Modeling of decision making processes in supply chain planning software : a theoretical and empirical assessment of i2 TradeMatrix

Citation for published version (APA):
Zoryk-Schalla, A. J. (2001). *Modeling of decision making processes in supply chain planning software : a theoretical and empirical assessment of i2 TradeMatrix*. [Phd Thesis 2 (Research NOT TU/e / Graduation TU/e), Industrial Engineering and Innovation Sciences]. Technische Universiteit Eindhoven. https://doi.org/10.6100/IR549655

DOI:
10.6100/IR549655

Document status and date:
Published: 01/01/2001

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Modeling of Decision Making Processes in Supply Chain Planning Software

a theoretical and empirical assessment of i2 TradeMatrix

Modeling of Decision Making Processes in Supply Chain Planning Software

a theoretical and empirical assessment of i2 TradeMatrix

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
Rector Magnificus, prof.dr. R.A. van Santen,
voor een commissie aangewezen door het
College voor Promoties in het openbaar te
verdedigen op dinsdag 4 december 2001 om 16.00 uur

door

Anastasia Juliane Zoryk-Schalla, geb. Roumeliotis

geboren te Aachen, Germany

Dit proefschrift is goedgekeurd door de promotoren:

Prof.dr. A.G. de Kok

en

Prof.dr.ir. J.C.Wortmann

Copromotor:
Dr.ir. J.C. Fransoo

Zoryk-Schalla, Anastasia Juliane

Modeling of decision making processes in supply chain planning software : a theoretical and empirical assessment of i2 TradeMatrix / by Anastasia Juliane Zoryk-Schalla born Roumeliotis. – Eindhoven: Eindhoven University of Technology, 2001. – Proefschrift. –

ISBN 90-386-1537-X
NUGI 684

Keywords: Supply Chain Management; Hierarchical Planning; Decision Support; Modeling; Anticipation; Advanced Planning and Scheduling; Empirical Research

Printed by: Eindhoven University Press

To my father,

Paris Roumeliotis

† 4th June 1998

First do what is necessary,
then do what is possible,
and suddenly you
create the impossible.

Franz von Assisi

Acknowledgements

I greatfully acknowledge and express deep appreciation to the many wonderful people who made this research project possible. Writing this book became part of my life and filled me with passion about my work. The nature of the research was such that only with the aid of many people from science and industry, could the project goals be achieved.
Firstly, I want to express my gratitude to my promotor Ton de Kok and my co-promotor Jan Fransoo. Their ideas, comments and suggestions always helped keep me on track and made working with them a great honour and pleasure. Although it was not your duty, you both helped me with your advice and encouragement in a difficult situation in my professional life.
I am greatly indebted to the members of the core committee, Ken McKay, Hans Wortmann and Will Bertrand. Without their enthusiasm and interest for this type of research, especially their ideas and guidance, this project would not have been successful. Of course I would also like to thank the many people from the industrial companies involved in this research. Although answering the questionnaire was time consuming, they supported this project with their willingness to cooperate and provided many interesting discussions. I thank Jeroen Elsten and Thomas Kreuzberg for their assistance in performing the interviews and their contributions to both conceptual and practical issues. I am especially indebted to Heinz Buhl, Martin Bork and Karl-Friedrich Danielmeier who enabled me to finish this project whilst working for PricewaterhouseCoopers. I also thank Marja van de Bosch, secretary of capacity group LBS at Technische Universiteit Eindhoven (TUE), for taking over all kinds of annoying and time-consuming jobs and hence keeping me focussed on my work.
Looking back, I went a long way round until I finally could start this project, which has been a dream ever since I started my professional life. A few people supported me during that time and gave me guidance whenever it was necessary. In this regard, I thank Bernd E. Hirsch. I also want to thank Akbar Akbari for many things, but in particular for laying the groundwork many years ago so that this project could start. I thank Erwin Bronk for continuing to smooth that way for me.
I must specifically thank Johannes Krauth, who advised me to contact Technische Universiteit Eindhoven (TUE). I would like to thank TUE, and especially Ton den Kok and Hans Wortmann, for giving me the opportunity to start this research project following a two year search for a university.

Finally I wish to express my sincere thanks to my best friend Markus Rühl. During the last years he was the one who supported me with his advice, practical help and by just being there.

Anastasia J. Zoryk-Schalla October, 2001

MODELING OF DECISION MAKING PROCESSES IN SUPPLY CHAIN PLANNING SOFTWARE

a theoretical and empirical assessment of i2 TradeMatrix

Chapter 1

Introduction and Research Questions

This chapter begins with an introduction to Supply Chain Planning and gives an overview of different approaches that can be used to tackle the planning problem, developed since the 1970's until today (section 1.2). The objective is to illustrate the key problems and decisions in modern Supply Chain Planning and to explain the design structure (section 1.3) of modern Advanced Planning and Scheduling (APS) systems with respect to problem decomposition and hierarchical ordering (section 1.4). In section 1.5 the research questions are defined explicitly. The scope of the research is addressed in section 1.6 by additionally separating the relevant questions and aspects which can be related to our subject but that are not considered in this thesis. The outline of the thesis is given in section 1.6.

