NMP-related literature is presented and inadequacies are shown. Chapter 4 provides insights into the sources of complexity in industrial practice and provides links back to the literature to show that they are new or at least unrecognised. Chapter 5 derives concepts from the NMP as-is situation and especially from implications in practice. Chapter 6 presents a case study that was set up in addition to apply the knowledge about NMP. It shows that it is possible to implement the proposed concepts in practice and discusses the observations. Based on the findings from the literature review, as-is analysis in practice and action research by tool implementation, chapter 7 presents the findings about NMP characteristics and the kind of knowledge that emerged when trying to solve the problem. Chapter 8 summarises the key statements of the research and formulates the contribution to knowledge.

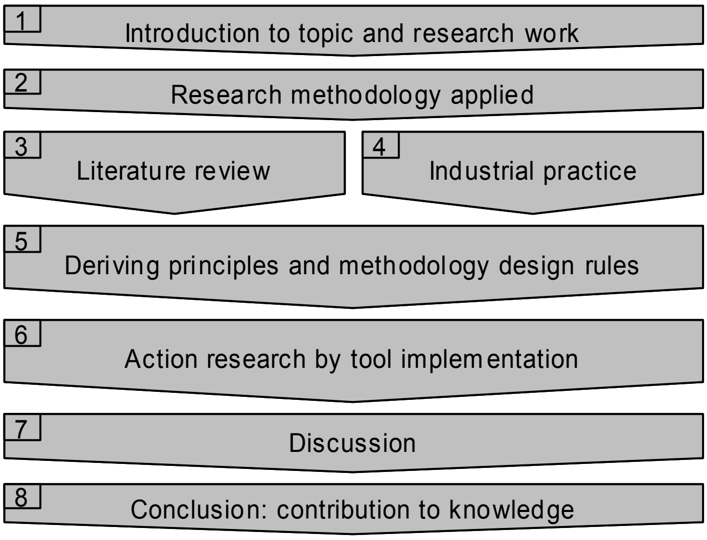


Figure 1.1: Thesis navigator

2 Research design and methodology

This chapter describes the research approach chosen for this work, discusses its appropriateness to the research question, the background of the researcher and the limits of a PhD, and describes its strengths and weaknesses. It is presented how the researcher handled the subject from an academic point of view and what choices he made to come to the final research approach.

2.1 Research approach

According to Robson (2002) and Jankowicz (2000), the purpose of designing a research methodology is to make certain that the research aims are reached through a conscious, consistent, and valid method rather than through ad-hoc driven assumptions. Thus, the researcher applies research tools in order to ensure sound and coherent research that enables him to bring the research approach to life. Yin (1994) points out that the research approach and the tools applied cannot be chosen freely but are heavily dependent on the type of research. The following sections present an overview of the approach chosen.

2.1.1 Inductive perspective, Phenomenology

There are two major approaches that can be taken: deduction and induction. Generally, a deductive approach to research is intimately bound up with Positivism while an inductive approach is linked with Phenomenology.

Deductive research entails the development of a conceptual or theoretical structure before it is tested and, perhaps, modified through empirical observation (Gill & Johnson 2002). This is done through development of hypotheses that form a theory or are generated by one, predictions about where the hypotheses are expected to hold true, and, finally, the testing of the conclusion by gathering appropriate data (Blaikie 1993). Research activities that have no influence on the subject studied are of Positivist nature, like a fully definable, controllable, and repeatable experiment in a laboratory.

Inductive research implies moving from observation of the empirical world to the construction of explanations and theory based on what has been observed (Gill & Johnson 2002). The aim for the researcher is to stay open to the observed without preconceptions in order to observe and record data without selection or guesses about their relative importance. Consequently, data are analysed, compared, and classified without using hypotheses, and based on this analysis generalisations are inductively drawn as to the relation between them. The generalisations, then, undergo further testing (Blaikie 1993). Phenomenology seeks to study subjects in their real context, looking at the totality of the situation, and analysing, for instance, reactions to changes applied. Figure 2.1 illustrates the deductive and the inductive process in Kolb's learning circle.

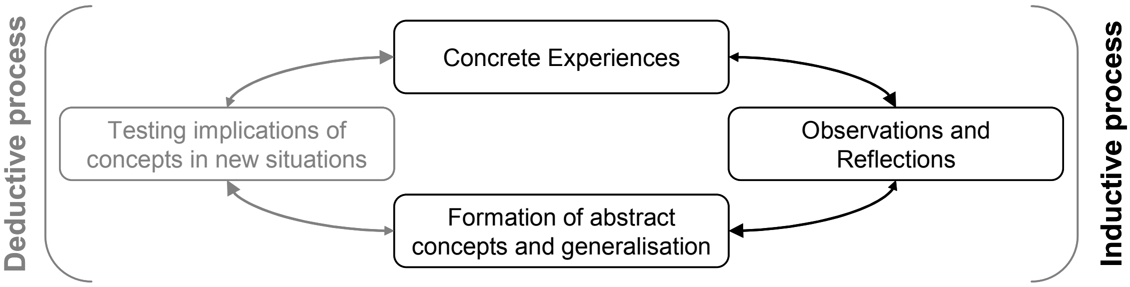


Figure 2.1: Kolb's learning cycle (adapted from Gill and Johnson 2002)

The research of this dissertation is based on an inductive perspective, using Phenomenology. This is due to the nature of the research project. It would not be sensible to try to come up with hypotheses and test them as a deductive perspective would suggest. The general research aim of this work is to explore and gather information, understanding, and knowledge of one thinly covered area of *Supply Chain Planning*. This is thoroughly done through investigation of phenomena in their real context.

2.1.2 Type of research

Phillips and Pugh (2000) suggest a distinction between three basic types of research: exploratory, testing-out, and problem-solving research. Exploratory research is tackling new problems about which little is known so far. Due to the novelty of the research topic, the research problem often cannot be concretised clearly. The main objective is to expand the limits of knowledge rather than pragmatically solving problems (Phillips and Pugh 2000). Target audience is, thus, mainly the academic world (Robson 1993). Testing-out research aims to explore the limits of previous generalisations (Phillips and Pugh 2000). By trying to refine these, researchers try to increase and expand previous knowledge. Problem-solving research starts at an actual real-world problem that the researcher tries to solve, at least partially. Hence, a sound problem definition and a comprehensive requirements analysis are the basis for developing a methodology or tool that could solve the initial problem (Phillips and Pugh 2000). The problem-solving approach is similar to action research as it is assumed that understanding of something can be gained by changing it and studying how it develops over time (Robson 1993). Data collection via action research is presented in chapter 6.

The research of this project is clearly driven by actual needs of production planners of an industrial company and by a need detected through the analysis of the literature in the field. The main objective of the author is to provide a solution for effective Network Master Planning that meets operational problems and, simultaneously, expands current knowledge. The evolutionary steps of the developed concepts are validated in business context by testing tool prototypes which incorporate these concepts. The present research is, thus, of a problem-solving nature and can be classified as action research based on tool implementation.

2.1.3 The role of the researcher

Gill and Johnson (1997) suggest a taxonomy of roles that a researcher can take within research, like illustrated in Figure 2.2. Whereas the observer – being an outside spectator – tries to avoid any involvement in the subject of research, the participant-observer role induces full participation of the observer. The phenomenon that the subject of research may behave differently being aware of the researcher's presence is considered as overt research by Gill and Johnson (1997). Covert research, in contrary, suggests that the researcher does not have an impact on the research subject.

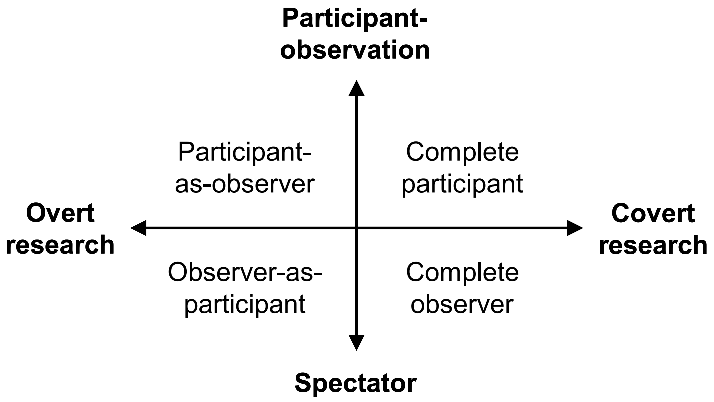


Figure 2.2: A taxonomy of researcher roles

This research took place within the context of an inner-company, industrial project. The author was actively involved in the development of an understanding and contributed to solutions from the beginning of the project. Thus, the author was over a period of two-and-a-half years frequently on-site at the business division where the project took place, applying different research tools and doing extensive testing in real-life business environment. Consequently, the participant-as-observer role is assumed for this research.

2.1.4 Quantitative vs. qualitative research

The two basic approaches for research data collection are quantitative and qualitative research. Table 2.1 lists characteristics of both. Traditionally, Phenomenology would suggest qualitative methods and tools for data collection and validation (Esterby and Smith 1991), whereas Positivism builds on quantitative data.

Qualitative data/ research	Quantitative data/ research
• Deals mainly with the exploration of issues and the generation of theories within new and emerging subject areas. • Is used to develop insight and understanding of a subject. • Seeks to create gestalt and holistic interpretations.	• Is used in research that requires data in order to answer the research question (through verification of hypothesis). • Seeks to measure, test, and quantify elements in order to explain or describe something.

Table 2.1: Qualitative vs. quantitative research

In view of the facts that understanding of Network Master Planning is an emerging subject and that this research is conducted as a single case study, qualitative data research is adopted in this work. The planning procedure is developed and validated on the base of real-life data.

2.2 Case studies and action research for data collection

2.2.1 Case studies vs. surveys

According to Yin (1981), the case study as a research strategy does not imply the use of a particular data collection method. The focus is on understanding the dynamics present within single settings (Eisenhardt 1989). Yin (1994) claims that the case study is particularly suitable when the research questions are ‘why’ and ‘how’ as opposed to the survey strategies research questions of ‘who, what, where, how many and how much.’ Furthermore, a case study can be used to accomplish various aims: from providing a rich description, to testing or generating theories (Eisenhardt 1989). There is also a discussion whether to use one or multiple cases and what generalisations can be made from case studies (Eisenhardt 1989; Yin 1994). Traditional researchers, like Ellram (1996), claim that a single case is used to “test a well-formulated theory, an extreme or unique case, or a case which represents a previously inaccessible phenomenon." Multiple cases, on the other hand, "represent replication that allow for development of a rich theoretical framework" (Ellram 1996). Stake (1994) states that although we may simultaneously carry on more than one case study, each case study is a concentrated inquiry into a single case. Consequently, "generalizations from differences between any two cases are much less to be trusted than generalizations from one" (Stake 1994).

This finding leads to a vital point in case studies: relevance. Colotla et al. (2003) claim that to get access to complex situations, testing hypotheses by using quantitative methods "simply is not enough." Atkinson and Hammersley (1994) state that this positivistic view fails to capture the true nature of human behaviour, especially since it relies on what people say rather than on what they do. Consequently, the rejection of positivism usually refers to forms of research having the following features:

- A strong emphasis on exploring the nature of particular phenomena, rather than setting out to test hypotheses about them.
- A tendency to work primarily with 'unstructured' data.
- Investigation of a small number of cases, perhaps just one case, in detail.
- Analysis of data that involves explicit interpretation of the meaning of functions, the product of which mainly takes the form of verbal descriptions and explanations, with quantification and statistical analysis playing a subordinate role.

Dingwall (1997) takes this discussion one step further when he claims that researchers can only gain "extreme relevance" by two basic methods. One is "asking questions," the other one is "hanging out," meaning spending time in organisations.

2.2.2 The role of action research

Originally formulated by social psychologist Kurt Lewin, action research (AR) is a disciplined method for intentional learning from experience using a three-step spiral process of (1) planning, which involves reconnaissance, (2) taking actions, and (3) fact-finding about the results of the action (Coughlan and Coghlan 2002). Thus, it is a type of applied research characterised by intervention in real-world systems followed by scrutiny of the effects. The aim of AR is to improve practice and it is typically conducted by a combined team of practitioners and researchers. The action research cycle is depicted in Figure 2.3. According to Coughlan and Coghlan (2002), AR is an emergent process, i.e. the second action cannot be planned in detail until the evaluation of the first action has taken place.

Plan > Act > Observe > Reflect > Revised Plan > Act >...

Figure 2.3: Action research cycle

The core idea of action research is that the researcher does not remain an observer outside the subject of investigation. Instead, she/he should actively participate in the project (Checkland 1993). Summarising, the key characteristics of AR are (Coughlan and Coghlan 2002):

- AR focuses on research in action, rather than research about action.
- AR is based on a preliminary theory that is tested and refined on the field.
- AR is a cyclical process of planning, taking action, evaluating the action, and leading to further planning and so on.
- Members of the system that is being studied, participate actively in the cyclical process.
- Researchers participate actively in the process, purposefully influencing the system.
- AR aims both at achieving practical results on the field as well as at developing new knowledge.

Action research is intimately connected to the systems-thinking world-view, which implies that the foundation for understanding lies in interpreting interrelationships within systems (Checkland 1993; Senge et al. 1990). These interrelationships are responsible for the manner in which systems work. Systems-thinking is thus, more than anything, a mindset for understanding how things work. In systems-thinking, researchers look for patterns of behaviour, not necessarily cause-and-effect relationships, but interrelationships. In this perspective, action research is a research approach for tackling real-world, managerial, and organisational problems. Colotla et al. (2003) state that problems that organisations face are often unstructured. Such situations may be recognisable as a problem, but they are often difficult to define. According to Colotla et al. (2003), “research should include these problems as well, since it is the reality of many managerial fields, such as logistics and supply chain management.” In order to handle these problems and identify possible solutions, both academia and practitioners have to understand them first.

The author is aware that in action research there are the risks of self-evaluation of (preliminary) solutions, and that his presence in the research context may have potentially biased the research outcomes and findings (Gill and Johnson 1997). In order to overcome this danger, different research tools have been used with the participating practitioners, like, for instance, a mix of personal involvement and task delegation to other participants. Thus, different perspectives were taken into account.

2.3 Research tools applied

In order to ensure reasonable research and good data quality, different research tools have been applied during research. These are outlined below.

2.3.1 Approach chosen due to concrete research background

Due to the concrete research background, perspective, and the nature of the research question, the data collection methods depicted in Table 2.2 were applied.

Data collection methods	Information source
Literature search	Investigation into NMP related fields including e.g. production networks, hierarchical production planning, capacity planning.
Expert interviews	Semi-structured interviews were conducted.
Action research based on tool implementation	Developed methodology elements and tool modules were tested and critically discussed in iterative circles with practitioners from the involved departments.

Table 2.2: Data collection methods and information source.

Literature search was mainly conducted by screening journal articles on *Emerald* and *Taylor and Francis*, but also by free searches on the *Google* search engine. The search strategy was to be comprehensive but not exhaustive. The material was restricted to English and German language publications, as there were insufficient resources for translation from other languages. Search terms included ‘Production Network,’ ‘(Hierarchical) Production Planning’, ‘(Rough-cut) Capacity Planning,’ ‘Master Planning,’ ‘Aggregated Planning,’ ‘MPS’, ‘Tactical Planning’, ‘Demand Planning.’ The review on surrounding topics helped to define corresponding fields, identify differences between them, and illustrate the overall context wherein the research field emerges.

Real world access for the research was realised by project work within *Robert BOSCH GmbH* (BOSCH), an automotive supplier, for a planning environment with more than 15,000 part numbers. The corresponding production network contained nine sites, consisting of 27 production lines. The planning process was actively supported and analysed over a time of 18 months, i.e. three live planning cycles, and sources for the unusual situations were investigated.

Expert interviews for data collection were conducted with practitioners working at BOSCH. The format of the interviews was semi-structured in order to encourage the interviewee to tell her/his perspective on the issues debated and to take the conversation to areas that might not have arisen if a questionnaire approach had been taken. A checklist was consulted to guarantee that the key elements were included (see Appendix E). Furthermore, workshops (from two to ten practitioner attendees) helped in gaining a deeper understanding of NMP and revealed sources of complexity and difficulties.

Observation by ‘hanging out’ with people who were, actually, doing the planning was the most important technique for data collection in this research. Watching them doing their job and registering occurring problems was a vital point and created starting points for developing concepts. The action research process, based on implementation of proposed ideas and concepts, is described in detail in chapter 6.

2.3.2 Summary

In summary, the chosen research approach can be described with the following attributes:

- Inductive perspective.
- Problem-solving type.
- Researcher is participant-as-observer.
- Qualitative approach.
- Data collection by means of literature review, interviews, and action research.

3 Introduction to Network Master Planning

This chapter introduces Network Master Planning as an important field of operations management that is often neglected in literature and practice. In this context, the author presents the literature that is of relevance to his subject and demonstrates how the research problem can be positioned in existing literature. Furthermore, conditions, requirements, and related planning approaches are introduced and the reasons for NMP being special are discussed. Particular attention is given to the fact how customer behaviour influences mid-term planning tasks. Finally, specific gaps in the current knowledge are summarised and the author's proposed research is positioned within these.

3.1 Basics on production networks and production planning

To be able to position Network Master Planning (NMP), as it was observed in practice, in the academic world, the literature search on NMP was started with the term 'Supply Chain Management' in general. Subsequently, more detailed searches on keywords such as 'global production networks,' 'tactical planning,' 'capacity planning,' or 'production scheduling' were conducted. In addition to books like e.g. APICS's *Production and Inventory Control Handbook* (APICS 1997), an extensive review of journal articles on related subjects was performed. Examples are:

- International Journal of Physical Distribution & Logistics Management
- International Journal of Operations & Production Management
- International Journal of Production Research
- Supply Chain Management: An International Journal
- Production Planning & Control
- Journal of Business Logistics

3.1.1 Introduction

The core interest of this work is production networks in high-volume, multi-variant manufacturers. A definition is given in the following. Furthermore, the underlying theory of *intra-organisational* supply chains is differentiated against their *inter-organisational* counterparts. Finally, similarities and differences between the two fields are presented to have a clear distinction, on the one hand, and to open up the possibility to transfer solution principles for planning.

In literature, a substantial amount of articles, books, and essays can be found dealing with supply chains in one way or the other (e.g. Oliver and Webber 1992; Waters 1992; Cooper et al. 1997; Lambert et al. 1998; Chopra and Meindl 2001; Mentzer et al. 2001). The context in which the term is used ranges from strategic, long-term company planning to short-term production control approaches and the corresponding software solutions. To understand the full meaning of the term ‘supply chain,’ it is necessary to know the theoretical background as well as its origin and development over time.

3.1.2 Definitions

The terms *supply chain* and *Supply Chain Management* are often used interchangeably in practice, and it appears that even in literature few authors clearly distinguish the definitions of both (Ballou et al. 2000; Croom et al. 2000). To have a solid basis for this work, clear definitions are given in the following.

3.1.2.1 Supply Chains and Supply Chain Management

Generally speaking, a supply chain can be seen as a sequence of business processes that “together – and only together – transform inputs into outputs” (Garvin 1998). The image of a linear chain of elements promoted by the chain metaphor is easy and comprehensible but also misleading. Although there are cases where the linkages can be depicted along an “end-to-end” dimension on a linear chain (Ballou et al. 2000; Cooper et al. 1997), more often they stand for connections in complex networks (e.g. Ellram 1991; Stadtler and Kilger 2002). A supply chain usually represents a network of organisations, connected through upstream and downstream linkages, that are involved in the different processes and activities that produce value in form of products and services in the hands of the ultimate customer (Davis 1993; Christopher 1998).

The term *Supply Chain Management* (SCM) appeared in the early 1980s, referring to the management of materials across functional boundaries within an organisation (Oliver and Webber 1992). It was soon extended beyond the boundaries of one company to include upstream production chains and downstream distribution channels (Womack and Jones 1996; Womack et al. 1990). Although several definitions of SCM have been given and have evolved up to today, there are commonalities among the theories. SCM mainly involves two classes of managerial problems at different levels: *configuration*, dealing with the design of the supply chain at a strategic level, and *coordination*, concerning the management of the supply chain predominantly under tactical and operative levels (Giannoccaro and Pontrandolfo 2001). Christopher and Ryals (1999) state that the main objective for SCM is to gain sustainable competitive advantage through provision of the best comparative value to customers while improving the firm's profitability at the same time.

Following Mentzer et al. (2001) for the purpose of this work, SCM is defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."

3.1.2.2 Inter- vs. intra-organisational supply chains

Although certain authors, like Ellram (1991), state that SCM theory is only applicable for the external supply chain, others explicitly include the management of the internal supply chain in their definition (e.g. Christopher and Ryals 1999; Ballou et al. 2000). Looking at an intra-firm chain, there appear to be parallels, indeed. Broken down to the basic principles, in both cases structures with related entities do exist, linked by supply relationships. Following Mabert and Venkataramanan (1998), in a "one company internal supply chain" the complementary partners have to be coordinated as well. Hierarchy and ownership are not sufficient to guarantee a profitable, self-organising system.

Consequently, according to Harland (1996), there are four main uses of the term *Supply Chain Management*:

1) Business functions involved in the flow of materials and information from in- to outbound ends of the business – the internal supply chain.
2) The management of a dyadic relationship with immediate suppliers.
3) The management of a linear chain of businesses from supplier's supplier to customer's customer.
4) The management of a network of inter-connected businesses involved in the ultimate provision of product and service packages by end customer.

These four uses can be aggregated to a two-stage supply chain typology: *intra-organisational* supply chains (1) and *inter-organisational* supply chains and networks (2-4; see Figure 3.1).

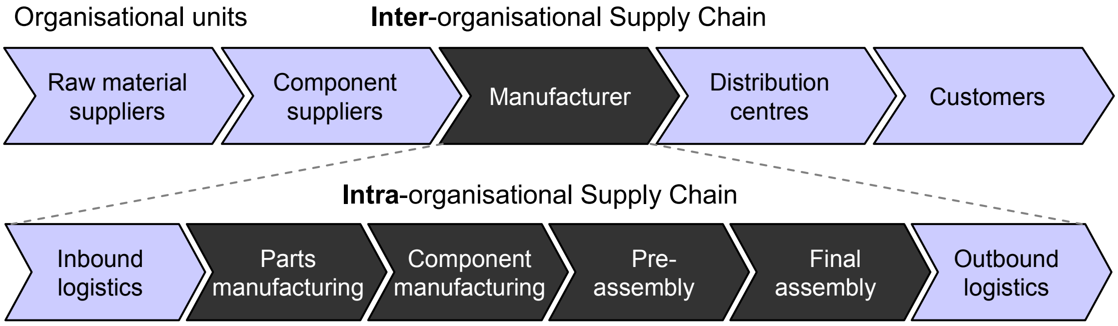


Figure 3.1: Inter- vs. intra-organisational supply chains

3.1.2.3 From supply chain to production network

As mentioned before, *supply networks* can be seen as one step beyond the linear chain topography. In most cases, this definition refers to temporary co-operations between independent companies. Yet it is also used for the co-operation of organisational units within one single company (Ballou et al. 2000). Sturgeon (2000) claims that the difference between chains and networks lies in additional linkages, speaking in terms of information and material flow between the actors in the network (see Figure 3.2).

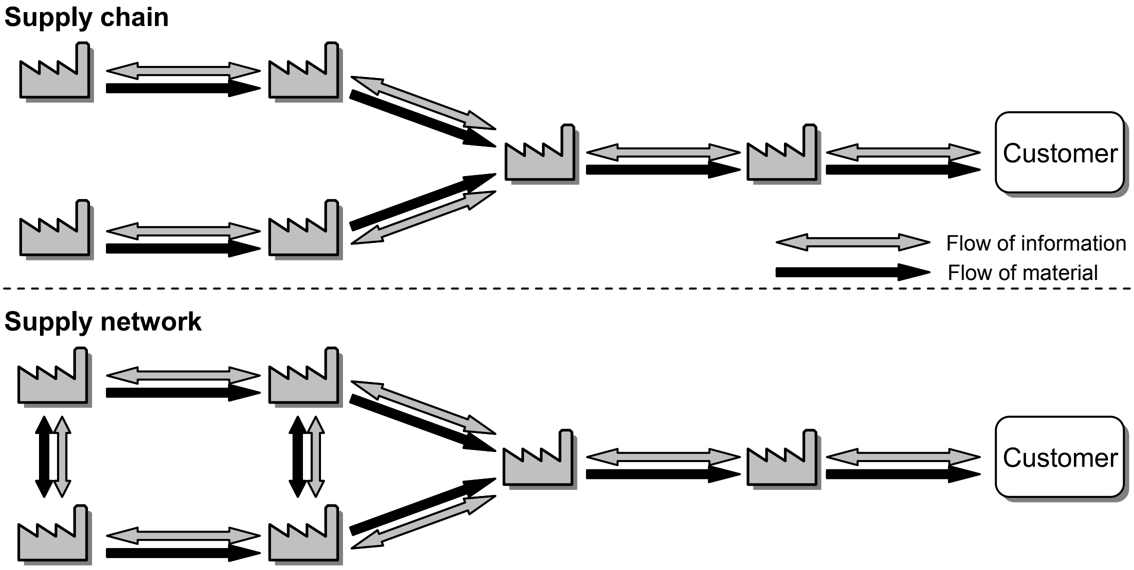


Figure 3.2: From supply chain to supply network (following Lutz et al. 1999)

In literature, the term *production network* is defined in a number of ways. To make things worse, there are even different words in use referring to production networks. *International/Global/Multi-national Production Network*, *Supply Chain Network, Extended Manufacturing Enterprise* or *Intra-organisational echelon* are only some examples (e.g. Waters 2003; Wu 2000; Svensson 2003). As a result, a wide range of interpretations occurs in theory and daily practice (Merath 1999).

Underlying all theories is the model of distributed production entities and the existence of supply relationships. These can also include relations to external suppliers (Merath 1999). Eichiner (1985) defines the production of transportable parts or components and their supply to another site for the next in step value adding as characteristic for a production network. In contradiction to this, Rilling (1996) sees linkages of material flow between different production sites as no necessary precondition to define a production network. Given the case of a parallel production of similar end-items at different plants, immaterial linkages have also to be taken into account, e.g. the transfer of production know-how, data provision on a central server or investment planning for resources in the network. In contrast to networks between independent firms, intra-organisational production networks normally have a long-range nature and are characterised by a high degree of repetition of activities (Rilling 1996).

In the framework of this research project, a production network is defined as the entirety of distributed production sites with redundant and complementary production resources that are coordinated by a central instance, producing a defined product spectrum for an indefinite period.

3.1.3 Inter-organisational types of networks

3.1.3.1 Intentions for collaboration

The term *inter-organisational network* represents the collaboration between several legally and formally independent companies (Siebert 2003). The spectrum of types of inter-organisational networks is wide. It reaches from loose and sporadic bindings between mostly autonomous acting companies to very well developed structures linking closely interacting partners. Common to all constellations is the objective to create a win-win-situation for all participants by means of collaboration (Lambert et al. 1999). One central intention is to reach the scale effects and the dominant position of big businesses and, at the same time, have the advantages of a small company such as flexibility, fast reaction time, and close contact with the customer. By connecting small units, usually less money has to be spent on hierarchical-driven coordination efforts than in big businesses with comparable potential (Siebert 2003). Another reason for collaboration stems from the approach to focus on a narrow set of specialised activities – the so called ‘core competencies’ – and outsource non-core operations in order to stay competitive (Prahalad and Hamel 1990; Dyer 2000). In other words, access to technologies and resources and, thus, an expansion of one’s own competence is another objective that companies aim at when linking activities with others and concentrating capacities.

3.1.3.2 Degrees of collaboration

In practice, a variety of organisational forms of inter-company networks can be observed (Figure 3.3). Five basic forms are presented in the following: Virtual Enterprise, Business Alliance, Joint Venture, and Corporation with autonomous divisions, as well as Integrated Corporation (Lambert et al. 1999; Sturgeon 2000).

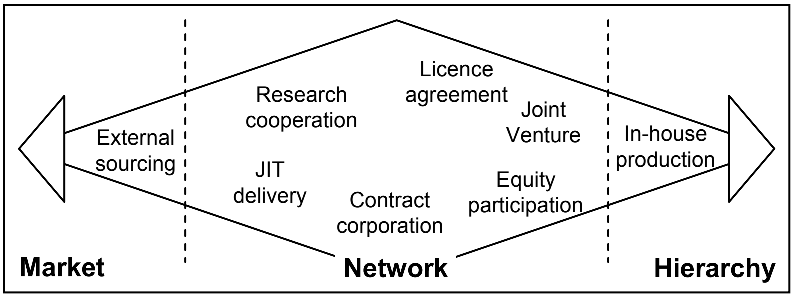


Figure 3.3: Inter-organisational networks between market and hierarchy (examples)

A *Virtual Enterprise* is a firm that outsources the majority of its functions and concentrates on coordinating the designing, making, and selling of products or services (Dyer 2000; Lutz et al. 2000). The advantage is that the network of collaborating entities allows increasing production rapidly without having to train people and develop competencies slowly at one single firm. The term *Business Alliance* stands for companies bound by an agreement for a certain time, usually motivated by cost reduction and improved service for the customer. Code sharing in airline alliances is an example for this. Many airlines participate in one or more business alliances (Kuglin and Hook 2002). A *Joint Venture* is a strategic alliance between two or more companies that creates a new, independent business unit together. The parties contribute to the new entity with money, resources, and know-how. Revenues, expenses, and control of the *Joint Venture* are shared between the strategic partners (Cooper and Gardner 1993). In the context of this work, the term *Corporation* refers to a legal entity formed by a group of companies in accordance with a governmental framework. The degree of business-process integration between the parties varies. The two extremes are *Corporations* with predominantly autonomous divisions at the one end and fully *Integrated Corporations* at the other (Ellram 1991).

Figure 3.4 qualitatively shows that with the rising rate of monetary and organisational involvement, a company's willingness to take risks decreases. On the other hand, the ability to solve conflicts and coordinate activities increases the more stable and more long-term oriented the collaboration is set up (Lambert et al. 1999).

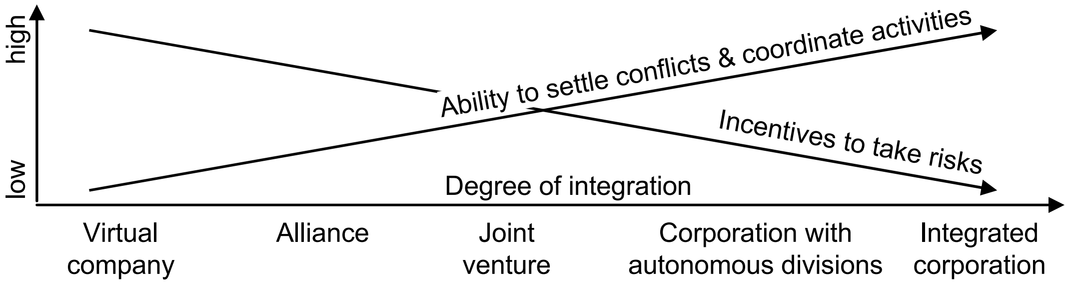


Figure 3.4: Degrees of collaboration

In summary, it is proposed that inter-organisational networks are defined as “two or more organisations that are involved through upstream and downstream linkages, in producing value in the form of products and services” for the final customer (Koulikoff-Souviron 2002).

3.1.4 Intra-organisational types of networks

The objective of this section is to show that SCM is not only relevant in the inter-firm context but also in the intra-firm (Christopher and Ryals 1999; Mabert and Venkataramanan 1998).

3.1.4.1 From one-site to multi-site manufacturing

Rapid developments in the globalisation of markets and international trade not only caused worldwide inter-business relationships but also let the scope of firms evolve beyond single-location manufacturing. Companies are increasingly devoting themselves to international expansion in order to be present at important markets and, thus, gain competitive advantage (Leung et al. 2003). Especially businesses with high-volume, multi-variant production face this need, because they usually have to cope with a high complexity in manufacturing. Taking the example of country-specific variants and adding governmental rules for local production, this scenario, on the one hand, broaches the necessity of production resources distributed all over the world that are capable to perform highly-specialised processes. On the other hand, activities with manual effort are transferred to so-called low-cost-locations, speaking in terms of labour cost, in order to configure a ‘cost-optimal’ production network. As a result, all this causes manufacturing companies to turn away from locally concentrated linear chain constructs to more complex, spread networks (Lee and Billington 1993). Figure 3.5 provides an exemplary visualisation.

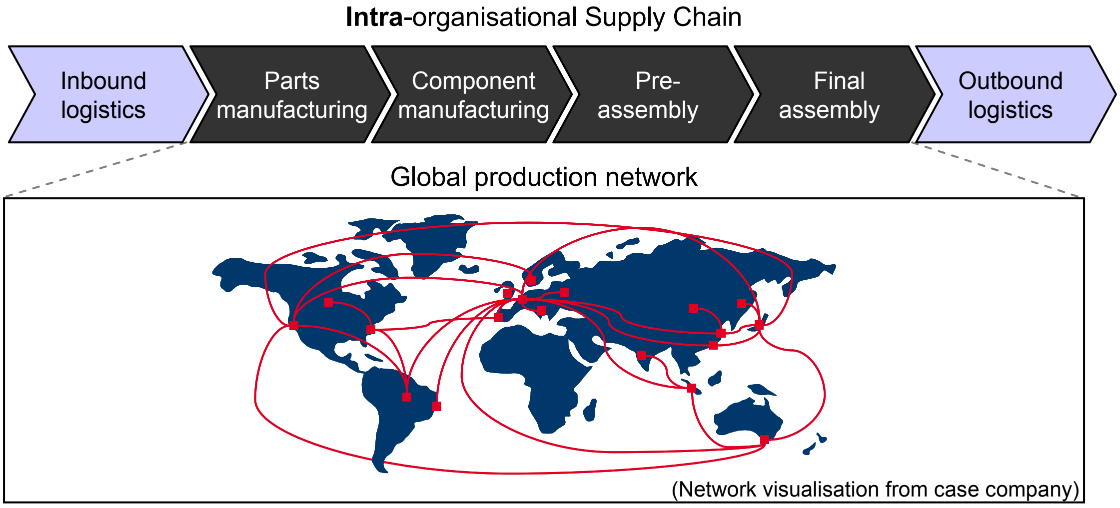


Figure 3.5: Intra-organisational supply chain and network

For short-term operations planning in production networks, many approaches, software specifications, and corresponding mathematical models can be found in literature. These are mostly derived from factory planning. The same goes for network configuration, also known as ‘location allocation problem,’ which is usually approached by heuristics (e.g. Brimberg and ReVelle 1998).

Looking at the strategic planning aspect, research has focused predominantly on the strategic aspect of inter-firm collaboration since the 1990s (see 3.1.3), whereas it is hard to find literature explicitly related to intra-firm network coordination (Luecke and Luczak 2003).

As with networks consisting of independent organisations, several terms can be found in theory and practice for intra-firm networks too. On the one hand, the same terms as for inter-company networks are in use, e.g. *Horizontal Production Network* or *Global Manufacturing Network* (Croom et al. 2000). On the other hand, the peculiarities of the one-company context are taken into account by terms like *Internal Echelon* (Svensson 2003) or *Intra-company Supply Chain* (Cooper et al. 1997).

3.1.4.2 Network topographies

Intra-firm networks range from mostly independent business units with only rudimentary centralised planning to fully integrated step-by-step value adding ‘chains,’ which require central control on a quite detailed level.

The primary criterion of differentiation between types of internal production networks can be seen in the kind of economic linkages between the involved sites (Philippson 2002). Horizontal correlated sites show certain redundant attributes, mostly in production-technology capabilities. The differentiation of sites in that case is usually done by product or market specific criteria. Thus, different sites serve different customers or have a completely different product spectrum, though having similar capabilities. Characteristic for a structure with vertical linkages are customer-supplier-relationships between the sites. Within this system, usually there is no allocation of certain product types to specific sites, but each site performs a relatively narrow range of production activities. Thus, the sites are linked by intra-firm flows of inputs and outputs, and products are finished systematically by going through the sequence of sites. Figure 3.6 exemplarily depicts both of these forms of relationship in production networks.

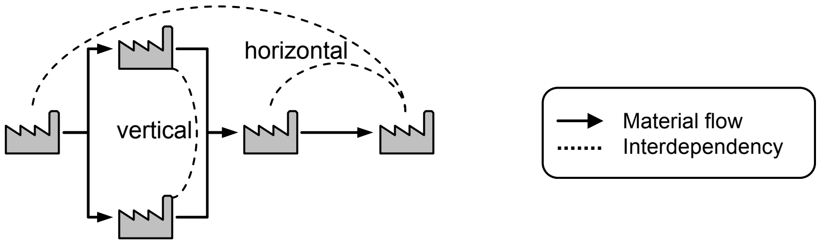


Figure 3.6: Relations in a production network (Adapted from Luecke and Luczak, 2003)

In the context of this work, horizontal relationships between sites and, above all, the horizontal distribution of total production quantities of similar products to several production resources are of particular interest. Rilling (1996) defines this kind of partition as parallel production, taking the implicit redundancy in the network into account. The chance to react to breakdowns by shifting of production quantities and the positive effect of a certain kind of competition between the production sites are the main advantages Rilling sees in parallel production. The above review supports the view that also internal networks demand for some kind of SCM.

In summary, it is proposed that intra-organisational networks be defined as “two or more divisions/units of the same company that are involved through upstream and downstream linkages, in producing value in the hands of the ultimate customer” (Koulikoff-Souviron 2002).

3.1.5 Global production

After defining the term *production network* and looking at distributed production, this concept is now to be expanded to an international perspective. Therefore, the origin of international production and reasons for spreading a large company all over the world are presented.

3.1.5.1 Global footprint design

Today, operational and economic criteria determine above all which location is best suited to an individual task, not tradition, or geography (MacCarthy and Atthirawong 2003, Thuermer 2002). In this context, the trend for industry to transfer operations abroad is accelerating. Apart from lower production and infrastructure costs, new business opportunities in growing markets and sales increases also come into focus (Strutt & Lawrence 2004). Undoubtedly, modern IT and transport technology has contributed a lot to global distribution of production. According to a joint study conducted by *Roland Berger Strategy Consultants* and the *Rhineland-Westphalian Technical University* (RWTH) in Aachen, for example 90 per cent of German industrial companies are planning further offshoring in the next five years. Most of them will go to Eastern Europe or Asia (Roland Berger 2004).

Yet the international engagement of companies is no new phenomenon but can be traced back to the 19th century, when the ‘industrial revolution’ led to first approaches in that direction. Nowadays, this development has reached a state that makes it almost inevitable for large companies to be present in the three main industrial centres Western Europe, Asia, and North America (Sturgeon 2000; Pontrandolfo and Okogbaa 1999). The decision process that is related to global production consists of configuration and coordination activities. *Configuration* comprises long-term, strategic aspects like installation of a network of subsidiaries in foreign countries or investment in new production resources at existing sites (Colotla et al. 2003). Tactical, i.e. medium-term, decisions in different areas of the company with the aim of effective and efficient planning of the global production network are key aspects of *coordination* activities (Pontrandolfo and Okogbaa 1999).

One part of the activity of network configuration is the term of ‘global footprint design,’ introduced by Roland Berger (2004). “A company's global footprint shows how it distributes its value chain links across its worldwide network” (Roland Berger 2004). To design an optimum global footprint – which is mandatory to stay competitive in the long term – industrial companies must determine what parts of the value chain constitute their core competencies. They also have to find the optimum locations for these links in the value chain, especially in terms of quality, cost, and availability. The process of defining, controlling, and mastering a company's global footprint is called ‘global footprint design’ (Roland Berger 2004).

According to Wrede (2000), four different strategies for internationalisation of value-adding chains can be differentiated (see Figure 3.7).

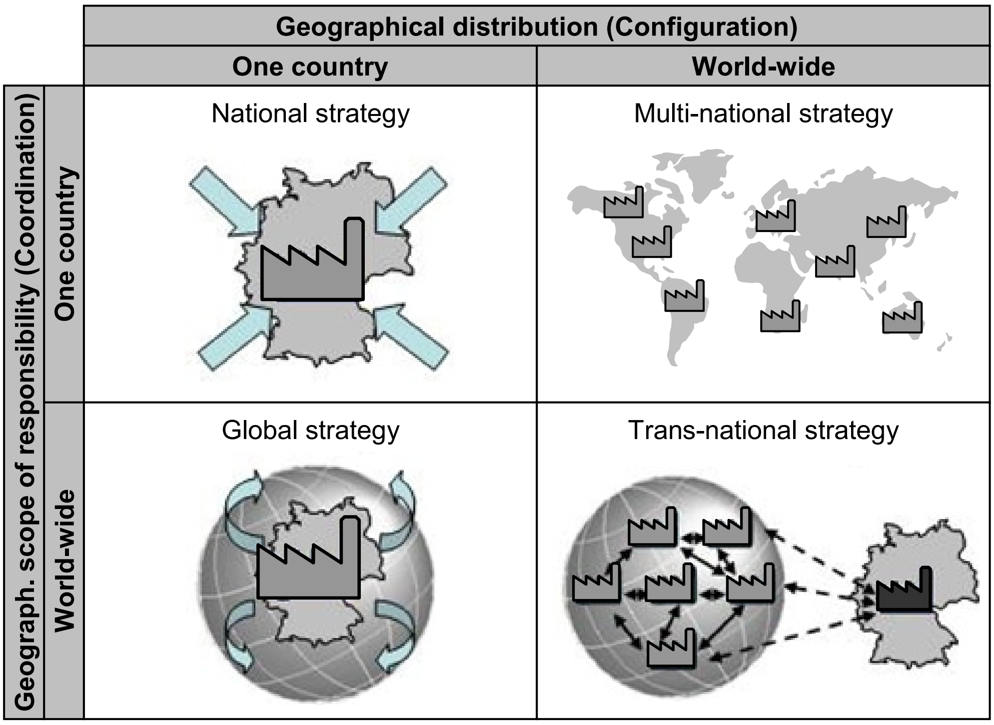


Figure 3.7: Strategies for internationalisation

In case of a *national strategy*, production is concentrated at only one single location, which makes coordination with other sites obsolete. A *global strategy* also focuses on production in one place but aligns activities to a global market. In a *multi-national strategy*, activities are spread worldwide but there are no inter-site supply relationships. Each location plans on its own, coordination with other site’s planning does not occur. In case of a *trans-national strategy* production is also globally distributed in a network. However, in contrast to a multi-national strategy, activities are coordinated and master planning for the whole network is carried out. The aim is to combine the advantages of a multi-national strategy like flexibility and proximity to markets with those of a global strategy, namely scale and learning curve effects. One form of a trans-national strategy is the distribution of the value adding process on the individual locations. This leads to several possible combinations of sites for the production of end-items (Wrede 2000).

Looking at the need for coordination of activities between several sites, an international production network can be seen as part of a trans-national strategy.

3.1.5.2 Reasons for distributed production and resulting advantages

Improvement of the competitive situation, cost savings, and flexibility are identified as the key reasons for the decision to set up or join an international production network (e.g. Koulikoff-Souviron 2002). In the following section these aspects are presented and examples are given.

Being part of a multi-national network opens up new strategic options of acting. For example, market access – in form of a clear definition of customer requirements and good, i.e. fast, customer service – is easier to gain for a company that is already in reach of the market, i.e. in the country or geographic region (Colotla et al. 2003). Given this fact, most firms have realised that they cannot operate their global business without the support of local partners (Harland et al. 1999). In some markets, e.g. the Chinese, transforming to a 'local' by setting up joint ventures with local partners is the only way to overcome governmental restrictions and gain access to the new market (Cooper and Gardner 1993; Mohamed and Youssef 2004). Acquiring access to resources and knowledge of partners in the network is another advantage. This enables the network as a whole to develop and manufacture more complex products as well as more customer specific variants, which is another key contributor to a good position in competition.

Apart from diversification by expanding the product portfolio, direct cost savings are another crucial point for keeping a company competitive. One approach is to allocate tasks that require a high manual effort to so called low-cost countries and concentrate activities with a high degree of automation or those demanding highly-skilled personal in regions with high wages. Global sourcing, i.e. the supply of raw material and components from advantageous world-wide markets, can also contribute to cost saving (Zeller and Schwegmann 2004). Looking at high customs fees and administrative effort for exporting goods to quasi-closed markets, the potential for cost savings by producing in those markets becomes obvious (Zeller and Schwegmann 2004).

Last but not least, flexibility is expected to rise when setting up a network with customer-near, distributed entities (Siebert 2003). This is important because customer service is still regarded as the top-most objective for companies – although complexity in product structure and production technology is rising and production programs undergo a shift from mass production to mass customisation (McCarthy 2004; Pine 1993).

Therefore, fast reactions are necessary in delivering goods physically to the customer as well as in responding to customer requests. However, this is not enough. In addition to changes on the product side, the conditions for bringing those products to the customer will change too. Continuous changes in the market, e.g. the re-clustering of market segments, as well as newly occurring ways and channels of distribution and others getting unprofitable, demand for flexible businesses that are able to manage change in a defined way.

After presenting reasons for production in networks with internationally distributed elements and a definition for *Global Footprint Design*, we now take a closer look at the network entities and the planning process on different hierarchical levels. These can be partners in a network consisting of different independent firms as well as several plants of the same company (see 3.1.2).

3.1.6 Production Planning

In a company of the manufacturing sector several items have to be planned on a regular base: product generations and life cycles, production resources and control, channels of distribution, and supply – to name only some. Capacity planning in a production network as the subject of this work is part of the higher level production-planning process. This section depicts the total process and positions capacity planning within it.

3.1.6.1 Positioning production planning in the field of business planning

In Figure 3.8, the three basic levels of business planning are shown: strategic, tactical, and operational planning. They differ in the planning horizon, their strategic importance for the company, the degree of data aggregation, and the involved management level (Guenther and Tempelmeier 2003).

Strategic planning as the top-most level sets up the framework for all lower planning levels by creating constraints. *Operational planning* comprises short-term processes, which are usually performed on a daily basis to ‘keep business running.’ Processes on the *tactical level* build a bridge between strategy and operations. In this perspective, the most important organisational processes constitute the tactical level of the organisation (Naeslund 2002). To understand the correlations between the planning levels and the constraints formulated by strategic planning, an overview of strategic planning is given below.

		Importance for company				
		high	medium	low		
Planning horizon	long	Strategic			high	Degree of aggregation
	medium		Tactical		medium	
	short			Operational	low	
		high	medium	low		
		Management level				

Figure 3.8: Levels of business planning

From an organisational point of view, strategic planning itself consists of three levels: company planning, business unit planning, and functions planning (Wrede 2000). On the level of *company planning*, the 'global' strategies for the company are defined. This comprises finding and setting up fields of activity and the allocation of resources to those fields. Thereby the base-line of development for the company's fields of activity and its geographical framework is determined. *Business unit planning* defines the strategic positioning against competitors for each business unit. Decisions are made in accordance to constraints from company planning. *Functions planning* concretises strategies and coordinates functions like sourcing, production, and distribution.

The production strategy, as one part of functions planning, is of particular interest for this research work, because it defines the long-term production program and allows identifying the necessary production resources and technologies. Subsequently, decisions are made about investment in additional resources or de-installation of equipment in the network. The corresponding planning task of allocating resources to sites is called 'site structure planning' (Wrede 2000). The results of these planning tasks, then, set up the framework for production planning, which is defined in the following section.

3.1.6.2 Objectives and aspects

The top-level objective of production planning is to satisfy customer demand out of efficiently running production systems. Gutenberg (1983) defines three main subjects for production planning: supply, production process, and production program. The allocation of these planning tasks to steps in the production process is depicted in Figure 3.9 (Hechtfischer 1991).

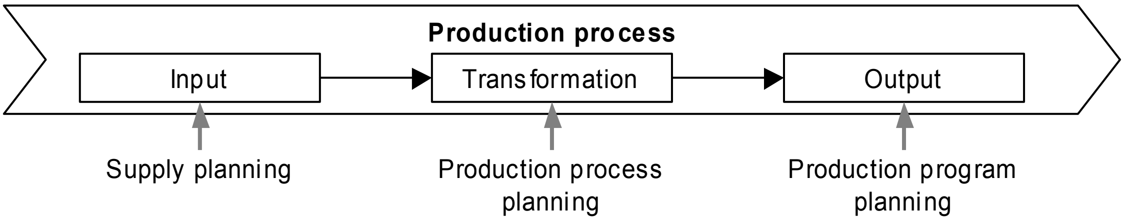


Figure 3.9: Allocation of planning tasks to steps in the production process

Supply planning contains all decisions referring to an economic supply of all necessary production factors like production resources, material, and work. These have to be provided to production according to demand in time, quantity, and quality (Hechtfischer 1991; Steven 1994). *Production-process planning* includes coordination and timing of production processes with the aim to allocate resources to operations and determine the sequence of production jobs. Thus, it can be divided into lot sizing and scheduling. *Production program planning* determines the production output for a certain planning horizon in matters of end-item types, quantities, and dates. The result is a production plan for which producibility and marketability are verified (Koulikoff-Souviron 2002).

Production program planning can further be subdivided in sales, inventory, primary demand, and rough-cut capacity planning. *Sales planning* determines production quantities for an assortment of products in a specified period of time. For this process, close interaction between the sales department and production is necessary to assure marketability as well as production capability in context with limited resources. *Inventory planning* aims at keeping cost for stocks low while, at the same time, avoiding missing parts. This way, the required inventory levels per end-item or end-item group are defined. In the course of *primary demand planning*, rough primary demands are calculated by adding up data from sales planning and further internal demands, e.g. in case of inter-plant transfers. Taking the actual inventory into account, a net primary demand can be determined. In the course of *rough-cut capacity planning*, the resulting preliminary production plan is aligned to available resources, speaking in terms of material, machines, personnel, and auxiliary goods. If the primary demand can not be satisfied, changes in the production program are necessary. This can be done either by postponing certain production quantities or by expanding the available capacity, e.g. by extra shifts. If even system set-up-changes do not lead to a satisfaction of demand, changes in the sales plan can become inevitable (Luczak and Eversheim 1999). Finally, the resulting aligned production plan is broken down in *production planning and control operations*. Since these aspects go beyond the scope of this research project, they are not presented and discussed here.

3.1.6.3 Planning across hierarchical levels

To connect the various levels and parts of business planning, different models can be applied. The danger in a multi-layer planning environment is that the top-level objective of long-term profit-maximising is lost out of sight due to inter-dependencies that are not acknowledged. Therefore the ideal approach is a total model, which comprises all planning tasks and takes them into account at the same time (Woehe 2000). However, business environment reality is far too complex to allow applying a simultaneous total model. Hence it is necessary to split up the field of decisions and plan the partials gradually (Koulikoff-Souviron 2002). The weakness of gradual planning and the corresponding partial models in pure form is that the information flow is unidirectional and decisions are made in a fixed sequence. Thus, no feedback is given to previous processes, regarding e.g. feasibility of communicated figures, which, in the end, leads to sub-optimal solutions (Steven 1994).

As a result from the problems with the diametrically opposed approaches of gradual and simultaneous planning, the concept of ‘hierarchical production planning’ originated (Buxey 1990). The aim was to combine the advantages of both approaches to a concept with the overview of an integrated approach and the solvability of clearly defined individual problems, at the same time. To achieve this, planning is split up in subtasks and feedback-loops are installed via defined interfaces between the levels (Steven 1994). Among authors, a strong correlation between planning horizon, the number of objects, and the planning hierarchy is commonly suggested (e.g. Buxey 1990; Bonney 2000). Figure 3.10 depicts this correlation schematically. On hierarchical top-level, network planning, based on aggregated product lines for a long-term-horizon, dominates the picture. Going down in hierarchy lets the planning horizon and the number of production resources decrease while the number of objects rises.

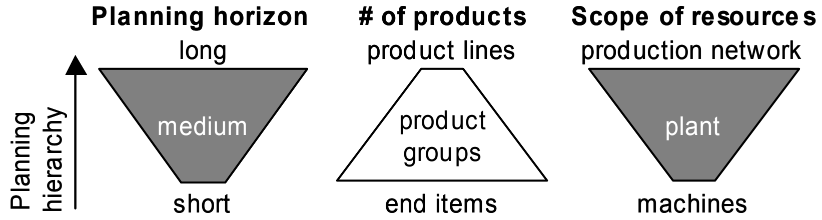


Figure 3.10: Correlation of planning objects and hierarchy

To reduce complexity, hierarchical production planning uses the following key elements (Meyer 1997):

- Hierarchisation,
- Decomposition,
- Rolling planning horizon,
- Interconnection of planning levels, and
- Aggregation and disaggregation.

Hierarchisation in this context means assigning the planning tasks to different levels. The vertical arrangement of the levels and the kind of relationships define hierarchy. *Decomposition* stands for splitting up a planning task into several sub-tasks. In the case of similar sub-problems on the same hierarchical level, horizontal decomposition seems advantageous. In consequence of horizontal decomposition, a central planning entity is necessary to coordinate the individual sub-teams.

The concept of *rolling planning* is above all applied at the top levels of hierarchical production planning (Steven 1994). A rolling planning horizon is used to solve multi-period problems. Several periods are planned regularly. However, only the results for the first period are obligatory and implemented at each planning cycle. Results for the following periods have no more than a preliminary character. The planning process in the following period updates data and shifts the horizon one period forth. Figure 3.11 exemplarily shows a sequence for two points in time: t_0 and t_1 (Thorn 2002).

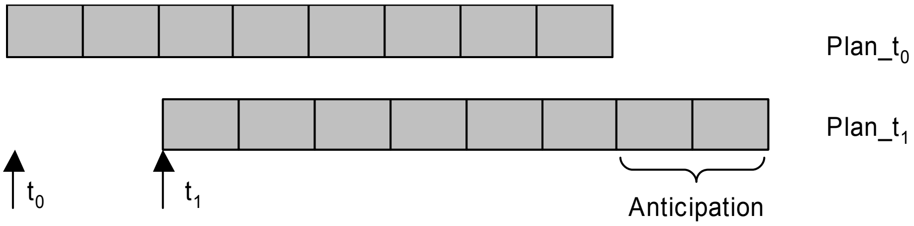


Figure 3.11: Rolling planning horizon

The mechanism of *interconnection* between hierarchical levels is shown in Figure 3.12 for the example of two planning levels. Essential for top-level planning and constraint creation is appropriate access to information that allows taking into account actualities and anticipating decisions from the base level. For the purpose of being able to react to conflicts that only surface in the process of detailed planning on base level (Miller 2002), feedback loops have to be installed (Thorn 2002). In the worst case, several iteration loops can be necessary, until a feasible solution is achieved and ready to be implemented (Meyer 1997). In any case, the number of necessary iterations has to be reduced as far as possible. Multiple iteration loops bear the danger of reaching an 'optimal' result that is invalid because the underlying assumptions have changed in the meantime. In this context, Liberatore and Miller stress the importance of well-designed formal procedures for information exchange in the network to ensure a rapid and good quality planning (Miller 2002).

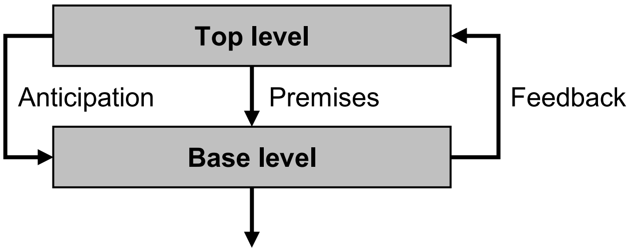


Figure 3.12: Interconnection of hierarchical levels

The summarisation of similar objects to groups by means of a common generic term is called *aggregation*. According to Bitran and Hax (1977) "most researchers have realized the difficulties imposed by a detailed formulation of the problem and have advocated an aggregate approach to production planning". By reducing the number of planning objects, complex planning problems can be modelled easily and, thus, solved in less time. Yet, Bitran and Hax's main concern are inaccuracies in planning based on detailed long-term forecasts. Axsäter (1985) takes this discussion one step further when he states that "the planning decision at the higher level is normally expressed in aggregate terms because it is not worth the effort to include all the details of the process when dealing with a long time horizon".

Zipkin (1977) notes that "the significance of aggregation depends strongly on the context in which it occurs". Thus, before aggregating data an aggregation analysis must be done. According to Vicens et al. (2001) five aspects have to be determined during analysis. These are:

- Cluster entity (time, product, and resources),
- Similarity measure,
- Cluster procedure,
- Level of clustering, and
- Method for combination.

Hax and Meal (1975) identify three levels of planning: end-items, families, and types. Aggregate decisions on level of product types are made first and impose constraints for more detailed decisions. To transfer the results from aggregated planning back to the original problem and degree of detail, disaggregation is conducted.

3.2 Production network planning on tactical level

3.2.1 Introduction

The concept of hierarchical production planning seems to be applicable to planning of resources in an international production network too. Unfortunately, the aspect of international production was not taken into account in the traditional theory of production planning. As a reaction to the transformed requirements, the extended *Aachener PPS-Modell* was developed in order to add network related tasks to the initial model of local and inner-company tasks developed by Luczak and Eversheim (1999). This model divides the reference task perspective into a local and a network part (see Figure 3.13 - following Schiegg and Luecke 2004).

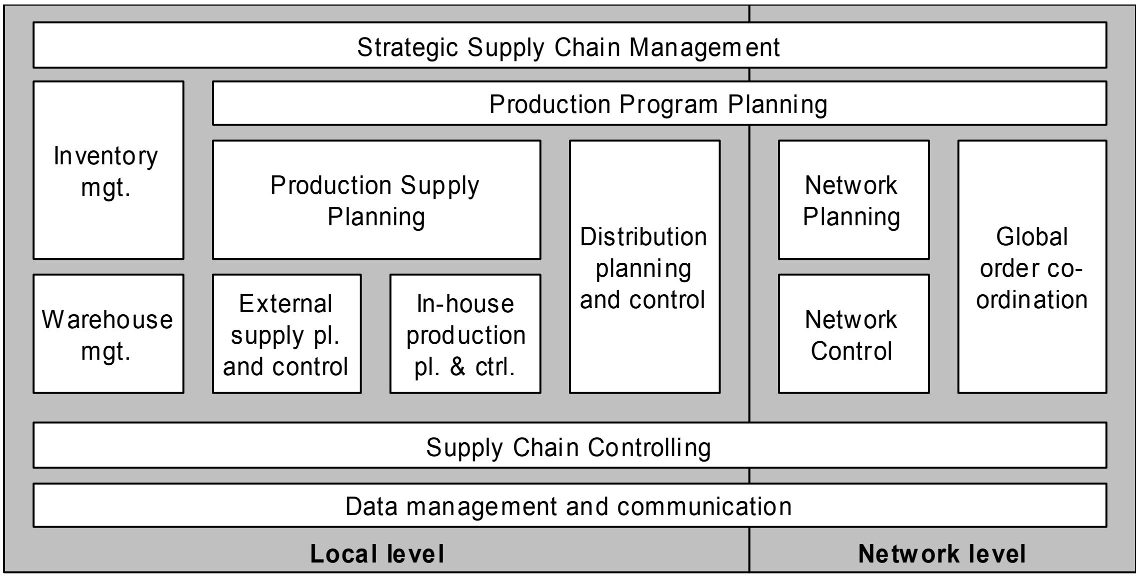


Figure 3.13: Extended Aachener PPS-Modell - Task perspective

The tasks on the local level correspond mainly to traditional *production planning and control* (PPC) tasks like long-term production program planning and short-term supply planning (see Figure 3.9). On the network level, the tasks of network planning, network control, and global order coordination are located. While network control has a short-term operational focus, network planning comprises the creation of a mid- to long-term network production program and plan as well as planning of material flow between involved sites. According to Schiegg and Luecke (2004), production planning in a multi-site environment can be positioned in the field of network planning. The ‘network production plan’ allots total demand to the individual production sites, taking capacity supply and inventory situation into account. By breaking down ‘global’ figures and constraints from this network production plan, the production plan of an individual site in the network can be derived. The field of interest in this research project therefore can be located to network planning in the extended *Aachener PPS-Modell*.

On the single production resource level, Slack et al. (1998) define ‘capacity planning’ as the task of setting the effective capacity of the operation in a way that it can respond to demands placed on it, involving decisions on how fluctuations in demand are to be handled. For a production network, the general approach to capacity planning is to calculate the overall technical production capacity in the network and compare it to the total customer demand. If capacity supply is sufficient, the total demand can be passed on to production resources. To provide valid planning results, a number of constraints has to be taken into account. The main challenge in this task is that it is performed for a future mid-term planning horizon on the basis of prognosis data that may change daily.

The objective for this step in intra-organisational network planning is to achieve an allocation of total demand to single resources in the network, answering the following questions:

- Which depth of production is to be realised at the sites?
- Which sum quantities are to be produced at the single sites?
- Where shall certain products, product groups, or components be located?

3.2.2 Approaches to production network planning

As discussed in section 3.1.6, the additional task of coordinating distributed sites is what differentiates production planning in a network from planning of a simple ‘one-site-problem.’ The crucial point is the necessity to allocate prognosticated demand to resources in the network. Planning complexity is fairly high due to the possibilities of combination, resulting from the number of orders, sites in question, and time periods to be planned (Loukmidis et al. 2002).

3.2.2.1 Centralised vs. decentralised planning

Approaches to overcome planning complexity differ mainly in the chosen degree of centralisation, speaking in terms of the distribution of planning and decision competency. The two extreme forms in theory are completely decentralised planning with bi-directional coordination directly between involved partners, on the one side, and purely centralised planning by a coordinating entity that is authorised to issue directives, on the other side (Kistner and Steven 1993). In actuality, the boundaries between these extremes are flexible. Many 'hybrids' can be found with some competencies given to the central planning entity, while others remain at the individual network partners (Wiendahl 1998).

Sharing of planning tasks inevitably leads to interfaces due to interdependencies between the sub-tasks. The resulting need for coordination between the planning entities can either be satisfied by hierarchical or by non-hierarchical coordination. The concept of hierarchical coordination is based on a control loop principle, while the procedure is derived from hierarchical planning (see 3.1.6.3). The key element of non-hierarchical coordination is negotiation between peer partners, which all have their own objectives. Completely centralised concepts need a system of hierarchical coordination, whereas decentralised concepts are closely related to non-hierarchical coordination. Hybrid forms of task sharing, therefore, require a special form of coordination that has to be customised to the concrete case (Wiendahl 1998).

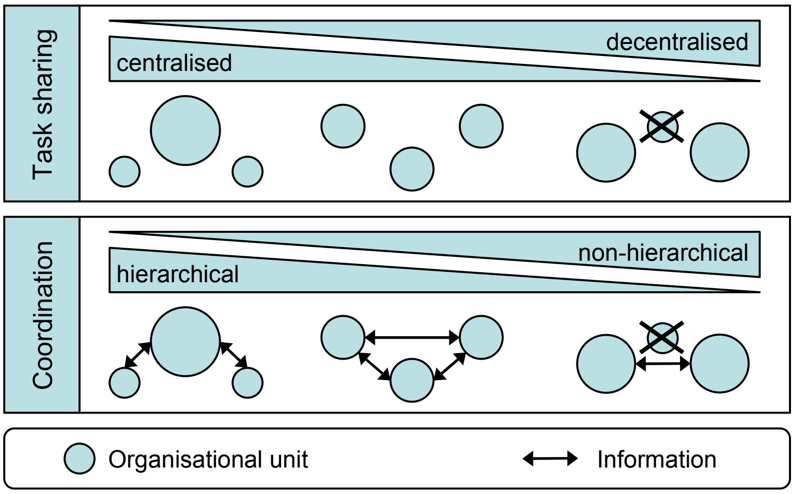


Figure 3.14: Types of centralisation (WIENDAHL 1998)

Figure 3.14 shows forms of planning centralisation in a network of several sites in regard of the possibilities of task sharing and coordination between sites. In the literature, many of the approaches can be found leaning to the side of flexibility and autonomy of decentralised coordination between independent entities (e.g. Chapman and Corso 2005; Ernst 1997). Those approaches usually are based on the theory of multi-agent systems (e.g. Philippson 2002). However, their focus mainly lies on single and small batch production and, therefore, is difficult to apply to high-volume, multi-variant manufacturers – the object of this research work. Remarkably, though, even authors that postulate complete decentralisation express the need for a central entity to control the decentralised entities to a certain degree (Wrede 2000).

3.2.2.2 The central planning entity

Without a central planning entity the sites in the network could easily plan their activities uncoordinated, taking only their own objectives into account. The crucial task of the central planning entity, therefore, is to avoid a sub-optimum by coordinating the local objectives for the benefit of a total optimum for the whole network (Luecke and Luczak 2003). According to Wrede (2000), the selection of tasks performed by the central planning entity, however, should be limited to those that have a comprehensive character and need a ‘central view’ to be performed efficiently. Examples are the management of product life-cycles or core logistical decisions like the allocation of total demands to production resources in the network.

The central planning entity needs a well-designed and fully working information flow to fulfil the task of coordination efficiently. In this context, the importance of information technology (IT) for coordination of business processes in general and particularly for the planning and control of distributed production resources becomes obvious (Ernst 1997). The connection of individual sites by IT enables the planner to create a broad set of data that can be used as the basis for decisions. Using virtual presence of necessary information, the disadvantages of local distances in the production network can partly be compensated. Some authors even state that with decreasing costs for information supply and improved communication technologies, the concept of central planning gains even more attractiveness (Wrede 2000).

Luecke and Luczak (2003) summarise the business goals and tasks of a central planning entity in an intra-organisational production network as follows:

- Rough-cut order planning and control for several production sites.
- Postulation of guidelines as decision support to balance conflicting objectives in the network.
- Centralisation of tasks that contribute to detection of defects.
- Creation of adequate control mechanisms.

Wrede (2000), additionally, differentiates between core and cross-section tasks for a central entity in the context of decentralised production sites. *Core tasks* refer to order processing, starting with production program planning and comprising the allocation of production quantities to sites, among other things. *Cross-section tasks* have a comprehensive character, like central inventory planning and control.

In summary, it can be stated that planning of distributed sites in a production network can only be performed efficiently by a central entity that is able to take all relevant inter-dependencies into account. A well-designed IT architecture as well as reliable and accessible data in the network are vital for its success.

3.2.2.3 Hierarchical network planning framework

In the previous section, the importance and role of a central planning entity in an international production network was presented. Due to the correlation between task sharing and the form of coordination it can be concluded that a hierarchical planning system seems advantageous for coordination of distributed locations (Tempelmeier 2001).

Approaches for *hierarchical production planning* are usually designed to address simultaneously the process of generating production plans and the verification of sufficient capacity to implement these plans (Adenso-Diaz and Laguna 1996). The *American Production and Inventory Control Society* (APICS) suggests a hierarchical planning framework that serves as a general basis for the process of production-network planning unfolded in this work. Figure 3.15 shows a simplified version of their planning framework containing the main modules that constitute a typical strategic and tactical level. In general, it can be stated that both – length of the planning horizon and the consequences of decisions – increase when going up in the planning hierarchy (APICS 1998).

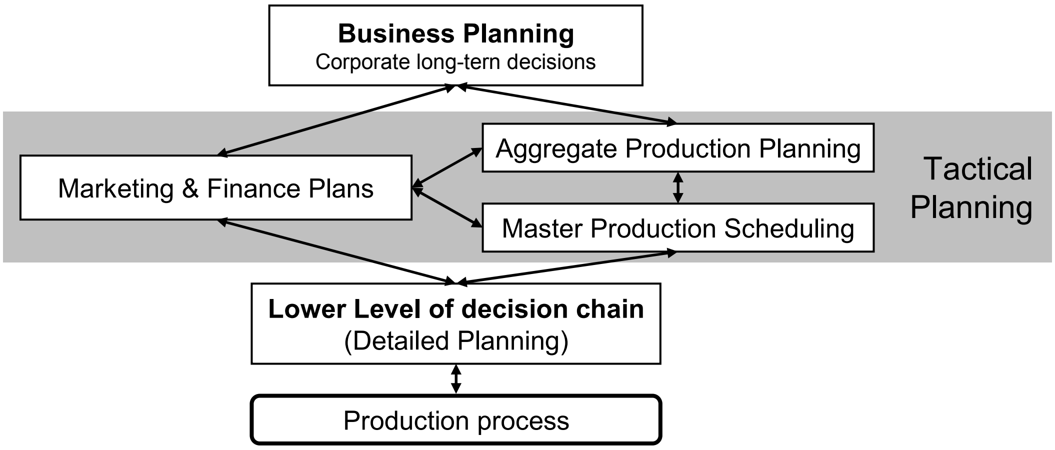


Figure 3.15: Hierarchical production planning framework (following APICS 1998)

Positioned between long-term decision-making in corporate business planning and short-term detailed planning on lower levels is the vital field of tactical planning (Waters

2003). It is constrained by the corporate business plan, while the resulting tactical plans should be used as a target to be followed on the lower level. The basic objective of tactical planning is to tune the industrial resources of the companies in order to meet the fluctuating demand requirements and minimise the expected total production costs (Silva Filho 1999). Within tactical planning, different levels of detail, planning horizon, and scope of planning can be differentiated. According to Waters (2003), the correlating planning approaches can be summarised under *Aggregate Production Planning* (APP) and *Master Production Scheduling* (MPS). Whereas APP focuses on aggregated product groups and production resources and is, therefore, more capable of planning production networks as a whole, MPS is usually limited to planning of parts of the network due to its more detailed perspective and the resulting amount of data. Since these two approaches build the bridge between abstract business plans and actual resource scheduling they are investigated in the following and it is checked if they can be applied to the planning task that is the core interest for this work.

3.2.3 Tactical Planning – two representative approaches

Several authors have given an overview of the origins of tactical planning approaches in the 1950s and their development since then. Buxey (1990) presents an introduction on the beginnings referring to studies in a paint factory and derived techniques. A review on models and methodologies, especially for APP, can be found in Nam and Logendran (1992), where 140 journal articles and 14 books are categorised into optimal and near-optimal classifications with respect to models and methodologies.

3.2.3.1 Aggregate Production Planning and Master Production Scheduling

Waters (2003) defines aggregate planning as making “the tactical decisions that translate forecasted demand and available capacity into schedules for families of activities.” For the production-planning sector, Nam and Logendran (1992) specify, “*Aggregate Production Planning* is performed to best utilize the human and equipment resources of a company to meet some anticipated consumer demand.” Taking the discussion one step further, they state that APP deals simultaneously with a company's production, inventory and employment levels over a finite time horizon, and aims to minimise the total relevant costs while meeting time-varying demand, assuming fixed sales and production capacity. Further objectives of APP are maximisation of contribution to profit and minimisation of inventory investment, back orders, and changes in workforce level. In order to carry out APP, end-items need to be aggregated to product groups. Underlying is the assumption that all products are homogeneous and capable of aggregation.

Planning usually is performed with a frequency of two to 18 months (Leung and Wu 2004).

Aggregate planning has certain required inputs that are inevitable. They include:

- Information about the resources and the facilities available.
- Demand forecast for the period for which the planning is done.
- Cost of various alternatives and resources. This includes cost of holding inventory, ordering cost, and cost of production.
- Organisational policies regarding the usage of the above alternatives.

Typical outputs of APP are production plans and staffing plans, i.e. manufacturing aggregate plans and service aggregate plans. The first is a managerial statement of the period-by-period production rates, work-force levels, and inventory investment, given customer requirements and capacity limitations. The latter refers to staff size and labour-related capacities, given customer requirements and capacity limitations. The outputs of APP serve as constraints in *Master Production Scheduling*.

According to Waters (2003), “the master schedule gives a timetable for activities […]. Its aim is to achieve the activities described in aggregate plans as efficiently as possible.” Higgins and Browne (1992) describe MPS as the “key decision-making activity” in an integrated production planning and control system. MPS translates an aggregated production plan into a dynamic and comprehensive product-manufacturing schedule, from which all lower level schedules are derived. Master scheduling requires ongoing analysis, measurement, and adjustment to achieve revenue goals and ensure profitability through the careful allocation of materials and resources. In comparison to APP, planning periods shorten; the usual length is weeks. Items under consideration may be product groups, individual products or parts of products like components or sub-assemblies. The demand figures are usually a mixture of forecasts and orders (Higgins and Browne 1992).

In the context of this work, the MPS facet of ‘rough-cut capacity planning’ is of particular interest. In order to ascertain whether a schedule is feasible, it has to be checked against resources and capacity requirements. Consequently, the production quantities have to be converted into units of measure relevant for resources, like labour hours, machine hours, or space. Subsequently, these figures have to be time-phased and compared to the capacity supply of the corresponding resources (Burcher 1992).

3.2.3.2 Benefit, origin and fields of application

Obviously, the biggest benefit of tactical planning is that it provides several strategies for responding to fluctuating demand. These may be applied purely or in combination (Buffa and Taubert 1972):

a) Adjust the workforce through hiring and firing.
b) Adjust the rate of production through overtime/undertime.
c) Maintain a constant production-level absorbing fluctuations in demand through inventory backlogging or allowing lost sales. Additionally, the manager may have the opportunity to use subcontracting as an alternative – if suitable.

Alternative a) holds a certain risk regarding production-system continuity and in some cases may not be applicable due to governmental regulations. Alternative b) is frequently used to adjust a production system to changing demand, but is limited to a certain range of adjustment. Decoupling of production from fluctuating demand in mid-term view by 'breathing' through inventories is suggested by alternative c). The achieved flexibility opens up the possibility to early plan reconfigurations of relevant resources in the production network and reasonably adjust the system. By doing this, even changes in the market that exceed network flexibility in a short-term view can be covered. Furthermore, extreme production load fluctuations can be smoothed out and, e.g., a pure hire-and-fire policy following each up and down can be avoided.

Tactical planning based on aggregated data can be applied to nearly any field of industry. In the relevant literature, examples can be found for various fields of industry, e.g. process industry (Qui and Burch 1997), or household products (Erkut and Oezen 1996). Buxey (1990) presents an overview of companies' relevant strategies, goals, constraints, and mechanisms for tactical planning by providing an industrial sample resulting from 25 factory visits. Industry sectors covered were e.g. food, clothing, chemicals, appliances and electrical equipment, as well as transport equipment. Burcher (1992) takes the discussion one step further by evaluating planning levels and processes of eight exemplary companies and assessing the actual planning performance.

The fundamental characteristics that lead to a need for tactical planning can be summarised as follows: a production environment with multiple production resources, a product portfolio that allows to aggregate end-items to groups or families, and seasonal demand or demand fluctuations that exceed the flexibility of the production system.

3.2.3.3 Solution approaches

Research literature on APP since 1950 reflects various graphical, mathematical, and heuristic techniques designed to be used to implement generally these specific APP strategies (Nam and Logendran 1992). At the broadest level, two categories of techniques exist. The first classification includes techniques that produce an exact, mathematically optimal solution, while the second includes those that do not. The key to understand this classification scheme lies in the recognition that optimising, in a decision-sciences-sense, implies that planners can find solutions that can be guaranteed to be a global maximum or minimum. Table 3.1 shows a classification of selected mathematical approaches following a suggestion by Nam and Logendran (1992) who provide a detailed discussion of models, solution procedures, as well as strengths and weaknesses for each option.

Optimisation approaches	Near optimal approaches
• Linear Programming • Linear Decision Rule • Lot Size Model • Goal Programming	• Search decision rule • Production switching heuristics • Management coefficient model • Simulation model

Table 3.1: Classification of models for aggregated planning

3.3 Supplier vs. customer planning

3.3.1 Planning as an automotive supplier

Additionally to the planning activities and conditions presented in section 3.1.6, the situation of being the supplier in the automotive environment holds some specific requirements. Especially suppliers with a high-volume, multi-variant product portfolio that serve multiple customers as tier-1 supplier, face the challenge of mandatory 100 per cent delivery on the one side and volatile demand on the other side. To a certain extent, customers dictate conditions, speaking in terms of price, short-term demand increases and so on. Because the supplier's sales plan can only be aligned to constraints resulting from production, any changes on the customer side can directly provoke re-configuration of the network of production resources.

One key issue known to have an impact on the effectiveness of a supply chain is uncertainty (Davis 1993). Wilding (1998) introduces the *Supply Chain Complexity Triangle* to provide an explanation for the generation of uncertainty within supply chains. He identified three independent effects that in combination cause dynamic behaviour and, thus, increase uncertainty within supply chains: deterministic chaos, parallel interactions, and demand amplification (Figure 3.16).

Deterministic chaos refers to the fact that outputs of a system usually are generated following certain rules, but these rules show a strong sensitivity to changing environmental parameters and, therefore, are only to a certain extent predictable. Hence, an infinitesimal change to a system variable's initial condition may result in a completely different response. The 'beer game' is a well-known example for the generation of uncertainty and chaos in a comparably simple supply chain (Wilding 1998).

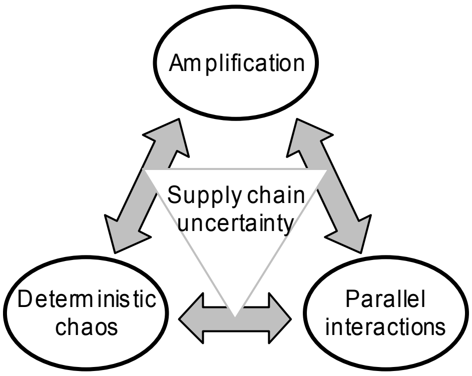


Figure 3.16: The supply chain complexity triangle (following Wilding 1998)

Parallel interactions within the supply chain were observed by Jones (1990) in an automotive supply network. The term has been defined to describe interactions that occur between different channels of the same tier in a supply network. A typical example of parallel interactions occurs when a tier-1 supplier cannot supply a customer; this, in turn, has the result of re-scheduling within the customer organisation. In effect, the customer changes his requirements from other tier-1 suppliers. Thus the supplier is affected by an occurrence in a parallel supply chain, which at first would seem unrelated (Wilding 1998).

SCM requires co-operation and co-ordination between companies' activities (Davis 1993). Otherwise, the variability of business activities tends to be amplified as it is moved upstream in the supply chain. This phenomenon is referred to in literature as the 'bullwhip effect' (Lee et al. 1997). Forrester (1961) initially analysed and introduced this effect of demand *amplification* in a supply chain. Several authors have taken the original concepts of Forrester and used examples of relevance to today's market conditions (e.g. Lee et al. 1997; Thorn 2002) or created dynamic simulation models (e.g.

Disney et al. 1997). Svensson (2003) applied the bullwhip effect theory to intra-organisational echelons.

In contrast to the above described uncertainty in the supply chain, suppliers nevertheless have to perform their planning for mid- to long-term future horizons. Prognoses for sales quantities are calculated on base of historical sales data, forecasted market developments and, if existent, customer orders. Therefore the supplier has to rely on systems or the experience of planners who generate the demand figures on customer side. Furthermore assumptions have to be made in case no or unreliable forecasts are available.

3.3.2 Objectives for planning

Traditionally, every manufacturing business seeks to find the optimal trade-off between the metrics: cost, quality, and time; often illustrated as corners of a so-called ‘magic triangle’ (Woehe 2000). Depending on the specific context of an individual company, the focus can be shifted between the corners.

3.3.2.1 Company internal objectives

Looking at production, on the network level as well as on the single shop floor level, the aim is to have a stable environment with defined requirements resulting in a comparably constant load of production. Ideally, short-term demand fluctuations do not exceed the flexibility of the production system, and bigger changes are communicated early enough to have the chance to reconfigure the system reasonably. As this ideal situation is not reality, the objective of a manufacturing company is to gain robustness – not only regarding the system in question but also the planning process itself.

In general, robustness is the insensitivity of an object or system against casual environmental influences (Schneeweis 1992). It can, therefore, be seen as the opposite of a phenomenon referred to as ‘nervousness’ – a term mainly used in correlation with detailed MRP planning (e.g. Sridharan et al. 1987). Scholl (2001) states that the robustness of a plan is characterised by the fact that the realisation of the plan leads to acceptable results for almost every coming circumstances. An illustration that can be adapted to explain more vividly the term robustness is the so-called *P-Diagram* proposed by iSixSigma (Phadke 2003). It was originally developed for product design and divides the environment of a system into input, output, noise, and control factors (Figure 3.17).

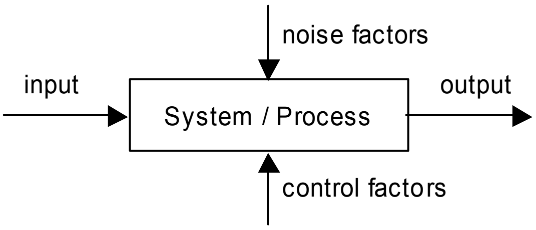


Figure 3.17: P-Diagram (following Phadke 2003)

Applied to planning processes, the system or process transforms inputs to outputs. The job of the designer is to select appropriate control factors and their settings so that in case of 'noise' the deviation from the ideal is at the minimum. Such a design is called a minimum sensitivity design or a robust design (Leung and Wu 2004). A robust production system can stand fluctuating inputs without significantly changing the expected output or, in the worst case, collapsing. On the other hand, a robust planning process and the resulting production plans are capable to cover a certain extent of these fluctuations.

3.3.2.2 Company external objectives

Customer satisfaction is a goal that unifies all efforts throughout the supply chain (Hines 1993). However, as demand becomes increasingly volatile (Lowson 2003), the challenges for SCM continue to escalate (Christopher 1999). This trend is enforced by the fact that the de-coupling of production from customer demand is complicated further due to increasing product customisation. Thus, companies that want to stay competitive need to align their production procedures with customer demands. Successful organisations of the future are likely to be those that develop the capabilities to match the emerging characteristics of demand with new supply capabilities, creating competitive advantage through customer responsive supply chain strategies (Harrison and Godsell 2003). Customer responsiveness can therefore be considered as the "crafting and execution of supply strategy to meet changing market needs" (Harrison et al. 2004). Customer satisfaction by 100-per-cent delivery comprises the factors time, quantity, and quality.

3.3.3 Customer orders

3.3.3.1 Customer order behaviour

Aligning strategies to the customer gets difficult when the planning base alternates steadily. In general, a customer provides the supplier a preview of prospective deliveries some time in advance (APICS 1997). Figures given at an early point may not necessarily match the actual quantity released later, but, in combination with planners' experience, they enable to give an estimate for what is going to be demanded. As the supplier needs a strategic planning horizon for decisions about dis-/investment, he has to allocate capacities and prospective production quantities in advance and has to base his planning on the preview. In progress of time, the customer concretises his prognosis by giving new figures to the supplier. Assuming the best case, the planner could rely on the figures received in the first instance. Unfortunately, in reality only few customers can be counted to this ideal type (Harrison et al. 2004). In case of deviations from original figures, the supplier has to find a strategy to deal with these.

3.3.3.2 Spontaneous demand changes

In addition to the complexity arising from partly unpredictable customer behaviour, spontaneous changes in planned production quantities have to be handled in the planning process. Whereas lowered demands may lead to underemployment, increased demand requests usually are a bigger problem, especially in a system that runs at the upper limit of capacity (Waters 2003). In effect, even changes in the network configuration can become necessary. Additional Demand Requests (ADR) can be caused by customers or by the organisation itself, if actual customer demands diverge from prognosis. An ADR refers to a specific product and contains the desired quantity and date of delivery and means additional load for the production system. In order to be able to respond to an ADR, it is necessary to adjust the distribution of demands to production resources. In this context, production capacities for finished products, components, and critical raw material have to be evaluated for each resource within the production network. With respect to the high value of customer satisfaction, the answer on an ADR is almost determined in advance to be "yes." Hence, the only remaining parameters, in case it is impossible to satisfy the additional demand in time, are shifts between resources in the network as well as a minor delay in time. Above all, to answer the increased requests, a fast response to the customer is necessary.

3.4 Network Master Planning – a definition

In case of parallel production resources, there is no one-to-one correlation between products or steps in value-adding and production resources. Thus, an allocation problem with the objective of an overall optimum has to be solved. According to Kistner and Steven (1993), problems of this nature originally can be found in the field of order scheduling for parallel machines, but, as demonstrated in section 3.2.2, the allocation problem is also relevant in production network planning.

3.4.1 Introducing Network Master Planning

Network Master Planning (NMP) – as the author names the corresponding planning task – seeks to allocate specified items to specified resources in a global production network, taking several constraints into account. The objects that have to be allocated are called 'allocation orders' and represent a set of one end-item and the corresponding production quantity. One allocation order may represent multiple customer orders. NMP can therefore be positioned as a coordination problem (orders), from a planning procedure perspective (see 3.1.6), or as a selection problem (resources), from a production theory perspective (Wrede 2000; Hoitsch 1993). The planning task is typically performed on a quarter- or half-year base (Tempelmeier 2003a). Further it can be initiated irregularly by changes in customer demands or company internal requirements (Harrison et al. 2004). The main objective is to balance the load on each plant in the network while increasing profitability.

In general, the production resources in question are characterised by different capabilities for order processing. For example, product variants differ in technical specifications, like exterior dimensions or used components. Thus, technological capabilities of resources constrain planning heavily. On the other hand, it is a question of priorities in criteria how the allocation process proceeds. Wrede (2000) suggests as criteria e.g. production cost for alternative sites, transport costs, and times between site and customer or between sites in case of a distributed production process. Furthermore, the quality levels of single sites as well as country-specific factors can influence the decision (Wrede 2000).

The allocation of orders to resources has to be seen as the basis for further capacity planning in the network. Supply and demand can only be reasonably compared after a general pre-selection. Due to its characteristics and importance, NMP requires a defined methodology and a central planning entity to be performed most efficiently. In the context of this research, capacity-fine-planning in the context of NMP is a vital aspect and will therefore be discussed in detail.

3.4.2 General sources of complexity for planning

General sources of complexity for the above illustrated task of *Network Master Planning* are:

- Methodology has to be robust and flexible at the same time.
- All constraints – external and internal – have to be taken into account.
- All inter-dependencies between planning tasks have to be taken into account.

3.4.2.1 Flexibility and Robustness

Flexibility and robustness are vital features a planning-design-approach has to take into account besides the optimisation of total costs under constraints. Flexibility refers to production output – regarding total amount of production and product mix – and robustness to the organisational and process design in view of changing input variables. Both requirements have a direct impact on the configuration and coordination of the production system.

The need for a flexible production system under the impact of dynamic markets and volatile demand is stated by many authors (e.g. Wolfe 2005; Harrison et al. 2004). The effects on supplier's planning caused by customer behaviour are presented in the previous section. As presented in section 3.3.2.1, the generated system as well as the planning process have to be robust to external and internal 'noise factors'. Changing customer order quantities and delivery dates are examples for external noise factors, whereas changes in available resources in the production network or changes in product classification and structures are internal ones (Leung and Wu 2004).

3.4.2.2 Multi-objective planning

Looking at total customer demand and the resulting orders that have to be allocated in a planning cycle, the entirety of possible production programs forms the alternatives. These have to be evaluated based on company and production objectives. Evaluation is done by using monetary or time-related quantifiable metrics. Complexity in the decision process rises with the number of concurrent objectives. In general, constraints limit the scope of the plan (Bowersox et al. 2002). This means that depending on type and characteristic of constraints the so-called solution space is reduced (Wrede 2000).

3.4.2.3 Inter-dependencies between planning steps

The discussion in section 3.1.6 showed the characteristic differences between gradual and simultaneous planning. The central finding is that gradual planning often neglects the existence of inter-dependencies and, therefore, does lead to a sub-optimal or even an invalid result. Planning different parts of the problem simultaneously leads to a near-optimal result, but requires a rather complex overall model, which makes data collection, model implementation, and problem solving in reasonable time challenging

(Wrede 2000). However, simultaneous production planning does not necessarily mean performing several planning steps at the same point of time. However, the focus lies on taking all relevant inter-dependencies into account to achieve the best possible result for the system in question (Burcher 1992). Thus, solution alternatives for order sequence, order allocation, and capacity planning have to be developed and an optimal combination regarding inter-dependencies has to be selected.

3.4.3 Positioning NMP in the hierarchical production planning framework

NMP is closely related to the widely documented fields of *Aggregate Production Planning* (Nam and Logendran 1992) and the corresponding *Master Production Scheduling* (e.g. Burcher 1992). For example, these fields all deal with the "management of finished products in particular time periods in the future" (Burcher 1980), especially the allocation of items to constrained resources and identification of bottle-necks. Furthermore, they are closely related in the hierarchical framework of production planning as presented in Figure 3.18. The author positions NMP at the interface between long-term *Business Planning* (BP) and medium-term APP. Outputs of BP influence on NMP and decisions made at NMP level set the corridor for APP.

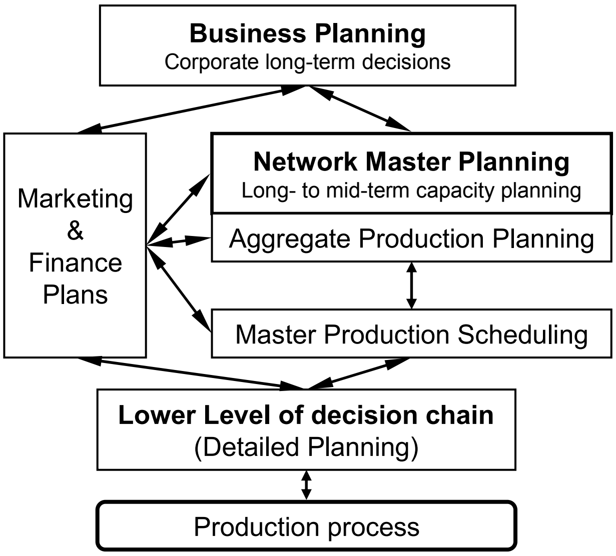


Figure 3.18: Extended hierarchical production planning framework

3.5 Literature review summary

3.5.1 Literature classification

Regarding the context of this research project, the author has reviewed various areas of research in literature. The search started with SCM in general and the different levels of planning in particular, for example: strategic decision science, location allocation, and global footprint design, or network coordination. Further fields covered are characteristics of intra-organisational supply chains and networks, production planning, tactical (capacity) planning, and customer behaviour.

SCM research can be classified into three categories: operational, tactical, and strategic. Operational SCM is concerned with the daily operation of an organisation to ensure that the most profitable way to fulfil customer order is executed. The focus is to develop mathematical tools and software that aid the efficient operation of the supply chain as a whole. On the opposite side of the range, strategic SCM decisions include critical evaluation of alternative supply chain configurations and partnerships, and the determination of opportunities that can enhance the competitiveness of the firm as a part of the supply chain or the network of supply chains (Huang et al. 2004).

Tactical supply chain planning focuses on the design and coordination of the chain (Mourits and Evers 1995). In this context, many researchers advocate planning on aggregated level (e.g. Bitran and Hax 1977). The aspect of information-sharing and its control is widely discussed in correlation with centralised planning in a production network (see 3.2.2).

3.5.2 Summary on existing approaches and models for tactical planning

The investigation of the literature found two groups of scientific articles about approaches to tactical planning. On the one side, there are theoretical and survey-based essays aiming to generate common understanding about general inter-dependencies (e.g. Burcher 1992; Dombrowski 2004) or specific aspects (e.g. Higgins and Browne 1992). The other group is formed by articles dealing with mathematical models for specific parts or simplified versions of the problem, presenting solution algorithms (e.g. Leung et al. 2003; Silva Filho 1999). Essays based on real-world data and dealing with the original complexity are still rare.

Aggregate Production Planning is widely discussed in literature. Bitran and Hax (1977) and Axsäter (1985), which most authors refer to as foundation for their own works, are strong advocates of aggregation. They have proposed reasonable models to access the field of tactical planning and techniques to integrate specific aspects of planning. Many of the proposed concepts seem quite useful to the author – in contexts where aggregate planning is applicable. However, the rules for aggregation have not been fully presented. Neither a description of sensible criteria for the applicability of aggregation nor an explanation of the meaning of 'normal' or 'usual' contexts for 'good aggregation' – terms extensively used by the aforementioned authors – could be found.

3.5.3 Reasons for existing focus

The reasons why authors did focus on the topics presented above can be summarised as follows. The simplest explanation for certain approaches found in the literature is that planners face problems in their day-to-day work and want to solve them. Thus, tools are developed to support planning activities, even if they only work on a rather rough level with partially simplified data. Furthermore, describing real-world problems in mathematical models is tempting as it promises to enable the planner to exactly explain and predict the behaviour of the system. The danger lies in simplifications that are usually necessary to handle the problem but lead away from real-world conditions. Last but not least, it is scientifically attractive to develop solutions that compute a higher number of data sets in less time. Unfortunately, these approaches are often also built on assumptions that are inappropriate for the requirements found by this research work.

3.6 Conclusion

3.6.1 Relevance of existing approaches and applicability to NMP

The central finding from the literature search and analysis is that existing approaches for operational planning are not directly transferable to tasks with a longer time-horizon. However, individual planning principles may serve as a general guideline which activities to carry out during planning and in what way to perform them.

Probably the greatest shortcoming of the presented tactical planning approaches is their limited scope of use in practice. This is due to the specialisation for individual contexts. For example, only some of the approaches allow planning in a multi-product environment (Nam and Logendran 1992). Other theoretical assumptions, like deterministic demand or accurate accounting systems do also narrow their use and acceptance in industry. Aspects like complex supply structures or multiple and interfering products which follow different and unpredictable demand patterns are usually omitted from analysis (New and Payne 1995).

In contradiction to a large number of models and heuristics presented in the literature, industry does not appear convinced of these approaches (Buxey 1990). At least, the practical use is doubtful as long as authors develop solutions for non-real-world conditions with only theoretical merit (Nam and Logendran 1992). An exemplary statement of Nathan and Venkataraman (1998), referring to the problem formulation may demonstrate this: “The MPS problem […] is solved under the assumption of perfect forecasts of demand for the end-items.”

NMP takes elements from existing approaches and applies them to a different planning context by combination or adaptation. Whereas, for example, aggregated planning and the mid-term planning perspective are taken from APP, detailed planning on the end-item level and allocation to production resources stem from MPS. In the following, the central differences of NMP to the related approaches of APP and MPS are presented.

3.6.2 How NMP is different to other planning approaches

Initial analysis of literature aimed to identify existing approaches for the field of NMP. Backed up with insights from industry, which are presented in chapter 4, it was found that a gap in knowledge between the specific company planning environment – as presented in this work – and the published approaches still exists.

	NMP	**APP**	**MPS**
Planning horizon	0.5 -10 years	2 - 18 months	1 - 12 months
Frequency of planning	2 times a year + as reaction to ADR	Usually monthly	Usually monthly
Time frames	6 months	1 month	1 month
Production resources	Lines	Plants	Lines
# Production resources	>20	1-3	1-3
Planning objects	End-items	Product groups	Product groups, End-items, Components
# Planning objects	> 10,000	< 100	>10,000 (grouped)

Sources: **NMP**: Aspects from several sources (e.g. Luecke and Luczak 2003; Wrede 2000)
& author’s insights from industry, which are presented in chapter 4.
APP: Nam and Logendran (1992); **MPS**: Buxey (1990), Higgins and Browne (1992)

Table 3.2: Comparison of NMP with related planning approaches

Although the related fields of APP and MPS are widely documented (e.g. Nam and Logendran 1992; Burcher 1992), a full transferability on the presented problem is not feasible, e.g. due to different levels of aggregation as well as the planning database and frequency. Table 3.2 presents a comparison of NMP, APP and MPS characteristics.

In summary, it can be stated that, on the one hand, NMP is more complex than existing approaches. For reasons of planning relevant product properties, technical production capabilities and inter-dependencies regarding total plant capacities, the network has to be planned on a detailed level. Furthermore, planning is done on a system that is at its limit regarding capacities. Therefore, feasibility checks on an aggregated level are not sufficient. Hence, NMP breaks with traditional approaches of aggregated planning on tactical level to a certain extent. This aspect will be discussed in detail in chapter 4.

Additionally, capacity planning as tier-1 supplier in an automotive environment brings the risk of direct dependence on the customer. To a certain extent, customers dictate conditions like quantities and dates. In order to stay competitive, the supplier has to align its planning and actions to those of the customer, even if they, in the end, change their minds and do not stick to contracts and agreements. On the other hand, NMP is simpler, because it does not even pretend to cover the whole field of production, inventory and work level planning but focuses on production quantity and capacity planning.

3.6.3 The need for research about NMP

The literature gap consists for NMP, as it is introduced by the author, as well as for approaches to planning, which leave out much of the complexity of real-life behaviour. These two aspects are summarised in the following.

According to Stadtler and Kilger (2002), “coordinating material, information and financial flows for […] a multinational company in an efficient manner is still a formidable task.” Referring to this statement, which is valid for performing operations within the system as well as tactical planning of the system, and taking the above given reasons into account, it is obligatory for companies to optimally set up a system of globally distributed production facilities. Consequently, the task of mid- to long-term *Network Master Planning* is crucial. Yet although especially the field of *Aggregate Production Planning* is evolving since the 1950s and, in general, numerous models have been developed to solve tactical problems, only few approaches were implemented in real world situations (Nam and Logendran 1992). This indicates that efforts may have been invested at the wrong places, developing e.g. further algorithms for the '3 products, 2 machines' problem, considering more and more parameters, but giving too little attention to real-world planning problems that include noisy, incomplete, or erroneous data. Thus, there is still a need for further development, which is detailed in chapter 4.

The author has introduced a planning task with specific characteristics in this chapter. Due to its stage of immature research, it has not been possible yet to find literature that addresses exactly this planning task as a topic. It is likely to be embedded in articles about aggregated planning, but the complete field is blurred and literature that links tactical planning to detail planning on level of individual resources and end-items seems to be missing. The lack of literature on this vital field may result from specific conditions in the analysed industry context that do not apply to many companies. However, as presented in section 3.1.5, production in global networks is not uncommon nowadays. Therefore, network coordination activities are also a necessity. More likely though is that companies are not aware of the related chances for competitive advantages, because they do not realise the importance of a well-designed planning process.

In order to better understand NMP, the topic has to be searched through the lens of practice. Hence, NMP is explored further in a real case in chapter 4.

4 Sources of complexity for NMP practice

This chapter introduces the unusual situation of NMP in practice and discusses what sources of complexity for NMP exist and what impact these factors have on the planning process. Further, the author shows where and how the NMP environment and conditions differ from other forms of planning. As a result, this knowledge is transformed into a set of requirements for successfully taking on NMP by means of a planning methodology including integrated tool modules.

4.1 Chapter content and origin of research data

4.1.1 Introduction

In the previous chapter, the scene was set for production planning in global manufacturing networks, considering especially the situation and context of high-volume, multi-variant automotive suppliers acting under uncertainty. This chapter contributes to an understanding of and provides an insight into NMP in practice, especially in the planning process and the sources of complexity. The author demonstrates that NMP is exceptional and distinctive for a number of reasons. These mainly result from implications of the environment in practice. The implications are analysed and categorised. Furthermore, their origins and characteristics are described in detail as well as the effect they have on the production system in general and on NMP in particular.

Regarding sources of complexity, different aspects are highlighted. First, the author points to relations and dependences to other planning tasks as well as the necessity of reliable data. Environmental influences are investigated to get a clear picture of how they imply on the planning process. Next, complexity caused by constraints, input data, generation of specific outputs, and customer behaviour are examined. Finally, this chapter summarises the requirements for NMP which serve as basis for deriving solution principles and design rules for a planning methodology and integrated tool modules.

4.1.2 Data analysis

4.1.2.1 Active observation

In order to analyse the actual planning process and the sources of complexity, an investigation within the BOSCH business division *Diesel Systems* was conducted. Real world access for the research on NMP was realised by setting up a project with the department responsible for the coordination of production networks for all diesel products, i.e. ca. 15,000 end-item part numbers. To reduce complexity, the investigation focused on the production networks and related processes for two products. The primary focus throughout the three year project was on diving deep into the real-world environment of *Network Master Planning* (see 2.2).

One way of getting into the subject of NMP was that the author spent a lot of time with the practitioners responsible for the planning. A project team was constituted consisting of the author and a limited number of practitioners. Interaction focused mainly on four planners from a *Diesel Systems*' central department, as well as three from an Eastern-European and two from a German lead-plant. Actively facilitating the planning task helped the author to gain insight into the specific context and the requirements for planning and to adopt their perspective. One important element of facilitating the planners was assisting them in their daily work on-site by performing supportive actions like data preparation or report generation. Besides this, the author supported activities for input-data format specification and database re-design.

In the course of the research project, the author conducted semi-structured interviews and discussions with 18 practitioners to make sure that the relevant characteristics were understood correctly. Further, the meetings were used to present the author's ideas for solution principles and methodology steps and to debate alternatives. To broaden the base for understanding NMP at BOSCH, the interviews and workshops were not limited only to Diesel Systems but were also conducted in two other business divisions: Chassis Systems and Automotive Electronics. As mentioned before, to perceive more than one view on the planning problem, practitioners from different hierarchical levels were involved, namely NCU, lead-plant coordinators, and further logistics practitioners.

4.1.2.2 Action research by tool development and implementation

Relying on the emerging understanding of NMP the author proposed specifications for tool module prototypes which were then made subject of discussion. After approval by the practitioners, selected prototypes were developed by the author. The application of these tool modules in practice was used to check if the general understanding of NMP and the ideas and concepts developed were useful or had to be modified.

Tool testing was initially done based on exemplary data to assure that the tool behaved as expected. After successfully passing this first row of tests, the tool prototype was tested in a live environment by means of using it parallel to manual planning during three planning cycles. Results were compared and, depending on the outcome, new specifications were formulated or existing ones were modified to improve the mode of action and the results of the prototype.

Between the test using phases, there was time to reflect on the observations – on average three months. In case of results deviated from the descriptions and expectations of the practitioners, the situation was analysed and the theory adapted to the real situation, if necessary. The mode of action corresponds with the action research cycle depicted in Figure 2.3. Following this approach, the researcher developed an understanding of the planning-process plus the actions and decision criteria as they are 'lived' in reality and not only described. Using the combination of action research and literature review for data collection allowed the author to acquire knowledge of what NMP is and where complexity originates. This kind of procedure "to ensure that what we conclude from a research study can be shared with confidence" is defined as validity (Garver and Mentzer 1999).

In summary, it is important to note that the research outcomes, e.g. new system definitions, did not originate solely in the author's theoretical knowledge of the subject but were collectively developed in the project team. The split of actions is depicted in Table 4.1.

Researcher's actions	Practitioners' actions
• Observation of phenomena and analysis of the observed. • Preparing and conducting interviews and workshops. • Feeding back information to check if concepts etc. were understood correctly. • Proposing picture of AS-IS situation. • Proposing elements of TO-BE situation. • Proposing specifications of tool modules. • Developing tool modules. • Using & testing tool modules in practice. • Providing specification to IT department.	• Reviewing researcher's proposals. • Checking proposals against practice. • Providing expert knowledge. • Defining elements of TO-BE situation. • Using and testing tool modules in practice. • Feeding back information to researcher.

Table 4.1: Overview of split of actions in project team

4.2 Network Master Planning in practice

4.2.1 Production networks – theory and practice

As presented in section 3.1.4, companies are turning away from locally concentrated, linear chains to more complex, spread networks. In this context, the objective of *Business Planning* is to set up an efficient intra-organisational production network. A common approach is to create a 'clean' system-design with dedicated resources (Vos 1991); either by localisation or by centralisation of production.

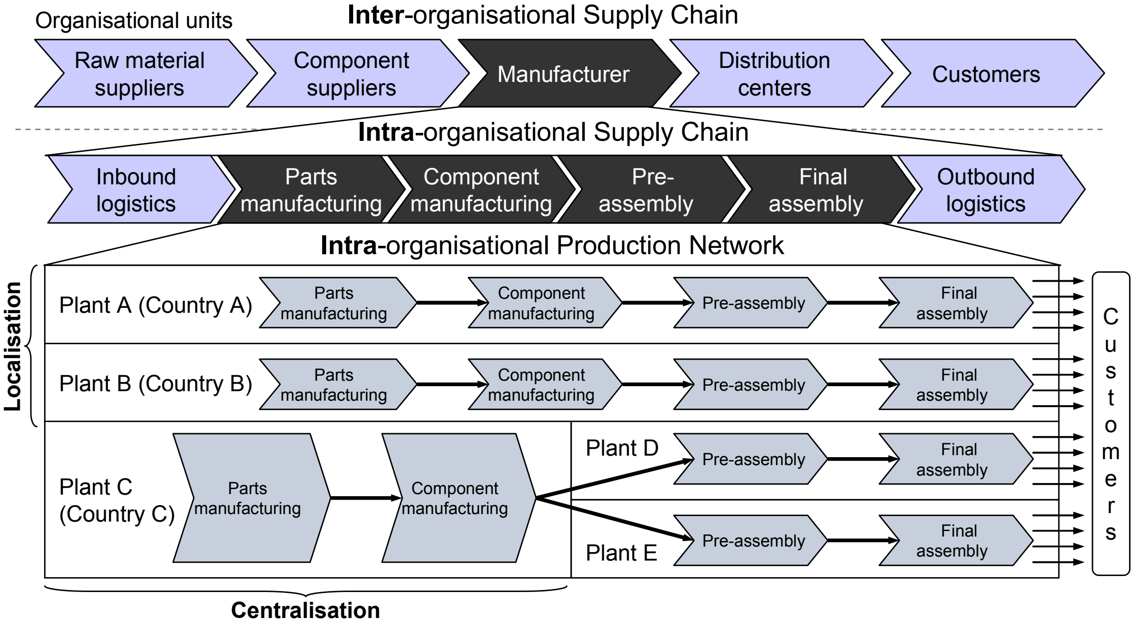


Figure 4.1: Clean intra-organisational network design

Localisation criteria are e.g. specific products or customer regions. Centralisation represents the concentration of process steps at plants with low labour costs or with cost-intensive production resources that need high utilisation to be profitable (Luecke and Luczak 2003). Figure 4.1 illustrates the correlation of inter- and intra-organisational supply chains and compares them to an exemplary, clean production network design.

The problem with dedicated resources is the correct choice of size. Due to a volatile environment – which is discussed in depth later in this work – it is impossible to design a system that exactly meets future demand. Consequently, capacity mismatches occur at individual operations in the production network. Bottle-necks result out of increased customer demands. Reduced customer demand leads to overcapacity. Hence, re-planning of the system is necessary (Luecke and Luczak 2003). Bottlenecks can be removed by installing capacity at the operation in question, e.g. by setting up an additional production line. Capacity supply can be reduced by reducing the shift model or, in the extreme case, by dismissing staff. Both options are usually cost-intensive and neither is fast to implement nor contributing to a company's stability. The alternatives are, on the one hand, to send work away to parallel operations at other sites in the network – in case of bottle-necks – and, on the other hand, to pull work in to increase the utilisation of underused resources. As illustrated in Figure 4.2, the clean network design of *Business Planning* is given up by allowing such inter-plant transfers. Consequently, there is a need for adjusting the production network over time.

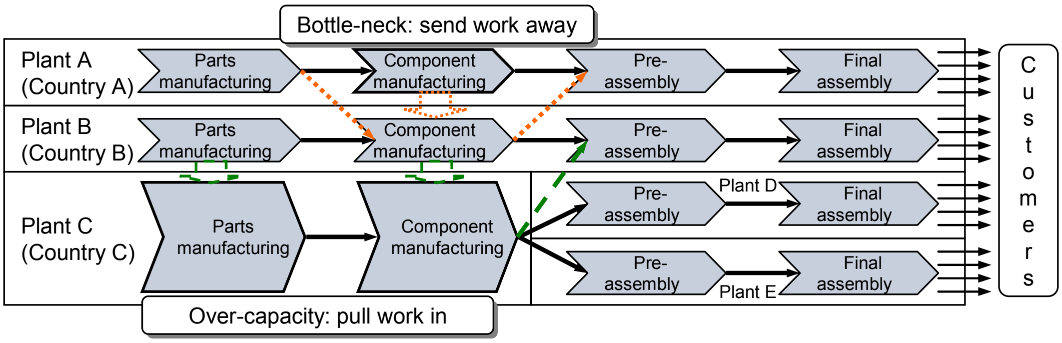


Figure 4.2: Intra-organisational production network with inter-plant transfers

The fundamentals for NMP in intra-organisational production networks can, therefore, be summarised as:

- Work is shared between the network resources.
- A vertically-integrated company is caring for utilisation throughout the network.
- Some work is interchangeable in the network through resource redundancy.

4.2.2 NMP at BOSCH

4.2.2.1 Production networks at BOSCH

According to the explanation in chapter 3, the term *production network* at BOSCH is used for a product-specific network of production sites with parallel and partly complementary production resources. Thus, every business division contains multiple production networks, where each produces a different product portfolio. Sites can belong to more than one production network (see Figure 4.3).

In most cases, the individual sites in a production network can perform all relevant process steps for production of an end-item. In case of limited technical capabilities at one site, the 'missing' production steps have to be performed at another site. Thus, the supplying sites have to provide additional capacity on the component-production level in a way that inter-plant transfer is possible. The intra-organisational supply relationships in question are subject to strategic decisions and can be regarded as fixed in the context of this work.

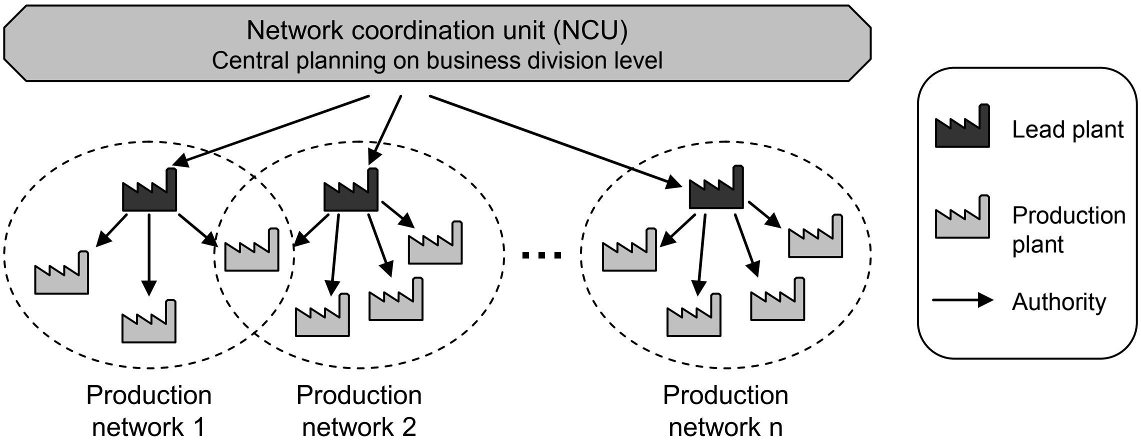


Figure 4.3: Production networks within BOSCH

As shown in Figure 4.3, two levels of production-network organisation and planning can be differentiated: site planning on the production plant level and network coordination on the super-ordinate network level. Planning on the network level is performed by a so-called *network coordination unit* (NCU). This term represents the co-operation of a central planning-department and the so called 'lead-plants.' While the central department is in charge of business-division wide network coordination, the lead-plants are responsible for coordinating the individual production networks. Whereas the central planning entity gives guidelines to the lead-plants, these provide data and know-how. On single plant level, production planning and control are performed decentralised based on constraints and parameters from NCU. Thus, the total planning process can be counted as part of *hierarchical production planning* (see 3.2.2). Capacity planning by assigning customer demand to resources in a production network – which is of interest for this research work – can, consequently, be positioned in the field of network planning, as introduced in section 3.2.1.

4.2.2.2 Task and objective of NMP

NMP, as one variety of tactical planning, seeks to allocate production quantities of specified end-items to specified production sites in a network, therefore enabling long-term business planning and driving the *Master Production Schedule* for each site. According to Buffa and Taubert (1972), the biggest benefit of tactical planning is that it provides several strategies for responding to demand fluctuations that exceed the flexibility of the production system. Examples for reactions are shifting work load in form of orders between individual sites in the network or adjusting the workforce through hiring and firing in a long-term view. Objectives of NMP, therefore, are to identify and remove bottle-necks and reduce overall cost while maintaining flexibility in the network. Regarding the fundamentals of NMP, which were presented in the previous section, the planner can allocate quantities to another site in the network, if e.g. a low-cost location (LCL) is the bottle-neck. In MPS, for instance, this is not possible (see 3.2.3.1). The negative side is that increases in customer demand have direct production-cost implications, if work has to be moved away from a low-cost location.

NMP has a mid- to long-term horizon of up to ten years corresponding to budget-plan preview timeframes in the given company environment and is currently performed on a regular basis twice a year. Further, it is initiated irregularly by customer requests. Because fast responses to customer requests are necessary to stay competitive, the importance of streamlined *Network Master Planning* becomes apparent.

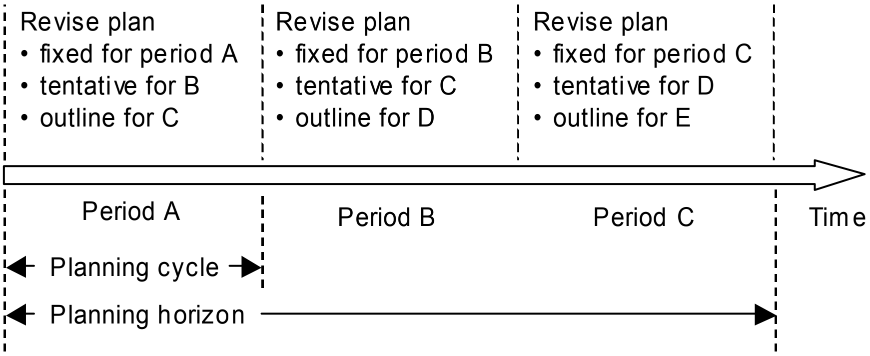


Figure 4.4: Revision of plans during cycles (following Waters 2003)

The overall process of NMP over time is a rolling horizon planning, as illustrated in Figure 4.4. Whereas figures for near future planning periods are fixed and, thus, have to be absolutely reliable (Adenso-Diaz and Laguna 1996), those of more distant periods are tentative, mainly because long-term future data is likely to be inaccurate.

4.2.2.3 Position of NMP in planning hierarchy

Capacity planning in a production network is done at different levels, reaching from long-term, strategic resource (dis-)investment plans to short-term, operational shifting of production-quantities between individual machines to satisfy customer demand (Luecke and Luczak 2003). Figure 4.5 positions NMP in the hierarchical framework of production planning as suggested by the *American Production and Inventory Control*

Society as well as in the total production planning hierarchy observed at BOSCH (see 3.2).

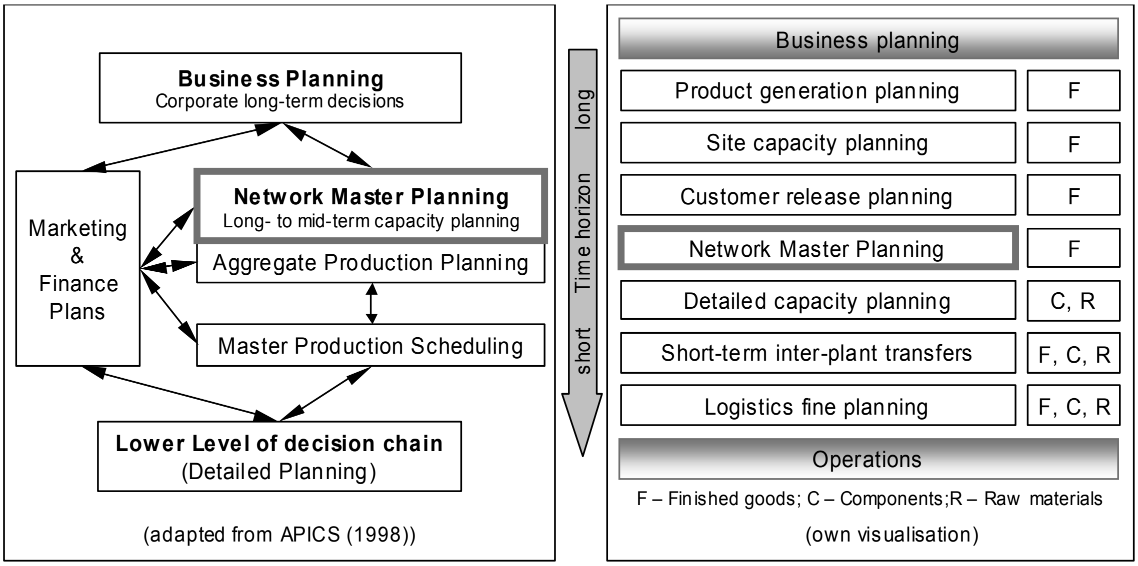


Figure 4.5: Position of NMP in the production planning framework

According to the hierarchical framework for production planning, depicted above, different planning levels are involved in the production planning process at BOSCH.

Business planning on the level of executive management defines the strategic goals – where it wants to position the company with its products. Furthermore, conditions for the production network, e.g. reserve capacity in the network, are determined. These decisions have long-term character and define the strategic direction of development. *Product generation planning* is performed with a perspective of 5-10 years. The objective is to find an optimal product introduction and a strategy for generation change. The next step of planning is *Site capacity planning*, which can be counted as being part of supply planning (see 3.1.6.2). Based on the future production program, the necessary production resources are planned and positioned in the production network. The aforementioned four planning steps define the production strategy (see 3.1.6.1). *Customer release planning* is concerned with the assignment of production lines to defined customers. It takes the technical capabilities of the resources into account and compares them to the requirements of customer-specific product variants, e.g. geometrical characteristics. Since each customer has to give permission to the production of his products on defined resources, release-planning additionally comprises the initiation and process preparation for new customer releases, as illustrated in Figure 4.6.

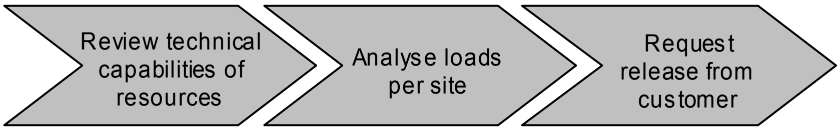


Figure 4.6: Procedure for new customer release

Network Master Planning takes the results of the higher planning levels as input and performs the task of allocating – but not sequencing – specified parts to specified resources. Looking at the hierarchical production planning framework (Figure 4.5), a remarkable fact is that NMP performs on detailed level of actual and prognosticated customer demand, whereas the levels below (APP) and above (BP) deal with average demand. This is due to the fact that NMP is also used to respond to customer requests which refer to production at defined times in the future. Finally, the mid- and long-term plans are concretised and realised by *Detailed capacity planning* and *Logistics fine planning* at the single sites.

It is important to note that the planning steps are principally sequenced as described before and illustrated in Figure 4.5. However, there are feedback loops necessary to perform the planning efficiently (see 3.1.6.3). Actually, between all steps some sort of feedback-loops are installed to consider interdependencies and to avoid invalid plans. For example, if no satisfying solution is found with the existing network set-up, NMP implies on site capacity planning, such that the network design has to be reconfigured, using preliminary results of demand allocation as inputs.

4.2.2.4 The NMP as-is procedure

Additionally to fine planning, other subtasks are conducted in the context of NMP, as shown in Figure 4.7: Data collection, feasibility checks, strategic decisions, and data consolidation.

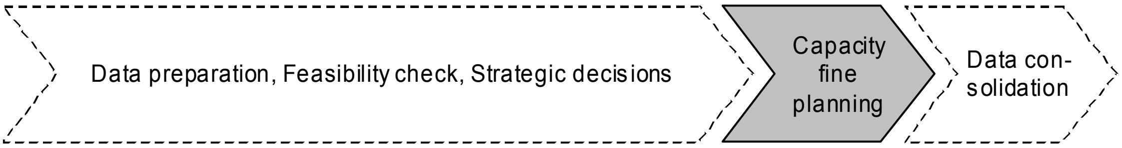


Figure 4.7: NMP sub-tasks

During the data collection and preparation phase, production planners of the individual plants submit data to the NCU, mainly based on *Excel* files. One basic example is production line capacities, which are measured in end-item quantities. Other information, e.g. customer releases for new part numbers, has to be actively collected by the NCU.

NCU pre-processes further the total-sales planning figures (VPZ) received from *Market and Sales Planning* (MSP). The VPZ represents total customer demand – actual and predicted. These sets of data are broken down manually according to individual products or product groups. Each product represents one production network. The further planning process is performed for individual production networks. An example of necessary data preparation is manually inserting columns to be able to accommodate additional information. The result of NMP are technical planning figures (TPZ), representing allocated production quantities. The TPZ can be broken down to site-specific technical planning figures. Figure 4.8 depicts the correlation of VPZ, TPZ, and technical production capacity (TEC).

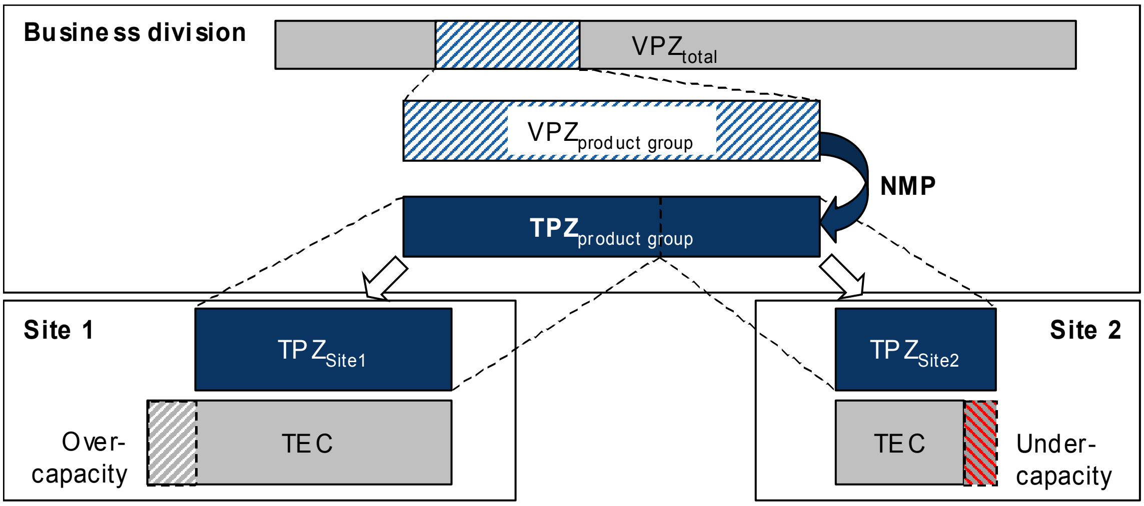


Figure 4.8: Correlation of VPZ, TPZ and TEC

To get an overview of the current situation, feasibility checks for the network in total and defined geographical regions are performed based on total customer demand. Depending on the outcome of these checks, strategic decisions may result such as starting up new resources or closing down existing ones. The process step of fine planning retrieves data and additional information from the data collection and preparation activities. Constraints for planning stem from system parameters, external reasons, and strategic decisions. After capacity fine planning, the plans of the individual production networks are, on the one hand, consolidated to a business division total TPZ and, on the other hand, handed over to the corresponding lead-plants for further detailed capacity-planning.

An important observation of NMP in practice is the inability to plan on the level of aggregated product groups. If the NCU allocates only groups of products to resources, the decision about allocating specific end-items has to be made on a lower level in the hierarchy. However, neither can a business-division-wide optimum be guaranteed in this case, nor is it possible to aggregate and disaggregate product groups in the context of the specific product characteristics without loosing relevant information for planning. Thus, infeasible plans are likely to occur. This aspect is discussed in later sections in this chapter and is summarised in 4.5.4.

4.3 Complexity caused by input data and environment

In addition to sources of complexity faced in any kind of planning, such as that certain assumptions have to be made, in the NMP context further complications can be observed. Some of these originate directly in the NMP environment; others are unique to networks or the industry context. After giving a definition of terms, these different sources of complexity are presented in the following sections.

4.3.1 Defining the terms ‘complexity’ and ‘constraints’

4.3.1.1 Complexity

“You don’t have to bring complexity to the world of business: it’s already there” (Lewin 1999). Following Lewin’s statement, complexity in real-world systems and their behaviour lies in the middle between chaos and perfect order. Complex systems tend to behave non-linearly, even though they may consist of a simple set of sub-processes. This effect is called ‘surface complexity’ (Lewin 1999).

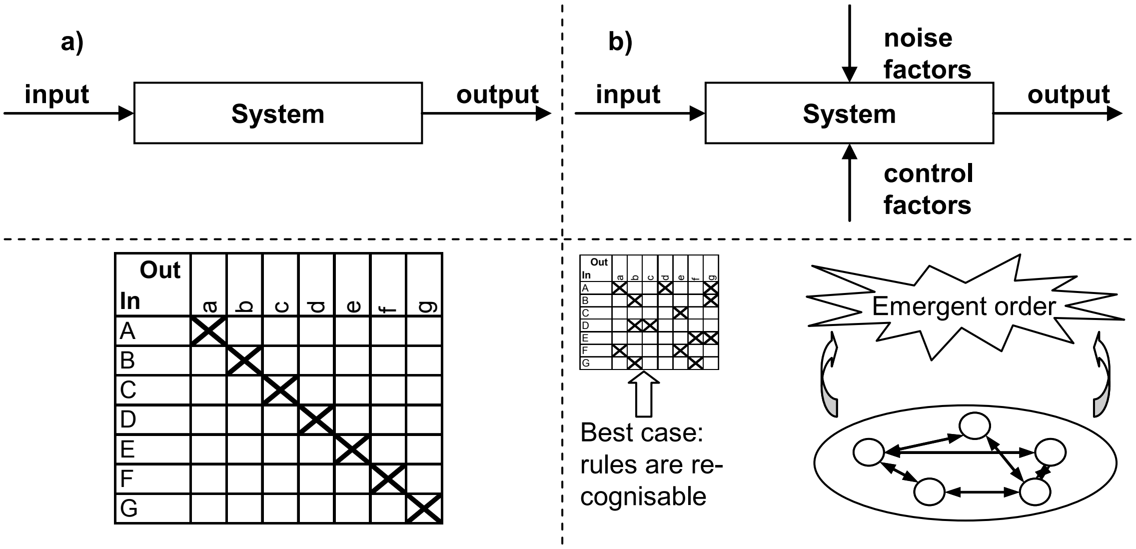


Figure 4.9: Simplicity and complexity in a system (adapted from Lewin 1999)

To get closer to the meaning of complexity in the context of this research, it is compared to its opposite: simplicity. Simplicity of a system and its environment is characterised by a defined one-to-one relationship between inputs and outputs (Figure 4.9a). For each input “A” one output “a” can be discerned. In case of complexity (Figure 4.9b), additional noise factors (see 3.3.2.1), arising e.g. from interdependencies between inputs influence the system. These noise factors may be all individually known, but it is their multiplicity that leads to a system that is difficult to predict. Furthermore, not in all cases are the correlation of inputs and outputs clear, but an order somehow emerges (Lewin 1999). Thus, permanent control is necessary to turn unintended consequences into predictable and constructive reactions of the system.

4.3.1.2 Constraints

Derived from mathematics, a constraint is a restriction to viable solutions to a problem. Following Goldratt (1988), any business system has at least one constraint; otherwise its performance would be infinite. Constraints may be physical (e.g. materials, machines, people, demand level) or managerial. It is important to identify these constraints to be able to cope with them accordingly or even overcome them.

Referring to this research work, all factors that limit the planner in assigning any end-item to any resource have to be seen as constraints. A constraint is anything that makes NMP complex or limits the solution space. Examples are technical capacity limits, managerial decisions not to produce a specific product variety in a specific site, or cost factors that prevent from allocating products to a specific region. In this context also input data has to be seen as constraints.

4.3.2 Complexity caused by input data and information flow

4.3.2.1 Sources for input data

Besides customer demand and resource capacities as basic input data, other information is necessary to carry out NMP. These are technical capabilities and customer releases, each referring to specific end-items as well as specific production lines. This aspect is detailed in section 4.4.2. Furthermore, strategic objectives serve as constraints to NMP. Table 4.2 summarises the different types of input data, names responsible organisational units, and shows the kind of system and data format in which the information is available.

Type of data	Source for data	System
Customer demand	MSP database	Proprietary database
Resource capacities	Production planning and control (Plants)	Excel
Resource capabilities	Production planning and control (Plants)	Excel
Customer releases	Production control/ NCU	Excel
Costs	Finance departments (Plants)	Proprietary databases
Strategic objectives	various	various

Table 4.2: Input data necessary for NMP

4.3.2.2 Customer demand and flow of information

Projected customer demand is taken from a proprietary database, containing market and sales planning figures, and transferred to the NCU in form of an *Excel* sheet. Remarkably, these figures do not originate in marketing department but are generated by a sequence of activities in several organisational units as shown in Figure 4.10.

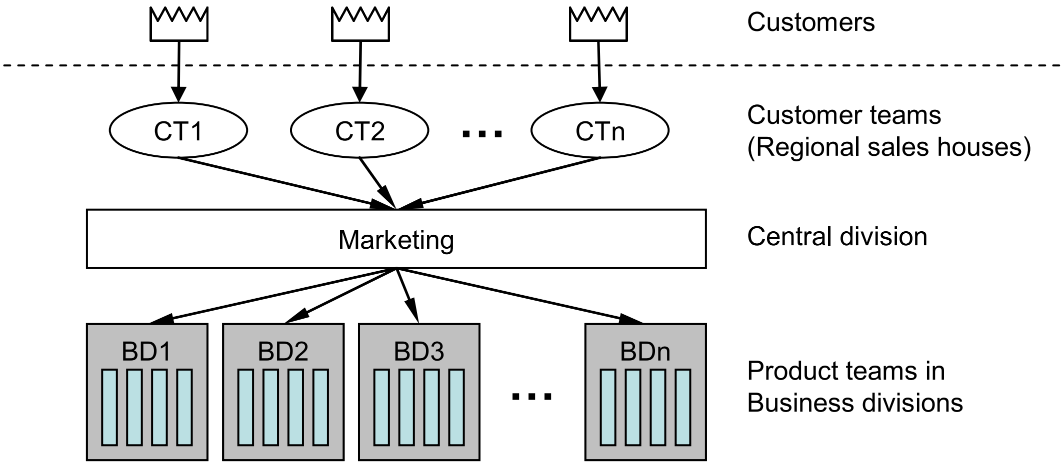


Figure 4.10: Information flow from customer to production planning

In order to realise a ‘one face to the customer’ policy and, thus, minimise the number of contact persons for a customer, so-called customer teams were instigated in sales departments. Customer teams consolidate all customer-specific information, such as demand previews. This enables them to develop a customer classification framework. An example for such a classification is presented in 4.3.4.3. Based on the experiences with the customer and the resulting classification, the demand previews received from customers can be realistically estimated and possibly modified. The modified demand figures are subsequently handed over to the marketing department, which is the next planning entity.

In the marketing department, further adjustments are applied to the modified set of demand data. Examples for adjustments are future product-promotion actions that may lead to an increase in orders, or the start of production of a product successor, which usually leads to reduced sales of the 'old' product over a certain time horizon. The effect of these types of developments on the actual customer orders can only be estimated based on experiences and by means of forecast techniques. The plausibility of planned sales quantities is checked by means of market observations and general development of sales quantities. Finally, the demand figures are clustered into business division-specific sets of data and handed over to the corresponding departments of the company.

4.3.3 Degree of detail in input data

4.3.3.1 Planning time frames

The planning horizon is segmented in several planning periods according to the theory of a rolling planning-horizon (see 3.1.6.3). The length of the time slots varies along the planning horizon. Time slots for planning in the analysed case are six months for the years 1 to 4 and 12 months for the remaining years. Planning is conducted regularly twice a year – this frequency is expected to rise in the future (see Appendix C).

4.3.3.2 Planning objects and resources

Planning on NMP level is conducted for end-items. Figure 4.11 exemplarily depicts a tree-structure of one product. End-item part numbers are customer specific. The corresponding products differ, e.g. in geometrical characteristics, like the position of connections or flanges.

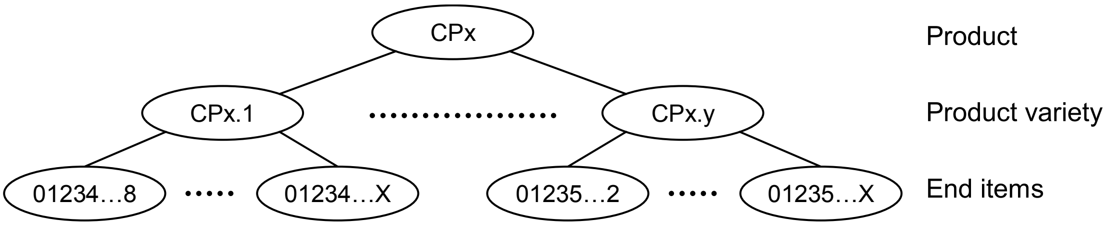


Figure 4.11: Product structure (exemplary)

The individual varieties of a product usually have different technical and functional characteristics and originate mainly in technological progress. Due to a four-to-ten-year planning horizon even emerging part numbers – which are necessarily tentative – have to be planned.

The planning environment in the analysed case comprises a product portfolio with more than 15,000 part numbers. While this alone creates complexity in planning, additionally a relatively high database change rate between two planning cycles in *Network Master Planning* can be observed due to starts and ends of production for items, on the one hand, and part numbers changing from preliminary to regular ones for emerging products, on the other. It was observed that approximately 15 to 30 per cent new part numbers occur from one planning cycle to the next, so that the necessary effort for data preparation and completion at the start of a planning cycle must not be under-estimated.

As it is presented later in this thesis, NMP is allocating end-items on the level of production lines. Throughout BOSCH, production networks consisting of five or more sites with altogether close to 30 production lines can be found, as illustrated in Table 4.3.

Business division	Product name	# of sites	# of lines
Diesel systems	<Product DS1>	9	27
	<Product DS2>	4	13
	<Product DS3>	6	22
	<Product DS4>	5	17
Gasoline systems	<Product GS1>	5	19
	<Product GS2>	4	11
	<Product GS3>	5	21

Table 4.3: Examples for production networks at BOSCH (BOSCH 2005c-d)

4.3.4 Industry related factors

4.3.4.1 Product variants and dedicated production lines

In the automotive supplier industry, it is not unusual to have more than 100 customer specific variants of one product instead of one-fits-all-solutions or a few standard modules. In effect, planning of the complete set of end-item part numbers for one product is complex. Differences in product characteristics like geometrical or technical attributes and its implications on producibility at individual production lines hinder aggregation of products to families or groups during planning. A production network consisting of flexible resources that are capable to handle each product variant cannot be maintained for a longer period of time, because it is impossible to design production resources that meet the requirements of all future product varieties. Furthermore, installing 100-percent flexible resources throughout the network would be too expensive in the analysed context. On the other hand, for competitive reasons, it is not regarded as feasible to reduce the number of product variants and offer customers only standard products based on few universal modules.

4.3.4.2 Tier-1 supplier

As part of the supply chain, every supplier is subject to the phenomenon of the bullwhip effect (see 3.3). Due to insufficient exchange of information, there is a constant 'chasing' of demand. In effect, this leads to delayed and amplified fluctuations in planned-production quantities (see Figure 4.12). Unsynchronised planning processes of customer and supplier worsen the problem. In the worst case, a customer request is received exactly at a point when the supplier has finished its planning. This results not only in planning uncertainty but also in frequent re-planning activities.

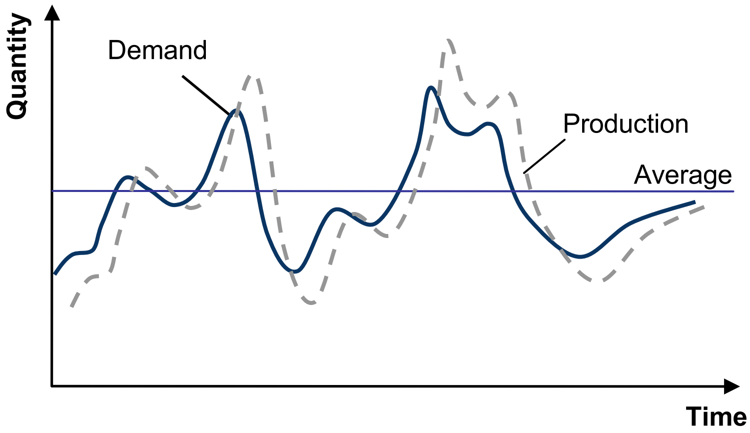


Figure 4.12: Chasing of demand

4.3.4.3 Customer behaviour

A further element of the complexity of aligning plans to volatile demand is demonstrated in customer behaviour classifications like the one exemplarily portrayed in Figure 4.13. The classification has been derived from real-world customer-demand data for one product, covering 73 representative end-item part numbers and 4,800 deliveries to 20 external customers, mostly vehicle manufacturers, and three internal customers, i.e. other BOSCH plants (BOSCH 2003). A more detailed view on source data and the method of classification can be found in Appendix A.

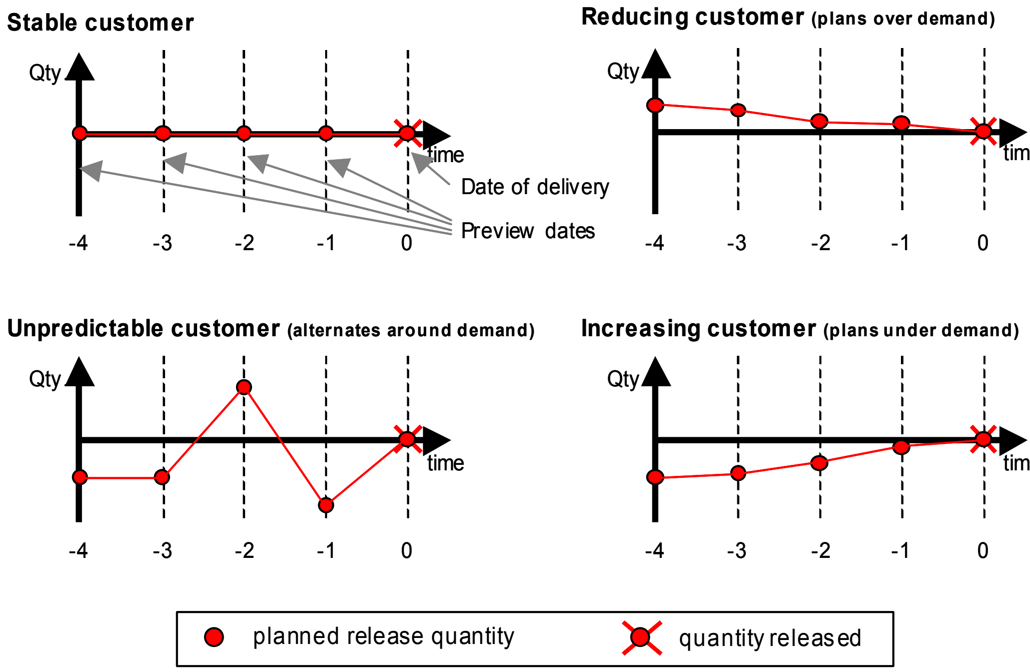


Figure 4.13: Customer classification (schematically)

As the supplier needs a mid- to long-term planning horizon for decisions about production volumes and dis-/investments respectively, the planning has to be based on preliminary customer order previews (APICS 1997). In general, a preview of prospective deliveries is provided some time in advance (Point *-4*) and regularly updated (*-3*, *-2*, *-1*). Best case assumed ('stable' customer), these figures match actual quantity released (Point *0* in Figure 4.13). Unfortunately, the other types of customer order behaviour occur more often. In case of a 'reducing customer,' figures initially received have to be brought down to a certain level so that no excess capacity is reserved. Looking at the opposite pattern, capacity shortages would result if one relied on demand previews of an 'increasing customer,' who goes up in his previews closer to the date of delivery. To be able to assess customer figures and base one's own planning on it by means of estimation, it is necessary to know how the customer plans. Therefore, a customer classification as depicted in Figure 4.13 has shown to be a useful planning aid. In the case of an 'unpredictable customer,' it is up to the planner to either prepare for the worst case (highest demand) or take the risk of planning at a lower level.

Another source of complexity arises from irregular, event-driven requests from customers, regarding additional end-item demands. These so-called additional demand requests (ADRs) from customers may change the planning basis significantly even within the 'frozen zone' of a planning horizon. In order to assign additional demand, additional planning cycles are necessary to check the capacity situation for each resource within the production network. In general, the number of ADRs is seen to rise (BOSCH 2003). For example, in the analysed case (see chapter 6), up to 40 ADRs from customers had to be handled during one year, speaking of nearly one possible trigger for re-planning per week on average. The range of additional demands can go up to 100 per cent referring to the original demand of one customer. In effect, not only the end-item in question has to be planned once more but the total production network. The reason is that the demand increase for one end-item can make it necessary to shift a number of end-items around, i.e. re-allocate them in the network.

4.3.4.4 Load situation in network

Specific to NMP is the high load on the production network which leads to feasibility statements on an aggregate level that are not reliable. A plan that looks feasible on an aggregate level may turn out as infeasible when broken down to end-item level (see also Vicens et al. (2001) for critical reflections on ‘perfect aggregation’). Thus, planning on the end-item level is required. Given a different situation such as the one found in vehicle manufacturers, where there are currently more than 20 per cent overcapacity world wide (KPMG 2005, Dressler 2004), planning of the production network is more likely to succeed via APP (see 3.2.3), because of the limited number of planning objects and a high possibility of aggregation.

4.4 Complexity caused by constraints

4.4.1 Monetary constraints

4.4.1.1 Production related costs

Originating from production, the following types of cost constrain planning of the production network:

- Machine costs
- Personnel costs, direct and indirect
- Material costs

Machine costs on the single-machine level usually are measured in cost per machine hour and depend on various factors like degree of automation, age of machines, or write-off costs. For a complete production system of one plant, the cost factors of all relevant resources have to be added. The type and number of involved machines can vary from one product variant to another. Taking the necessary machining times of individual products into account, machining costs can also be calculated per single end-item.

Personnel costs for production of an end-item depend on the degree of automation and the number of involved persons in the production process. Direct personnel costs refer to product-related costs that can be distributed cause-related, like production employees. Additionally there is an apportionment of indirect costs, e.g. for employees in a product-independent planning-department. Due to differences in hourly wages of employees, the resulting personnel costs per end-item differ considerably between sites.

Material costs refer to raw material and externally purchased parts and components costs. In the analysed production networks, material costs are comparable between sites due to frame contracts negotiated by a central purchasing department with international suppliers providing material to multiple sites in the network.

4.4.1.2 Further monetary constraints

Additional costs are used as constraints if regarded important by strategic decision makers in the individual situation. Selected examples are:

- Transport costs
- Customer release costs
- Production transfer costs

Transport costs refer to the transportation of finished end-items to customers and not to company-internal transports of components. Transport of goods is operated by external service providers with whom frame contracts exist. Costs for transport are calculated based on distance and weight or volume of goods. To save transport costs, customers are usually supplied from a site within their geographical region.

The process of initiating customer releases, which is described in section 4.4.2.2, does also produce costs. Once initiated, a release expires if not used during a certain period and is to be requested again. Therefore, the objective is to keep all existent releases alive, especially parallel releases.

Production transfer costs result from the movement of production resources from one site to another in case of strategic network-redesign. In correlation with production transfer, not only costs for de-installation, shipping, and installation at a new site are relevant, but also costs for starting production and the above-described release costs for the new production location.

4.4.2 Non-monetary constraints

4.4.2.1 Resource capability and capacity

Resource capabilities refer to the product varieties that a resource can produce from a technological point of view. Technical capacity (TEC) indicates the maximum quantity of end-items that a resource can produce in a certain period – given stable conditions regarding worker shift model, utilisation rate and so on. Calculation is based on an averaged cycle time for all end-items. Figure 4.14 shows exemplary visualisations.

Plant A	PV 1	PV 2	PV 3
Line 1	x	x	
Line 2	x	x	
Line 3	x	x	
Line 4	x	x	x
Line 5			x

PV: Product variety

Plant A	Max. TEC
Line 1	10,000
Line 2	10,000
Line 3	10,000
Line 4	15,000
Line 5	7,500

TEC: Technical capacity

Figure 4.14: Resource capacities and capabilities

4.4.2.2 Customer releases

Before a customer can be supplied from a specific site, a release for the allocation in question is necessary. Releases are defined site- and line-specific. The release process has to be initiated by the supplier (see 4.2.2.3). The individual steps depend on the customer. The range goes from giving permission based on producibility proof from the supplier to a detailed auditing process. A visualisation of customer releases is illustrated in Figure 4.15.

			2005/1			**2005/2**			**2006/**		**2008/1**			**2008/2**		
Part number	**Customer**	**Product**	**Site A**	**Site B**	**Site C**	**Site A**	**Site B**	**Site C**	**Site A**	**Site C**	**Site A**	**Site B**	**Site C**	**Site A**	**Site B**	**Site C**
1234567890	C1	CR-CPx.y	**x**			**x**			**x**		**x**			**x**		
1234567891	C2	CR-CPx.y	**x**	**x**		**x**	**x**		**x**		**x**			**x**		
1234567892	C3	CR-CPx.y			**x**			**x**		**x**			**x**			**x**
1234567893	C7	CR-CPx.y										**x**			**x**	
1234567894	C4	CR-CPx.y		**x**			**x**	**x**		**x**		**x**	**x**		**x**	**x**
1234567895	C8	CR-CPx.y		**x**			**x**	**x**		**x**		**x**	**x**		**x**	**x**
1234567896	C4	CR-CPx.y		**x**			**x**					**x**			**x**	
1234567897	C4	CR-CPx.y			**x**			**x**		**x**			**x**			**x**
1234567898	C2	CR-CPx.y	**x**		**x**	**x**		**x**	**x**	**x**	**x**		**x**	**x**		**x**
1234567899	C9	CR-CPx.y						**x**		**x**			**x**			**x**
1234567900	C1	CR-CPx.y			**x**			**x**		**x**			**x**			**x**
1234567901	C2	CR-CPx.y	**x**		**x**	**x**		**x**	**x**	**x**	**x**			**x**		

Figure 4.15: Customer releases on end-item level

The specificity of releases can go so far that in case of any changes the supplier has to initiate a new release process. Examples for such changes are modifying a line at one site technically, setting up an exact duplicate at another site, or even moving one line to another site. In case the supplier's planning shows that one release for an individual end-item is insufficient in terms of capacity, parallel releases for a second or third site are necessary.

As stated in section 4.4.1.2, customer releases expire if they are not used for six month. Subsequently, the release process has to be initiated once more. This means that in case of a parallel two-site-release for an individual end-item, both have to be used to keep the releases alive. Therefore, even if, regarding capacity, production could be concentrated on one site, a certain minimum quantity, e.g. 1,000 items, has to be allocated to the second site in each planning period. As mentioned in section 4.4.1.2, the release process not only takes time (up to six months) but also consumes money (up to 100,000 Euro).

4.4.2.3 Capacity reserve and release flexibility

Capacity reserve refers to spare capacity in the network, adding up plant specific unused capacities ($TEC_{Reserve}$). Release flexibility is defined per production site. It refers to product varieties (PVs) with parallel customer releases, i.e. those that are produced at more than one site. Figure 4.16 depicts an example.

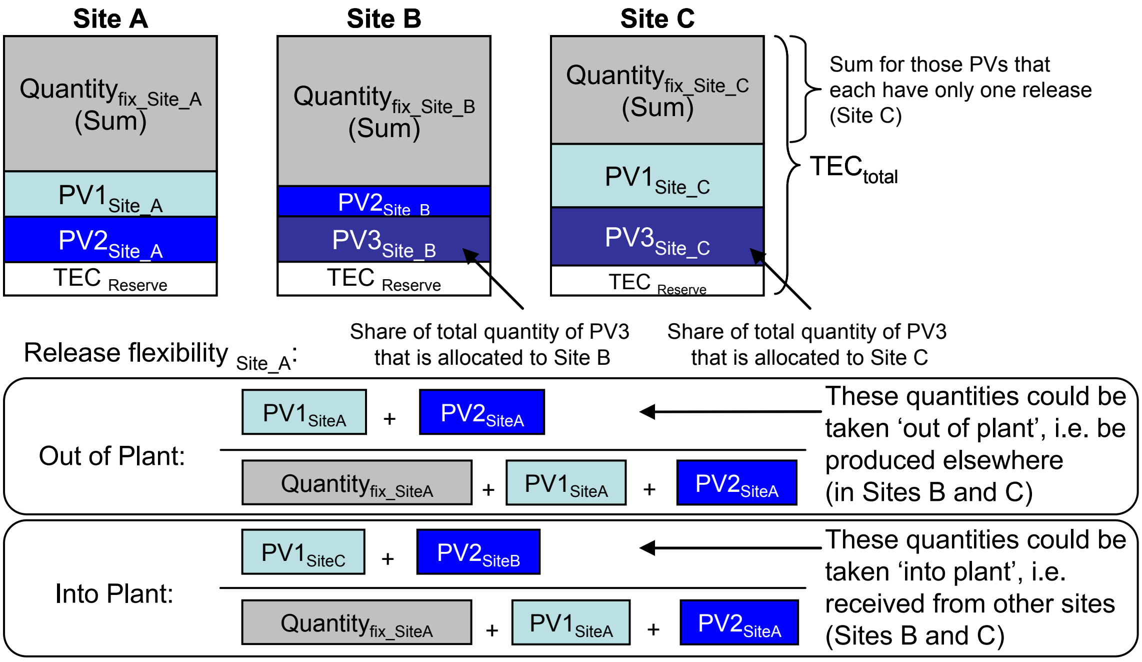


Figure 4.16: Release flexibility and capacity reserve

PV1, PV2, and PV3 have parallel releases. For example does PV1 have customer releases for Site A and C (may be part number …898 from Figure 4.15). Release flexibility is differentiated in 'out of plant' and 'into plant', describing a Site's ability to 'give' and 'receive' production volumes. This calculation considers only customer releases, not technical capacity.

'Out of plant' defines the ratio of end-item quantities with a parallel release that could alternatively be produced in another plant, i.e. be taken out of plant. 'Into plant' describes the quantities that could be produced in the same plant, i.e. be additionally allocated to that plant. Consequently, the release flexibility 'out of plant' for Site A is calculated by dividing the sum of the shares for PV1 and PV2 that are allocated to Site A by the total production volume of Site A. The total production volume does also contain the quantities of all those PVs with only one customer release, i.e. those with a fix allocation, e.g. part number…890 in Figure 4.15.

The indexes release flexibility and capacity reserve are used by strategic decision makers to determine the future configuration of the production network. Depending on the actual situation, additional resources may be installed or negotiations with customers about parallel releases may be initiated.

4.4.2.4 Further non-monetary constraints

Further non-monetary factors additionally constrain NMP. Examples are:

- Load level and work force level per plant.
- Customer proximity.
- Local content quotas.

The term 'load level' refers to the ratio of assigned production quantity to available capacity per plant. The desired load level in total per plant is – as release flexibility and capacity reserve – subject to strategic planning. Furthermore, it is negotiated during each planning cycle between the NCU and the plants (see planning steps in 4.2.2.4). For reasons of intra-network competition on the one hand and stable conditions regarding work force level on the other, each plant seeks to achieve a stable and high load-level.

Customer proximity expresses the need to be near to the customer. The motive is being able to understand his needs and align production accordingly. Furthermore, products manufactured within the customers' market promise better acceptance and 'image.' The constraint of local content quotas originates from production in regulated markets and in this context refers to defined production quantities that have to be allocated in the country to be allowed to access the market in question (see also 3.1.5.2).

4.4.2.5 Initially not quantified constraints

Even more difficult to handle than the aforementioned types of constraints are those that are initially not quantified. If something cannot be expressed in form of figures on a scale, an objective function cannot be developed and it is difficult to evaluate the degree of achievement afterwards. A selection of possible limiting factors that may be formulated by decision makers is given in Table 4.4. Which decisions or conditions apply to the planning in the specific situation depends on various factors like economic situation, product characteristics or strategic objectives.

Constraint	Description
Strategic objective: Market access	Objective: "being" in a future market for reasons of competitive advantage
Work load level at sites	Objective: as constant as possible
No mixing of sources for products and related components	Objective: Do not source product from plant "A" and component from plant "B".

Table 4.4: Examples for initially not quantified constraints

4.4.3 Constraints characteristics

4.4.3.1 Hard and soft constraints

For reasons of correct handling during planning, the entirety of constraints has to be divided in hard and soft constraints (Wolfe 2005). Hard constraints are absolutely fixed and do not allow deviation from the set value. Soft constraints usually set a corridor of objective values or define a single value that should be met, but can be broken to some extent. Examples for these two categories are listed in Table 4.5.

Hard constraints	Soft constraints
• Production capacities • Resource capabilities • Customer releases • Costs • Local content quotas	• Minimum loads per plant • Release flexibility • Capacity reserve

Table 4.5: Hard and soft constraints

4.4.3.2 Variability of constraints over time

It is important to note that due to the long planning horizon of NMP the above-presented constraints are not fixed over time, but may change from one planning period to another. Therefore, the single planning cycles have to be considered separately and constraints have to be set individually. On the technological side, resource capacities usually are subject to progress, developments, and *Total Productive Maintenance* activities. In effect, capacities rise over time, e.g. 5 to 10 per cent per year. On the other side, objectives like minimum load factors per plant or desired release flexibility originate from human decision processes and, therefore, can also show variability over time. Similarly, the value of constraints cannot only change between periods, but also between individual end-items within one planning period. For example, end-items for the same customer can have different releases.

Furthermore, particular attention must be paid to the fact that the presented partition of constraints in the categories *hard* and *soft* is valid for a specified point in time. However, this division changes. Whereas, for instance, resource capacities cannot be exceeded in a short-term perspective and, thus, have to be regarded as hard, they can change to soft for planning periods that are further away in the future due to the possibility of investment in additional resources. The same goes for technical modifications of existing resources or requesting additional future customer releases.

4.4.3.3 Emerging and changing constraints

In addition to the characteristics of constraints presented above, complexity rises due to the fact that not all constraints are readily available and can be set prior to planning but ‘emerge’ during planning. Some cannot be accessed at the start, because they depend on other parameters and, thus, originate or have to be calculated at defined points in planning; others may be not yet known at the beginning for reasons of being subject to strategic managerial decisions that are made later. Examples are:

- A capacity quota for resources shared with other products. It was observed that this quota could only be fixed after preliminary results of other planning steps and constraints still existed.
- Capacity shortage at a resource that is shared with other products due to changes in the other products’ planning.
- Decisions concerning the production of a certain product variety in a specified region as strategic objective.

4.5 Critical reflections and specification of requirements

The main problems in the NMP actual situation according to practitioners are: different systems for source data, limited data availability and fidelity, a high number of inter-dependent constraints, unclear responsibilities, no standardised procedure (methodology support), and no appropriate tool support. These aspects are reflected below. Further, the author justifies why NMP deviates from traditional approaches of aggregated planning. Finally, the author discusses the universality of the observations within BOSCH.

4.5.1 Database incompleteness and inconsistencies

4.5.1.1 Incorrect and incomplete set of data

Cycle times for individual product varieties differ. Therefore, the capacity of a production line has to be defined as product-variety-specific. This means that a production line can for example have a capacity of 3,000 units for the product variety ‘A’ but 3,500 unit for variety ‘B.’ Due to these inter-dependencies, the total capacity of a production line and, consequently, an individual plant depends on the mix of product varieties loaded on it. In current planning, resource capacities are based on average values without taking different cycle times for the product varieties into account. Therefore, these substantial figures are inexact. However, because complexity is expected to rise significantly when going into detail, this inaccurateness is accepted by practitioners.

In case of future end-items for which the complete set of data and especially an individual part number has not yet been specified, ‘dummy’ part numbers are used as placeholders. Dummy part numbers refer to end-items that have similar characteristics as the new one and, therefore, allow a general positioning. This leads to further inaccurateness on the planning basis because multiple future part-numbers can be subsumed under one dummy number. Therefore, differentiated planning for this product quantity is impossible.

4.5.1.2 Lack of data standardisation hinders accessibility

There is a lack of standardisation in terms of the absence of a ‘global’ database for source data. For reasons of historically grown production networks, heterogeneous systems for data management are common. Due to miscellaneous data structures, formats, and degrees of data detail existing in the individual site systems, availability of information can differ from one end-item part-number to another. In effect, communication and data transfer between the sites as well as central access by the NCU are hindered. Usually, production costs are the main input to objective functions which are used to evaluate alternative solutions. However, these are difficult to access in the analysed network, which is discussed in the following section.

4.5.1.3 Cost fidelity and comparability

The actual production costs of an end-item is calculated and stored within the proprietary site systems (see 4.3.2.1). Since NCU has no direct access on the cost figures in the single systems, it depends on the cost information that is provided by the individual sites. The main questions in this context are:

- Are costs reliable over the complete planning horizon?
- Are costs comparable throughout the network?
- Can cost data be trusted?

NMP has a planning horizon of up to ten years and the planning is done on the end-item level. This means that production costs need to be available too in the same detail if they are to be used as an input factor in planning. For a short-term perspective, it seems possible to generate detailed cost data, even if some assumptions would have to be made due to incomplete data. However, looking at more distant planning periods, the interviewed practitioners stated that it is impossible to provide cost data on the same level of detail.

In addition to the above described scenario of different amounts and formats of data, data availability is also limited for another reason. Different production depths at the individual sites and inter-plant transfer with components hinder direct comparison of production costs per end-item. Figure 4.17 illustrates an example.

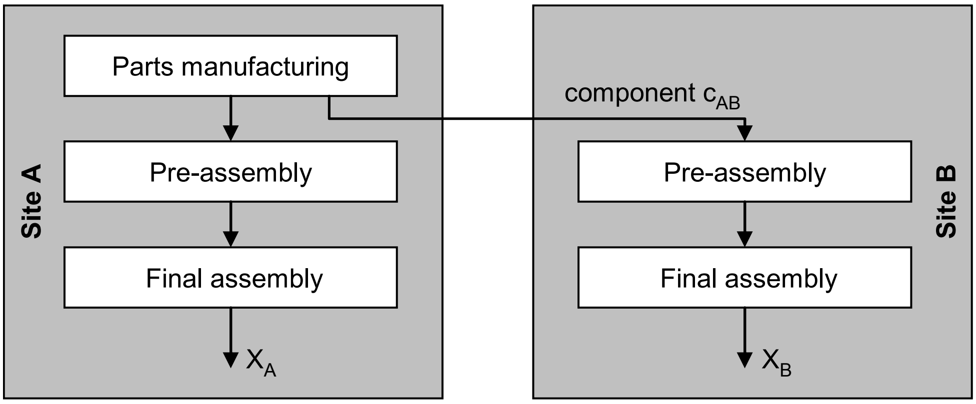


Figure 4.17: Different production depths hinder comparison

Product X is assembled at two sites A and B (represented by X_A and X_B), but one main component (c_{AB}) is only manufactured at plant A. Therefore, the production costs for product X_A can be calculated based on effort consumed for all value-adding steps in plant A, whereas for the case of X_B only assembly-costs at plant B are available. Total labour cost for X_B have to be calculated taking, additionally, the labour cost of component c_{AB} into account. Therefore, the production cost for X_A and X_B depend on the quantity ratio between the two sites, which increases planning complexity. Alternatively, planning could be performed based on a production cost index which takes only the costs for the final assembly into account. As these are also not easy to generate, this approach is prone to fail and, thus, was dismissed by practitioners.

Last but not least, it is also a matter of trust if NCU can rely on the provided cost data or not. The individual sites in the network find themselves in a competitive situation against the other plants. The total production quantities per plant are allocated on the strategic level. Decisions are based on factors like the plant’s business result of the previous planning cycle, strategic importance of the plant, and production costs. Each plant has the objective to get a ‘piece of cake’ as big as possible in order to best utilise its resources. Although all plants are part of the same company, the question occurs, whether the cost data provided is 100-per-cent correct or whether statistics are embellished by the plant management to improve their competitive situation.

4.5.2 Heavily constrained system

4.5.2.1 Conflicting constraints

Implications between individual constraints lead to conflicting objectives for planning. On the one side, there are permanent implications that are obvious even before the planning process starts and that need to be decided on a higher level. On the other side, various obstacles caused by constraints occur during planning. Examples for both are shown in Table 4.6 and explanations are given below.

Permanent conflicts	In the course of planning
• Capacity reserve ⇔ Degree of utilisation • High load for LCL ⇔ Profitability of HCL • Release flexibility ⇔ Costs and effort • Customer proximity ⇔ Manufacturing depth	• Parallel production ⇔ Variant complexity • Constant load level ⇔ Overall profitability • Release flexibility ⇔ Quality aspects • Independent planning ⇔ Shared resources

Table 4.6: Conflicting constraints

Capacity reserve vs. degree of utilisation: Capacity reserve is needed to react in case of unplanned events, like backlogs after production breakdowns or additional customer requests. On the other hand, each production resource has been calculated prior to acquisition based on utilisation and is supposed to have a high degree of utilisation.

High load for LCL vs. profitability of HCL: Considered separately, companies aim to load low-cost locations (LCL) as high as possible due to advantages in costs. As a result, the load factors of high-cost locations (HCL) decrease to reach the required average capacity reserve in the production network as a whole. In effect, on a calculation base HCL get comparably even more unprofitable than in the original state.

Release flexibility vs. cost and effort: The aim of production flexibility in the network conflicts directly with the cost and the effort necessary to initiate additional releases.

Customer proximity vs. manufacturing depth: Supplying customers from within their geographic region in the triad was formulated as one non-monetary constraint in section 4.4.1. On the other hand, a potential strategic objective is to save resource investment costs by having not all steps of value-adding at all sites installed and accept interplant transfers with components (see 4.2.1).

Parallel production vs. complexity reduction: Parallel production of multiple end-items in the network for reasons of flexibility counters reduction of complexity by means of product variant reduction at the single sites.

Constant load level vs. overall profitability: A constant or only minimally changing load level at single sites is aimed at creating long-term stability in operations as well as planning on site-level. At the same time, profitability of the network as a whole is one measure for success.

Release flexibility vs. quality aspects: A further obstacle to network flexibility are quality aspects in production. In the case of parallel production, multiple processes have to be monitored and controlled. Problems encountered at one site cannot be automatically averted at a parallel process. In addition, products manufactured at two sites are never exactly identical. Therefore, assembly complexity is easier to handle if components for one product are supplied only by one defined plant instead of multiple ones.

Independent planning vs. shared resources: As described in section 4.2.2.4, NMP is performed for individual products separately. Thus, planning activities are, in principle, independent from each other. Complexity enters when different product groups share common resources, like in parts manufacturing. In that case, either fixed capacity slots have to be given to each product, or planning is performed on a dynamic basis, probably resulting in multiple iteration cycles.

4.5.2.2 Solution space can vanish

As introduced in section 4.3.1.2, each constraint cuts away a number of possible solutions to a planning problem (see 3.4.2.2). Due to the aforementioned concurrent constraints, it may happen that the so-called 'solution space', i.e. the entirety of feasible solutions to a problem, is significantly reduced. In the case of a high number of constraints that are partly opposed to each other, the solution space can even vanish. This means that the planning problem is not solvable under the given conditions and requires decisions about changing some constraints. Figure 4.18 exemplarily illustrates the solution space in multi-objective planning.

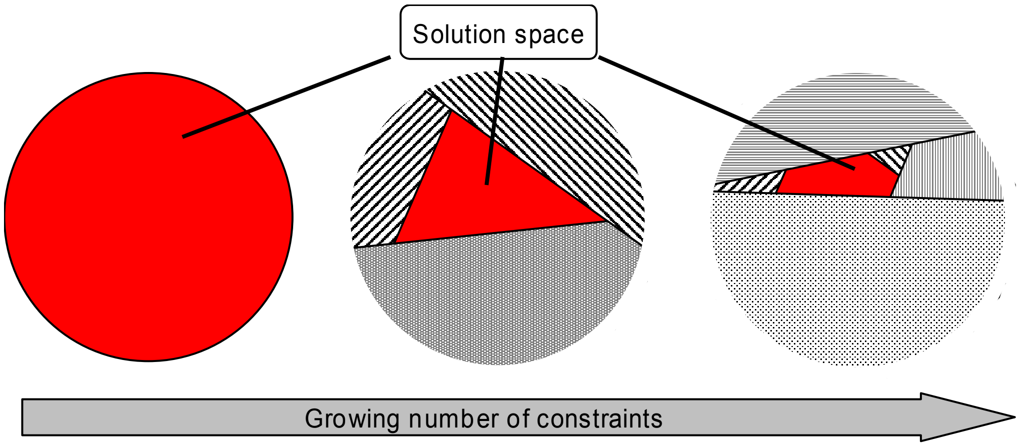


Figure 4.18: Solution space in dependence of concurrent constraints

4.5.2.3 Time restrictions

According to Harrison and Godsell (2003), successful organisations of the future are likely to be those that develop the capabilities to match the emerging characteristics of demand with customer responsive supply capabilities. Against the background of limited time in budget-planning and an escalating number of ADRs (see 4.3.4.3), the need for fast statements based on accurate and reliable planning is intensifying. Therefore, doing the job 'good' is not sufficient. In addition, speed has become a more and more tangible factor in competitive advantage (Gubi et al. 2003).

4.5.3 Planning process

4.5.3.1 Lack of formalisation

Apart from the pure technical approach of finding solutions to the capacity allocation problem, the methodological point of view must not be disregarded. During the analysis of the actual situation, no structured methodology could be observed. On the contrary, ad-hoc-driven actions occur. Neither inputs, outputs, nor exact content of process steps, nor their timely sequence are clearly defined. Particularly the flow of information is informally organised. In effect, if information is required from production plant experts, it is requested the very moment when needed. The time until receiving the required information depends on the time to find the appropriate expert.

4.5.3.2 Iterative cycles

Iterative loops in the planning process mainly originate from three causes. The first is the adaptation of constraint values during planning because of changes in objectives on higher levels of the hierarchy or more detailed specification of constraints. Second, constraints emerging along the planning process can make it necessary to go back some steps in planning or contact a higher level of hierarchy for a decision. Last, many iteration cycles exist because the decision competency is centralised at the NCU, but product and cost data are available only at decentralised plants, distributed all over the production network.

4.5.3.3 Inappropriate tool support

As-is analysis showed that also nowadays there are tools in use that support the planner in his work. Apart from some historical ERP-tools, these are mainly proprietary *Excel* sheets that were developed in uncoordinated ways. Regarding the amount of data that has to be handled in current planning, these tools are at their capacity limit. For example, it was observed that – although their stability is very limited – *Excel* files of 60MB are not unusual. Furthermore, the tools are not aligned to each other, but exist isolated in parallel; they are not integrated in a holistic methodology for planning. In summary, current tool support is inappropriate and, thus, unsatisfying.

4.5.4 Inability to aggregate

4.5.4.1 Summary of observations from the real-world case

Ideally, planners strive for perfect aggregation but, according to Thorn (2002), aggregation-mismatches are a reality in a complex system. In general, the number of items typically gets smaller while the number of resources rises when going up in a planning hierarchy, like schematically displayed in Figure 4.19 (e.g. Buxey 1990). However, it has been observed in NMP practice that in spite of its relatively upper-end position in the planning hierarchy, the number of products NMP deals with is fairly high (see dashed line in Figure 4.19).

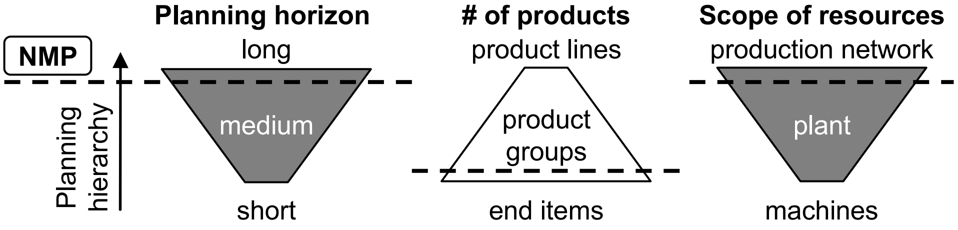


Figure 4.19: Correlation of planning objects and hierarchy

The inability to plan on aggregate level in NMP is mainly caused by five aspects:

- Detailed demand planning (actual and prognosticated) (see 4.3.4.3).
- End-item specific product properties (see 4.3.3.2).
- End-item specific customer releases (see 4.4.2.2).
- Constrained production resource capabilities (see 4.4.2.1).
- Running a production network at capacity limit (see 4.3.4.4).

4.5.4.2 Disaggregation is the major difficulty

During this research project, the author observed that the approach of aggregating end-items is a time-consuming process requiring the creativity of an experienced planner for aggregation criteria definition. Customer demand, planning objects, and constraints change over time, which in effect, leads to an unacceptable effort for redefining groups and assigning end-items. Buxey (2005) notes that “since it is impossible to manufacture ‘aggregate products’, the […] aggregate plan needs to be disaggregated”. Thus, along with the effort for aggregation that for disaggregation rises with the complexity of the original problem.

What is more, due to the lack of information on the aggregated problem at lower decision levels, the solutions cannot guarantee optimality or even feasibility (see also Vicens et al. (2001)). This provides a strong argument against letting the individual sites in the network negotiate end-item-specific production volumes amongst each other based on aggregated volumes. Moving the production volume for a specific part number can, for example, lead to the need to re-allocate all other part-numbers. Thus, the planning process would have to be fed back to the upper hierarchy level to adapt the aggregate plan.

4.5.5 Universality of the described process within BOSCH

The afore-described planning process and the sources of complexity refer to the planning environment at the BOSCH business division *Diesel Systems*. There are differences between the single divisions stemming, on the one hand, from historical developments of organisational structures, and, on the other hand, from product-related characteristics like production quantities, number of variants, size of products, and the type of customers. The depicted planning process, therefore, cannot be mirrored or applied to all business divisions. However, very similar patterns were observed in the other divisions of the BOSCH automotive sector, for instance *Automotive Electronics* and *Chassis Systems* (BOSCH 2001).

4.6 Conclusions

In this chapter the author presented an overview of characteristics of NMP in practice and sources of complexity for NMP. In summary, the insights presented can be subsumed under three questions:

- What is NMP?
- What are the sources of complexity?
- What requirements for a holistic NMP methodology can be derived?

4.6.1 NMP is …

- Performed in intra-organisational production networks with the fundamentals: globally shared work, vertical integration, resource redundancy (see 4.2.1).
- Balancing rules, implicit ones and explicit ones. If these rules are not followed, the system fails (see e.g. Mourits and Evers 1995).
- Positioned high in the hierarchical planning framework (Tempelmeier 2003) but is performed at an untypical level of detail in planning data (see 4.3.3).
- Co-operation of different hierarchy levels (Luecke and Luczak 2004); centralised decision competency but decentralised technical know-how (see 4.2.2.4).
- Planning for production networks running at capacity limit unlike, e.g., planning for a vehicle manufacturer network (see 4.3.4.4).
- Planning based on part-number-specific customer releases (see 4.4.2.2).

- Time-critical; unlike to MPS or APP (Burcher 1992; Nam and Logendran 1992) NMP is performed to give direct answer to external customer requests (see 4.3.4.2 and 4.3.4.3).
- Conducted without appropriate tool support (see 4.5.3.3), dissimilar to other disciplines in planning framework (APICS 1997).

4.6.2 Sources of complexity for NMP are …

Three groups of factors can be identified which are presented in the following: NMP context, input data, and planning constraints. The individual sources of complexity are listed in the next section.

Regarding NMP context:

- Variation in customer demand has direct cost-implications on NMP, e.g. when moving work away from a low-cost location (see 4.2.2.2).
- Cannot change demand (see 4.3.4.2); e.g. MPS can (APICS 1997).

Regarding input data to planning:

- Cannot average demand (see 4.2.2.3).
- Cannot aggregate products (see 4.2.2.4).
- Uncertainty regarding customer demand, raw data from various sources, inaccuracies, missing data, no standard for data structure (see 4.3.2).
- High number of inter-dependent planning objects: production resources and products (4.3.3).

Regarding constraints:

- Constraints have particular characteristics that make them hard to handle, like hardness and softness, variability over time, or emergence. These hinder formulation of simple rules and a complete description of the system prior to planning (see 4.4.3).
- High number of concurrent constraints reduces solution space (see 4.5.2.2).

4.6.3 Requirements for tackling NMP can be specified as …

The observations presented in this chapter helped the author to gain knowledge about the unusual situation of NMP. Additionally to the need originating from literature, which is presented in chapter 3, the need resulting from current practice is revealed. In order to generate a common understanding of NMP in academia and improve its use in practice, the development of a standardised planning methodology with integrated tool modules is proposed. The necessary requirement-specification is presented in the following. It has been derived from the sources of complexity, which are listed in Table 4.7.

Technical requirements for NMP / **Sources of complexity = Challenges for tool**	Iterative procedure with feedback loops	Holistic planning procedure	Consecutive architecture	Flexibility in setting parameters during planning	Horizon split in periods	Planning of individual end-items	Multi-objective planning	Quick planning	Production resources: variable aggregation	Mid- to long-term horizon
NMP as part of budget planning	◑				●		●	●		●
Task sharing in hierarchical framework	●	●	●	◑					◑	
Volatile demand	◑	◑		●	◑	●		●		
Regular & irregular trigger for planning	●			●				●		
High number of production resources		◑	◑[1]					◑	●	
Interdependencies between objects	●			●		●	●			
Capabilities of prod. resources differ		●		◑	◑[2]	●			●	
Production network at capacity limit		◑	◑[1]			●			◑	
Customer releases per end-item	◑[3]	●	◑[1]		◑[2]	●			◑	
High number of constraints	●	◑					●			
Hard and soft constraints	●	●	●[5]	◑	◑[4]		◑			
Constraints changing over time	●		●	●	●					
Emerging constraints	◑		●	●	◑					
Conflicting constraints	●		◑	◑			●			
Limited data availability and fidelity	◑	◑		◑	◑					
Time restrictions for planning process		◑	◑		◑			●		
Routine work and decision processes	●	●	●							
No ready-to-use input data	◑	◑	◑							
Totals	**11**	**8.5**	**8**	**7.5**	**5.5**	**5**	**4.5**	**4.5**	**3.5**	**1**

Coverage: ● full ◑ partly [ ] no correlation

1) routine process for tool modules; 2) may also differ over time; 3) in case existing ones are not sufficient; 4) change from hard to soft over time; 5) Hard ones can be formulated as tool constraints

Table 4.7: Transformation matrix for specification of requirements

Cross-checking with literature allowed identifying sources of complexity that are already subject of academic discussion for related planning problems and new ones. For existing sources, the corresponding technical requirements were taken from literature and adapted if necessary, e.g. from literature about *Decision Support Systems* (Mourits and Evers 1995; Adenso-Diaz and Laguna 1996, Koutsoukis et al. 2000; Loss et al. 2005). The transformation of new sources into technical requirements was conducted using the author's insights into practice and his understanding of NMP. Thus, on the one hand, the procedures and tools that were already in use in the analysed company were reviewed and translated into specifications. On the other hand, ideas for solutions had to be developed by the researcher and subsequently evaluated in co-operation with practitioners.

It is important to note, that there is no one-to-one relationship between individual requirements and the situation or complexity items, but most requirements deal with more than one source of complexity. Table 4.7 shows the correlations and coverage. Correlations are discussed deeply in chapters 5 and 6.

5 Network Master Planning concepts

This chapter discloses that the complicated problem of NMP is accessible via certain concepts. Principles, design rules, and an architecture are introduced that contribute to unlocking the problem. In addition to the final versions of concepts, alternatives that were considered and, eventually, dismissed are described. Finally, a holistic planning methodology for NMP is proposed, which incorporates the aforementioned concepts.

5.1 Introduction and proposed contribution to knowledge

Based on the portrayed real-world access to the complex situation of NMP, this chapter describes how a solution for NMP support has to be designed and, even more important, how to arrive at solution concepts. The term concepts includes proposed principles, design rules, and an architecture starting from the requirements of practice. The objective is to develop a NMP methodology that helps to improve planning by means of a holistic and structured planning approach as well as integrated supporting tool-modules. The main objectives for a planning support by methodology and tools are, first of all, easier and faster planning on a regular basis as well as a fast reaction to irregularly occurring ADR. Furthermore, faster planning shall open up the possibility for creating more than one planning scenario and, therefore, validate decisions soundly. Thus, a "good" planning process in this context consists of both – quality of outcome, i.e. the best possible meeting of constraints, and the time consumed by the planning process itself. The way to develop a design specification out of requirements from practice is described below.

5.2 Deriving principles and design rules from observations

As a first step, solution principles are derived from the requirements driven by the needs of the situation. One has to clearly differentiate between principles and architectures to understand the approach that is presented in the following. Principles are universal and describe higher-level design characteristics. Formulated as design rules, principles can be implemented in different ways, speaking in terms of detail procedure designs. Consequently, alternative architectures that describe the detail design are discussed (see 5.3). According to conditions and implications from practice, finally, the most appropriate architecture is selected. Figure 5.1 illustrates this procedure exemplarily.

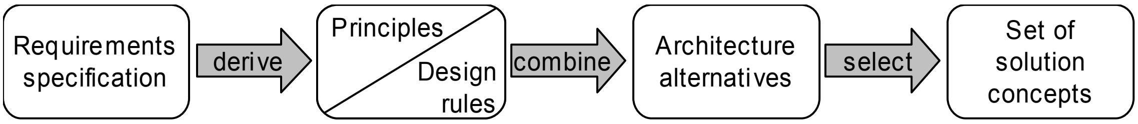


Figure 5.1: Rationale solution development

5.2.1 Drivers and the process of deriving

5.2.1.1 Mechanism for deriving principles

Observing practitioners doing their job and subjectively identifying positive aspects as well as shortcomings allowed the researcher to develop first ideas on NMP principles. The preliminary hypotheses the researcher drew from these ideas built the base for interviews and discussion forums with practitioners from the case company, i.e. experts in the field of mid-term capacity planning, who reflected on them along with their observations. In effect, some hypotheses had to be adapted, others were added. In case that the researcher had drawn wrong conclusions from his observations, the corresponding principle was adapted – based on the practitioners' input – or dismissed. New ideas that came up during this phase of data collection were either directly made subject of discussion by the researcher or collected to reflect upon them at a later time and subsequently feed them back to the practitioners for validation (see also 4.1.2 for a description of complementing actions of researcher and the involved practitioners).

Further, a literature review and investigation into various fields of capacity and production planning approaches was conducted. Basic characteristics found there were taken into account when formulating initial hypotheses on NMP principles. Some of the ideas found were adapted, e.g. combining human and tool planning, others dismissed due to relevant differences in the contexts.

Subsequently, testing the refined set of principles in a live planning-environment in parallel to traditional, manual planning allowed validation, i.e. testing the principle's usefulness and applicability. Thus, the observations made and the data generated in this phase enabled the researcher to review and refine principles to their final versions. The stage of testing ideas in a live system and the observations made on NMP done with/ without the proposed principles are presented in the steps of development sections for the single tool modules and in the reflections on methodology and tool use in chapter 6 (see 6.2 and 6.3).

5.2.1.2 Principles influenced by limits in available technology

It is important to note that, on the one hand, principles are directly driven by observations of real-world behaviours and inter-connections. On the other hand, principles are driven, not to say dominated, by limits in the available technology for realisation. 'Flexibility' in planning (Principle 3) serves as an example. As soon as there is artificial intelligence as powerful and flexible as that of humans, there will be different ways of defining this principle, not reliant on human abilities.

5.2.1.3 Presenting final versions of principles

The principles presented in the following sections were derived from literature and from the emerging understanding of the complex situation of NMP in practice. Furthermore, reflections of ideas in co-operation with practitioners and testing tool-module prototypes in a real-world planning environment did contribute to knowledge. Thus, the principles did not occur spontaneously or were developed linearly but emerged in a reiterating research process by testing the author's theses. Hence, the interpretations and main concept shifted throughout the research (see Action Research, 2.2.2). Once more, the aforementioned 'flexibility' serves as an example for this.

Initially, the flexibility of a planning aid was just seen as the possibility to apply the approach to different products, i.e. partially different planning environments. Based on the observation that constraints for planning change between planning cycles, flexibility was defined as 'setting tool rules' prior to planning dynamically, i.e. depending on the concrete case. In a next step, the researcher observed that not all constraints can be fixed prior to planning and that others change throughout the planning process. Therefore, the final version of the term 'flexibility' subsumes the entirety of the aforementioned aspects. These are: set individual constraints prior to planning, change constraints during planning, and use the human ability to judge new situations. However, for better understanding in this chapter only the final versions of principles are presented in sections 5.2.2 - 5.2.11. How these final versions emerged is described in chapter 6.

Each principle is introduced by explaining its meaning and implications on the planning process. Furthermore, alternatives to the principle in question are identified and reasons given why the ones presented have been selected. For each principle at least one corresponding design rule was developed. Design rules refer to the planning methodology, to the supporting tool-modules, or to the system in which the principles are implemented. Finally, these design rules build the basis for the development of solution-architecture and the necessary changes to the surrounding system.

5.2.2 Principle 1 – Use a holistic procedure

Using a holistic procedure is necessary to avoid sub-optimisation (APICS 1997). This requires looking at the whole system instead of focussing only on a part of the system, e.g. fine planning (see 4.2.2.2). Thus, the surrounding process-steps that potentially have an impact on the one in question also have to be taken into account. Furthermore, analysis cannot be limited only on directly involved persons, taking the organisation around them as fixed and unchangeable. Departments indirectly interfering or being affected by the planning process and results have to be identified too and, if reasonable, integrated into the development of methodology (Lewin 1999). In effect, the system performance losses at mistuned interfaces can be reduced. To give an example: if the effect of their actions is not communicated to persons responsible for supplying input data, they have no chance to identify and implement the necessary changes.

To avoid getting stuck at optimising only a small part of a bigger system, at first, effort has to be invested to create a holistic and integrated planning methodology that matches reality in such a way that, e.g., each planning step in the actual process has its counterpart in the planning procedure. By designing the planning methodology as a whole, the single elements are connected to each other by means of defined interfaces and cause-and-effect relationships. This also ensures that all relevant data is collected at the right time and sources – humans or systems – and that every essential intermediate step in planning is considered. Integrated tool-support by means of defined modules helps the planner and supports constant quality of planning based on standardised process steps.

5.2.3 Principle 2 – Use standardised, robust processes

A standardised planning procedure consists of the definition of the following elements:

- Individual process steps;
- Interfaces and information hand-over between process steps;
- Inputs and outputs of each step, including data structures and formats;
- Integrated, supporting tool modules at specified points;
- Clearly differentiated tasks for humans or tools; and
- Responsibilities of planners and departments.

Robustness in planning methodology as a whole refers to using the above described standardisation in procedure and data. In effect, a volatile environment does not cause uncontrollable changes. On the individual process-step level, robustness refers to stable sub-systems that transform inputs into outputs according to defined rules (Phadke 2003). Assuming the best scenario, the design of the process-step prevents changes in the 'transformation function' which could be caused by external noise factors. If this is not possible, standardised control factors have to be applied to ensure the correct transformation (see 3.3.2.1). According to Lane (1993), "it is important to create plans […] which are adequately robust and do not breakdown easily in the face of frequent disturbances." This provides a strong argument against striving for 'optimal' plans, since these are "brittle, they break down easily and are difficult to repair" (Lane 1993).

In addition to the aforementioned objectives, a standardised planning-procedure helps not only to assist the planner but also improves the planning-performance by decreasing waste in form of the necessity to 'invent' process steps and ways of process-step-realisation each time again. Furthermore, no surprises by unforeseen interactions between non-standardised steps have to be expected or – acting in a real-world system – at least the number of surprises can be reduced. One additional benefit of a standardised procedure and robust process steps is that the planning results are mainly independent from their producer and the current system's environmental conditions.

To support the planning process and enable the planner to act along a standardised set of steps, each planning step has to be clearly defined. Especially in an iterative procedure, it is important to know exactly the content and boundaries of every step in case an individual step has to be performed once more. Thus, process-step descriptions, on the one side, help experienced planners to base their acting on a standard and, on the other side, support novices to become involved in the process and learn on the job. On the tool side, a set of relevant forms, tables, or partly automated calculation modules additionally support this guidance through the process by prompting all relevant information and data.

5.2.4 Principle 3 – Keep procedure flexible

In addition to standardisation and robustness, the author observed flexibility to be another necessary attribute of the planning procedure. Flexibility refers to degrees of freedom for the aspects time, data, and constraints (Lane 1993). Time flexibility represents the ability of the NMP procedure to cope with time-related factors that may vary, like the length of the planning horizon, the length and number of planning periods, or the frequency of planning. Data flexibility is necessary to ensure applicability of the NMP approach to multiple end-items and the corresponding data structures that may differ from those analysed in this work (see 4.5.5). These points mainly have to be covered by the architecture of supporting tool-modules and standardised forms. Constraint flexibility takes the characteristics of NMP into account, e.g. constraints that change or emerge throughout the planning process (see 4.4.3.3). Furthermore, parameters and constraints are variable over time, i.e. they can change between planning periods. Therefore, it is important not to take only a snapshot of values but individual values over the complete planning horizon.

The possibility to stop or to repeat a process or change parameters at multiple points ensures procedural flexibility. In the opposite case, one has to perform a full run of a fixed procedure, consequently apply changes and run the whole procedure again – as often as necessary. Therefore, it is better to design small building blocks of action with defined interfaces than one big ‘black box.’

This kind of thinking leads to a consecutive approach with single elements that are to be used one after the other but can also be used as stand-alone processes. Reiterating feedback loops and backward bypasses ensure that reactions to changes are possible. Thus, to realise such changes it is not sufficient to analyse the values for parameters and constraints only once prior to planning, but these have to be monitored for changes throughout the process. Additionally to this need to actively collect information (pull), the communication in case of changes also has to be institutionalised at other parties involved, like higher hierarchy levels or departments responsible for input data supply (information push). In Figure 5.2 such an approach is illustrated.

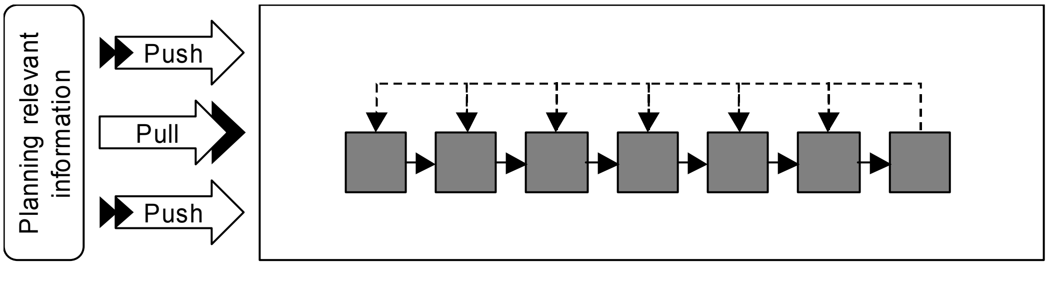


Figure 5.2: Consecutive planning procedure and information transfer

Furthermore, flexibility is preserved by using tool modules only for routine works and parts of the problem that are easy to implement in a tool and lead to comprehensible results. Tasks with constraints that are prone to change benefit from making use of human flexibility rather than trying to formulate rules that cover all sorts of possibilities. For reasons of having adequate decision competency available, the planning process may be distributed on several relevant hierarchy levels (see 4.2.2.3). The danger that lies in implemented feedback loops and the corresponding reiterative process is that this could lead to unacceptable delay in planning if the process is not reasonably controlled.

5.2.5 Principle 4 – Combine the strengths of human and tool planning

The challenging requirements of NMP in practice (see chapter 4) make it necessary to create a working procedure that allows performing the planning process in the best possible way. Looking at the aspect of what drives the planning process, two basic approaches are possible: human or tool planning (Adenso-Diaz and Laguna 1996). For NMP, the author proposes to combine human and tool planning steps using the specific advantages of both to create a solution that provides better planning results than any of the both approaches alone. Table 5.1 lists the specific strengths of both.

Humans are good at:	Tools are good at:
• Providing expert knowledge • Reacting flexibly to changes and new situations, subsequently taking decisions • Sensing when a plan is getting better	• Storing of data, copy/paste data • Processing big amounts of data quickly • Performing complex calculations • Decide according to precisely specified rules, such as ‘if A then B’ • Providing visualisations

Table 5.1: Comparing strengths of human and tool planning

To be able to apply an approach that combines the strengths of human and tool planning on a planning problem, the core task is to allocate sub-tasks of the total planning process to human and tool processing (Mourits and Evers 1995). For this, decisions have to be made regarding which steps in planning require human skills and which are appropriate for automation. This can be done by using a sequence of steps like the ones listed below:

- Analyse and structure the process into individual tasks that can be regarded as separate process steps.

- Separate the tasks into those that need human processing, those that can be supported by a tool, and others that can be processed completely by a tool.
- Specify the interplay between tasks, especially between human and tool process steps.
- Create or adapt tools that are appropriate to the tasks in question.

5.2.6 Principle 5 – Vary outputs not inputs of tool processing

A usual approach in tool-supported-planning is to set rules, parameters, and constraints at the start of the planning with the objective to achieve a desired result after tool processing (Figure 5.3 top, see also e.g. Koutsoukis et al. 2000). One risk in these approaches lies in over-determining the system, not leaving any solution space. Another risk is having to run through the process multiple times and not being able to solve the problem in reasonable time (see also Vicens et al. 2001 for 'limitations of HPP systems'). For NMP, the author proposes a different approach. Due to the complex situation of NMP with changes likely to occur throughout the process (see 4.4.3) and mathematically hard to define decision constraints (see 4.4.2.4), it is suggested to solve the problem only to a certain degree with tool support and deliberately leaving the above-mentioned aspects to human decision (Figure 5.3 bottom). By combining manual and tool processing, the risk of being trapped in never-ending reiterative circles of setting parameters, tool-processing, adjusting parameters, tool-processing, and so on is reduced.

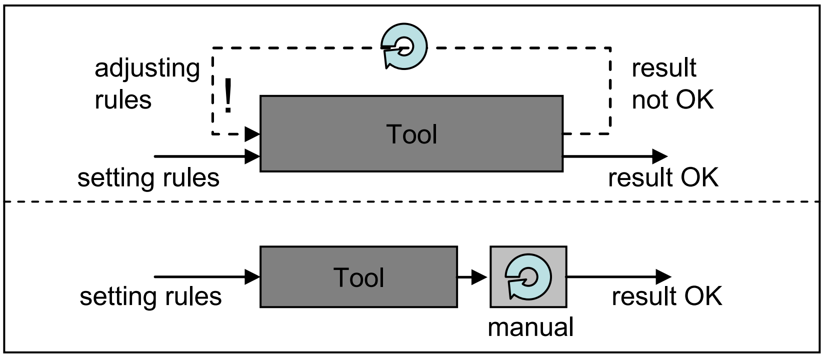
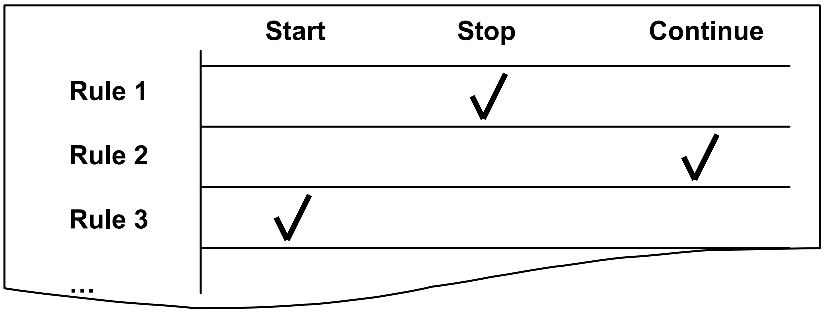


Figure 5.3: Vary outputs not inputs

In order to set up an efficient planning process and preserve solvability of the planning problem, the system must not be over-determined. Therefore, only those constraints are set as rules where a tool can be supportive by performing routine calculations. The remaining constraints should be handled by manually post-processing the tool's outputs. In this context, it is very important to design the supporting tool in a way that the quality and standard of preliminary tool-results match the requirements for manual proceeding, speaking in terms of data structures, manageability, and comprehensibility.

For those constraints formulated as rules, the effort for setting and adjusting these rules has to be as low as possible in order to be supportive to the planner. Especially thinking of adjusting rules in a later stage or a new planning cycle, these have to be clearly visible to the planner and easily adjustable. For example, this could be realised by a rule-overview visualisation based on the scheme illustrated in Figure 5.4.



	Start	Stop	Continue
Rule 1		✓	
Rule 2			✓
Rule 3	✓		
…			

Figure 5.4: Setting rules

5.2.7 Principle 6 – Provide planning results fast

Time was observed to be a restricting factor in planning (see 3.2). Therefore, as mentioned in section 4.5.2.3, a good *Network Master Plan* is not enough: it must also be provided fast. On the one hand, in budget planning there is only a short period of time reserved for NMP (see 3.1.6). On the other hand, when performing NMP as reaction to customer requests, a quick response is required. Thus, the speed of planning plays a vital role. In this context, it is also important to identify and communicate inevitable bottle-necks early to give all involved parties the chance to adapt quickly to the new situation. Furthermore, striving for a fast 90-per-cent solution can contribute more to a usable planning result than following a lengthy optimisation path to achieve the 100-per-cent-perfect solution (that perhaps will never be reached).

In order to achieve fast planning results with tool support, the objective has to be to implement simple and fast tools that help getting near the 90-per-cent solution rather than heuristics or algorithms that try to make the best out of the last 10 per cent by means of a real optimisation process. On the one hand, this would not be reasonable because in the NMP environment conditions are unlike typical optimisation problems, mainly because not all constraints are definable prior to planning. On the other hand, tool-optimisation holds the risk of incomprehensibility of the planning result to human planners, as discussions with practitioners revealed. However, transparency is absolutely necessary due to alternating human and tool action. Short feedback-loops between planning levels allow proceeding efficiently in a reiterative process, because corrections of constraints or other parameters can be directly discussed and, if agreed upon, applied.

Creating a culture of clear and direct internal and external communication builds the basis for mutual trust between the involved parties. Such a culture is particularly helpful for joint-solution development in case of unforeseen changes or inevitable bottle-necks. To be able to communicate bottle-necks, these have to be made easily visible to the planner. Visualisation in planning therefore plays an important role, as presented in Principle 10 (5.2.11).

5.2.8 Principle 7 – Allow high level of detail for planning objects

Many authors do not believe that a detailed formulation is necessary to capture the essential trade-offs and constraints inherent in the production planning process on a tactical level (e.g. Bitran et al. 1982). In contrast, the author could not ratify this statement from the observation of NMP practice. Originating from the concern for capacity utilisation in the production network, many movements of production quantities are done in NMP. End-items are dynamically allocated to production resources. Observation showed that the need for movements cannot be identified in a system of aggregate data, because bottle-necks may be overseen on the level of product groups and total production capacity. Due to a high degree of utilisation of production resources in the network and restrictive customer releases that are referring to specific end-items (see Table 5.2), individual part-numbers have to be taken into account for planning.

Part-number	Site 1	Site 2	Site 3
1234	**x**		**x**
1235		**x**	
1236	**x**		

Table 5.2: Customer releases on end-item level

Furthermore, the given conditions of high product-diversity between part-numbers have been observed to strongly limit the possibility for aggregating items into groups (see also Buxey 2005). There are two alternatives: either to cluster on a rather rough level and loose a great deal of planning relevant product details in which case disaggregation becomes difficult and invalid plans are likely to occur. Or, on the other hand, to differentiate on a fine level, and end up with a number of aggregated groups that is not much smaller than the original number of items. In this case, criteria for data aggregation would have to be defined and steadily updated – with circumstances likely to change over time. An exemplary analysis in the case under inspection brought the result that a total of roughly 250 part numbers could reasonably be aggregated to ca. 190 groups. Yet, due to a high change rate in the database and updated constraints, in the next planning cycle the 250 part numbers had to be considered one by one, again, to confirm their assignment to previous groups or to define new groups.

Vicens et al. (2001) note that there are four basic strategies to come to a feasible solution regarding aggregation and disaggregation:

- Do nothing [i.e. Do not aggregate; *Note from author*],
- Exclusive weight updating,
- Exclusive reclustering, and
- Iterative refinement of clusters.

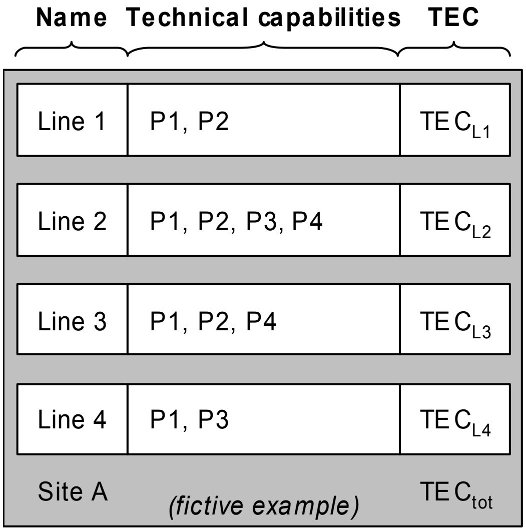
The author believes that aggregation is only sensible if it helps in performing the planning process. In the context of the aforementioned aspects and those presented in section 4.5.4, he opts not to aggregate end-items in NMP to avoid endless cycles of aggregation-criteria redefinition.

This principle is not to say that the researcher is not aware of the risk coming along with detailed planning: forecast inaccuracy. However, in NMP this risk is outrivaled by that of generating invalid plans. Therefore, the higher complexity resulting from planning end-items is accepted. On the other hand, to reduce forecast errors, time is aggregated to buckets of half and full years, respectively (see also Mehra et al. (1996) for 'temporal aggregation'). Furthermore, resources are planned on the partly aggregate level of virtual production lines (see 5.2.9).

5.2.9 Principle 8 – Plan virtual production lines

Each physical production line in the network has a defined production capacity, speaking in terms of available net-production-time. Considering production-time-demands per product variety, a total number of producible end-items can be calculated. However, since each production line is capable of producing several product varieties (see 4.4.2.1), the total number of producible end-items depends on the product mix allocated to that line. In effect, it is impossible to calculate the production capacity per product variety for one physical production line, unless fixed quotas for individual product varieties are defined. However, fixing quotas would pre-define the allocation of products too much and, therefore, is not seen as a valid approach.

Thus, production capacities are to plan on a partly aggregated level based on product variety-specific 'virtual' lines. In order to perform a validity check for one site, technical capacity (TEC) and capabilities per production line (see 4.4.2.1) are required as input data. Based on these, capacities have to be calculated per product variety and for the site in total. Only by taking both factors into account, valid statements regarding the feasibility of plans can be made (see Figure 5.5).



Name	Technical capabilities	TEC
Line 1	P1, P2	TEC_{L1}
Line 2	P1, P2, P3, P4	TEC_{L2}
Line 3	P1, P2, P4	TEC_{L3}
Line 4	P1, P3	TEC_{L4}
Site A	*(fictive example)*	TEC_{tot}

Input data:

- Technical capacity (TEC) per line
- Technical capabilities per line

Calculation:

Capacity in total

- $TEC_{tot} = TEC_{L1} + TEC_{L2} + TEC_{L3} + TEC_{L4}$

Capacity per virtual line

- $TEC_{P1\_max} = TEC_{L1} + TEC_{L2} + TEC_{L3} + TEC_{L4}$
- $TEC_{P2\_max} = TEC_{L1} + TEC_{L2} + TEC_{L3}$
- $TEC_{P3\_max} = TEC_{L2} + TEC_{L4}$
- $TEC_{P4\_max} = TEC_{L2} + TEC_{L3}$

Validity check for planning scenarios

- $TEC_{Px} < TEC_{Px\_max}$ (x = 1, 2, 3, 4)
  and
- $TEC_{sum} < TEC_{tot}$

Figure 5.5: Validity check on base of virtual lines

5.2.10 Principle 9 – Allow multi-objective planning

In order to provide valid planning results, all relevant parameters and constraints have to be taken into account. This has to be done by integrating them into methodology or into possible objective functions in tool-modules. The individual objectives cannot be subsumed under a general one because they may be partially conflicting, which makes multi-objective planning necessary and leads, in case of heuristics, to multi-objective optimisation (Eiselt and Laporte 1998).

Due to the high number of concurrent and conflicting constraints, it is likely that the so-called 'solution space', i.e. the entirety of all valid solutions, is significantly reduced (see 4.5.2.2). In the case of vanishing solution space, individual constraints have to be changed or loosened to come to a solution at all. It is better to leave these decisions to experienced planners rather than formulating algorithms for a tool that try to cover all and each eventuality.

In order to make multi-objective planning accessible to the planner, a procedure and visualisation like the one shown in Figure 5.6 can be helpful. The fixing of certain points in planning is visualised in such a way that the objectives that are already covered and those that are still 'open' are separated and easily recognisable. Thus, a score representing the number of fixed cells can be used to monitor the progress in the planning process.

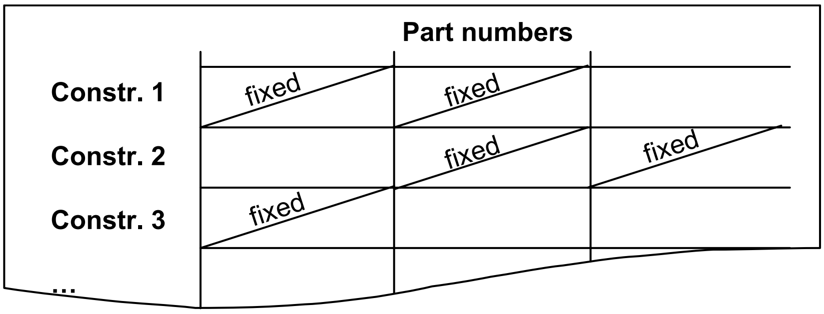


Figure 5.6: Multiple objective score visualisation

For those parts of the planning process that are supported by optimisation, the author proposes to apply algorithms that allow 'soft optimisation.' This means that, speaking in terms of evolutionary theory, the 'fitness' of planning solutions has to be evaluated rather than ending up with black and white 'validity/invalidity' statements.

5.2.11 Principle 10 – Visualise

As mentioned in some of the principle descriptions above, visualisation is crucial to guide the planner and enable him or her to quickly get an overview of his actions and the preliminary results of tool-processing. Furthermore, standardised visualisation helps to gain a common understanding of situations and to communicate results to persons not directly involved in the planning process. As general rules for visualisation in planning, the following aspects can be named:

- Use a common style for presentation of results;
- Use common metrics; and
- Allow the user to choose the degree of aggregation in visualisation;

Whereas a common style and common metrics contribute to the accessibility of information and the acceptance of communicated results, flexibility in data-aggregation allows the performance of analyses and cross-checks with regard to validity of solutions on different levels.

One example for the benefit of visualisation is signalling a hard planning-constraint broken in tool-processing, e.g. by a red light (Adenso-Diaz and Laguna 1996). The decision about ignoring it or analysing this instance lies in the responsibility of the planner. Thus, visualisation gives the planner direct feedback of the quality of the solution and points him or her to conflicts that require special interest. Because the identification of bottle-necks is a crucial task of NMP, the visualisation of used and available capacity per resource is of particular interest for planning a system. Figure 5.7 exemplarily shows one possibility for capacity visualisation.

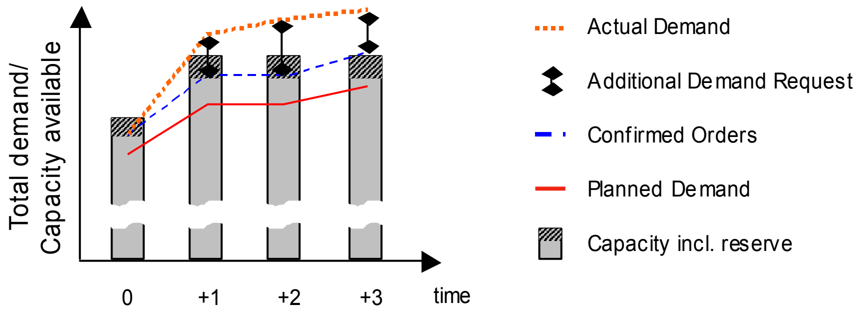


Figure 5.7: Visualisation of bottle-necks

5.3 Procedure architecture

Based on the ‘universal’ NMP principles given above, various alternatives of solution architectures can be developed by combining design rules. In the following, the author discusses dimensions for architecture design. After that, selected ones are introduced.

5.3.1 Focussing on one dimension

5.3.1.1 Views and dimensions for problem access

This work focuses on the explanation of NMP and its complex real-world environment. In this context process steps, functions, and attributes of NMP are described. Furthermore, implications from practice (noise factors) and how to cope with them (control) are examined. However, it is important to note that this is only one dimension to access the problem of *Network Master Planning*. Figure 5.8 illustrates different views on NMP on a general-perspective level.

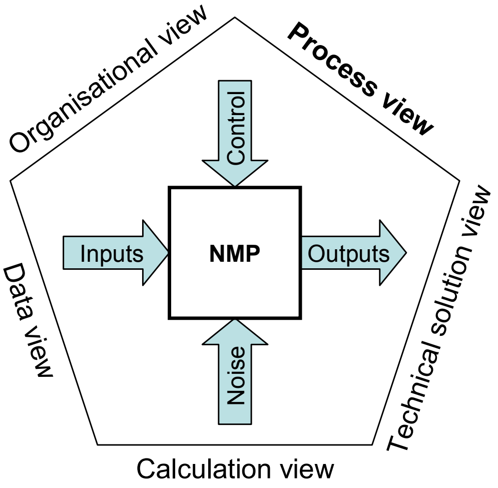


Figure 5.8: Views on NMP

The according dimensions are shown in Table 5.3. The list of dimensions is certainly not complete but gives examples of how NMP could be accessed and what researchers could find interesting to analyse and develop solutions for. Following the clusters given, the main interest of this work lies on the process view; first of all on the 'shared processing,' i.e. an integrated architecture for combined human and tool planning.

Views	Dimensions
Process view	Definition of sub-tasks in planning methodology Shared processing (human ⇔ tool)
Organisational view	Psychological factors in hierarchical, reiterative procedure Persons/departments to involve
Data view	Input data structures (Databases re-design) Responsibilities and procedures for filling of DB (who, when, how)
Calculation view	Detailed cost factor analyses Quantification of non-monetary constraints Cost function creation Heuristics for planning/optimisation
Technical solution view	Software specification and development Interfaces to existing systems for input data Management Information System (visualisation) Fuzzy logic (Artificial Intelligence that utilizes stochastics) Knowledge Management (Expert systems, databases, …) Distributed IT structure (IT networks, agent theories)

Table 5.3: Views and dimensions for problem access

The reason for focussing on the process view originates in the practical observation that this one is of particular importance. In the author's opinion, a sound process and procedure definition builds the base for all other research approaches, because it specifies relevant elements, like actions, planning objects, structures, requirements, or involved persons. Due to this crucial importance of the process view, the other ones are deliberately neglected in this work of research. Nevertheless, further views and dimensions are touched upon, because none of these can be seen completely isolated due to the implications and interconnections between them.

5.3.1.2 Shared processing

The essence of shared-processing is the split of the total planning process into smaller units, namely human actions and automation. This is achieved by combining the two opposite approaches of pure manual processing and complete automation, as shown in Figure 5.9. The displayed pattern of shared processing is only a qualitative example. In fact, there are many ways of designing such a procedure, so-called architectures. 'Architecture' in the context of this work only refers to a methodology-design, not to software systems design, where this term is frequently used. Alternative architectures for shared processing are presented below.

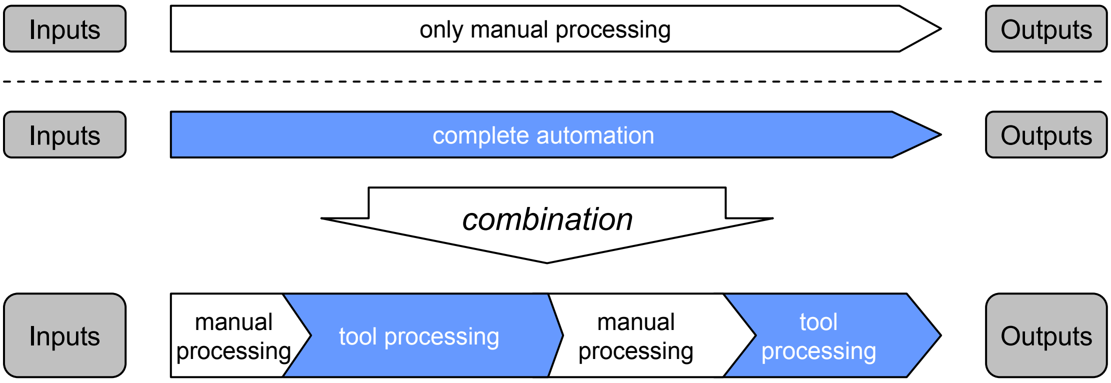


Figure 5.9: Shared processing

5.3.2 Architecture design

5.3.2.1 General architecture alternatives

For the design of the planning procedure different approaches are imaginable. The first alternative, at the automation end of the range, would be a tool that finishes the planning procedure automatically after some manual data-pre-processing (Figure 5.10a). Alternatively, tool-supported planning could exclude some exceptions resulting in reduced effort for manual pre-processing, tool design, and rule formulation for the tool. In this case, e.g. the last 20 per cent of the planning procedure would have to be done manually. So, one could speak of an '80/20' architecture (Figure 5.10b). Alternating manual and tool processing offers the third possibility for planning procedure design. Planning then would be done step by step with individual tool-modules for specific tasks (Figure 5.10c).

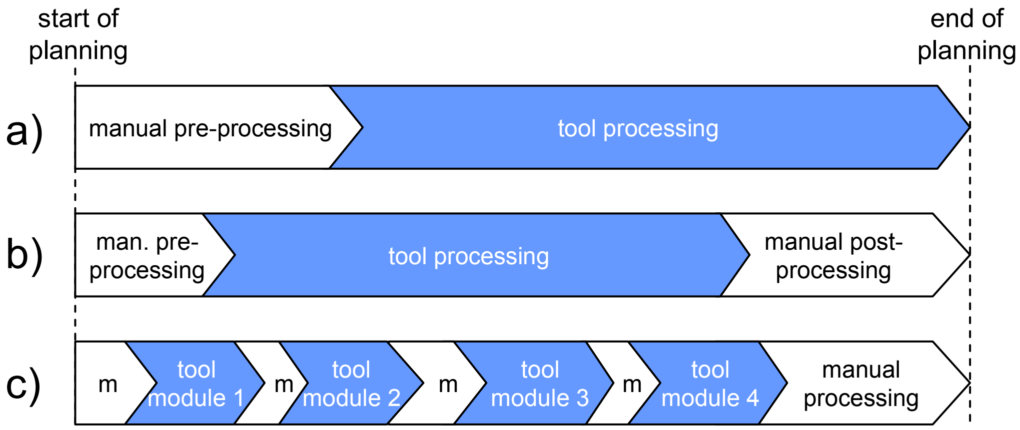


Figure 5.10: Planning procedure architecture alternatives (schematically)

Each architecture type requires taking individual characteristics into account. For a tool-only solution, the methodological focus has to be on the creation and implementation of rules. On the opposite end of the design range, the focus lies on splitting up the planning process into sub-tasks, subsequently designing the consecutive steps and choosing appropriate points for tool support. In the following sections, the characteristics of the three basic approaches are described and advantages and disadvantages of each discussed. Finally, the preferred option is proposed.

5.3.2.2 'One-click' architecture

The idea of a one-click architecture is to create a system that takes over the job of today's planners to a great extent. Planning in such a system could be performed 'on press of a button' by means of 'automatic optimisation' – taking all relevant parameters and constraints into account. Figure 5.11 schematically presents this design idea and the resulting steps for performing the planning.

At the beginning of the planning cycle, demand data and constraints have to be set or updated respectively, and imported into the tool. Based on this data, the tool would perform an optimisation following rules and trying to optimise the result of the objective function. The resulting alternative scenarios are, then, visualised (Principle 10) and have to be compared. Finally, one is selected by the planning team. Optimisation in case of NMP requires heuristics that are capable to handle a high number of planning objects and multi-objective optimisation (see Principles 7 and 9).

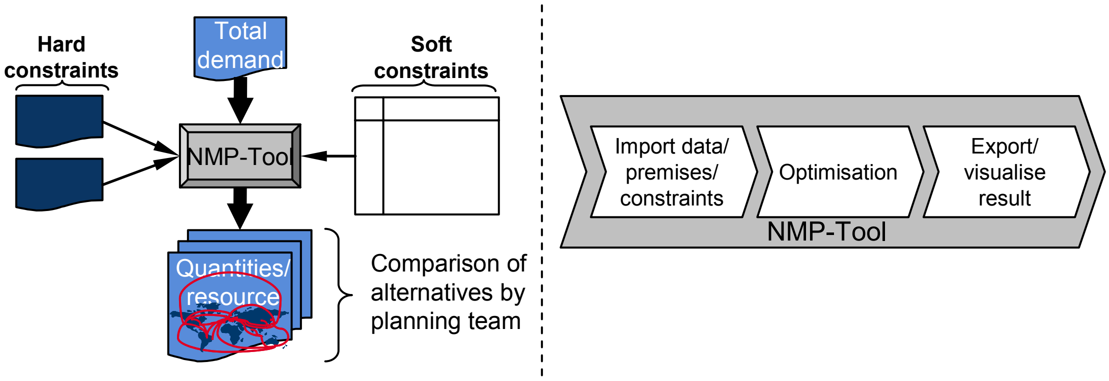


Figure 5.11: Central role of tool in 'one-click' architecture

As mentioned before, in the NMP context complete automation without any human interaction seems impossible (see 4.3). Therefore, even in case of a one-click architecture manual effort is necessary for data preparation and pre-processing, especially for setting or updating constraint rules (see Figure 5.10a and Figure 5.11).

5.3.2.3 '80/20' architecture

The second basic alternative is the aforementioned '80/20' architecture, which is illustrated in Figure 5.10b. The same tool could be used as in the 'one-click' architecture but tool processing stops at a certain point in the planning process, excluding by definition those constraints and exceptional cases that are hard to implement. These last 20 per cent are handled flexibly by an experienced planner. The objective is to create a fast 80-per-cent solution as basis for manual planning and not to wait for a 100-per-cent solution generated in a lengthy, reiterative process. According to Principles 5 and 6, in order to reduce the number of reiterative cycles and thus save time, outputs, i.e. preliminary results of tool processing, and not inputs are varied to achieve a desired result.

Using this approach, particular attention has to be paid to the integrated tool-design, which allows a smooth transition at the interface from tool to manual processing. Furthermore, it has to be ensured that a good preliminary tool-plan is not interfered with or bungled by following manual post-processing. This can be realised by monitoring the 'quality' of the preliminary results throughout the process of human actions (Principle 10). The benefit of the '80/20' architecture lies in a reduced number of rules that have to be formulated for tool-processing. Therefore, the total effort for manual data-pre-processing decreases.

5.3.2.4 Consecutive architecture

Building blocks of the consecutive architecture are small units of manual or tool processing that represent independent entities. These can be used as stand-alone modules that are, nevertheless, aligned to each other (Principle 1) and fully integrated in a top-level methodology (Figure 5.10c). While the aforementioned two architectures of ‘one-click-optimisation’ and ’80/20-planning’ try to implement all process steps in a mainly automated tool, a consecutive architecture takes an opposite approach. It only automates those steps of the process that promise to be used with reasonable effort and show real advantage to human processing, e.g. number crunching for large amounts of data (Principle 4). On the other hand, a consecutive approach strongly focuses on a holistic methodology integrating all planning steps, i.e. also those of data pre- and post-processing (Principle 1). The objectives are to cover the whole range of direct and indirect related tasks to create a common perspective and understanding and to reduce interface losses.

The decision about automating individual process-steps depends on the context of the planning task in question. As a general guideline may serve to automate only those process steps where routine work can be taken away from the planner. Similar to the ’80/20’ architecture, constraint areas that are hard to implement and process steps requiring decisions about new situations are left to manual planning by an experienced planner (Principle 3).

5.3.2.5 Comparison of architecture alternatives

After presenting three basic architectures how NMP could be approached, advantages and disadvantages of each are now more closely inspected to identify the preferred solution. The insights presented in this section have not only been developed from a theoretical point of view but did mainly result from the action research phase based on tool-implementation (see 2.3). The way of gaining knowledge and the observations made are presented in chapter 6.

Though the concept of automatic optimisation in general promises the best support possible for the planner by taking over all planning tasks, it seems not applicable to the complex situation of NMP in practice. Because all eventualities for the high number of constraints have to be covered by rules, the amount of the manual effort for formulating rules and setting constraints must not be underestimated. Furthermore, emerging constraints can make it impossible to fix the complete set of rules prior to planning. Last but not least, not all constraints can be formulated 'water-proof' with reasonable effort or need to be subject to flexible human decision (Principle 3).

The fact that the set of rules necessary for tool processing cannot be created completely in advance does also have an impact on an '80/20' architecture. In case of changing or emerging constraints or vanishing solution space (Principle 9), constraints have to be adapted after tool-processing. In effect, the complete tool-processing has to be run multiple times, with an immense effect on the total time for planning. To avoid the trap of never-ending planning cycles, possibilities for shorter feedback and cross-checking cycles have to be generated (Principle 6).

According to observations in practice (see chapter 4), statements from planners (see chapter 6), as well as statements in literature (e.g. Correll and Edson 1990, in: Adenso-Diaz and Laguna 2001), a consecutive architecture is found to be most appropriate to NMP requirements. Proceeding step-by-step and leaving crucial decisions to a human expert rather than relying on a mathematical model provide the flexibility required (Principles 3, 4). Looking at the consecutive architecture illustrated in Figure 5.10c, it becomes obvious that the need for designing an integrated package of planning methodology and planning tool to ensure a smooth transition between steps is even greater than in the '80/20' architecture.

Especially in the context of a hierarchical planning-environment with a central entity and decentralised lead-plants, as shown in 4.2.1, a consecutive approach can improve efficiency because defined and standardised tasks can be allocated to the correlating responsibilities (Principle 2). In this context, the increased effort for coordination can be compensated by the reduced complexity of the system and the decisions to make. Considering the above given reasons, the author suggests a consecutive architecture as the route to follow for NMP. Table 5.4 shows a summary on which principles are covered by the presented architecture alternatives.

Principle **Architecture**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
One-click	-	O	-	-	-	O	X	X	O	X
80/20	-	O	O	O	X	O	X	X	X	X
Consecutive	X	X	X	X	X	X	X	X	X	X
Key: '-' not covered 'O' partly covered 'X' fully covered										

Table 5.4: Comparison of principles covered by architecture alternatives

5.3.2.6 Scope and focus of chosen approach

When assessing the alternative architectures, it became apparent that a flexible planning methodology with integrated tool-support alone is not sufficient. Expanding the scope of consideration to adjacent fields that were not initially seen as directly related to NMP, simplifies the task of NMP rather than making it more complex. For example, extensive data-pre-processing is only necessary due to historically grown structures and relations. Thus, additional benefits can be achieved when including these fields in NMP research thinking and methodology development. By means of a holistic approach, NMP processing in practice can be improved (Principle 1).

The ‘80/20’ and the ‘one-click’ architectures as tool-centred approaches clearly focus on supporting solely the core process. ‘Periphery processes,’ i.e. all others than fine planning, are not explicitly integrated in the architecture and have to be handled ‘somehow’ manually. In contrast, a consecutive architecture can easily be expanded to the whole process-chain, as illustrated in Figure 5.12.

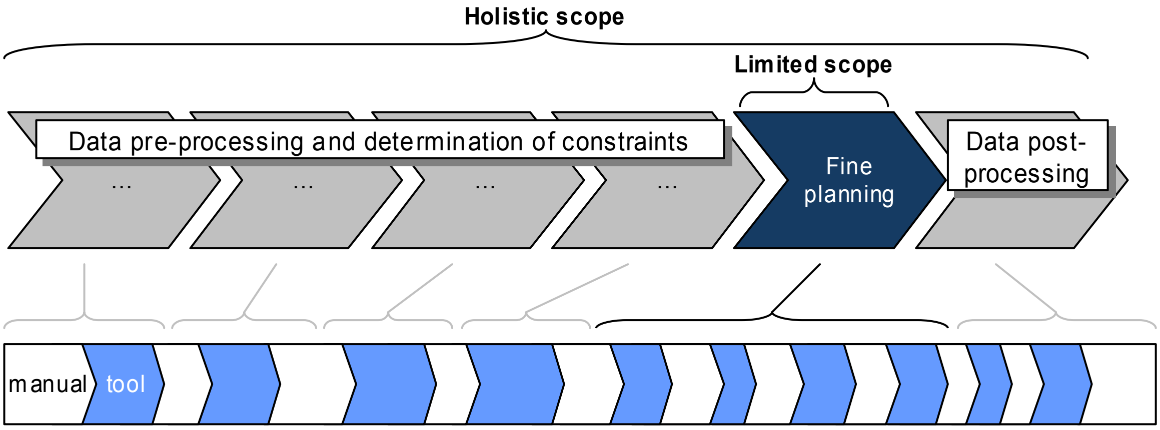


Figure 5.12: Expanded scope of work

5.4 Development of a planning methodology

Based on the traditional as-is planning-process, as described in section 4.2.2 and the derived principles, design rules, and architecture, this section presents the to-be NMP procedure. The development process and the research observations, which built the basis for the emergence of knowledge, are portrayed in chapter 6.

5.4.1 Overview of NMP steps

Figure 5.13 shows an overview of NMP planning steps. Compared to the as-is situation, the step headings are similar, but the changes can be found beneath the surface. It is important to note that the steps and concepts presented below are final versions of an evolutionary process that is described in detail in chapter 6. A summarising table that illustrates inputs, outputs, and responsibilities for each process-step can be found in Appendix B.

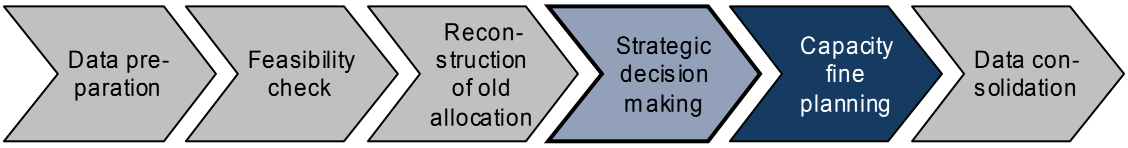


Figure 5.13: Overview of NMP steps

5.4.2 Detail step design

5.4.2.1 Data collection and preparation

As in the actual situation (see 4.2.2.4), a data preparation phase initiates the planning cycle. Because NMP is done for individual products (see 4.3.3.2), the total demand volume from Market and Sales Planning (MSP) has to be split up according to individual products. Furthermore, plausibility checks are conducted in order to discover corrupted data and ensure data reliability prior to planning.

In contrast to the traditional procedure, the to-be process step of data-preparation does not include formatting input data by inserting additional columns or renaming existing ones. This aspect is to be covered by actions concerning data structure re-design as well as by actively transferring responsibility for data validity to those departments that create the data.

5.4.2.2 Feasibility check

To check the feasibility of demand satisfaction in total, planning starts with a comparison of total customer demand and cumulated capacity supply of the production network. Technical capabilities of production lines and customer releases are not taken into account in this first step. In case that capacity shortages for certain planning periods are revealed already in this phase, it is necessary to communicate this directly to the appropriate level of hierarchy (Principle 6). Only then, possibilities of capacity expansion can be discussed and corresponding actions initiated at an early stage.

Generally, it is intended to supply customers from a site located in their geographical region. The second step in planning, therefore, splits the demand of the product group in question into delivery regions according to the triads Asia-Pacific (APA), America (AME), and Europe (EUR). Subsequently, a capacity check is performed for the individual regions by comparing region-specific customer demands and site capacities. Capacity shortages within one region can be eliminated either by investment in additional resources in that region, relocation of resources, or supplying the customer from another region. Information derived from capacity checking build the basis for decisions about the allocation of production quantities to sites within the regions.

5.4.2.3 Reconstruction of old allocation

In a next step, the customer demands are distributed according to the assignment of part-numbers to network sites of the previous planning cycle. The objective is to get an overview of capacity utilisation at the single sites, i.e. identifying resources that make it necessary to leave the pattern of the previous cycle. Furthermore, analyses referring to the demand developments of individual customers enable the planner to get a sense for the changes needed.

The comparison of current numbers for product varieties with those of the previous planning cycle helps to gain an overview of changes in the demand situation and allows estimation to what degree the allocation of single part-numbers can be kept. Currently, this comparison is accomplished manually by cross-checking *Excel* tables. In the to-be status, tool support is to be provided too.

5.4.2.4 Strategic decision making

In the fourth planning step, more strategic decisions are made. On the one hand, these refer to the aforementioned reactions to capacity shortages or overcapacity. Furthermore, the preferred total-production quantities and resulting load factors for each site in the network are negotiated by the NCU and the representatives of the single plants. For example, in the analysed case the objective is to achieve maximum load for the low-cost locations (LCL) and equally-distributed utilisation for the high-cost locations (HCL). For a first quick overview, capabilities of production lines for individual product generations and customer releases are disregarded. This step builds the basis for the aforementioned negotiations but is likely to be inaccurate. Therefore, it is advantageous to perform the step on a more detailed level after the first negotiations, taking capacities and customer releases into account. In case that the subsequent step of fine planning cannot achieve strategic constraints under the given conditions, constraints have to be reconsidered. By this, a reiterative process is initiated, which may be necessary to run several times to achieve a valid production program. The detail procedure of fine planning is presented in the following.

5.4.2.5 Capacity fine planning

In general, this planning activity finds its theoretical basis in rolling-planning-horizon theory (see 3.1.6.3). Therefore, the planning activity cannot be separated into independent jobs but is continuous over time. It is organised in such a way that plans for several future planning periods are created. Plans for the near future are fixed, while those for the long term are still tentative. According to this theory, each new planning cycle starts with the updating of figures and a revision of plans of the previous cycle (Waters 2003). Figure 5.14 gives an overview of capacity fine planning.

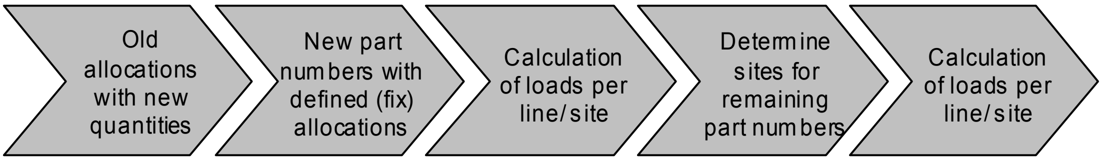


Figure 5.14: Capacity fine planning: steps in detail

Statements regarding the capacity situation of the sites can only be made after a preliminary capacity-planning based on the existing releases. For this planning step, the allocation relations of the previous planning cycle are used, but demands are adjusted to the current sales quantities. The reason for sticking to the previous allocation scheme is to have a certain stability in the production programs of the individual sites. Furthermore, the complexity and effort for planning that starts from zero are much higher than those for adaptation. In case that no solution can be found with the configuration given, the inherited allocations have to be modified in the further planning process.

To begin with, planning is conducted against unlimited capacities. Additionally to ‘old’ part-numbers, newly added items with defined releases can be directly allocated, too. In case of multiple customer releases for a new part-number, the start of production for that product is assigned to only one production line. This means that in the first periods only one release is used. This first allocation gives an impression of the load situation at the individual sites. Due to maximum capacities being disregarded, the load factors can exceed feasible values. In this case, the planning process has to jump back to strategic-decision-making to determine capacity expansion. Otherwise, the allocation of the remaining end-items that do not have customer releases yet, can start based on these load factors. Taking the technical capabilities of the sites into account, for each item a preliminary production location is defined. To finalise the allocation process, confirmed customer releases are required (see 4.2.2.3 for procedure).

5.4.2.6 Data consolidation

After allocation, the plans for the individual products are consolidated and numbers are aggregated. Consolidated numbers serve, for instance, as top-level management information.

5.4.3 Tool support in an NMP architecture

After the presentation of principles, design rules, a proposed NMP architecture and a methodology, the question of useful tool-support is discussed. Since the individual arguments have been introduced in the previous sections, the requirements for integrated tool support are only summarised. Subsequently, the author suggests which steps of the methodology can or should be supported by tools and which should be left subject to human planning.

5.4.3.1 Requirements for integrated tool support

The most vital requirement for tool support in a planning methodology does not refer to tool characteristics but to data and processes. In general, prior to developing tool modules of any kind, one has to define the scope and task for every process-step in sufficient detail. This includes and has to focus on types, structure, and – last but not least – data formats of inputs and outputs at the interfaces between the individual steps. This was done in the previous section (5.4.2).

A design task not to underestimate is the smooth transition between tool and manual steps in planning. Transparent and comprehensible actions contribute directly to increased acceptance by the planning persons and enable the planner to proceed easily with interim tool-step results.

5.4.3.2 For which process steps to build tool modules

Developing and implementing tool modules should not be an end-in-itself, in the sense of automating everything that can be automated in some way. However, the top-most objective of every tool-module must be best possible complementation of a soundly developed architecture. Therefore, tool-modules are to be developed for those process steps where the specific characteristics of computer-based planning contribute most. Examples are the processing of calculations on a big amount of data, sorting or filtering of data according to different rules, or the visualising of results that enable the user to select criteria, e.g. degree of detail, in displaying capacity.

When designing a planning architecture with integrated tool support, the brain has to be located in front of the computer (Mourits and Evers 1995). Thus, process steps requiring human ingenuity, flexibility, and case-based expert knowledge should not be implemented in a tool indeed for that reason fix rules cannot be formulated.

5.4.3.3 Starting points for tool support in NMP architecture

Database management and data preparation

First, database management can be supported by definition of standard formats, data structures, and, in general, information necessary for end-items and production resources. An integrated system is, first of all, necessary to have access to data for more than one planning cycle and to transfer data between cycles. The big challenge here lies in the management of change, speaking in terms of new part-numbers or changes in product classifications, structures, and identifiers. Thus, an integrated system also simplifies the reconstruction of data from a previous planning cycle.

Feasibility checks

Next, feasibility checks can be supported by providing standard visualisations of predicted and actual customer demands as well as ADRs (see 3.3.3.2), and of the capacity situation. An example is shown in section 5.2.11.

Strategic decision making

For the strategic allocation of production quantities, tool-support is mainly needed for fast ‘what if’ analyses. As described in section 4.2.2.4, strategic allocation does not take technical capabilities or customer releases into account under current conditions. Thus, the aforementioned visualisations of capacity-and-demand-comparison can also be used for strategic allocation. Taking the discussion one step further, to reduce the number of necessary feedback cycles caused by infeasible strategic plans that neglected constraints, a tool that helps to consider various constraints already at that stage would improve the situation. Chapter 6 discusses this issue.

Capacity fine planning

Fine planning can be supported by providing a tool that allots end-items to resources taking clearly definable, fixed constraints into account. Therefore, taking away large calculations from human experts is the greatest benefit of a tool at this step. Tool designs applicable for this kind of task will be discussed in chapter 6. Furthermore, tool support is helpful for copying data – like planning parameters or certain constraints – from one planning period to the other, not having to type in one set of data multiple times.

5.5 Conclusion

How to derive principles?

Based on knowledge gained from literature review and discussions with experts in the field of mid-term capacity planning at BOSCH, the author developed different solution-principles and architectures in various level of detail. Testing ideas, approaches, and tool prototypes in a real-world planning-environment in co-operation with experienced practitioners allowed comparisons of results with those of traditional planning. An essential point is that principles were not only derived at one point but were developed, adjusted, or dismissed in favour of others over time.

What solution principles were derived?

In the course of the research project, the author derived the below-listed solution principles. These represent guidelines for NMP methodology-thinking and enable – after translating them into design rules – to design an appropriate solution architecture.

- Use a holistic procedure.
- Use standardised, robust processes.
- Keep procedure flexible.
- Combine the strengths of human and tool planning.
- Vary outputs, not inputs.
- Provide planning results fast.
- Allow high level of detail.
- Plan virtual production lines.
- Allow multi-objective planning.
- Visualise.

What methodology architecture is chosen?

A consecutive approach is the proposed solution-architecture for performing NMP (see 5.3.2.5). The individual methodology steps are illustrated in Figure 5.15. Characteristics of the consecutive architecture are listed below:

- Fits the context of a hierarchical planning environment.
- Individual, standardised tasks are assigned to the appropriate facilities.
- Proceeds step-by-step.
- Leaves decisions regarding new situations to the planner, not a mathematical model.
- Provides the flexibility required for emerging and changing constraints.
- Integrates package of planning methodology and tool-modules; and
- Provides smooth transition between steps.

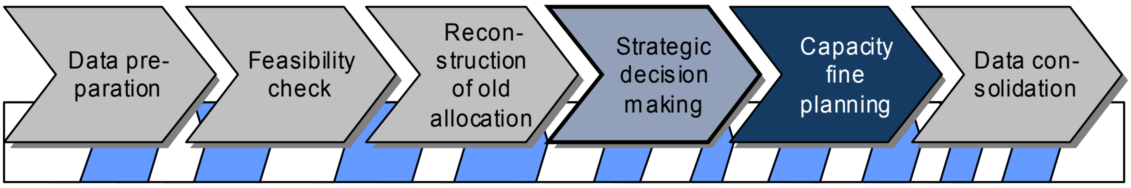


Figure 5.15: Methodology architecture and planning steps

6 Knowledge development through implementation of concepts

Within this chapter, the author investigates how the proposed NMP concepts behave when incorporated into real-world planning. The observations and reflections from specifying and using integrated tool-modules, which are based on the proposed concepts, are presented. The tool-modules allow validating these concepts. The author presents that some of the specified tool modules were developed and are usable in practice.

6.1 Using a real-life environment to gain knowledge

Apart from a literature review, which is presented in chapter 3, the author used a real-life environment to gain knowledge about the complex situation of NMP and about the appropriateness of proposed concepts, including principles, design rules, and architecture elements.

Section 6.1 presents some fundamentals on tools in research and the context for their implementation. Section 6.2 specifies the design of tool-modules based on principles and design rules, and further requirements of a real *Network Master Planning* environment. Furthermore, observations made during tool-development are described. Observations from methodology and tool use as well as a discussion of the appropriateness and reasonableness of NMP principles can be found in section 6.3.

6.1.1 Research data collection & analysis

The strategy of action research by tool-implementation was chosen as the way to develop theories on an approach not yet existing in the company, because it promised more valuable feedback than theoretical testing by, for instance, asking practitioners to attend a seminar or to observe the researcher using the tool in a demonstration (for a description of researcher's and practitioners' actions see also 4.1.2). Research data collection and analysis were done by incorporating proposed principles plus design rules and testing them in an actual work-environment. The methodology and the tools presented in this chapter represent building blocks of a solution that has some basic ideas, principles, and design rules implemented. It is highly unlikely that each building block is the best solution possible to the problem at hand, because developing the optimal solution to each particular or specific problem is not the objective of the research.

6.1.1.1 The use of tools in research in general

By evaluating tools, the researcher better understands principles that drove the design of the tool. Furthermore, evidence can be gained that improved principles enhance the performance of the system (see also Cagliano et al. 2005). In addition, by implementing tools the researcher is active as an external helper to the clients, which, in turn, enables them to inquire into their own situation and actually develop solutions (Coughlan and Coghlan 2002).

6.1.1.2 The concrete case

Based on the actual problems of a BOSCH division planning-department, a thorough investigation of the planning process and the sources of complexity was conducted. The planning department in question is responsible for a planning-environment of 18 product classes that consists of more than 15,000 end-items and 17 world-wide distributed production sites.

The research process was organized through a series of on-site visits that took place between October 2003 and July 2005 in two BOSCH plants. Practitioners provided insights in the situation and by this into new contents. The researcher had both the role of supporting the individual activities and observing the process in order to gather information relevant for the research. Each on-site visit had been planned and documented, trying to capture all the possible contributions – to research for this dissertation plus, perhaps, further academic work – from the field experience.

During the research project, different routes were followed to access the unusual situation of NMP. In expert interviews, workshops, and cases, the author checked hypotheses against practice and practitioner knowledge and adjusted them, if necessary. At the beginning of the project, interviews with experienced practitioners helped to get a basic understanding for the subject. Further, interviews and workshops during the project allowed to test hypotheses and get direct feedback. Subsequently, in a phase of concept design these hypotheses were used to derive solution concepts in order to unlock some of the problems observed in as-is planning situations. The data-collection process included the development of tool-modules and their testing in an actual work environment. Therefore, in course of the research project different approaches for a methodology as well as supporting tool-modules have been developed and tested parallel to traditional manual planning. The action-research process was constituted by performing the steps of tool-module development, concept implementation, and the consolidation of the observations made during these phases (see 2.2.2).

6.1.2 The products, production networks, and customer situation

During the initial interview and analysis phase, the author conducted a general investigation of the characteristics of production networks within BOSCH. In this context, a workshop with participants from different business divisions took place to elicit characteristics of NMP and to get first impressions of what works incorrectly in NMP. To address the most challenging conditions, the researcher decided to focus on the business division *Diesel Systems* for further work. In the course of the research project, the researcher facilitated three planning cycles for the products described in the following were (see 2.3.1).

6.1.2.1 BOSCH Common Rail System

The BOSCH Common Rail System (CRS), which is schematically depicted in Figure 6.1, sets the context for the research work. *Common Rail* direct fuel-injection is a modern variant of direct fuel-injection system for Diesel engines and can be found in many passenger cars as well as trucks these days. It features a high-pressure, i.e. more than 1000 bar pump (CP) and a common fuel-rail feeding individual solenoid valves for each cylinder of the engine, as opposed to low-pressure fuel-pumps that feed pump-nozzles or high-pressure fuel line to mechanical valves controlled by cams on the camshaft. Current common rail diesel systems (3rd generation, CRS3) feature piezo-injectors with fuel pressures up to 1800 bar for even greater accuracy.

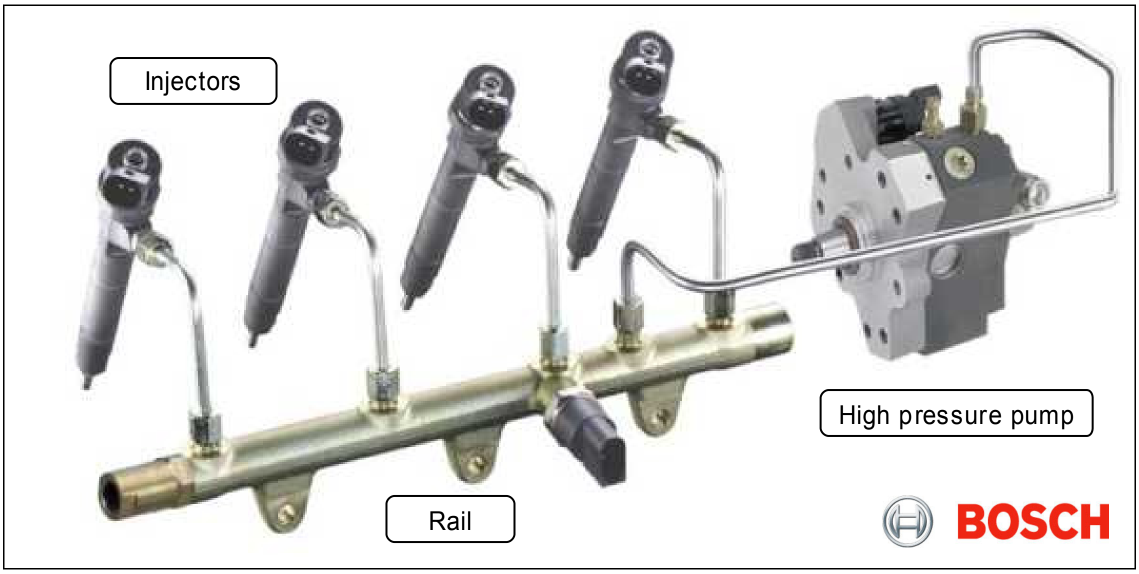


Figure 6.1: Common Rail System – Overview (BOSCH 2005g)

Solenoid or piezo valves make possible accurate electronic control over injection time and amount. The high pressure provides better fuel atomisation. In order to lower engine noise, a small pilot amount of fuel can be injected just before the main load, effectively reducing its explosiveness; some advanced common rail fuel systems perform as many as five injections per stroke.

6.1.2.2 Products selected

To understand and analyse the unusual situation of NMP, two CRS products have been chosen as representatives: a Common Rail High Pressure Pump (CP) and a Common Rail Injector (CRI).

The CP was selected initially as first product in focus, because of another analysis that had already been started at the beginning of this research project. Furthermore, the corresponding production network promised to be a good object of study, because it offers insights in all relevant aspects of planning but has a limited degree of complexity at the same time. The CRI was selected as the second object for analysis, because it provides the most complex situation in the analysed context, not only in regard of the number of product varieties and production resources, but also because of the time-variability of the production network design.

Although CP and CRI are two specific products with specific production networks, they are not unusual or unique. As described earlier in this document (see 4.2), manufacturers of high-volume, multi-variant products that act globally all face the problem of how to assign end-item quantities to individual resources in a network. There may be different characteristics or conditions to individual products but every manufacturer faces the same basic challenge regarding allocation.

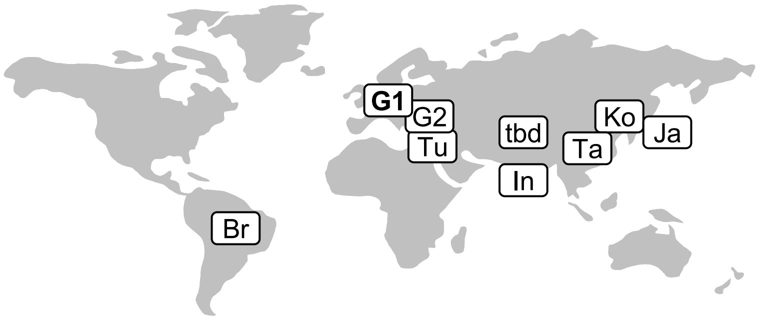
6.1.2.3 Product scope

To provide a better understanding, some numbers on the products in focus are given. The total set of *Diesel* products spans more than 15,000 products which have to be coordinated and allocated to 17 production sites in the corresponding networks. The product CP comprises roughly 250 product variants, i.e. end-item part-numbers, and CRI more than 300.

6.1.2.4 The networks

The CP production network consists of five production sites with in total more than 10 production lines. The corresponding production network for CRI at the time of the research project consisted of nine sites with in total more than 25 production lines – starting up one additional site was in discussion at higher hierarchy levels. Figure 6.2

shows the CRI production network. The production sites are coordinated by the lead-plant, which is located in Germany.



G1	Germany 1 (Lead Plant)
G2	Germany 2
Br	Brazil
In	India
Ja	Japan
Ko	Korea
Ta	Thailand
Tu	Turkey
tbd	To be defined

Figure 6.2: CRI production network

The fundamentals of intra-organisational production networks which make NMP what it is (see chapter 4) can be observed in BOSCH practice, as outlined in the task description of the central coordination-unit (BOSCH 2005e) and as stated by practitioners at a BOSCH-wide logistics meeting (BOSCH 2005f). The fundamental statements are:

- Work is shared between plants for reasons of avoiding buying new capacity or for reasons of avoiding redundancy.
- The network co-ordinator has a stated interest in managing cost-efficiency across the whole vertically-integrated supply chain.
- Some work is interchangeable in the network, i.e. there are resources at different locations with the same capabilities.

6.1.2.5 Customers and planning environment

Customers for CP and CRI products are vehicle manufacturers all over the world. The range goes from high-volume companies to manufacturers with only a small demand.

Besides the company-internal fundamentals, the environmental factors implying on NMP also could be observed in practice. The condition of volatile demand resulting from customer order behaviour, which has been introduced in section 4.3.4.3, has been derived from original customer demand data in an extensive study within another project (BOSCH 2003).

For getting a sense of how often and how much spontaneous demand changes from customers make alterations to the Network Master Plan necessary, an analysis into the frequency and quantities of *Additional Demand Requests* (ADR) for CP has been conducted. The result is depicted in Figure 6.3.

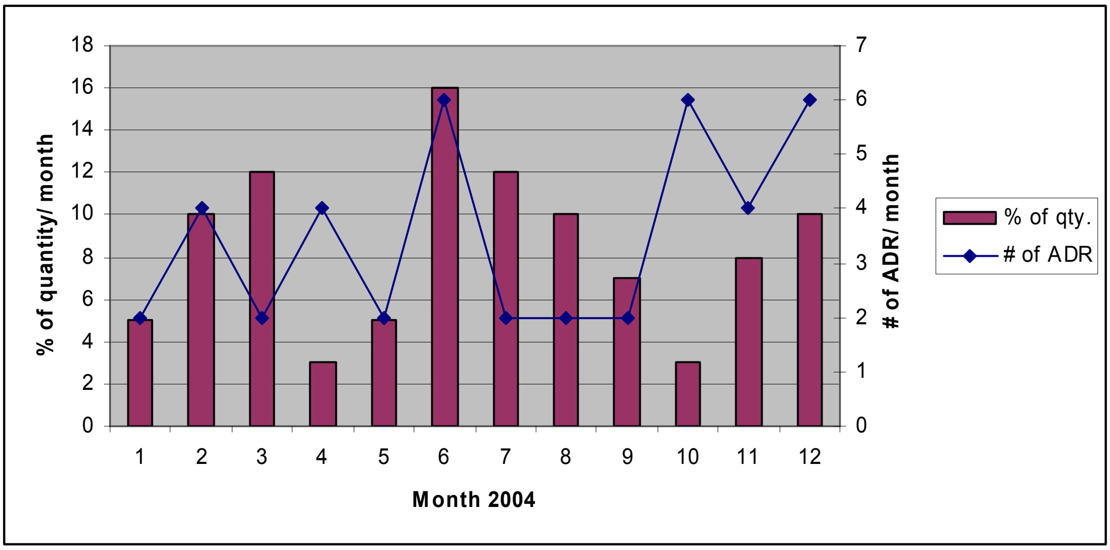


Figure 6.3: ADR distribution over year (exemplarily)

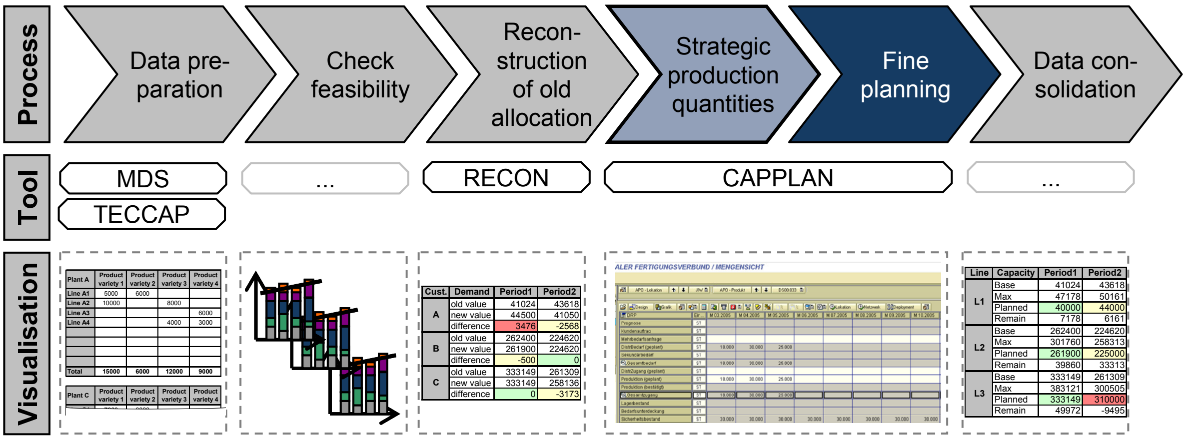
6.2 Specification of integrated tool modules

Based on the requirements and solution concepts formulated in the previous chapters, in this section specifications for tool-modules that are integrated in a holistic methodology are presented. As stated earlier in this work, the term 'tool-module' covers the range from *Excel* sheets to programmed pieces of software. Due to the fact that the specifications are the result of an action research process (see 6.1.1.2), not only the final version of the specifications but also the process of testing ideas in an actual environment and the relevant steps of the accumulation of knowledge that led to these final versions are described.

6.2.1 Tool module overview

In the course of the research work, the focus of 'tool thinking' has changed. At the beginning, the objective was to develop an intelligent optimisation-tool that integrates all decision rules but focuses only on fine-planning. This perspective widened to creating small and easy-to-handle pieces of support that do not need much data preparation but fit in the overall planning procedure. Furthermore, they should help planners to gain insight and a sense for the actual planning cycle, e.g. by analysing the change in numbers compared to the previous cycle. The observations made during the action research process that are described in this chapter largely contributed to this change in perspective. It is important to mention though that the overall objective of tool-development is to specify supportive systems that can be used by decision makers, i.e.

by NMP experts rather than technical computer experts. In Figure 6.4 the plan for an integrated tool-design including example visualisations is illustrated on an approximate level. Reiterative feedback-loops of the process are not depicted.



Plant A	Product variety 1	Product variety 2	Product variety 3	Product variety 4
Line A1	5000	6000		
Line A2	10000		8000	
Line A3				6000
Line A4			4000	3000
Total	15000	6000	12000	9000

Plant C	Product variety 1	Product variety 2	Product variety 3	Product variety 4

Cust.	Demand	Period1	Period2
A	old value	41024	43618
	new value	44500	41050
	difference	3476	-2568
B	old value	262400	224620
	new value	261900	224620
	difference	-500	0
C	old value	333149	261309
	new value	333149	258136
	difference	0	-3173

Line	Capacity	Period1	Period2
L1	Base	41024	43618
	Max	47178	50161
	Planned	40000	44000
	Remain	7178	6161
L2	Base	262400	224620
	Max	301760	258313
	Planned	261900	225000
	Remain	39860	33313
L3	Base	333149	261309
	Max	383121	300505
	Planned	333149	310000
	Remain	49972	-9495

Figure 6.4: Integrated tool modules with example visualisations

The individual tool modules which are described in the following sections are listed in Table 6.1. Each of these sections is clustered according to the same scheme:

- Objective and function of the tool module.
- Inputs, outputs, and interfaces.
- Observations during action research by tool implementation.

Module name	Description
MDS	Master Data Server for product-related data
TECCAP	Technical capacities and capabilities of production resources
RECON	Reconstruction of previous allocation
CAPPLAN	Capacity fine planning

Table 6.1: Tool modules specified

Based on a prioritisation conducted in co-operation with practitioners from the involved company, the tool-modules for the remaining steps of the procedure, e.g. feasibility checks, were only specified on an approximate level but are not directly discussed in this work. However, the observations derived from specification did directly feed the specifications of the tool-modules listed in Table 6.1.

6.2.2 MDS – Master Data Server for product-related data

6.2.2.1 Objective and function of tool module

The objective of the Master Data Server (MDS) is to have one central database for all product related data instead of multiple and proprietary ones. Examples for planning relevant product-related data per part-number are:

- Product generation,
- Product variety,
- Technical product characteristics, e.g. maximum hydraulic pressure,
- Customer-related data, e.g. the engine in which the product goes in, and
- Possible production plants according to customer releases.

6.2.2.2 Inputs, outputs and interfaces

After the re-design of the *Market and Sales Planning* (MSP) database, an interface has to be built to enable the planner to import the list of currently 'active' part-numbers into MDS. The initial filling of MDS with product-related data is to be supported by extracting data from proprietary systems and manually organising and re-structuring the extracted data sets in a standardised way to simplify copying of data into MDS. During the data-preparation phase, manual checks regarding data validity and completeness have to be performed. In case of missing or questionable data, it is necessary to get further input from the appropriate experts.

For the ongoing task of keeping the information up-to-date, an interface to MSP database is necessary to compare the list of part-numbers and import new ones. But in this step for complementing the corresponding data too, human expert knowledge and manual input are required. The outputs of MDS serve as inputs for almost all following steps and tool-modules in the planning procedure. The use of MDS data is, therefore, referred to in the sections of the other tool-modules.

6.2.2.3 Steps in development and related observations

During the research project, an extensive analysis of data structures and scope was conducted. The observations made in this context are listed below:

- The traditional, proprietary systems allowed a high degree of freedom for data format and structures.
- Data was stored decentralised at the single plants.
- There was redundancy in data storage because some data was also stored centrally at the NCU.

- Product attributes were sometimes not available in the systems.
- An overview of end-item-specific customer releases did exist only in incomplete form, distributed over the single production plants and often in form of human expert knowledge.

The researcher's initial proposal to integrate all existing customer-release-information in one separate standardised table was rejected by practitioners for reason of not wanting to keep an additional data source up-to-date. However, consent could be achieved on the need to consolidate and complement the information in one system. In this context, and taking the aforementioned aspects into account, it was decided that one central MDS system should be specified and developed. The actions taken during development are listed below and it is indicated who did the actions (see also 4.1.2):

- Analysing data-structures and capabilities of existing tools (Researcher (R)).
- Redefining necessary data fields and identifiers (R + Practitioners (P)).
- Interviewing practitioners about requirements (R).
- Defining capabilities, formats, in-/outputs and interfaces (R + P).
- Defining responsibilities for data input and administration (R + P).

One of the most important observations during the phases of analysis and specification was that historically grown structures are very persistent, but even if they are questioned, to change the process might not necessarily be given highest priority. This is to say that even if the waste of time and effort for data collection was obvious to the involved persons, this alone did not lead to improvements. A lot of energy was steadily invested to cope with the inappropriate existing systems, instead of once investing the effort in restructuring these. This neglect was not a matter of missing will of the involved planners. They simply did have neither the capacity to perform the restructuring task nor the power to decide about the investment of time and money. As soon as the appropriate priority was acknowledged, restructuring was conducted (for further reading on organisational improvement (*Kaizen*) see also e.g. Brunet and New 2003).

Regarding the problem of the low degree of data consistency between planning cycles, another result of the MDS-definition was that a re-designed MSP-database is urgently needed. Consequently, the specification for this re-design drew sources of many requirements from this research work. A detailed description of MSP-database re-design is not subject of this work. Individual aspects of the MSP-database are described in this work only if they contribute to a better understanding of the other tool-modules.

Besides all positive aspects of having a central MDS system, two basic challenges still exist. The one is that data fidelity heavily depends on other persons who are responsible for the input. The other is that for the long-term perspective there still is the problem of limited data-availability. For example, is it likely that certain attributes of part-numbers starting late in the planning horizon have to be estimated.

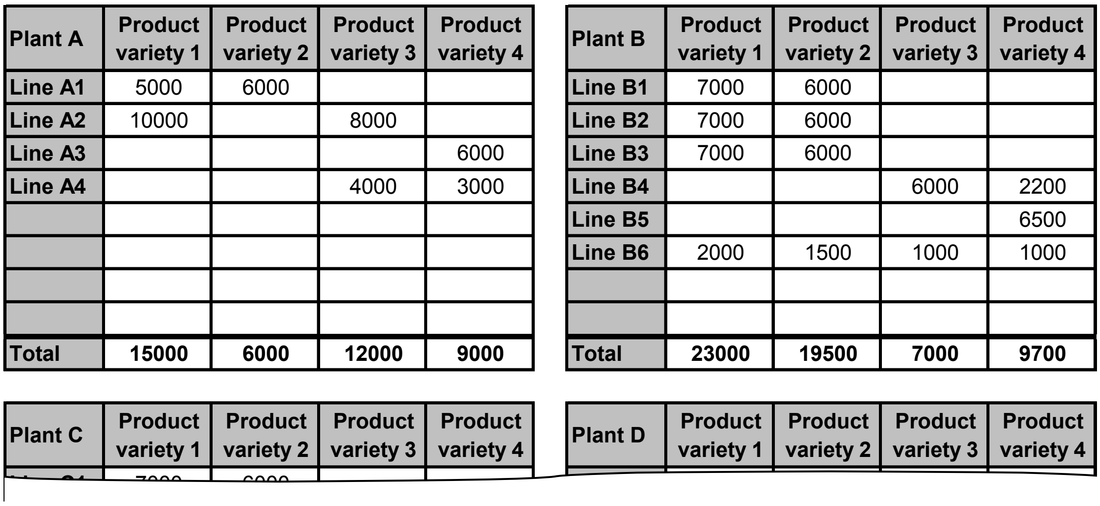
The status of MDS-development at the end of the research project can be summarised as follows:

- The specification as described above served as input for a tender document.
- Currently, the tool-module is under construction in the IT department.
- Rollout of the developed solution is scheduled for 2nd quarter of 2006.

6.2.3 TECCAP – Technical capacities and capabilities

6.2.3.1 Objective and function of tool module

The objective of the TECCAP tool-module is to store production-resources-related data at one place, i.e. capacity supply (TEC) and technical capabilities, referring to the production of individual product varieties. Furthermore, it is to give the planner a fast overview of these two parameters for each resource in the production network. In contrast to the visualisation in traditional planning (see 4.4.2.1) in TECCAP the TEC is presented as per product variety and not as an average quantity. Figure 6.5 shows an example.



Plant A	**Product variety 1**	**Product variety 2**	**Product variety 3**	**Product variety 4**
Line A1	5000	6000		
Line A2	10000		8000	
Line A3				6000
Line A4			4000	3000
Total	**15000**	**6000**	**12000**	**9000**

Plant B	**Product variety 1**	**Product variety 2**	**Product variety 3**	**Product variety 4**
Line B1	7000	6000		
Line B2	7000	6000		
Line B3	7000	6000		
Line B4			6000	2200
Line B5				6500
Line B6	2000	1500	1000	1000
Total	**23000**	**19500**	**7000**	**9700**

Plant C	**Product variety 1**	**Product variety 2**	**Product variety 3**	**Product variety 4**

Plant D	**Product variety 1**	**Product variety 2**	**Product variety 3**	**Product variety 4**

Figure 6.5: Standardised table showing technical capacities and capabilities

6.2.3.2 Inputs, outputs and interfaces

The standardised TECCAP-table is filled with technical data from plants, i.e. each plant delivers the technical capacities and capabilities of its production lines. Coordination and administration of the TECCAP-table is the responsibility of the NCU. The numbers are updated in such a way that the plants notify and transfer updated parameters in case of changes. Additionally, the NCU is requesting updates regularly from the plants. Because the plants have their own, individual computer systems, the project team decided not to develop different interfaces for data input but rely on manual input.

The output of TECCAP is a table with standardised fields and data structure which allows not only the human planner to access this information easily but simplifies data transfer to other tool-modules because they can access the sources via a standardised interface.

6.2.3.3 Steps in development and related observations

Similar to the description of the original status for product-related data in the previous section (6.2.2), the production-resources-related data had no standardised structure throughout the network. Furthermore, especially technical-capabilities-information was partially not in a system at all but existed only as human expert knowledge. This made it quite difficult for the NCU planner to access this information. Assumed the worst case, different sets of information existed in the network – out-dated information at the NCU and actual at the plant in question.

The steps of development for TECCAP are listed below:

- Analysing existing information and data structures,
- Interviewing practitioners about requirements,
- Defining a structure and reviewing this with practitioners,
- Discussing and defining inputs, outputs, and interfaces, and
- Determining responsibilities, especially referring to updating information.

The project team decided against investing effort for implementing TECCAP in *SAP*, because the necessary infrastructure at the time of the research was not given in the production network as a whole. Roll-out plans and a timeline for migrating the proprietary systems in the plants to *SAP* already existed but this migration had not taken place at all sites. Thus, the tool-module described above was developed and implemented for the time being in *Excel* and is currently in use as planning support.

Both, the specification of TECCAP and the experiences made during use, will build the base for integrating the functionality in *SAP* as soon as it is available everywhere in the production network. The tool-module developed during this research project can therefore be seen as a working functional model.

It was observed during discussions with practitioners and live-use of TECCAP that having only one central source for technical capacities and capabilities simplified the planning process. Instead of having to cross-check between multiple tables or even interrupt the data-preparation-process for chasing ‘the’ expert who can make a statement to a certain aspect, this information is now available and regularly updated in TECCAP. Furthermore, TECCAP ensures transparency in the planning base since it allows comparison across the network, most of all in case of redundant resources. The possibility of a common view on the technical parameters was observed to improve discussions and coordination between the involved persons.

In spite of the aforementioned advantages it has to be said that the quality of data and, therefore, the quality of the total planning results heavily depend on the data fidelity of the plants. Therefore, it is a matter of mutual trust. This, naturally, does not depend on the type of system in use – *Excel*, *SAP*, or any other – but is generally valid.

6.2.4 RECON – Reconstruction of data and parameters

6.2.4.1 Objective and function of tool module

This tool-module was specified for the traditional condition and configuration of NMP. The objective was to provide tool-support with simple means for allocation reconstruction, until the re-design and re-launch of MSP and instalment of the MDS were finished (see 6.2.2).

The objective of RECON is to provide planning support in a way that the planning result of the previous cycle can be directly applied on the VPZ-demand numbers of the current planning cycle. This means that if part-number ‘1234’ was assigned to plant A, it is again allocated to this plant, neglecting any TEC limits in this step. The benefit of using this procedure instead of starting each planning cycle with a blank sheet of paper is that the planner gets a sense for changes and trends in customer demand and for the feasibility in the network. In addition, using this approach, a certain continuity in the network is preserved since this initial allocation is used as the starting point for fine planning. In Figure 6.6, the transfer of allocations from one planning cycle to the next via RECON as well as the interaction of human and tool processing are depicted. The function and steps are described below.

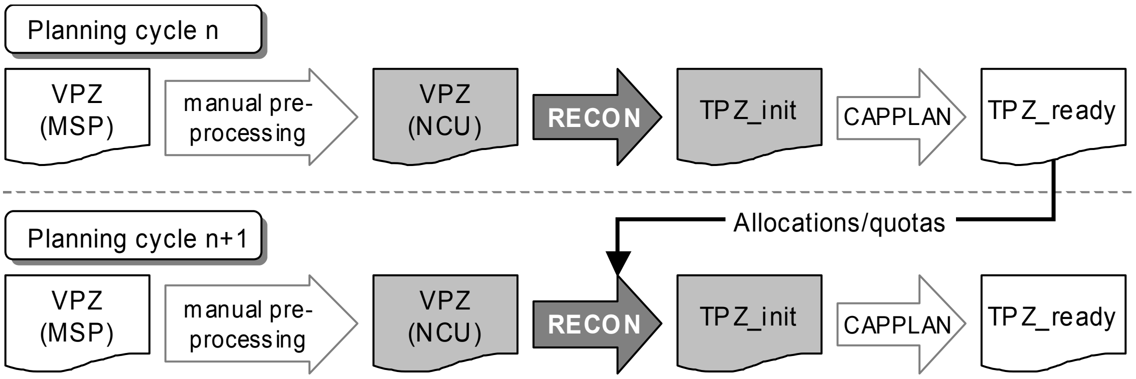
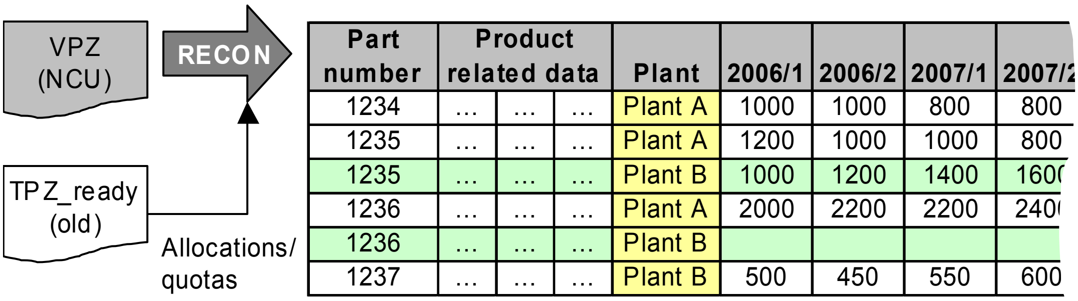


Figure 6.6: RECON – Procedure overview

Data sets of previous and current planning cycles are compared using an identifier with the objective to find the corresponding items. A simple comparison of part-numbers is inadequate because these can change between two planning cycles, especially in the case of preliminary part-numbers (see 4.5.1.1). In case the identifier matches, the plant assignments are copied from old TPZ in new VPZ (additional column). From this step on, the VPZ (NCU) is called 'TPZ_init'. In case of parallel releases for a specific end-item (see 4.4.2.2), the key is found multiple times in the old TPZ – allocated to different plants (see part-numbers '1235' and '1236' in Figure 6.7). Therefore, the row has to be duplicated in the TPZ_init, as illustrated in Figure 6.7. For the allocation of quantities in TPZ_init, the planner can choose between two options. Either to let the tool allot the whole production quantity for the specific end-item only to one plant and regard the additional plants as back-up options ('1236') or to distribute the quantity according to the shares of the old allocation ('1235'). In both cases, the following design rules apply:

- Duplicated rows (parallel releases) have to be marked by colour (visualisation).
- Part-numbers that are new in the planning horizon have to be marked by colour.
- Share of allocation distribution has to be calculated for each period individually.
- 'New' periods (rolling planning-horizon) inherit the share factors of the last period.

For additional support by visualisation, the planner can activate additional columns containing the quantities of the previous cycle next to the current values. By this, a direct comparison is possible and the planner can see the development of quantities for each end-item. An exemplary visualisation of TPZ_init is provided in Figure 6.7



Part number	Product related data			Plant	2006/1	2006/2	2007/1	2007/2
1234	…	…	…	Plant A	1000	1000	800	800
1235	…	…	…	Plant A	1200	1000	1000	800
1235	…	…	…	Plant B	1000	1200	1400	1600
1236	…	…	…	Plant A	2000	2200	2200	2400
1236	…	…	…	Plant B				
1237	…	…	…	Plant B	500	450	550	600

Figure 6.7: RECON – TPZ_init as starting point for capacity fine planning

To start the use of RECON, all relevant end-items have to be manually allocated once. In each planning cycle, the allocations are inherited for those end-items that have corresponding data in the previous cycle. Subsequently, missing data has to be added manually. The function and detailed procedure-steps of the RECON tool-module can be found in Appendix B.

6.2.4.2 Inputs, outputs and interfaces

As described above, RECON retrieves the previous end-item allocations from the 'old' TPZ, i.e. the result of the last planning cycle, as well as from current VPZ, i.e. demand data stored in the MSP database. Furthermore, manual input for completion of data is necessary.

The output of RECON is a pre-processed VPZ-table with an additional column for the production-plants and the proposed allocation of end-item quantities. This VPZ table serves subsequently as input for fine-planning.

Since the RECON tool-module in the aforementioned form is a preliminary solution to bridge the time until the launch of re-designed MSP database, it was decided not to develop automated interfaces for data input. Therefore, manual pre-processing is necessary to extract data from the MSP database and arrange it according to a standardised structure so that it can be entered into RECON more easily.

6.2.4.3 Steps in development and related observations

The author observed during development of RECON that it is of vital importance that the human expert is able to develop a sense for the current planning situation prior to fine-planning. Only then he can handle numbers and individual sub-tasks in an efficient way. Interviews with practitioners as well as observations of their actions during planning provided evidence for this claim. Planners performed actions, like conducting Pivot analyses and manual cross-checking, based on their own, previously-developed *Excel* sheets to acquire this sense. Thus, it can be stated that if there is no appropriate support in methodology or tools, too much effort is necessary and human planners' energy is wasted. Therefore, the emphasis must not only be on source-data quality and completeness, but also on 'soft factors' in the planning methodology, i.e. letting the planner acquire the necessary sense for the actual planning situation.

Another observation was that a unique key for planning object-identification is crucial for comparing previous TPZ and current VPZ. However, in the traditional planning and especially in the MSP database no such key existed. For the time being, a key could be constructed by combining three product-characteristic identifiers. To get an impression of the quality and usefulness of data from the existing MSP database, an analysis that refers to consistent data-keeping was conducted. The result was that only 50 to 60 per cent of VPZ planning objects had correlating entities in the VPZ of the next planning cycle. Analysis limited to planning objects that were part of the current production program, i.e. excluding those with later start of production, led to a match-rate of ca. 80 per cent. A selection of reasons for this small degree of data-consistency in the traditional system is listed below:

- Lack of standardisation for applying changes to data – different people have different approaches – hinders tracing of changes.
- When replacing a dummy part-number by a regular one, the old data set is deleted and a new one added.
- Text field formats do not underlie rules but are freely editable.

In summary it can be stated that with the traditional MSP-database, a reconstruction of data is difficult to realise. Due to the lack of standardisation and formal procedures, e.g. for data administration, a high amount of manual effort and experience is necessary for planning. Thus, RECON development contributed directly to specifying requirements for MSP-database re-design and MDS design.

6.2.5 CAPPLAN – Capacity planning

6.2.5.1 Objective and function of tool module

The objective of CAPPLAN is to provide support for the core task of NMP: allocation of specified items to specified resources in the production network, while taking monetary and non-monetary constraints into account. Figure 6.8 provides an overview of its general function.

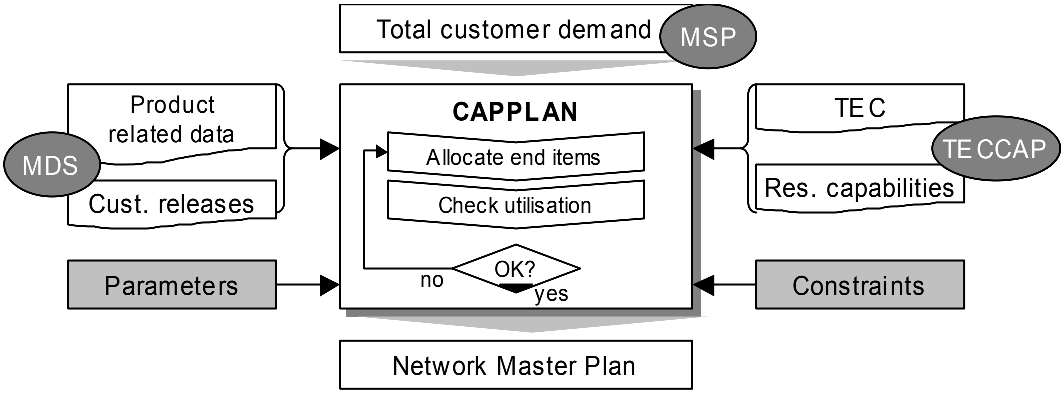


Figure 6.8: CAPPLAN – Function overview

Because the planning steps ‘Strategic decision making’ and ‘Capacity fine planning’ differ mainly in their level of planning detail but have the same basic requirements, the author suggests to support both with CAPPLAN. On a more approximate level, CAPPLAN can support strategic decisions of production quantities per plant by enabling decision makers to conduct *what if*-analyses faster than in traditional planning. When performed in more detail, the tool-module shows its potential to improve fine planning. The detailed step descriptions of these two tasks can be found in section 5.4.

The individual procedure steps for tool-module-supported strategic decision-making and capacity-fine-planning are shown in Figure 6.9. While the first five steps are equivalent, the rest of the procedure differs even if both contain similar elements, like e.g. TEC utilisation check.

The following comments apply to the depicted steps:

- Data preparation, i.e. completion/updating of input data, is to be conducted in the source systems. Only after this data is imported.
- Product-master-data comprises technical information plus customer releases.
- Base-line negotiations are based on feasibility checks (see 5.4.2.2) and rough-cut capacity utilisation calculation.

- Simulative planning is performed by a *capable-to-match* algorithm which generates one possible allocation but does not optimise.
- 'New part-numbers' refers to part-numbers added to the planning horizon since the previous planning cycle.
- Generally, the allocation of part-numbers with parallel releases has the objective of being cost-optimal. However, this is not achieved by an exhaustive, but fault-prone cost function but through loading plants in the sequence of their production-cost-index, which can be relative (see 4.5.1). Thus, this is the only cost component that has to be analysed, which saves time for data-administration.

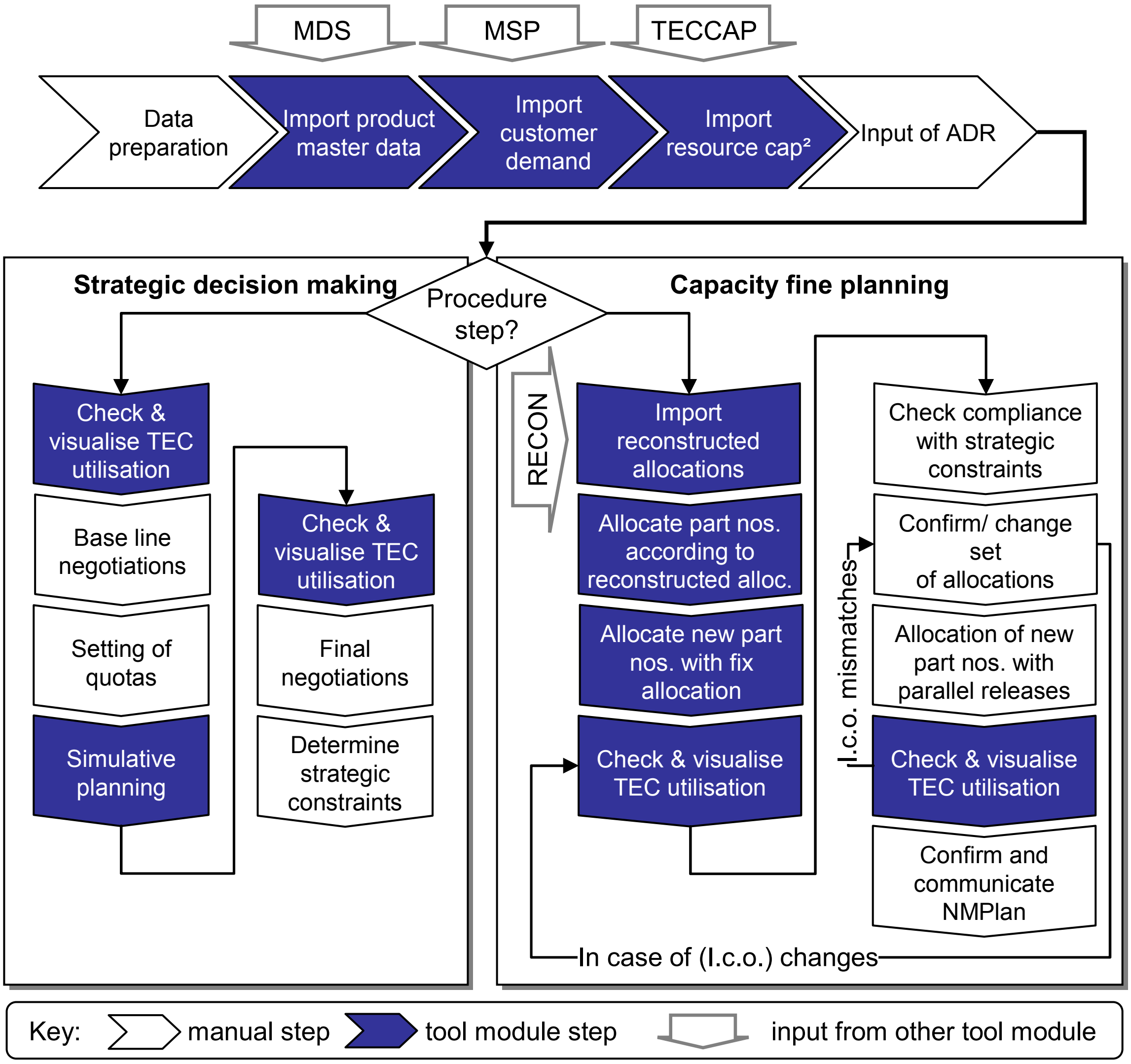


Figure 6.9: CAPPLAN – Procedure overview

6.2.5.2 Inputs, outputs and interfaces

In general, for the two procedure-steps in question one has to differentiate between inputs for the human planner and inputs for the tool-module. As depicted in Figure 6.9, CAPPLAN retrieves information from various sources. These are summarised in Table 6.2. Whereas information from these databases goes directly into the CAPPLAN tool-module, other information, the so-called 'soft facts,' is important for the planners to judge the development of numbers in the right way. Strategic constraints like future site concepts (see 3.1.6) or the results of feasibility checks (see 5.4.2.2) are examples.

Source	Data/ information
Master Data Server (MDS)	Technical product attributes, customer releases per part-number
Market & Sales Planning database (MSP)	Customer demand: actual, confirmed and prognoses
TECCAP	Resource capacities and capabilities (referring to product variety)
RECON	Part-number to resource allocations from previous planning cycle

Table 6.2: Inputs and required interfaces for tool module CAPPLAN

Outputs of CAPPLAN are:

- Alerts in case of missing data, like e.g. customer releases.
- Proposal for allocation of end-item quantities.
- Statements concerning feasibility.
- Reporting on allocation and capacity mismatches, e.g. bottle-necks.

6.2.5.3 Steps in development and related observations

Automatic optimisation

The process of CAPPLAN specification and development started with the objective of the involved practitioners to create an 'automatic optimisation tool', i.e. a tool that provides a 100-per-cent solution on press of a key (see 5.3.2). The basic workflow for this approach is depicted in Figure 6.10

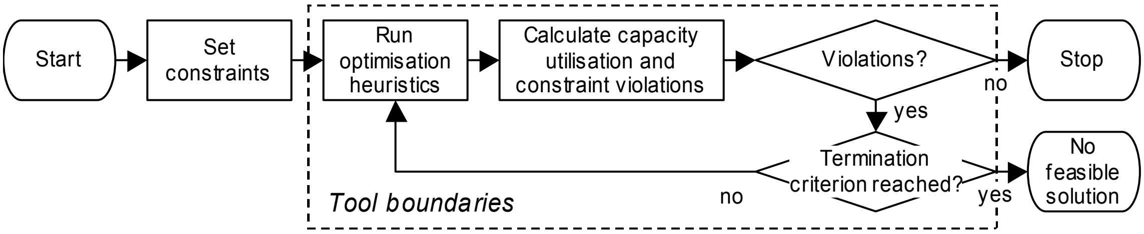


Figure 6.10: Automatic optimisation basic workflow

The following sections present how the initial approach was tested and in which way the approach was changed with growing knowledge about NMP, i.e. which new aspects were introduced and which were dismissed. Furthermore, other approaches that were also considered are discussed.

Genetic Algorithms (GA) were chosen to approach automatic optimisation using GA's core characteristic of being a global search algorithm. This allowed multi-objective optimisation; GA has a diversity-preservation-mechanism built-in that ensures the finding of the optimum in a solution space, regardless of the start-parameters. A short introduction to GA is given in Appendix D. In the following, the work done for developing a GA-based approach is presented.

As a framework, prototype-stages were defined (see Appendix C). Implementation was done by using *Excel* as a user interface and a data-pre-processing-module in combination with the *Tecnomatix* eM-Plant GA-module for optimisation. The researcher did not use simulation features of eM-Plant but the software served for modelling the production network resources. *Excel* post-processed results and provided visualisation. The advantage of this tool combination was seen in the well-known and flexible use of *Excel* (Koutsoukis et al. 2000), which could be supported by the VBA-code combined with easy modelling and automatic optimisation in eM-Plant. In the course of testing GA-prototypes, knowledge emerged about the situation of capacity-fine-planning and ways how to handle it. Observations made in this context are described below.

Reflections on automatic optimisation

First tests of the GA approach brought results that were comparable with those of traditional manual planning and were judged 'promising' by the project partners (see meeting notes in Appendix C). However, the disadvantage of heuristics – and especially of GA – is that convergence speed depends heavily on the design of the system to optimise, i.e. the number of resources and end-items, number of items with parallel releases, and so on. Furthermore, the optimisation parameters that were set influenced the convergence speed. Since quick optimisation is absolutely necessary for an acceptable NMP solution, experiments have been conducted with the objective to determine the optimal set of parameters for a fast convergence (see Appendix C). It was observed that advantageous parameters for individual systems could be determined with some effort. Universal parameters that could guarantee fast convergence for different system designs could not be found. With regard to the practitioners objective of automatic optimisation, this trail nevertheless was followed further – being conscious of the effort necessary for parameter adjustment in case of changes in the system design.

The fact that each planning constraint has to be implemented in the goal function of the GA, further contributed to problem-complexity. This brought, on the one hand, the necessity of prioritisation which posed a problem for practitioners. For the goal-function, fixed priorities had to be defined prior to planning. As opposed to that, in practice constraints are weighed against each other according to the conditions of the specific case. On the other hand, the high number of partly conflicting constraints leads to reduced solution space (see 4.5.2.2), which has a direct effect on the time consumed for optimisation. In the extreme case of vanishing solution space, no feasible solution could be found, at least not with the fixed constraint-priorities that had been defined.

The large number of constraints and rules was not formulated as a complete set at once by practitioners but emerged during the research project. To give an example: one statement often heard from project partners during on-site prototype testing was: “Yes, this is close to the real situation. But I forgot to tell you another rule.” Thus, every time a new constraint emerged, the objective function had to be adapted.

In general, the implementation of constraints raised the problem of how to keep the planning transparent, speaking in terms of visualisation for the user. The two important aspects realised in this context were the possibility to easily create or to activate or deactivate rules as well as the need for making active rules visible. Figure 6.11 illustrates this aspect using the example of the constraint of minimum-utilisation factors per plant. In summary, it can be stated that in the given context the effort for both manual pre-processing and checking and potentially updating of rules at the beginning of each new planning cycle would have exceeded the benefit of the tool support. In effect, the total planning time would have had increased.

BaW	ChW	FeW	JiW	RBKR
70	0	0	70	0

Figure 6.11: User interface for minimum utilisation factors (prototype status)

Another factor contributing to an increase in planning time was observed along with the research finding that resources had to be planned on the level of production lines and not plants (see 5.2.9). With regard to this, the number of resource objects tripled in the analysed case, which caused optimisation time to jump from 30 minutes to nearly four hours for one set of data. Thus, with a growing number of resources, the optimisation time increased disproportionally.

During research, the project group shifted the initial aim to build a tool that 'produces significantly better plans than human planners' to that of 'produces plans faster.' The reason is that even the intelligent algorithm cannot achieve a planning result that is better than manual planning, because the tool applies rules that were all originating from actual human experts planning behaviour. Therefore, the project group decided to put 'saving time' into focus instead of algorithms.

One central finding related to the aforementioned aspects was the realisation that planning could not be done completely by a tool because human experience, ingenuity, and flexibility in balancing objectives are required in NMP. According to the approach described in section 5.3.2.3 some effort was also invested in specifying and testing an '80/20' architecture, leaving those constraints that are hard to implement subject to human planning. This approach yielded good results regarding the general usability and reduced optimisation-time, but it failed, too, in that not all constraints could be defined prior to the planning process or they had to be changed after the first steps had been performed.

Alternative optimisation approaches

Because some authors suggested the use of *Linear Programming* (LP) for the related fields of scheduling and lot-sizing (e.g. Koutsoukis et al. 2000), this approach was analysed and a prototype to support strategic decision-making was developed and tested based on live data. The procedure is shown in Figure 6.12. The result of the LP test was that a general usability for the planning problem in question could be shown, but the limitations and short-comings observed with GA were also valid for LP.

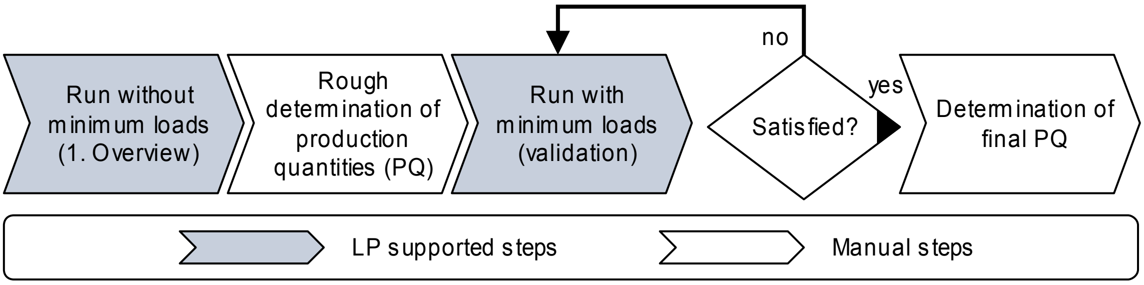


Figure 6.12: Strategic decision making supported by Linear Programming

In the context of the aforementioned results, no further optimisation approaches and heuristics for automatic optimisation were analysed in detail. Other approaches for optimisation e.g. neural networks that use artificial intelligence (Bowersox et al. 2003, Lane 1993), were only given a fleeting look because the researcher came to the conclusion that these were not suitable for NMP. Emerging constraints and the required flexibility for aspects which are not objectively accessible hindered the generation of a reasonable utilisation function.

In summary, the big advantage of human planning in heavily-constrained systems is that experienced planners sense when a plan is getting better, which a tool cannot (see 5.2.5). Even with an objective function comprising a lot of constraints a tool can only calculate fitness and try to minimise or maximise this, but will eventually violate many of the constraints. Therefore, the researcher decided to opt for a consecutive architecture (see 6.2.5.1, also 5.3.2.4), which incorporates tool-modules for supporting the planner in routine work but predominantly relies on human ingenuity.

Final approach

The following paragraphs introduce the finally developed solution. Since the skill and intelligence in tool-building is not the focus and extensive tool-description would go beyond the scope of this research work, the description does focus on the core points. Only that kind of information is provided that is necessary to see the concepts implemented and understand how the tool-module works.

The central IT department of BOSCH specified and realised the implementation of final versions of capacity-fine-planning concepts based on the *SAP-APO*-module *Supply Network Planning* (SNP). The functions realised, the solution principles implemented, and the correlated findings are described below (BOSCH 2005g).

The production network is modelled within SNP by defining resources, supply relations and resource attributes. Import of resource capacities- and capabilities-data is done manually via a standardised interface from TECCAP. Data administration, i.e. updating of attributes, is to happen in the source system. After alterations, the information is to be imported again. In the current state, customer demand figures are imported via an *Excel* flat-file, i.e. information is extracted from the source-system and manually imported into a standardised structure. An interface with the re-designed MSP will be specified later. Product-related data is currently imported via an *Excel* flat-file, too. The specification of a standardised interface for direct import from MDS is in progress. In any case, data is administered in the source-system MDS. For quick analyses, data can also be administrated within CAPPLAN where one does not have to import product- and resource-related data again. But this is not the preferred, standardised working procedure. Constraints are mainly administered in CAPPLAN, i.e. rules are set by selecting parameters or ticking boxes. Some constraints, e.g. minimum utilisation factors, can also be imported via a flat-file interface. All data that is available in CAPPLAN can be analysed in various ways, e.g. by filter, sort, or compare actions, according to the planners' requirements.

A *capable-to-match* (CTM) algorithm allots end-items to resources. CTM uses constraint-based heuristics that conduct multi-site checks of capacities and capabilities based on rules and prioritisations. The aim of a CTM planning-run is to propose a feasible solution for fulfilling the demands. As soon as one is found, CTM stops (SAP 2005). The results of CTM planning are visualised in a standardised form and can be analysed by the planner. In case of constraint violations, such as resource-overloads or under-usages, the planner gets all relevant information displayed by a so-called 'alert monitor,' where he can trace back the violations. As conceptualised in section 5.3.2, after tool planning the planner takes over and finishes planning by 'varying outputs.' It is important to note that he does this within the CAPPLAN planning system, so that the tool is active in the background to track changes, alert about violations, and enable analyses.

6.2.6 Tool module summary

6.2.6.1 NMP concepts are similar but different to usual scheduling concepts

The proposed NMP-methodology and tool-modules use common scheduling-concepts (APICS 1998; Wolfe 2005). These can be found throughout the whole planning methodology and especially in the CAPPLAN tool-module. Calculation of resource-capacity-utilisation builds the decision-basis for each of these scheduling concepts, which are:

- Assigning tasks to a set of resources over time;
- Satisfying constraints by creating feasible schedules;
- Removing bottle-necks and balancing loads; and
- Increasing production efficiency.

Additionally, both methodology and tool-modules incorporate new concepts, which could not be found in the literature – at least not discussed in the context of NMP. These concepts, i.e. principles, design rules, and architecture elements, were introduced and discussed in chapter 5 of this research work. The crucial aspects are:

- Using a holistic procedure.
- Building a consecutive, tool supported sequence of planning.
- Not expecting an algorithm to solve the problem, and
- Not aggregating planning objects.

6.2.6.2 Observations and conclusions from tool module development

Developing and testing a methodology and tool prototypes brought the following observations:

- The concepts proposed in chapter 5 may be built into tool modules directly or the methodology for using the tool-modules.
- Database incompleteness and inconsistencies lead to the situation that CAPPLAN cannot retrieve a complete set of data from other systems. Thus, manual data preparation and completion is necessary.
- New part-numbers, entering the planning horizon in a long-term view, increase the complexity since the planner has to (a) complete the set of data for these items, and (b), plan based on data that is provisional.
- A major disadvantage of highly complex heuristics is that they only work correctly if based on detailed data. In the analysed case, data with the required level of detail are likely to be inaccurate and would partly have to be generated specifically for this purpose.
- Manual planning, i.e. human intelligence, was observed to be absolutely necessary for making decisions and weighting conflicting constraints against each other throughout the whole procedure.
- Emerging variable constraints alone are a strong enough obstacle to hinder completely automated tool processing.
- A real optimisation of the NMP problem is difficult to achieve due to the fact that the “solution space” can be significantly reduced or even eliminated due to the high number of concurrent constraints.

Reflections on these observations led to a set of conclusions:

- It is possible to develop one tool-module for the two tasks of strategic-decision-making and capacity-fine-planning.
- CAPPLAN could also be used for planning critical components and raw material if these are defined accordingly.

- Input data availability and fidelity restricts planning more than technical manageability does. The question of who is responsible to track changes and update information should be more in focus than the question of how to import data.
- Applying the approach of loading low-cost locations (LCL) first as proxy for cost-optimal planning prevents getting stuck in math's and is a different and working strategy for something near-optimal.
- Human experience and flexibility contribute to the improvement of the planning process.

6.2.6.3 General applicability and reasonableness of developed tool solutions

During the tool-module development phase, prototypes incorporating the proposed concepts were tested in different environments. Action-research, based on a single case study was conducted to see if similar results could be found. The observations from the multi-moment analysis of two products allowed confidence in the consistency and robustness of the results and findings.

As mentioned before, the proposed approach and tool-module solutions are not claimed to be optimal. Other ways of realisation are possible. The important point that should be emphasized here is that the proposed concepts of this work were tested in real-life conditions to check their validity. Which concepts were implemented and what was learned is discussed in section 6.3.

6.3 Reflections referring to methodology and tool use

After description of tool-modules and observations made in the context of their development, this section discusses what can be learned from the use of these modules about the unusual situation of NMP and ways to cope with it. This is done by asking general, principle-related questions, e.g. 'looking if principle 3 works in the way it was introduced or needs correction.'

6.3.1 Observations and conclusions

As described earlier, the author tested preliminary ideas (see 6.2) as well as those versions of NMP concepts the research finally led to. The statements below refer to the use of final versions of methodology and tool. 'Final' in this context does not necessarily mean 'self-explanatory' or 'perfectly ready' for the end-user but stable concepts to build further development on.

The following observations have been made:

- The consecutive approach presented in section 5.3.2.4 is not only to be seen on the level of the planning methodology in total but also on level of individual planning steps. Most steps in the NMP procedure contain both manual and tool processing elements which have to be performed consecutively.
- Decision making depends not only on high data availability and quality but also, perhaps even more, on 'soft' factors, e.g. is a system easily understandable and usable for the human expert. This is an expansion of the view stated by many authors (e.g. Koutsoukis et al. 2000).
- A cost-function based tool-advice about installation of new resources provides little help, because strategic directions can change. Therefore, at the beginning of each planning cycle the planner would have to ask the strategic decision makers for the numbers to set before he can 'tick boxes' and start.
- Strategic soft constraints are hard to be handled by a tool, because the *softness*-factor is subject to strategic decisions or current circumstances. Taken the example of 80±5 per cent desired utilisation for a specific plant: a planner knows that 74.8 per cent still are o.k. for a good plan, whereas the tool would deem the solution invalid.
- What was observed during interviews and the testing of first ideas for tools was confirmed during the phase of tool use: human planners need to get a sense for numbers to plan efficiently.
- Tools can support the planner by performing number-crunching or providing standardised visualisation for a faster and easier overview of the situation.

From the above described observations the following conclusions were drawn:

- It is possible to implement NMP concepts in methodology and integrated tool-modules and to get these working.
- Decisions requiring ongoing input which is based on actual information such as strategic decisions lead to a reiterative cycle in hierarchy and should be left in the responsibility of the human planners.
- On the other hand, in order to protect the planner from attaining sub-optimal solutions, tools must actively support the manual process, e.g. by visualisation and the validation of results and assumptions made, if possible.

6.3.2 Reflection on proposed NMP principles

In chapter 5, a set of principles for NMP was proposed. After testing tool-modules which the author specified according to these principles, a summary of their use in the proposed NMP methodology is presented. Further, reflections about the principles' appropriateness for the given situation are discussed. Table 6.3 gives an overview of where the principles are implemented and is followed by a detailed discussion of each principle in the sections below.

Principles	**Implemented in …**
Use a holistic procedure	• Methodology in total
Use standardised, robust processes	• Interaction with others (information sources) • Data structures • All individual steps • MDS, TECCAP, RECON, CAPPLAN
Keep procedure flexible	• Methodology in total (by feedback loops) • All individual steps • TECCAP, CAPPLAN
Combine the strengths of human and tool planning	• Methodology in total • All individual steps • CAPPLAN
Vary outputs not inputs	• Methodology in total • Strategic decision making, Capacity fine planning • CAPPLAN
Provide planning results fast	• Methodology (communication → soft factors) • Feasibility checks, Strategic decision making, Capacity fine planning • CAPPLAN
Allow high level of detail	• Capacity fine planning • MDS, TECCAP, RECON, CAPPLAN
Plan virtual production lines	• TECCAP, CAPPLAN
Allow multi-objective planning	• CAPPLAN
Visualise	• MDS, TECCAP, RECON, CAPPLAN

Table 6.3: Principles implemented in NMP methodology and tool modules

6.3.2.1 Use a holistic procedure

Using a holistic procedure has shown to be necessary to set priorities right for investing effort in process improvement. With the initial scope of the research work being limited to capacity-fine-planning, it was not possible to see the whole picture and identify the appropriate points for change. Surrounding processes and conditions were taken as given and fixed. In effect, a solution would have resulted that would have tried to align the plan to the *as-is*-situation instead of making a real step forward. Thus, the system as a whole would be likely to perform sub-optimal.

6.3.2.2 Use standardised, robust processes

Even if it might seem quite obvious to organise processes as well as devices such as forms and tables in a standardised way: having this theoretical knowledge and being able to implement and ‘live it’ in practice are two different things. Many aspects have been observed where processes had developed over time and, as a result, non-standardised systems exist. As a reaction to this, the elements listed in Table 6.3 incorporate the principle of standardisation and robustness. An interesting fact is that the analysis of existing structures or ways of information transfer helped the involved persons already to get a common view which simplified the negotiation of the *to-be*-status.

One fact not to be disregarded is that recognising such situations alone is not sufficient. To make real improvements, the required actions and effort have to be approved at the appropriate hierarchy level (see 6.2.2.3).

6.3.2.3 Keep procedure flexible

This principle generally has been implemented in the planning methodology in total and especially in *capacity-fine-planning* by the proposed design-architecture. Since tool and user interact closely, the need for changes in planning are discovered early, which allows reaction to changes or inter-mediate results quite fast. By this, information can be communicated directly to others that may be necessary to prepare decisions or directly to decision makers, in case those constraints have to be adapted to achieve a feasible plan. If necessary, the consecutive approach allows moving on to another step, e.g. to perform a *what if*-analysis directly when a violation occurs and not only after finishing the planning and checking violations.

Additionally to the procedural flexibility, flexibility in data structures was observed to be essential too. This was implemented in the steps and tool-modules listed in Table 6.3, which had not only to cope with changing data-structures from one planning cycle to the next but also with data sets of different products during the research project.

6.3.2.4 Combine the strengths of human and tool planning

This request is one of the fundamental principles of NMP, perhaps the most important. By combining the specific strengths of human and tool planning, an improvement in the

NMP process can be achieved (see 6.3.3). In the proposed NMP solution, manual planning steps were, therefore, defined for tasks that require human expert knowledge, flexibility, and decisions on new situations. The expert's ability to actually sense a plan getting better collects extra points in its favour against the automation of process steps. Tool-modules are used for data processing and visualisation jobs.

6.3.2.5 Vary outputs not inputs

Varying outputs not inputs has been implemented in methodology architecture. Opposed to optimisation approaches, the tools integrated in the planning methodology are designed to complement the planners work and not to replace it. Therefore, only those constraints and rules are made subject of tool processing that can be reasonably implemented (see 6.3.2.4). Subsequently, the human expert takes over and finishes the planning step in question by varying outputs of tool-processing.

6.3.2.6 Provide planning results fast

Initially, this principle only referred to tool aspects such as implementing a fast algorithm for optimisation. Throughout the research project, this perspective was expanded, because it became obvious that this principle had to be applied to methodology as a whole. Taking the planning methodology into account, the author observed that, most of all, a clear definition and standardisation of human planning activities can speed up planning, because non-value-adding activities are removed. The redefinition of processes did also include standardised ways of information transfer (see 6.3.2.2). Furthermore, soft factors in human cooperation were considered. Creating a culture that favours communicating occurring bottle-necks early did also cut some 'dead' time out of the process.

This is not to say that speeding up tool-processing is inappropriate. For example, supporting calculations by computers contributes to this aim. But, on the other hand, it is worth reflecting that 'not implementing' a complex algorithm that tries to calculate the optimal solution and requires extensive data input can really save time. Maybe the 100-per-cent solution does not exist at all (see also 'vanishing solution space,' sections 4.5.2.2 and 6.2.5.3).

6.3.2.7 Allow high level of detail

The need for movements of production quantities could be observed in the course of tool use. During testing of different levels of data-detail, it showed that statements based on aggregated groups of items led to problems at other planning levels because information relevant for disaggregating was ‘lost’ in the aggregation process (see 5.2.8). Consequently, although NMP has a mid- to long-term perspective, the use of aggregated data is inappropriate. To provide valid results and be of real assistance, NMP has to be performed on a rather detailed level.

The principle of allowing high level of detail was implemented by designing the tool-modules listed in Table 6.3 in a way that they can handle data structures of great detail. The necessity of detailed product-related data was taken into account by designing a *Master Data Server*. In this context, the degree of detail as well as structures and formats of data retrieved from others were also standardised and communicated. For example, it is necessary to define customer releases on the level of specific end-items. This information is also stored in MDS. During the research project, the author had to alter the principle of high level of detail for production resources slightly. Section 6.3.2.8 presents this argument.

6.3.2.8 Plan virtual production lines

Looking at production-resource-related data, the observation was made that defining one-to-one relationships between product varieties and physical production lines predetermines the planning problem. Consequently, these are now handled on a partly aggregated level within the tool-module CAPPLAN. Aggregation by defining product variety-specific virtual lines is done based on physical lines’ data kept in TECCAP. The definition of this principle changed twice in the course of the research: from considering plants to individual lines and then to virtual lines. In this form, it was then added to the list of principles as one of the last ones.

6.3.2.9 Allow multi-objective planning

Basically, this principle did not change in the period of the research project. Due to a considerable number of constraints – that grew larger during research – multi-objective planning is still an important topic. Therefore, the design of CAPPLAN allows taking multiple constraints into account. Yet it is important to note that only a limited number of constraints are integrated in the tool-module. The complete set of constraints is now considered through the interplay of process steps, i.e. by the holistic planning methodology design.

6.3.2.10 Visualise

Visualisation is one core point of support by the specified tool-modules. This principle is implemented for example in CAPPLAN to visualise violations of constraints. Further, the tool-modules of MDS, TECCAP, and RECON enable to perform comparisons by simple parallel visualisation or by displaying calculation results. Finally, the possibility to filter or sort data according to various aspects supports the planner in getting an overview and develop a sense for updated data.

6.3.3 Usability, reasonableness

A general statement that can be made based on the observations from tool use is that it is possible to implement principles in a tool. The aspect of usability is discussed from two points of view in the following: feedback from practitioners and researcher's observations.

6.3.3.1 Feedback from practitioners

Like mentioned in section 4.1.2, the author discussed hypotheses and concepts with 18 practitioners from NCU, the two lead-plants for CP and CRI, logistics, and manufacturing departments. Nine of them were more closely involved in the research project. The author 'used' them multiple times along the three years project to test emerging knowledge such as methodology steps. Hence, the research work comprised workshops and testing with real-world data between planning cycles as well as facilitating three live planning-cycles. The final versions of tool-modules were validated by comparing tool results to those of manual planning – where possible. In addition, the author observed practitioners using those modules and afterwards discussed usability and utility.

General feedback from practitioners can be summarised to the following statements: the NMP device as a whole is working and does help planners do their job. The methodology proposed is a good re-definition of the traditional one, stressing its strengths and eliminating some weaknesses. The outcome of planning is a feasible and valid solution.

Looking at the use of tool-modules and especially of CAPPLAN in more detail, additionally to the points mentioned above, the following feedback was given:

- The results of *capacity-fine-planning* are comparable to those of traditional planning but are achieved faster.
- Support by tool-modules is provided at the correct points in the planning process.
- The individual steps of tool-support leave enough room for flexible, experience-based planning.

- Due to time savings, now *what if*-analyses are possible in planning, whereas in the traditional system planners were glad to generate one possible solution in the available time.
- Efforts to specify and implement CAPPLAN in practice were successful.
- The planning system is usable and provides all elements that were defined in the tender document.
- Tool-module generates valid results, which can be reproduced.
- In a mid-term perspective, an improvement of delivery reliability is expected because of consistent planning results.

The aspect of standardisation was subject of a separate discussion. Statements are:

- The findings from the research put focus on the topic such that it was given attention according to its importance.
- To convince decision makers of the necessity to restructure immediately might not have been possible without the clear and structured way of analysis.
- The results of this analysis built the basis for negotiations, e.g. about data formats and responsibilities between the involved parties from different organisational functions and hierarchical levels.

6.3.3.2 Further observations made

Additionally to the aspects discussed in the previous section, further observations from the researcher's perspective are given. Like the aforementioned statements, these refer to the use of methodology and tool-modules in practice. These observations are:

- During the three year period of observation of tool use – from first ideas to final versions – on average ca. 40 ADR per year occurred.
- The possibility to easily update data with RECON supports the planner actively.
- Mid- to long-term capacity bottle-necks occurred during planning. The decision about appropriate reactions ascended, which led to reiterative cycles of the pending decision in the structure of the hierarchy
- Changes in the production-network structure often lead to changing constraints. As opposed to the view stated by Lane (1993), the long-term horizon scheduling constraints are not seen as fixed. Consequently, flexibility is absolutely necessary.

- Another incident observed during one specific planning cycle is that the strategic plant-utilisation-factors changed, which was clearly driven by external circumstances and 'soft' factors and the 'politics' of that situation.
- Product variety names and other identifiers changed from one planning cycle to the next. Thus, they had to be updated in the system.
- Data structures were adapted during use. Therefore, the capability profile of the tool-modules had to be adapted to different requirement-profiles.
- Instead of trying to connect traditional systems via interfaces, with the gained knowledge now the effort is concentrated in defining standardised processes and rolling out one system over all involved production sites.
- For the time being, data is manually typed in or imported by means of standardised flat-files.
- Any possible limitations in the tool-modules result from assumptions of the programmer and not from a misunderstanding of NMP aspects.

6.4 Conclusion

Content summary

This chapter presented observations, conclusions, and results from testing the proposed NMP concepts in a live-case. The author used his observations to reflect on the meaning as well as on the detailed practice of NMP, i.e. principles, new characteristics, and new concepts for solving the NMP problem. Furthermore, he discussed what to do with a tool to make it work. In detail, the following topics were presented:

- Test case conditions;
- Tool-modules specification based on the proposed NMP concepts;
- Observations made during the development of modules as well as
- Observations from methodology and tool-module use;
- Conclusions drawn from observations;
- Reflections on appropriateness and validity of proposed NMP principles; and
- Statements regarding usability of the developed tool-modules.

The proposed tool modules did not only contribute to a better theoretical understanding of NMP and validation of NMP concepts but do also support NMP in practice. Table 6.4 provides an overview of their use in practice.

Module name	Actual status of use in practice
MDS	Specification finished; Go live is planned for 2nd quarter of 2006.
TECCAP	In use since 1st quarter of 2005.
RECON	Learning from use of prototype solution was used to specify MDS.
CAPPLAN	First stage of development in use since 4th quarter of 2005.

Table 6.4: Use of NMP tool modules in practice

Reflections on principles

- The validity of the proposed NMP principles could be shown.
- Standardisation needs special attention, because it is the basis of all process steps.
- Combining the strengths of human and tool planning is found to be essential. In the given NMP context, one should not expect an algorithm to do the job by itself.
- For fast progress in planning, every step of the planning methodology has to be tightened up.

Further observations

- According to feedback from practitioners, the methodology proposed is a good re-definition of the traditional one, stressing its strengths and eliminating some of its weaknesses. The outcome of planning is a feasible and valid solution.
- Input-data availability and fidelity are more a limiting factor than is technical manageability in a tool.
- Further, good decision making depends not only on high data availability and quality but also on ‘soft’ factors, like e.g. usability of approach.
- Transparent and comprehensible tool-modules and tool-module-results are important for human planners.
- Applying a near-optimal planning approach prevents getting stuck in mathematics and, thus, can save time.

Summary

- It is possible to implement NMP concepts in methodology and integrated tool-modules and to get these working.
- Human planners need to get a sense for the numbers to be able to plan efficiently and to improve of the planning process.

- On the other hand, in order to protect the planner from attaining sub-optimal solutions, tools must actively support the manual process, e.g. by visualisation, and the validation of results and assumptions made, if possible.
- Strategic soft-constraints cannot be handled by a tool because the *softness*-factor is subject to strategic decisions and to external changes of situation.
- Further, decisions requiring ongoing input based on *live*-information should also be left in the responsibility of the human planners.
- In a volatile environment one should not try to plan too close to the 100-per-cent solution.

7 Discussion and reflections

This chapter provides a summary of the aspects introduced in the previous chapters. It discusses the results from the tool-module-implementation case study as well as the experience gained by the author during 8 presentations, 5 workshops, and 18 expert interviews. The central findings of this work are presented and differentiated from existing literature. Finally, thoughts on cross-case learning are presented and the strengths and potential weaknesses of this work are discussed.

7.1 Research focus and utility

In this section, an overview and summary of the work presented in previous chapters is given. This includes a brief reminder of the gap between academic and practice knowledge.

7.1.1 Origin and objectives of the researcher's work

The field of interest for this research mainly originated from the author's industrial background. As he is employed in a central logistics-planning department of a global automotive supplier, he is concerned with capacity planning such as allocation of specific end-item quantities to specific resources in an international production network – a task introduced as *Network Master Planning* (NMP) in chapter 3. The author gained experience in the field of NMP through a literature review, presentations, workshops, and expert interviews at the company in question and – most of all – through testing and implementing ideas in a real-world environment. Due to a variety of fundamentals and consequences described in chapter 4, NMP provides a real challenge for practitioners. But neither is NMP subject of academic discussion nor could solutions for support in practice be found. In this context the objectives of this work can be summarized as follows:

- To better understand NMP;
- To communicate the knowledge and make it, in turn, accessible to academics and practitioners, and, thus
- To contribute to improvement of NMP practice.

For this purpose, the author conducted actions of analysing, conceptualising, and testing of ideas as described in the following section.

7.1.2 Summary on work done within research project

7.1.2.1 Analysing

Requirements-analysis had the objective to get a general overview of the topic by interviewing practitioners concerned with capacity planning on different levels of hierarchy. Subsequently, the author undertook a literature review in subject-related fields. Aspects covered by literature as well as, more importantly, those not mentioned in literature but experienced by practitioners were of interest to the researcher. In the course of the research, additional interviews and workshops with practitioners were conducted. However, ‘hanging out with practitioners’ turned out to be most important for an understanding of the situation. The researcher had the chance to support the planners during their work and, thus, experience and observe the actual situation under live-conditions (see 2.2).

7.1.2.2 Conceptualising and testing

Based on the knowledge and the insights gained from the analysing phase, subsequently NMP concepts were derived, speaking in terms of principles, design rules, and architectures. These concepts were, then, combined to a proposed NMP-methodology that contains both completely manual and tool supported process-steps.

In order to validate the proposed concepts, integrated tool modules which incorporate these concepts have been specified and developed. Subsequently, tests in a live planning environment were conducted.

7.1.2.3 Outcomes

The results of the work accomplished within the research project are:

- Good understanding of the NMP process and its requirements,
- A clear view on interfaces within NMP as well as to other processes,
- Suggested individual NMP concepts as well as a holistic methodology, and
- Proposed integrated tool modules for planning, partly in a prototype state, others are in use by practitioners.

7.1.3 Utility of the outcomes

Apart from the question of usability for practitioners discussed in section 6.3.3 the aspect of utility needs to be discussed when creating interactive systems (IUSR 2005).

7.1.3.1 Test objective, method and context

Following IUSR's (2005) *Common Industry Format* (CIF), the objective, method, and context as well as the results of utility testing are described below.

Test objective and method

The objective of testing usefulness is to gain insight into effectiveness and efficiency of the proposed NMP methodology and the integrated tool-modules. In-depth testing was conducted in co-operation with five experienced planners. Two of those worked at the NCU, one in the CP lead-plant, and one in the CRI lead-plant. All of them are responsible for capacity planning in production networks on a daily basis.

Context of use in test

Testing was conducted between and during live planning-cycles. Thus, besides using some new elements, planners did their job as usual. This testing in their normal environment had the benefit of avoiding a 'clean lab–situation.' The planners could be 'observed' under normal conditions. On the negative side though it must be said that in the everyday work environment interruptions to testing had to be dealt with.

7.1.3.2 Effectiveness

Improvement of the planning situation in general

Practitioners stated that better understanding of NMP practice and of cause-and-effect relationships helps planners to do their job. Furthermore, in-depth analysis, clear visualisation, and a redefinition of process steps enabled the project team to specify source systems. Last but not least, based on the common view created by analysing and conceptualising, the co-operation with persons responsible for input data, e.g. from *Market and Sales* or *Production*, was improved.

Evaluation of the planning methodology as a whole

Planners reported that the planning process is running 'smoother' at those steps that were redefined. In other words, the ratio of value-adding to non-value-adding tasks improved. The researcher observed this too, although he is aware of the fact that part of the improvement might have been caused by bringing special attention to the planning process and, thereby, creating consciousness of being observed (see 2.1.3). The ratio of improvement was not directly measured by counting the number of (non)-value-adding activities but is based on a comparison of total planning time and the reported and observed improvements.

Evaluation of the tool module CAPPLAN

The quality of results is comparable to traditional manual planning, yet the planning time is being reduced. The evaluation of plans is based on production-cost-indices per product for the individual plants in the network, made available by the accounting department. This approach promised to provide a picture that is closer to reality than developing and applying a total-cost function for optimisation that requires detailed data, which is difficult to generate and, therefore, likely to be replaced by estimates (see 4.5.1).

7.1.3.3 Efficiency

Planning time reductions

In the analysed cases, the total planning time could be reduced from approximately 17 to 13 days. The bigger part of this reduction stems from the fact that specific sub-tasks could be moved from the capacity-fine-planning phase to the preparation phase. Examples are the allocation of end-items or updating of data structure on base of preliminary VPZ data. More detailed numbers, referring to individual planning phases, are shown in Table 7.1. It has to be stated though, that these statistics should not be seen as absolute and precise, but as approximations. The numbers for traditional planning were provided by the planning department and, thus, are prone to be biased – even if unintended on their part. Numbers for planning with new NMP concepts are based on two planning cycles in the analysed case. Furthermore, due to the aforementioned interruptions in the planning process, which were assumed to be uniformly distributed over time, precise durations could not be measured. Regarding tool-performance measurement, it is important to note that no comparable tool existed before.

Another important observation is that planners did actively decide to use the possibility for generating scenarios, performing ‘what if’ analyses. By doing this, a certain amount of absolute time that could have been saved was used for additional value-adding activities.

Phase	**Traditional** [days]*	**New** [days]**
Data preparation and feasibility checks	3-4	2-3
Reconstruction of data	2	1
Strategic decision making and capacity fine planning	9-10	6-7
Consolidation and submission	2	2
		* BOSCH (2005e); ** Measured during testing

Table 7.1: Comparison of planning time in the analysed cases

User satisfaction

As mentioned before, one general feedback from practitioners is that they ‘feel’ better with the whole situation and procedure of the redefined NMP methodology. This correlates with the ratio of value-adding to non-value-adding activities, especially because in traditional planning much effort is necessary to align process and tool interfaces with information sources.

Data reduction

Through specification and implementation of a central *Master Data Server* (MDS), the total number of product-related data fields – which had mainly historically grown – could be reduced by approximately 30 per cent. Furthermore, the imminent danger of planning based on different data versions throughout the production network could be minimised by eliminating redundant data storage.

7.2 Discussion on findings – Lessons learned

7.2.1 Introduction

This section presents what can be learned about the proposed NMP concepts, i.e. principles, design rules, and architecture. The summary is based on conclusions from observations during development and use as well as observations on what worked and why under given circumstances.

For reasons of clarity in the presentation of findings, each statement is structured in a standardised form. To show reasonableness, observations and facts on which the finding is based are listed. Further, the correlating chapters in this work are referenced. The comparison to existing concepts and ideas including bibliographical data is meant to demonstrate novelty. The complete set of findings is clustered according to different perspectives that can be taken to access NMP. Namely, these are:

- What NMP is;
- Current challenges for NMP;
- How NMP might be unlocked;
- Usability and utility of the proposed NMP approach; and
- Other aspects.

7.2.2 What NMP is

NMP is a reality that exists for specific conditions - it can be organised either formally or informally.

Based on …

- A literature review (chapter 3).
- Interviewing and ‘hanging out’ with practitioners (chapter 4).
- Knowledge about what those fundamental conditions are by observation of a real-world planning situation (chapter 6).

This is similar to …

- Supply chain management and global production networks (e.g. Oliver and Webber 1992; Harland 1996; Lambert et al. 1998; Sturgeon 2000; Christopher and Towill 2001; Stadtler and Kilger 2002; Berger 2004; Koulikoff-Souviron 2002).
- Hierarchical Production Planning (e.g. Buxey 1990; Nam and Logendran 1993).
- *Multi-site capacity planning* (e.g. Luecke and Luczak 2003).

Different in the aspect of …

- Specific fundamentals to NMP: vertical integration in the production network, redundancy of production resources, interchangeable work.
- Level of data detail, length of planning horizon, direct implications from customer behaviour.

NMP is an essential planning task for companies that care for their production network resource utilisation.

Based on …

- Knowledge from literature search on vertical integration (chapter 3).
- Discussions with strategic decision makers in the analysed case/ company (chapters 4 and 6).

This is similar to …

- Coordination of multi-national production planning and control (e.g. Philippson 2002).
- Utilisation-optimisation approaches at shop-floor level (e.g. Wiendahl 1997).
- Production and logistics cost planning (e.g. Hobbs 1996; Brimberg and ReVelle 1998; Lin et al. 2001; Chopra 2003; Hellingrath et al. 2004).

Different in the aspect of …

- Resources are distributed world-wide and have different environments, e.g. labour costs or governmental restrictions.
- Not trying to develop a total-cost function that covers all eventualities.

NMP is an unusual planning activity due to various sources of complexity.
Based on … • Observations of practitioners performing the planning activity and interviewing them about the reasons for their particular planning procedure (chapters 4 and 6). • Characteristics observed in the analysed case and compared to literature (chapters 3 and 6) • Difficulties faced when prototyping and trying to implement (chapter 6).
This is similar to … • *Hierarchical production planning* (e.g. Nam and Logendran 1993). • Internal production networks (e.g. Luecke and Luczak 2003). • *Production program planning* (e.g. Wrede 2000).
Different in the aspect of … • Not concerned with short-term production control and order management. • Both external (customer) and internal (technical, managerial) constraints have to be taken into account simultaneously.

NMP is a series of steps combined in a holistic planning methodology not only an isolated task.
Based on … • Experience of trying to specify and develop an isolated 'tool' and the conclusion that this leads to sub-optimisation or no solution at all (chapter 5). • Observations made in the progress of the project: going two steps back to see the whole picture (chapters 4 and 6). • Authors' statements (chapter 3).
This is similar to … • Designing holistic, integrated systems to achieve a good system result (e.g. APICS 1997). • Focussing on eliminating problems, not on coping with their effects. (e.g. Lewin 1999).
Different in the aspect of … • Being applied to NMP: usually in mid- to long-term decision making the attention is not focused on the formalisation of the planning process.

7.2.3 Current challenges for NMP

Knowledge has been gained about requirements that should improve NMP practice.
Based on … • Actual requirements analysis, including planning steps, inputs and outputs, data quality (chapter 4). • Analysis of customer order behaviour (chapters 3 and 6). • Observations from methodology and tool module development and testing (chapter 6).
This is similar to … • Planning process design in general (e.g. Mourits and Evers 1995; Koutsoukis et al. 2000).
Different in the aspect of … • Being applied to NMP; existing approaches were not applied in this context until now.

High data quality and integrity are preconditions for NMP.
Based on … • Statements from authors referring to data reliability (chapter 3). • Experiences in tool testing (chapter 6).
This is similar to … • Planning process design in general (see above). • ‘Getting reliable data about what actually happens in terms of practice and performance is much harder than simply asking’ (New and Payne 1995). • ‘The probability of making errors can be made inconsequential in any business serious about reducing them’ (APICS 1997). • ‘Unsatisfying data quality mainly results from manual input errors’ (New and Payne 1995).
Different in the aspect of … • High level of detail necessary for NMP which poses special requirements on data quality. • Hierarchical planning: others are responsible for providing data: Planners have to rely on them for data fidelity and completeness. • Do step-wise improvement and not wait until the situation changes (Burnes and New 1996).

7.2.4 How NMP might be unlocked

An NMP methodology has been proposed.
Based on … • Requirements analysis by means of interviews with practitioners and observations of NMP practice (chapters 4 and 6). • Principles and design rules derived from the requirements-analysis (chapter 5). • Solution architecture alternatives (chapter 5).
This is similar to … • Planning process design in general (see above). • Multi-site capacity planning (e.g. Luecke and Luczak 2003).
Different in the aspect of … • Being applied to NMP; existing approaches were not applied in this context until now.

It is possible to implement the proposed NMP concepts in a practical procedure.
Based on … • Observations during specification of integrated, supporting tool-modules (chapter 6). • Prototype testing of concepts (chapter 6). • Statements of practitioners using the tool modules, confirming the concepts (chapter 6).
This is similar to … • The use of tools in research (e.g. Coughlan and Coghlan 2002; Cagliano et al. 2005).
Different in the aspect of … • Being applied to NMP; existing approaches were not applied in this context until now. • Not only the building of tool-modules for the creation of knowledge but also to hand some of them over to be used in practice.

Aggregation does not solve the problems of NMP.

Based on …

- Statements of practitioners (chapter 4).
- Observations from testing different scenarios with aggregated data (chapter 6).
- Observation that the need for movements cannot be identified based on aggregated data (chapter 6).

This is similar to …

- Hierarchical production planning (e.g. Nam and Logendran 1993).
- Allowing detailed planning for short horizons (e.g. APICS 1997).
- “If the detailed demand is available, a straightforward approach to guarantee feasibility is to add the detailed feasibility constraints, to other constraints at the aggregate level” (Axsäter (1985).

Different in the aspect of …

- Degree of resource capacity utilisation, planning horizon length according to hierarchy level.
- Applying detailed planning for mid- to long-term horizon.
- For NMP the APICS’ view of ‘data on groups is more accurate than on specific items’ is not valid.

Dynamic, multi-objective planning needs human decision makers.

Based on …

- Statements from authors referring to automation of decision processes (chapters 3 and 6).
- Observations in practice: as attributed to a volatile environment, flexibility is essential in planning (chapter 4).
- Experience of trying to specify and develop a fully automated system and the correlated observation that the intelligence has to be placed in front of the computer (chapter 6).

This is similar to …

- Using the computer for storing of data, calling attention to situations (visualisation) and recommending corrective actions – on the basis of rules set by human experts (Adenso-Diaz and Laguna 1996; APICS 1997).
- Computers cannot separate significant from insignificant deviations nor make intelligent decisions (e.g. APICS 1997). ‘It would be unrealistic though, to try to incorporate all possible design issues in the support system. (Mourits and Evers 1995).
- Do not expect an algorithm to do it for you (Lane 1993).
- All involved persons need continuous and steady training in understanding and skills. Next to time, people are a company’s most important resource (APICS 1997).
- Focus on managerial choice (New 1996).
- Staff at all levels of the company is “expected to be pro-active completers rather than reactive buck passers” (Burnes and New 1996).
- Regarding the observation that managers’ expectations or feelings (i.e. ‘soft facts’) are felt to be as important as hard data e.g. on stock turns or delivery patterns, this ‘presents a considerable challenge to a predominantly technical field’ (New and Payne 1995).

Different in the aspect of …

- Combining decision-support-system thinking with concern for ‘soft facts’.
- Being applied to tactical planning and especially on NMP, not only on strategic decisions.

Tool support in NMP means complementing human actions; not replacing them by ‘automatic optimisation’.

Based on …

- Feedback from practitioners referring to tool-module prototypes, such as ‘do not know what the system does,’ ‘having to cross-check manually,’ ‘need standardised visualisation’ (chapter 6).
- Observation that the planner’s job begins where a tool finishes and that this part of the job can be more difficult than the alternative of complete manual planning if the tool works with inappropriate rules and/or is not integrated in a holistic methodology (chapter 6).

This is similar to …

- The computer complements human actions, it does not replace them (e.g. APICS 1997).
- Concept of the integrated planning-support-framework: Using a tool to protect the planner from attaining sub-optimal solutions by supporting the manual process and the validation of results and assumptions made (e.g. Mourits and Evers 1995; Koutsoukis et al. 2000).
- A supporting tool ‘should be easy to use, quickly applicable to actual cases, understandable to the decision maker, easy to adapt to changing requirements, and applicable to a wide range of […] problems’. (Mourits and Evers 1995).
- Special focus has to be put on the interaction between tool and human planning, i.e. a smooth transition between the steps has to be ensured (ibid.).
- A main benefit of tool support is the possibility to let the tool highlight critical situations and, thus, enable the planner to initiate suitable actions. (Adenso-Diaz and Laguna 1996).

Different in the aspect of …

- The support system has to be tailored to the human perception and needs (New 2003) and adaptable to changing situations to provide real support (e.g. Mourits and Evers 1995).
- Being applied to NMP: the planner does not just review action messages from a tool or respond to changes in planning basis but is in charge of doing the greater part of the job.

Fast planning is vital in NMP.

Based on …

- Literature on ‘customer near’ planning activities (chapter 3).
- Observations of the analysed company’s reiterative decision processes (chapter 4).
- The context of the proposed consecutive architecture (chapter 5).

This is similar to …

- Decision support systems (e.g. Mourits and Evers 1995; Koutsoukis et al. 2000).
- Importance of aligning quickly to customer requirements (Harrison and Godsell 2003).
- ‘Intolerance of delays and time cushions, concentrating on speeding up all needed activities, and eliminating unneeded ones. Lost time is the worst waste’ (APICS 1997).
- Correct allocation of decisions reduces the number of iterative cycles (Qiu and Burch 1997).

Different in the aspect of …

- Not trying to implement expert systems or knowledge management databases in an automated system.
- Realising fast NMP via high data-quality and NMP concepts, ‘accelerating every individual process step, instead of intelligent tool design and ultra-fast algorithms’.
- Not creating and implementing a fast algorithm can save planning time; and not only the time directly saved for skipped development and adaptation, but in the planning process: Vary outputs not inputs to avoid getting stuck in an endless reiterative cycle.

7.2.5 Usability and utility of the proposed NMP approach

The NMP approach showed usability to practitioners.
Based on … • Practitioner judgements of NMP as an approach that is useful (chapter 6). • Observations of practitioners using tool modules as part of the methodology (chapter 6).
This is similar to … • Software design, usability testing (IUSR 2005).
Different in the aspect of … • Being applied to NMP: creating not only software but a planning procedure for NMP.

NMP showed utility in the analysed company context.
Based on … • Comparison of planning time and ‘soft factors’, such as degree of coordination between hierarchies, with and without implementation of proposed NMP concepts (chapter 7).
This is similar to … • Software testing (IUSR 2005).
Different in the aspect of … • Being applied to NMP; existing approaches were not applied in this context until now.

7.2.6 Other aspects

The process of the research enabled self-reflection for the NMP practitioners.
Based on … • Feedback from practitioners during discussions (chapters 4 and 6). • Observations of the change in planners’ attitudes towards individual aspects of NMP in the progress of the research project (chapters 4 and 6).
This is similar to … • Basic use of research: ‘learning something you don’t know’ but also ‘learning that you don’t know something’ (Phillips and Pugh 2000). • Change in behaviour and attitudes of staff is important (Burnes and New 1996).
Different in the aspect of … • Being applied to NMP; existing approaches were not applied in this context until now.

NMP is not limited to the one case analysed.
Based on … • Fundamentals and characteristics of NMP identified during research (chapters 4 and 7).
This is similar to … • Hierarchical production planning / capacity planning for other companies/industries with production networks, such as vehicle, clothes, or household product manufacturers (e.g. Erkut and Oezen 1996).
Different in the aspect of … • Being applied to NMP: product variety spectrum, capacity utilisation, customer behaviour.

7.3 Reflections and cross-case learning

In addition to the findings presented in the previous section, the author learned during the research project to address real-world problems and further research related aspects. Because these are considered to be important, especially for practitioners, they are presented below. At the end of this section the author discusses the aspect of cross-case learning.

7.3.1 Reflections

7.3.1.1 Appearances are deceptive

The actual system turned out to be different from what the people working within it had described. Instead of the initially assumed simplicity, the system provided more complexity in the real world. The author observed how the knowledge of planners about their own process and system evolved during the research project. Originally, they had described the system to be mainly 'mathematically fixed,' not recognising – or at least not reflecting on – their own heuristics being applied. Resulting from this research, changes in priorities and re-definitions of the actual description became inevitable. However, it has to be stated that even if priorities did change, the need for better NMP persisted.

A remarkable fact in this context is that among the involved planners the pre-eminent wish still exists to have a system doing the job. Yet now, after the collaboration, they do see that complexity within planning does not originate mainly from the planning process itself, but from internal and external noise factors, such as high production-network utilisation and erratic customers. Therefore, any process-design's performance suffers, unless the noise factors can be removed or at least reduced.

7.3.1.2 A system under pressure reveals problems more clearly

As presented in chapter 4, NMP in the analysed company is very specific and complex due to a high utilisation of resources in the production network. Furthermore, various concurrent constraints lead to massive reductions in the available solution space. This situation, which is negative for the planner because it means complicating his task, is, in hindsight, regarded as positive for the research project. The author is sure that without the urgent need to care for every detail related to NMP in order to come to valid solutions, the picture of what NMP looks like in heavily constrained systems would not have been that clear.

7.3.1.3 It gets worse before it gets better

As described before, not only the researcher but the practitioners too, learned about the situation of NMP and the sources of complexity through the course of the research project. The best example is the new constraints that continually appeared and were formulated by planners, after those same planners had insisted that the complete set of constraints was already documented. This rising complexity had the effect that the actual situation became clearer and, eventually, led to a new system definition. The introduction of virtual production lines serves as an example. Initially, planning on the level of plants was seen as sufficient. Although this simplifies modelling and clearly would have been easier to implement, it would have returned unreliable results in terms of feasibility. The recognition of this shortcoming made it necessary to descend to the level of physical production lines, which made the total situation worse. Yet only from this perspective was the final approach of planning virtual lines accessible. In other words, the awkward intermediate step got the project team one step closer to the actual real-world situation. After having gone through the ‘valley of tears,’ strategies for simplifying the process can be applied more easily.

7.3.1.4 The elephant cannot be divided in half

From today’s point of view, it is obvious that with the initial focus on the optimisation problem within capacity-fine-planning only one part of the whole system was considered. Consequently, only a sub-optimal solution could have resulted at best. Therefore, expanding the focus contributed directly to the quality and usability of the proposed solution.

7.3.1.5 Simplification can be dangerous

One item that was observed in the context of the learning- and redefinition-process by means of quick-and-easy-to-develop pilot solutions is that practitioners have difficulties to define only a limited set of requirements because ‘everything is important.’ Furthermore, there is the danger that such a solution is not accepted if it is too simple. Especially if keeping the tool lean means additional manual effort, e.g. for data preparation.

7.3.1.6 Not letting a cost objective function reign supreme

Unlike some other scheduling approaches, the researcher did not try to develop an all-correct cost-objective function in the given company environment. After analysing the requirements and conditions thoroughly, instead, he suggested a proxy for cost-optimal planning by applying the approach of loading low-cost locations (LCL) first and the others in the sequence of their production-cost-indices. This prevents getting stuck in optimisation mathematics and is a different strategy for creating something that is both near-optimal and feasible, which has shown to be applicable within the context of the analysed company.

7.3.1.7 The magic key: methodology

A further important result of this research project is realising the importance of the holistic view by going some steps back and, thus, taking a more complete picture. The shifting of focus from a purely tool-concentrated approach at the beginning of the research to a methodology-oriented view that sees the tool only in a supportive role is seen as crucial.

It does not always need a high sophisticated, universal tool. More often small, but specialised modules that are integrated in a holistic methodology can be of greater help. In this context, comprehensible tool-actions directly contribute to acceptance by the user.

7.3.2 Cross-case learning

It is very difficult to show that a specific case is typical and can be generalised. According to Blaikie (2000), researchers should not be concerned about whether the results could be declared as representative and their generalisation, but rather with suitability and aptitude. In the context of educational research, Bassey states that “an important criterion for judging the merit of a case study is the extent to which the details are sufficient and appropriate for a teacher working in a similar situation to relate his decision making to that described in the case study. The relatability [directly related to appropriateness] of a case is more important than its generalisability” (Bassey 1981). Following this argument, the author of this research-work prefers not to aim at generalisation. Instead, and in line with Bassey’s inquiry, he prefers to speak about appropriateness and value of the research findings to other cases.

Based on a literature review and an in-depth analysis of a real-world system, the following fundamentals for NMP have been found:

- A production network with multiple locations;
- An inter-changeability of operations between production sites; and
- Vertical integration within one company.

These fundamentals are not viewed as specific for the company of the analysed case. Different industrial sectors exhibit similar characteristics in their planning environment independent of their products or services. Vehicle manufacturers, other automotive suppliers, or the clothing industry are conceivable examples.

Solution principles for NMP have been derived from both the requirements-analysis and the testing of ideas during live planning-activities together with experienced practitioners. Since it could be shown that the proposed NMP principles work within the case context and that this context is similar to others, the researcher is convinced that the proposed concepts offer insights and enable access to other environments with similar characteristics.

7.4 Strengths and potential weaknesses of the research

7.4.1 Strengths

7.4.1.1 Uncovering a new, interesting and important topic

The research focused on a topic that, in spite of its importance for a company's long-term success, has been given far too little attention by the operations management community until today. The research has generated valuable insights which form the basis for further investigation as well as improvements in NMP practice.

7.4.1.2 Investigation of situations and problems in their real-world context

"It is possible to have academic research which scores high on 'rigour' and 'cleverness' but low on connection to 'real' problems. However, in [operations] management more than any other discipline there is a fundamental commitment to an encounter with that which managers and workers do. If this is not the case, then research could perhaps be more accurately labelled under a different heading" (New and Payne 1995). Applied to this research the following statements can be made:

- The findings are grounded in a real-world investigation and understanding of NMP.
- The research expanded the initially limited perspective of practitioners on the problem to a holistic methodology pointing to interfaces and inter-connections to related tasks.
- The findings were revealed to have a high degree of relevance to those involved in the research and experience of NMP.

7.4.1.3 Testing ideas in practice

Having the researcher located in an industrial company was shown to be helpful for attaining knowledge in an emerging field. Not only were observations of phenomena in their real-world context possible, the researcher's role of being a participant-as-observer also allowed the testing of first ideas of understanding and solution concepts against actual requirements. Furthermore, getting insights and feedback from practitioners as an 'internal' is seen as very positive and valuable.

7.4.1.4 Delivering something that can be used

This research work is not limited to hypotheses and concepts which form the basis for NMP understanding. It does also deliver results such as tool-modules or specifications that can be used by practitioners. Regarding the acceptance of the research findings the author sees this practicability as extremely valuable.

7.4.2 Potential weaknesses

7.4.2.1 Rigid boundaries in the identification of problems

The research is based on observations within one company. Thus, the identification of problems is based on just one case and on insight brought from practitioners that are all working within the same environment, having similar conditions. Even though the problems identified are revealed to be significant to other companies, more problems than those identified are likely to exist in production-network-capacity-planning.

7.4.2.2 Using a single case study for knowledge creation

Due to the researchers employment at BOSCH, the complete action research using methodology and tool implementation was done in only one division of that company. This restricted the research. Even though a multi-moment analysis was conducted based on multiple 'live sessions' and involving different persons, more undiscovered constraints to NMP are expected to exist.

7.4.2.3 Use of some indirect data

During the research, not all process steps and characteristics of NMP could be directly observed. Although the researcher spent a considerable amount of time together with practitioners on a daily work basis, he did not take part in top-level strategic decision meetings. For this reason, the data collected corresponding to these steps is based on accounts given by participators and on indirect means to understand the outputs, such as an analysis of resulting documents. Data related to these steps may, therefore, be distorted by a certain (even if not intentional) bias by the involved practitioners.

7.5 Conclusion

Observations of the characteristics of production networks and Network Master Planning in the analysed case were used to formulate hypotheses. Consequently, the hypotheses were refined in an action research process. In parallel, the validity of these hypotheses was tested in a literature review. Due to its stage of immature research, NMP was not found in literature as a tangible subject. Yet, parallels to certain aspects could be drawn from related fields of production planning.

The above described activities allowed the development of an understanding for pre-conditions for NMP, cause-and-effect relationships in planning, and characteristics of the specific planning environment. Consequently, fundamentals for the existence of NMP, i.e. the applicability of NMP theory on a concrete situation, implications from sources of complexity, and consequences to the planning process can be derived. A summary of these aspects is presented below.

7.5.1 Fundamentals

The fundamentals for NMP in intra-organisational production networks can be summarised as:

- Work is shared between the network resources.
- A vertical integrated company is caring for utilisation throughout the network.
- Some work is interchangeable in the network through resource redundancy.

7.5.2 Sources of complexity in practice

A variety of factors that increase complexity in NMP was revealed. Sources of complexity can be summarised as:

- Production networks that are running near the capacity limit.
- Statements for concrete points in time are required (not average over period).
- Demand fluctuates and there are Additional Demand Requests.
- Customers specify releases per end-item and per production line.
- Resources are dedicated to specific product varieties.
- Availability and fidelity of input data is limited.
- A high number of partly conflicting constraints restricts planning.

- Soft constraints exist that are difficult to handle.
- Constraints change or emerge during planning.
- Results of planning need to be provided fast.

7.5.3 Consequences

Consequences of the aforementioned sources of complexity that impose on a company's planning in practice are:

- It is not possible to design a physical production system that meets future demand without the great expense of over-capacity at all points.
- Re-planning is necessary to move work between sites. Consequently, NMP exists in any production network with the characteristics and circumstances presented in this research work. It can either be organised formal or informal.
- The volatile demand has direct cost implications.
- Demand cannot be averaged.
- Products cannot be aggregated.
- Rules have to be balanced, i.e. decisions have to be made, constantly.
- Human experience is necessary for planning.
- The planning process must not only focus on data quality but also on soft facts.
- Tool modules need to be integrated in a holistic planning methodology and can support the planner in 'number crunching' and by providing visualisations.

7.5.4 Validity of findings

The proposed NMP concepts were tested and refined on the basis of hypotheses in a real-world environment. Observations made during the research project were analysed in detail to find basic elements or patterns. Consequently, the new knowledge was compared to literature. The findings and reflections introduced in this chapter represent learning which goes beyond the scope of the analysed case.

8 Conclusion and Outlook

This chapter summarises the activities and findings presented in this thesis. Based on the research objectives and the proposed outcome formulated in chapter 1, the observations on what fundamentals are necessary for the applicability of NMP theory, the consequences for NMP practice, and, consequently, the 'nature' of NMP are presented. Further, this chapter summarises the findings that represent the major contribution to knowledge of this work. The chapter ends with a summary of the implications for practice and recommendations for further research.

8.1 Research objectives and outcome

The aim of this research was to propose Network Master Planning concepts that generate an understanding of the unusual situation of NMP and enable improvement of NMP practice. The research objectives introduced in chapter 1 have been transformed into sub-tasks, which contributed to this aim.

NMP is now positioned in the literature and business context. Active observation of the real-life NMP planning activity enabled the researcher to develop a specification of requirements. The analysis allowed the recognition of parallels to other fields of planning. Despite a thorough literature review on a broad range of topics, no literature dealing with the entirety of the particular requirements for the analysed planning task could be found. Yet, individual aspects and characteristics of NMP are covered in existing approaches. The relevant literature was used to focus and position NMP in the field of tactical production planning.

Consequently, solution principles and design rules could be derived or adapted and an architecture developed. The proposed planning methodology contributes to improvement of NMP practice by integrating relevant tasks of planning and defining responsibilities for planning activities and data administration. Integrated supporting tool modules, relying on the proposed NMP concepts, have been specified and tested in a real-world case. Observations made in this context allowed the researcher to reflect on these concepts and eventually refine the correlating hypotheses. Furthermore, the developed tool modules directly improve NMP practice because they free the planner from routine work and empower him to focus on those parts of the process that need human decisions.

8.2 Contribution to knowledge

The contribution to knowledge of this thesis is based on an understanding of fundamentals and requirements for NMP, proposed concepts to tackle NMP, which have been shown to work by means of tool testing, and generic findings.

8.2.1 Requirements analysis

The observations presented in chapter 4 contribute to a better understanding about the unusual situation of NMP, factors implying on NMP, and technical requirements. Fundamentals for the existence of NMP in a production-planning environment were elaborated.

One crucial task in NMP is identified as balancing rules which result from internal and external constraints and which have to be followed to generate feasible plans. Regarding sources of complexity, the main obstacles are inability to aggregate, uncertainty in input data, and constraint characteristics, like e.g. softness or emergence. Based on the as-is analysis, technical requirements for NMP were derived. These are:

- Iterative procedure with feedback loops.
- Holistic planning procedure.
- Consecutive architecture.
- Flexibility in setting parameters during planning.
- Horizon split in periods.
- Planning of individual end-items.
- Multi-objective planning.
- Quick planning.
- Production resources with variable degree of aggregation.
- Mid- to long-term planning horizon.

8.2.2 NMP concepts

Based on the aforementioned requirements for NMP, solution principles and design rules have been derived. A consecutive architecture that combines these elements is proposed to be applied on NMP practice. The derived principles are:

- Use a holistic procedure.
- Use standardised, robust processes.
- Keep procedure flexible.
- Combine the strengths of human and tool planning.

- Vary outputs not inputs.
- Provide planning results fast.
- Allow high level of detail.
- Plan virtual production lines.
- Allow multi-objective planning.
- Visualise.

8.2.3 Knowledge creation through tool implementation

Testing the proposed hypotheses and concepts in a real-world case led to the observation that it is possible to implement NMP concepts in methodology and integrated tool modules and to get these working. According to feedback from practitioners, the developed methodology is a good re-definition of the traditional one, stressing its strengths and eliminating the main weaknesses. Hence, the proposed concepts are appropriate.

8.2.4 Research findings

As presented in chapter 7 the observations made during the course of the research and the correlated reflections were checked against literature to find similarities and differences. The core findings of this work are:

- NMP is a reality that exists for specific conditions - it can be organised either formally or informally.
- NMP is an essential planning task for companies that care for their production network resource utilisation.
- NMP is an unusual planning activity due to various sources of complexity.
- NMP is a series of steps combined in a holistic planning methodology not only an isolated task.
- Knowledge has been gained about requirements that should improve NMP practice.
- High data quality and integrity are preconditions for NMP.
- A NMP methodology has been proposed.
- It is possible to implement the proposed NMP concepts in a practical procedure.
- Aggregation does not solve the problems of NMP.
- Dynamic, multi-objective planning needs human decision makers.
- Tool support in NMP means complementing human actions; not replacing them by ‘automatic optimisation’.

- Fast planning is vital in NMP.
- The NMP approach showed usability to practitioners.
- NMP showed utility in the analysed company context.
- The process of the research enabled self-reflection for the NMP practitioners.
- NMP is not limited to the one case analysed.

Novelty of the findings is ensured by a comparison of hypotheses to existing approaches, concepts, or ideas. The aspects for differentiation with existing knowledge are given in chapter 7. Some of the findings represent combinations of existing approaches, others transfer knowledge from other fields to that of mid-term, tactical production planning as it is presented in this work.

8.3 Implications for practice

As stated at the start of this work, the generated knowledge not only contributes to knowledge in the academic world but also has, and perhaps more importantly, practical implications. The statements in this section represent recommendations particularly for practitioners who are in a similar situation as the researcher and the project team at the analysed company. The individual points may serve as guidelines to support practitioners working in the field of NMP or restructuring an existing planning system.

Referring directly to NMP:

- Deal with NMP in an organised way and integrate it better into planning hierarchy, i.e. move NMP from an informal to a formal state.
- When having it formalised: do not try to automate it.
- Try to implement labour-based flexibility in production network design.
- Try to think about taking complexity out of your system, i.e. think before building a complex network that has to be Network Master Planned (see 7.2.2).
- Recognise the importance of good data quality.
- Be aware of the fact that – even in case of poor data quality – a plan which results from a defined and structured process provides advantages against ad-hoc actions, mainly with regard to transparency and acceptance of the plan.
- Define processes and responsibilities clearly.
- Conduct a customer behaviour analysis.

Referring to the progress of an NMP restructuring project:

- Recognise that it will get worse before it gets better.
- Try to involve all relevant hierarchical levels.
- Go two steps back and look again at the problem and – even more importantly – place it in its context before starting to analyse and conceptualise.

8.4 Recommendations for further research

As shown in this work, NMP is an essential field in company planning. Due to the restrictions arising from the researcher's background, it is likely that not all sources of complexity for NMP have been identified. Furthermore, it is expected that more constraints than the ones observed during the research project and presented in this work exist. Thus, the researcher sees this thesis as a starting point for further research. Recommended fields are:

- The research has not attempted to prove that the hypotheses are correct; it has developed new understandings in a difficult and under-researched subject area. Therefore, a logical step would be to develop a reliable and robust test for the hypotheses to prove their applicability.
- Check the findings through a replication of the research using different tools with the same purposes.
- Test the proposed concepts in other cases in the automotive industry.
- Apply the proposed theory to other environments with similar characteristics.
- Test the tool modules with other practitioners.
- Study the aspects introduced in this work as 'soft factors' and, thus, propose a model for co-operation across hierarchies in the context of production planning.

8.5 A final comment

This research was conducted with the aim of enabling both academicians and practitioners to understand the unusual situation of Network Master Planning better, learn about the fundamentals that apply to it and ways to confront it. In this context, NMP concepts have been proposed. A better understanding of NMP is expected to serve as a basis for further academic investigation, to help practitioners to realise the real potential regarding this topic and, thus, contribute to an improvement of NMP practice. The core point that this work makes is to contribute to academic and practitioner communities' realisation that Network Master Planning is different from traditional hierarchical planning approaches. Consequently, this realisation is expected to foster reflection on better ways to handle NMP and how to avoid some of its usual problems. It should, thus, contribute to well-designed NMP processes and successfully planned global production networks in the future.

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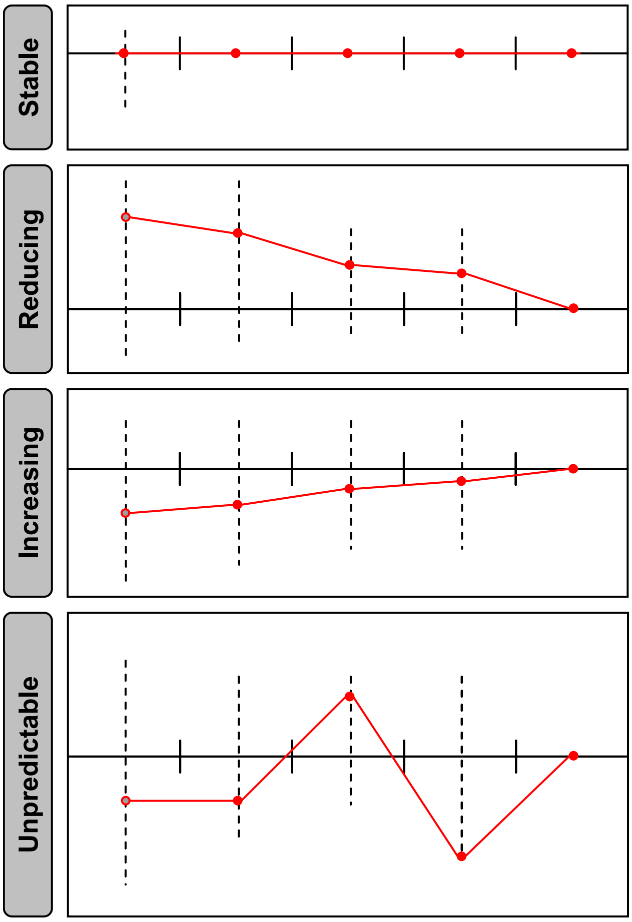
Appendix A

Figure A.1 depicts a classification of customer order behaviour which was derived from actual customer orders in the case company. The diagrams represent four specific customers. On the right side the corresponding end-item part numbers are shown. For each part number the average weekly delivery quantity as well as the maximum, minimum, and average deviation is displayed. Note: The classification refers to customers not to single part numbers.



1234 (1311;0;0;0)
1235 (832;0;0;0;)
1236 (1550;0.4;4;0)

1237 (3014;0;0;0)
1238 (1635;0;0;0)
1239 (1550;0.4;4;0)
1240 (10521;3.2;25)
1241 (4857;13.3;46;0)
1242 (4298;6.1;50;-33)
1243 (341;1.4;72;-29)
1244 (3350;48.3;279;0)
1245 (8083;102;825;0)
1246 (1698;230;1260;-59)

1247 (76;0;0;0)
1248 (6925;-1.5;0;-10)
1249 (16355;-1.3;14;-11)
1250 (5125;0.1;20;-25)
1251 (1253;-41.8;0;-100)

1252 (1700;-0.9;0;-10)
1253 (27446;2;10;-16)
1254 (9704;-4.2;3;-25)
1255 (2047;0;0;0)
1256 (4840;1.6;11;-3)
1257 (8000;-3;19;-61)
1258 (2224;8.3;100;0)
1259 (6295;2;73;-34)
1260 (135;9.4;107;-5)
1261 (448;-10.6;51;-68)
1262 (794;-18.7;22;-100)
1263 (1161;-1.4;50;-92)
1264 (913;-4.4;100;-55)
1265 (2214;1.8;131;-50)
1266 (717;20.8;166;-23)
1267 (8536;1.4;106;-100)
1268 (276;20;240;-25)
1269 (847;162;1470;-100)

Key: **Part number** (∅ weekly quantity; Average [%]; Maximum [%]; Minimum [%])

Figure A.1: Customer order behaviour analysis

Appendix B

Table B.1 summarises the individual process steps and responsibilities and provides an overview of interfaces to other planning disciplines.

Process	**Information/ Data**		**Persons/ departments**	
Step	**Input**	**Output**	**Who to involve**	**Data origin**
Data preparation	• Sales data (VPZ) • Demands (actual + forecasted) • Expert know-how	• VPZ clustered by products • VPZ clustered by regions	• Sales/ marketing departments	• Proprietary databases
Capacity check	• Resource capacities • VPZ clustered by regions	• Capacity utilisation	• Expert knowledge from lead-plants	• TECCAP
Reconstruction of old allocation	• TPZ of previous cycle • Resource capabilities • Demands (actual + forecasted)	• Customer demand developments • Capacity development	• Expert knowledge from lead-plants	• TECCAP • MDS
Strategic production quantities	• BP strategy • Site concept • Customer demand developments • HCL/ LCL overview • Capacity situation per region • Business results of plants	• Production strategy • Strategic production quantities per plant • Dis-/Investment decisions	• -	• RECON • Proprietary databases • Strategy papers
Fine planning	• VPZ per product • Resource capacities & capabilities • Customer releases • Strategic production quantities • Further constraints	• TPZ per product • Required future capacity: Overcapacities/ Bottle-necks	• Expert knowledge from lead-plants • Conflicting constraints: appropriate hierarchy level	• MDS • TECCAP • RECON
Data consolidation	• TPZ per product (for each product)	• TPZ in total • Capacity situation	• -	• CAPPLAN

Table B.1: Methodology step summary

Appendix C

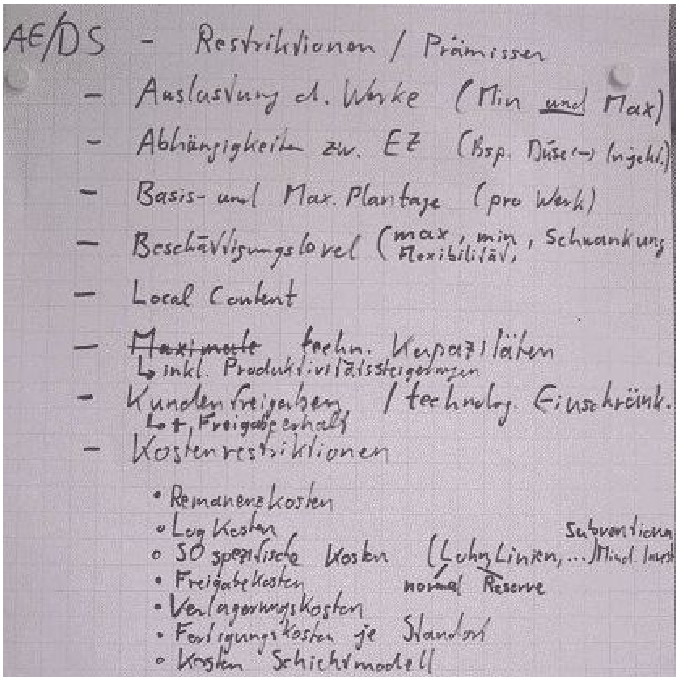
This section presents excerpts from development minutes and relevant aspects from meetings with practitioners.

Constraints, initially formulated objectives, and requirements

Actual situation for VPZ-TPZ-planning at NCU:

- Planning on level of single end-items
- Planning horizon is half years for years 1-4 and full years for 5-10.
- High manual effort due to necessary data preparation and interdependencies between planning objects and between constraints.
- Generation of solution alternatives is demanded by upper hierarchy level but is really time consuming.

Constraints:



AE/DS - Restriktionen / Prämissen

- Auslastung d. Werke (Min und Max)
- Abhängigkeiten zw. EZ (Bsp. Düse ↔ Injekt.)
- Basis- und Max. Plantage (pro Werk)
- Beschäftigungslevel (max, min, Flexibilität, Schwankung
- Local Content
- ~~Maximale~~ techn. Kapazitäten
  ↳ inkl. Produktivitätssteigerungen
- Kundenfreigaben / technolog. Einschränk.
  ↳ + Freigabeerhalt
- Kostenrestriktionen
  - Remanenzkosten
  - Log Kosten
  - SO spezifische Kosten (Lohn, Linien, ...) Subventionen, Mind. Inv
  - Freigabekosten normal Reserve
  - Verlagerungskosten
  - Fertigungskosten je Standort
  - Kosten Schichtmodell

Figure C.1: Constraints initially formulated by practitioners

Conditions:

- Constraints vary over time.
- Customer releases extinguish if they are not used within 6 months.
- High-volume products have parallel releases.
- Considerable production cost differences between sites in the network.
- Knowledge about product and production resource attributes is located at lead-plants (proprietary systems).
- Some resources are used by multiple products. The problem is to find the 'optimal' share ratio.
- Various systems, data models and structures at the individual plants.

Basic constraints:

- Customer releases
- TEC per resource depends on mix of products that is allocated
- Production costs

Reasons for constraints changing over time:

- New customer releases can be initiated by negotiation with customer. New releases cause release costs.
- TEC is variable due to increases in resource productivity. But rising number of product variants reduces available TEC (more frequent machine set-ups).
- Production costs: objective is to lower production costs over time.

Decision relevant costs per plant are:

- Personnel,
- Material, and
- Tool costs.

In the analysed case material and tool costs show no big difference between sites due to central purchasing and know-how transfer. Personnel costs differ. Because of the calculation model in use in the analysed business division, personnel costs per individual product are not directly available (only total production cost per product) but have to be estimated.

- Additional constraints formulated:
  - Load all HCL equally (percentage),
  - Release flexibility in the network has to be x%, and
  - Parallel releases are to be distributed 50/50.
- Hard constraints make solution space vanish.

Time variability of constraints

- Hard constraints can turn to soft, in case that no solution can be found with existing constraints. Expert needs to decide on how soft is still feasible.

Initial test scenario

- Product for first tests: Common Rail pump CP with ca. 60 SNR and 8 production lines at 5 internationally distributed sites.
- Initial constraints:
  - Resource capacities and capabilities.
  - Customer releases.
  - Required minimum utilisation factor per plant.
  - Product cost indices.
  - Logistics costs as cost factors for transfer between geographic regions.

Preliminary part numbers

- Preliminary part numbers are not assigned to a single customer but serve as identifier for groups of products with similar attributes.

Part number	Product	Variety	Customer	Country	Region
04450Z1234	CR-CP	CPxxxx	Customer1	Country1	Europe
			Customer2	Country2	Asia
			Customer3	Country3	Europe
				Country4	Asia
			Customer4	Country3	Europe
			Customer5	Country2	Asia

Figure C.2: Preliminary part numbers as one source of complexity

Visualisation

- Definition of comprehensible and easy-to-handle visualisation with practitioners.

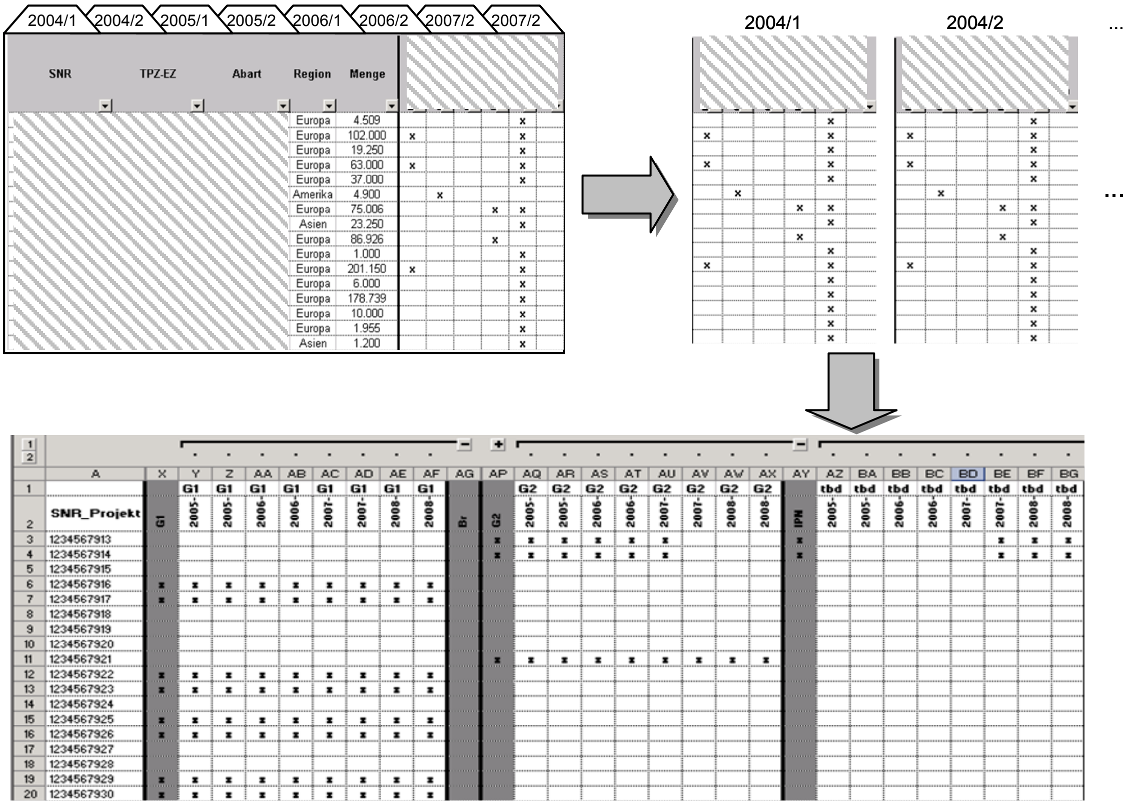


Figure C.3: Development of visualisation (example: customer releases)

Strategic constraints, data availability, and prototype validation

- Decision to leave strategic issues such as resource relocations (and corresponding costs) subject to human planning.
- Different production depths at individual plants lead to incorrect cost calculation.
- Solution alternatives:
  - Use assembly costs, i.e. personnel cost index, for calculation
  - Define correction factor per plant.

  → Both alternatives require generation and administration (!) of data on detailed level.
- Format and availability of necessary input data differs from one site to another:
  - Data provision from plants is problematic

- Decision to specify and develop a central Master Data server for input data.

Level of detail for resources

- Planning on level of product-variety-specific production lines leads to:
  - massive effort for data provision/generation
  - pre-determination of solution

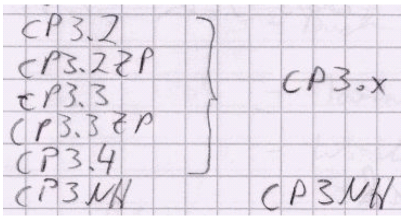


Figure C.4: From product-variety-specific lines to virtual lines

- But detailed view necessary for capacity/capability overview
- Emerging constraint: plan LCL on level of MaxTEC (instead of BaseTEC).

Human planner needs to develop a 'feeling' for numbers

- Planner needs to get a sense for VPZ to understand the result of tool planning.
- Decision about parallel releases for new part numbers need human expertise.
- Agreement on new approach:
  manual preparation → tool processing → manual finalising
- Total production-quantities per plant need to stay subject to human decision makers.
  → Capacity-fine-planning tool is useful to "fill" the quantities, not to define them.

Consequences of concurrent constraints

- Result of high number and concurrent constraints in GA planning:
  - All constraints have to be integrated in tool objective function.
  - In order to provide the required flexibility, a user interface for easy adapting constraint rules is necessary.
  - The objective function is getting more complex with growing number of constraints. Concurrent constraints are difficult to integrate.
  - In the given environment it is hardly predictable, when the total minimum is reached, like illustrated in Figure C.5.

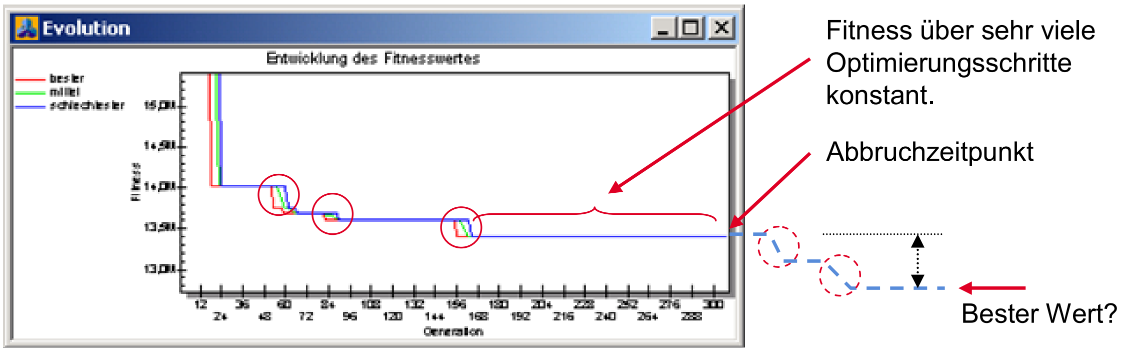


Figure C.5: Evaluation of fitness of solutions

GA parameter testing

- The author conducted tests with different sets of input data, i.e. CP and CRI data from different planning cycles.
- The objective was to find GA parameters (number of generations, generation size) which allow fast convergence – mainly independent from input data.
- No such universal parameters could be found. Each set of input data showed another characteristic (see Figure C.6).
- The depicted examples show that even a small change in generation size can lead to a significant difference in the best fitness value and number of found valid solutions.

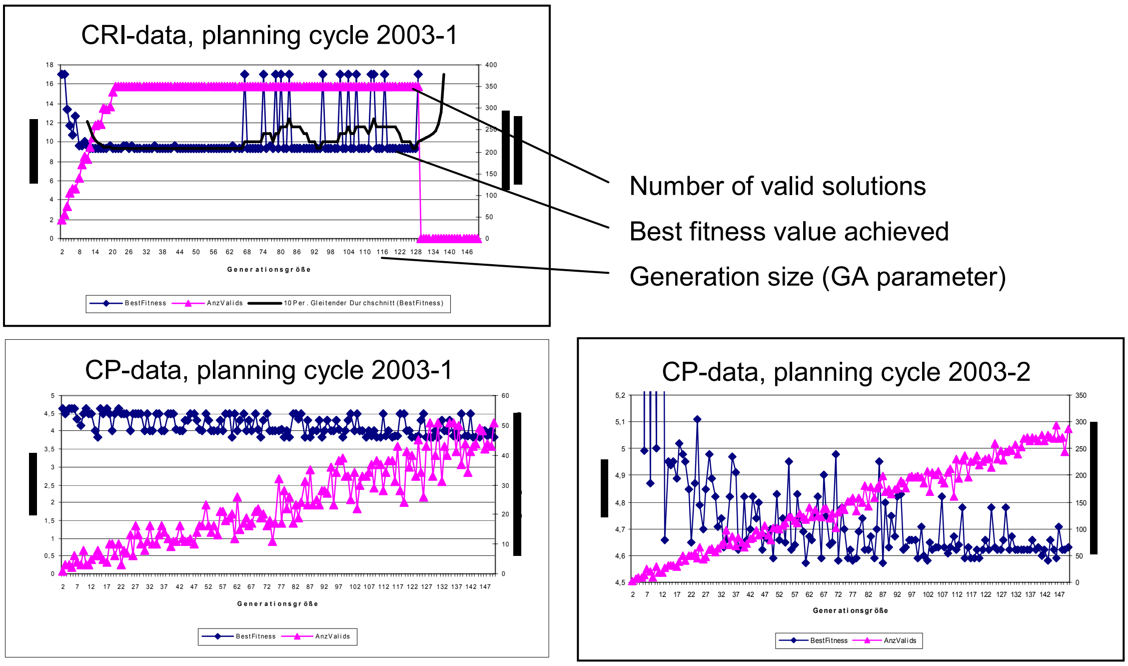


Figure C.6: GA parameter testing

Expansion of scope

- Expand scope of research work from capacity-fine-planning to complete planning procedure.
- The objectives are:
  - to redefine process steps and align them to each other,
  - to specify appropriate tool support, and
  - to improve quality/usability of in-/outputs.
- Formalisation of iterative feedback loops in procedure.
- Tests with ‘80/20-architecture’ tool

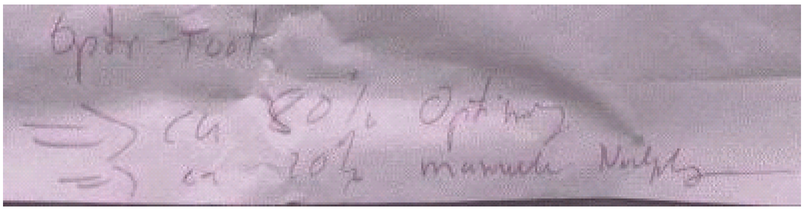


Figure C.7: 80/20-architecture

Planning-process inputs and outputs

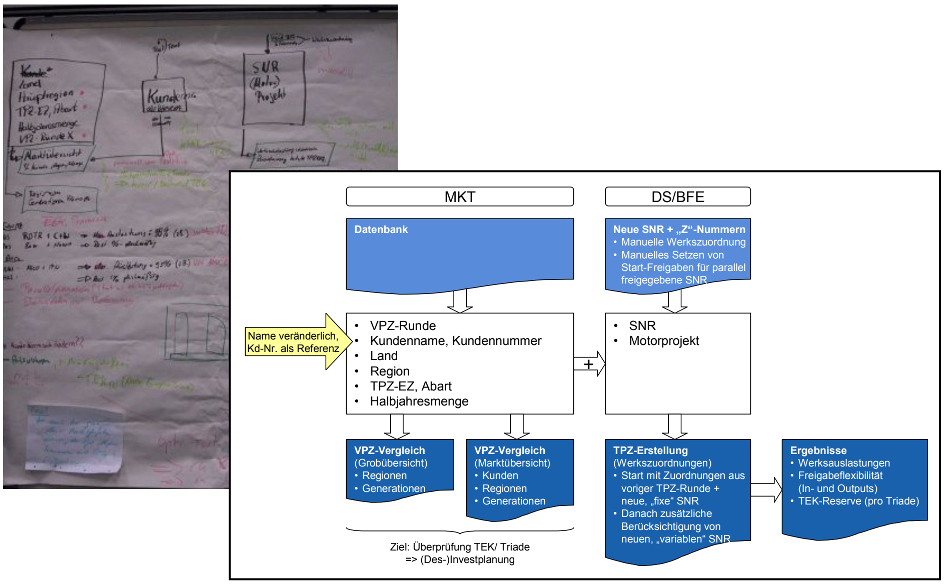


Figure C.8: Planning-process inputs and outputs for example CRI

Specification of RECON

- There is no unique key in MKT database that allows to track certain items between planning cycles → but it could be generated by combination of unique product characteristic IDs.
- Data transferability from TPZ_{old} to VPZ_{new} is less than 60%.
- General idea of tool support:

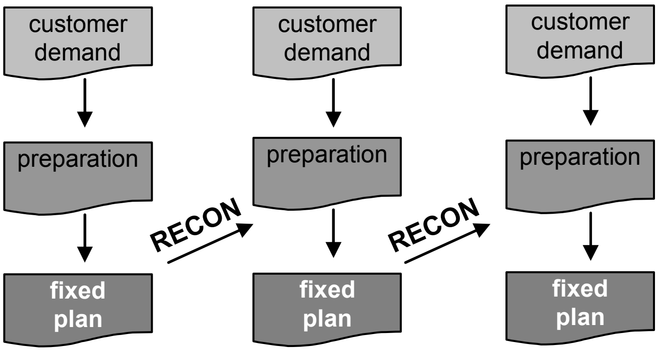


Figure C.9: Basic procedure with RECON

- Detail procedure steps for RECON:

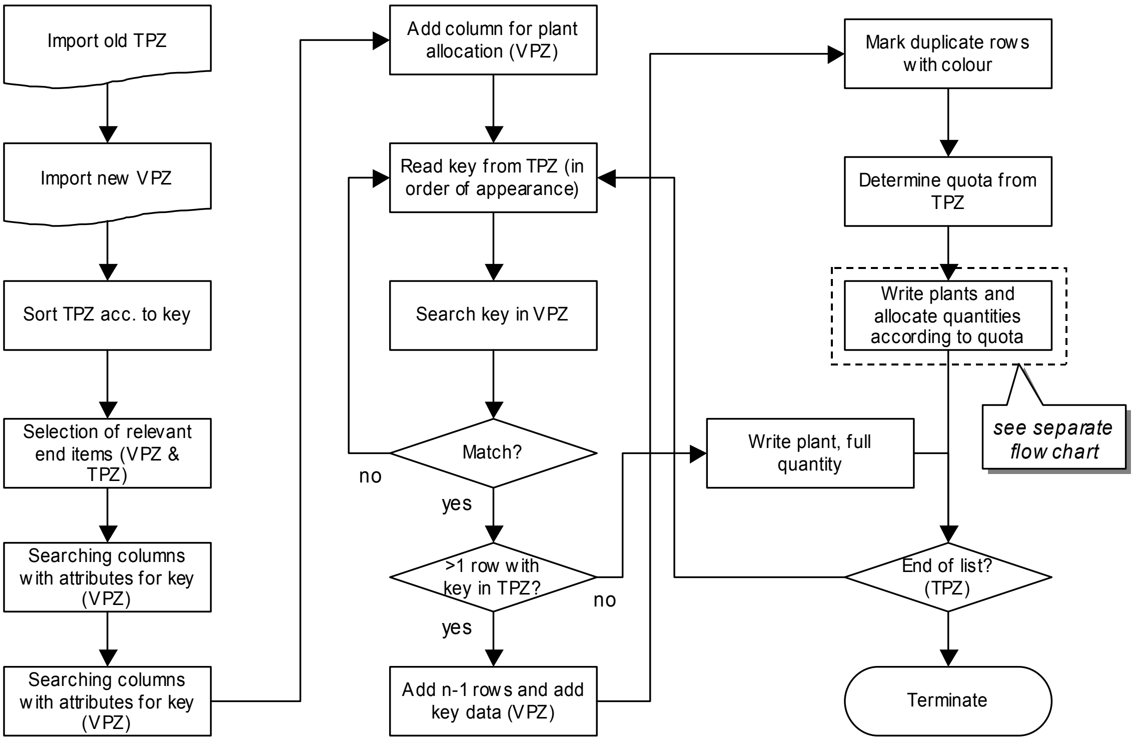


Figure C.10: RECON – Detail procedure steps

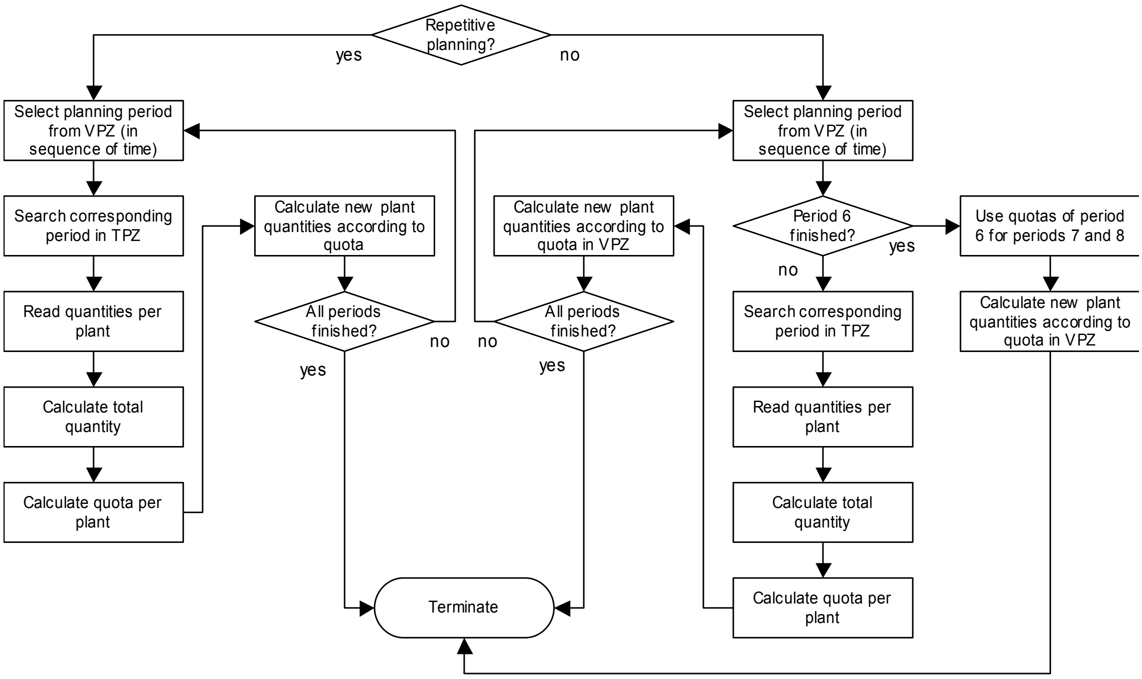


Figure C.11: RECON – Determination of quotas

Introduction of ‘virtual lines’

- Product mix decides if a certain quantity per resource is feasible.

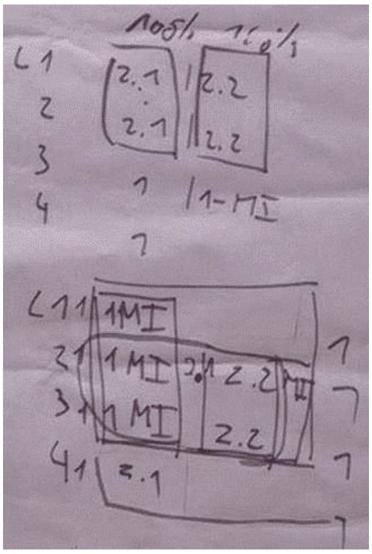


Figure C.12: Definition of virtual lines

Specification of MDS

- All TPZ-relevant master-data is stored in MDS (ca. 15000 sets of data).
- The result of NMP, i.e. allocation of plants, are stored in MDS.
- Production plants are selectable from a pull-down menu.
- Production quantities of previous planning cycle can be displayed to discover trends and get a feeling for current figures (see Figure C.13).

Product	**Part number**	**Plant**	**current TPZ**			**previous TPZ**		
			2007/1	**2007/2**	**…**	**2007/1**	**2007/2**	**…**
CRI-CRI	1234567890	VPZ-quantity	500	500		500	500	
		# NA	0	**100**		0	0	
		Plant1	250	200		250	200	
		Plant2	150	200		150	200	

Figure C.13: MDS – comparison of planning cycles (example)

- Tool support is getting even more important because in future planning is to be done 3-4 times a year on a regular basis.
- Number of data fields is expected to be reduced by one third.

Appendix D

Genetic Algorithms (GA) provide an ‘intelligent’ heuristic for solving many types of combinatorial problems (see e.g. Reeves 1993 for an introduction). The main idea in GA is to employ the mechanics of natural selection and natural genetics to evolve a population of initial solutions. Given the population of solutions at any iteration, each solution is evaluated to give some measure of its ‘fitness’. A new population is then formed for the next iteration by choosing individuals to act as parents. The parents then breed using some ‘genetic operators’ to produce the children of the next generation (Goldberg 1989). Whereas many traditional methods only work on a specialised type of problem, a key aspect of the GA has been the issue of robustness, enabling the method to be employed on a wide range of problems (Wilson 1997; Kumral 2004).

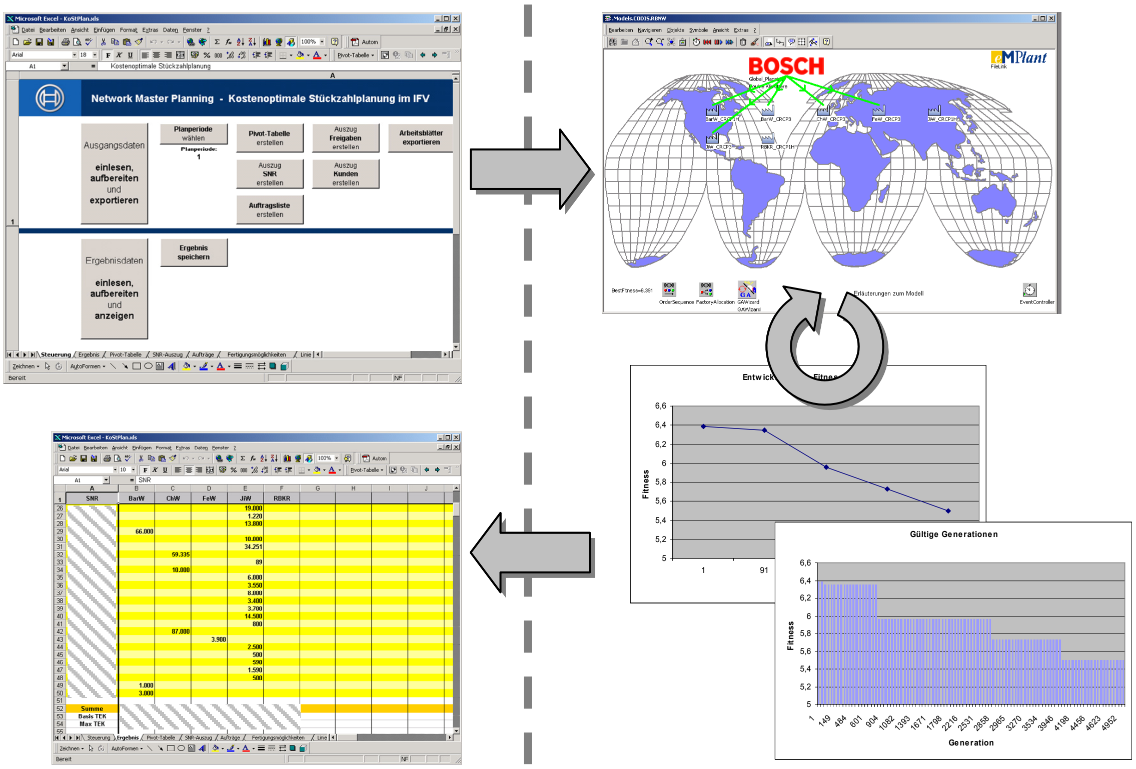


Figure D.1: Overview of GA-based prototype procedure

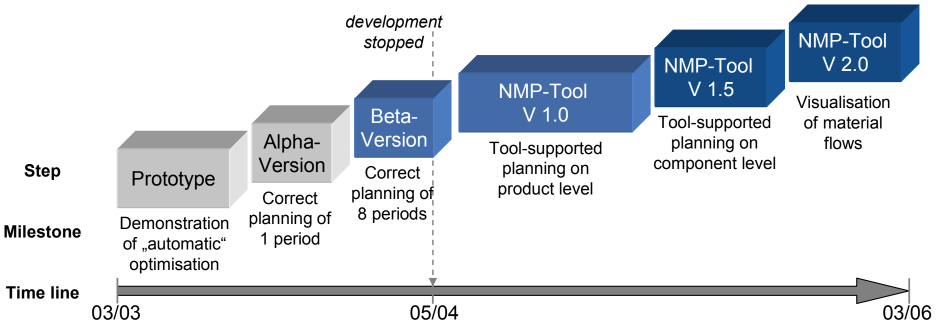


Figure D.2: Initially planned steps of development for automatic optimisation

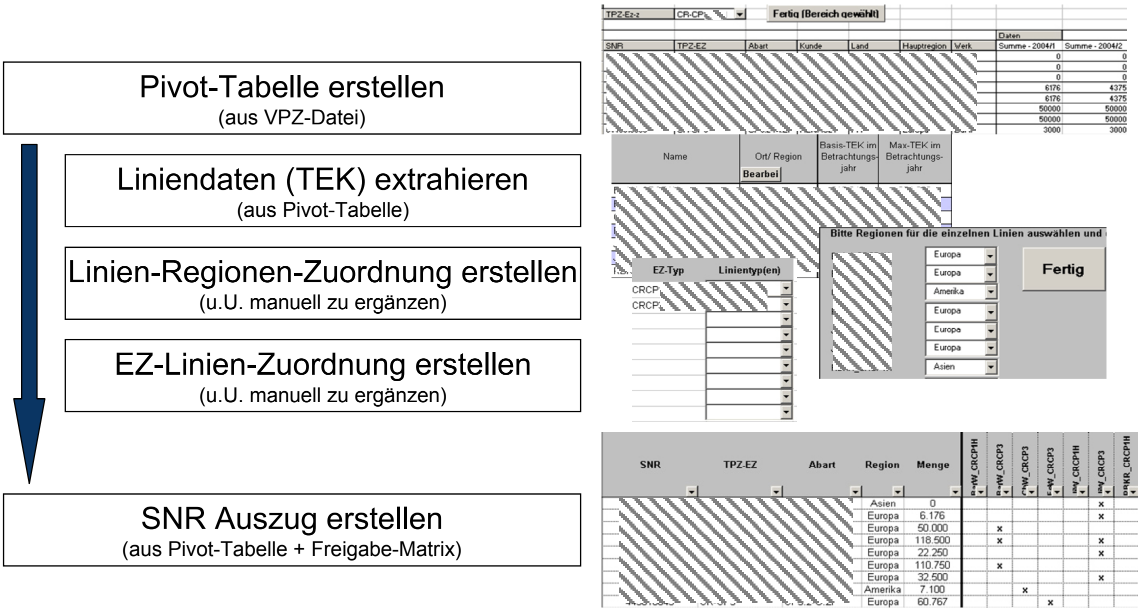
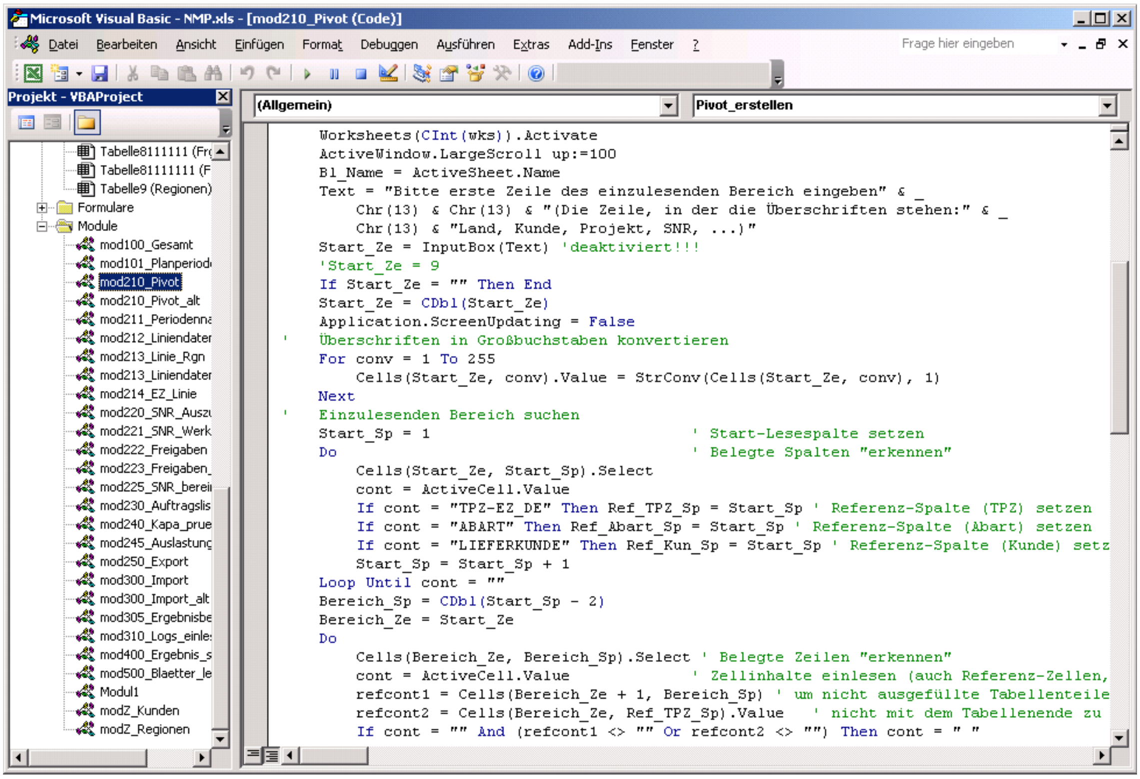
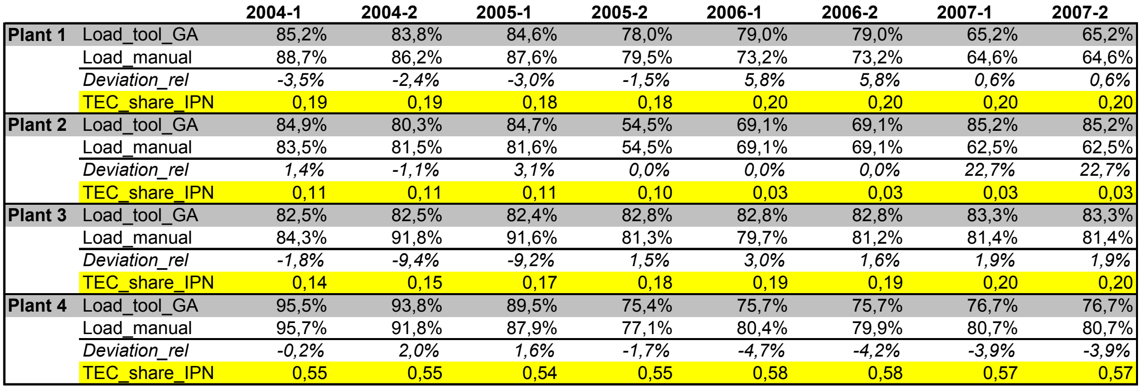


Figure D.3: Screenshots from Excel-tool



```
    Worksheets(CInt(wks)).Activate
    ActiveWindow.LargeScroll up:=100
    Bl_Name = ActiveSheet.Name
    Text = "Bitte erste Zeile des einzulesenden Bereich eingeben" & _
        Chr(13) & Chr(13) & "(Die Zeile, in der die Überschriften stehen:" & _
        Chr(13) & "Land, Kunde, Projekt, SNR, ...)"
    Start_Ze = InputBox(Text) 'deaktiviert!!!
    'Start_Ze = 9
    If Start_Ze = "" Then End
    Start_Ze = CDbl(Start_Ze)
    Application.ScreenUpdating = False
'   Überschriften in Großbuchstaben konvertieren
    For conv = 1 To 255
        Cells(Start_Ze, conv).Value = StrConv(Cells(Start_Ze, conv), 1)
    Next
'   Einzulesenden Bereich suchen
    Start_Sp = 1                                ' Start-Lesespalte setzen
    Do                                          ' Belegte Spalten "erkennen"
        Cells(Start_Ze, Start_Sp).Select
        cont = ActiveCell.Value
        If cont = "TPZ-EZ_DE" Then Ref_TPZ_Sp = Start_Sp ' Referenz-Spalte (TPZ) setzen
        If cont = "ABART" Then Ref_Abart_Sp = Start_Sp ' Referenz-Spalte (Abart) setzen
        If cont = "LIEFERKUNDE" Then Ref_Kun_Sp = Start_Sp ' Referenz-Spalte (Kunde) setz
        Start_Sp = Start_Sp + 1
    Loop Until cont = ""
    Bereich_Sp = CDbl(Start_Sp - 2)
    Bereich_Ze = Start_Ze
    Do
        Cells(Bereich_Ze, Bereich_Sp).Select ' Belegte Zeilen "erkennen"
        cont = ActiveCell.Value                 ' Zellinhalte einlesen (auch Referenz-Zellen,
        refcont1 = Cells(Bereich_Ze + 1, Bereich_Sp) ' um nicht ausgefüllte Tabellenteile
        refcont2 = Cells(Bereich_Ze, Ref_TPZ_Sp).Value   ' nicht mit dem Tabellenende zu
        If cont = "" And (refcont1 <> "" Or refcont2 <> "") Then cont = " "
```

Figure D.4: VBA-Code for one example



		2004-1	2004-2	2005-1	2005-2	2006-1	2006-2	2007-1	2007-2
Plant 1	Load_tool_GA	85,2%	83,8%	84,6%	78,0%	79,0%	79,0%	65,2%	65,2%
	Load_manual	88,7%	86,2%	87,6%	79,5%	73,2%	73,2%	64,6%	64,6%
	Deviation_rel	*-3,5%*	*-2,4%*	*-3,0%*	*-1,5%*	*5,8%*	*5,8%*	*0,6%*	*0,6%*
	TEC_share_IPN	0,19	0,19	0,18	0,18	0,20	0,20	0,20	0,20
Plant 2	Load_tool_GA	84,9%	80,3%	84,7%	54,5%	69,1%	69,1%	85,2%	85,2%
	Load_manual	83,5%	81,5%	81,6%	54,5%	69,1%	69,1%	62,5%	62,5%
	Deviation_rel	*1,4%*	*-1,1%*	*3,1%*	*0,0%*	*0,0%*	*0,0%*	*22,7%*	*22,7%*
	TEC_share_IPN	0,11	0,11	0,11	0,10	0,03	0,03	0,03	0,03
Plant 3	Load_tool_GA	82,5%	82,5%	82,4%	82,8%	82,8%	82,8%	83,3%	83,3%
	Load_manual	84,3%	91,8%	91,6%	81,3%	79,7%	81,2%	81,4%	81,4%
	Deviation_rel	*-1,8%*	*-9,4%*	*-9,2%*	*1,5%*	*3,0%*	*1,6%*	*1,9%*	*1,9%*
	TEC_share_IPN	0,14	0,15	0,17	0,18	0,19	0,19	0,20	0,20
Plant 4	Load_tool_GA	95,5%	93,8%	89,5%	75,4%	75,7%	75,7%	76,7%	76,7%
	Load_manual	95,7%	91,8%	87,9%	77,1%	80,4%	79,9%	80,7%	80,7%
	Deviation_rel	*-0,2%*	*2,0%*	*1,6%*	*-1,7%*	*-4,7%*	*-4,2%*	*-3,9%*	*-3,9%*
	TEC_share_IPN	0,55	0,55	0,54	0,55	0,58	0,58	0,57	0,57

Figure D.5: Comparison of results for GA supported planning (dummy data)

Reasons for deviations in quantities between manual and tool planning in periods ‘2007-1’ and ‘2007-2’: The constraint ‘load Plant 4 (LCL) near 100%’ had not been formulated prior to the tool planning run. However, manual planning followed this rule.

Results of prototype validation for capacity-fine-planning:

- The tool in principle generates valid and reproducible results
- The tool generated plan is comparable to manually generated plans.
- Deviations stem from rules that were not implemented in tool, like strategic constraints.

Appendix E

Guideline questions for semi-structured interviews and discussions with practitioners:

Objectives
What are your objectives (incl. weighting of importance)?
Which factors do you optimise?
What are you measured by? • For example: performance of supply chain or single department/ machine pool/ ...
How do you know when you have a good plan/ system-design?
Is there any pressure to prove your system's robustness?
Methodology
Do you have rules/ guidelines for designing or is it all experience-based? • For example: never create a certain product mix.
Is there a standard procedure/ process to create a plan/ system-design? • Do you change it? And where? How?
Do you create alternative plans/ system-designs for alternative scenarios?
Is your plan/ system-design easily adaptable, or do you wait and re-plan/ re-create if needed?
How do you plan/ create a system-design? • Type of system; procedure of manual planning.
What are your possibilities to react to changes (in the variables)?
How do you react?
Challenges
How often are there changes that affect your plan/ system-design? • Little; much; excessive, i.e. complete change of plan necessary.
Where do changes (of variables) come from? • Supplier; customer; own company, e.g. from management decisions or machine failure.
What makes your job difficult; what can make your job easier?
If you could make three problems disappear, what would they be? For example: • Bad quality of customer demand preview. • Have half a day to plan, without phone or email, instead of 2 days with interruptions.
Are there any trends and if, how do they affect the answers to questions given above? • Globalisation • Are demands of customers changing? • Is customer behaviour changing?
Tool support
Are there any tools that help you?
Are there any tools that might help you (that should be built)?

Table E.1: Guideline questions