1.1 Introduction to Supply Chain Planning

The supply chain represents a fundamental part of any business – covering all the physical processes and information flows from raw material procurement to delivery to the end customer A formal definition for a supply chain has been given by Handfield and Nichols (1999): *"A supply chain* encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through the end user as well as the associated information flows. Material and information flow both up and down the supply chain. *Supply Chain Management (SCM)* is the integration of these activities through improved supply chain relationships, to achieve a sustainable competitive advantage"

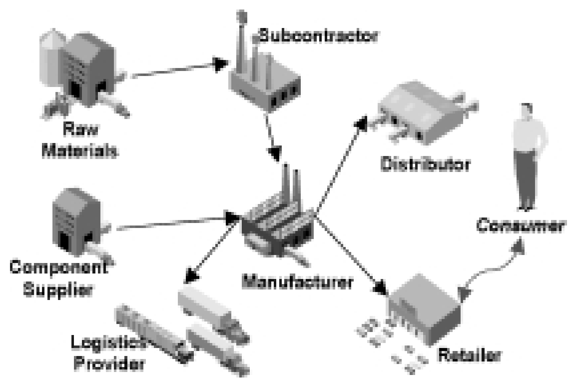

Figure 1: Supply Chain Management

Recent developments in the current global environment, such as increased demand, decreased customer loyalty, shorter product life-cycles and mass product customization, forces companies to lower costs while increasing the quality and variety of products and services supplied. Companies today are progressing from the notion of supply chains to extended supply chains and supply networks to electronically connected supply networks, which facilitate information sharing, transaction execution and collaboration on plans.

Regarding this development, the basic internal supply chain is still a key factor for success, since further applications are based upon it. Considering the recent developments of a global or regional supply chain - and in contrast to market developments - there is still a gap between vision and reality. Some manufacturers have achieved elements of global supply chain management, but generally through economic necessity rather than through a conscious operational strategy.

Many of the larger companies have implemented Enterprise Resource Planning (ERP) systems over the past years, and a considerable number of those companies are also well underway implementing supply chain planning software. The implementation of supply chain planning software remains a crucial process as supply chain planning capabilities remain the basis of all further developments in the e-business context. Accordingly, it is still the planning problem itself, which needs special consideration.

By looking back, during the peiod of time over which supply chain planning became an issue, different approaches to tackle planning problems have been developed. The most important approaches are Material Requirements Planning (MRP-I and MRP-II), Just-in-Time (JIT), Optimized Production Technology (OPT), and more recently Supply Chain Planning (SCP). It has been shown (Betrand *et al*)

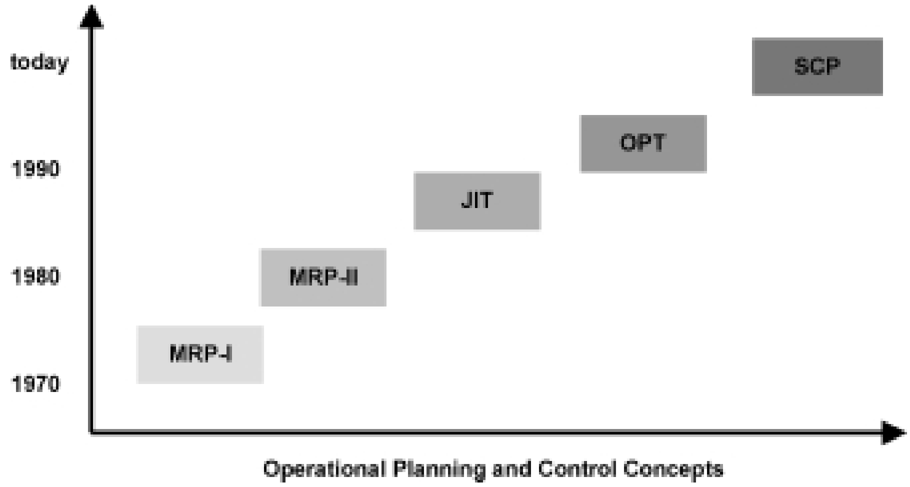

Figure 2: Operational Planning and Control Concepts

(1990) that the approaches and frameworks developed differ and have a restricted applicability. A major point of criticism was that each of the principles implies an approach which does not do justice to the richness of variety which exists in production planning and control situations.

The Manufacturing Resource Planning framework (MRP-I and MRP-II) (Vollmann *et al*.) is probably the most well known example of a hierarchical planning framework. In the MRP-II framework planning levels and execution levels have been distinguished as, for example Business Planning, Sales&Operations Planning, Master Production Scheduling, Material&Capacity Requirements Planning, Execution of Capacity and Material Plans. In addition we can say, that the MRP-II approach is the refined successor of MRP-I, by extending MRP-I with the Master Production Scheduling concept. Criticism has been made (Bertrand *et al.* 1990) that the MRP-II framework does not distinguish between on the one hand decision functions, which can be assigned to organisational positions, and on the other hand decision support systems and models. MRP was a standard system and as such it became profitable to invest in the development of MRP software. In many individual situations, however, the application of the MRP software turned out not to be straightforward, as changes in the structure of the organisation were required.

After the MRP-era the next move was towards the JIT approach (Schonberger). The rise of JIT was closely linked to the success of Japanese manufacturing firms and the development of the KANBAN system. With the JIT approach emphasis is not on the information systems, and on the production control interface, which plays such an important role in MRP, but on the japanese Kanban system in which the successive phases in a production process are controlled via a pull-system. Neither MRP nor JIT considers the efficient use of scarce capacity resources via intelligent scheduling and planning techniques. This latter aspect is the essence of the OPT approach. More recently OPT has been extended to a general approach of production management (Goldratt/Cox, 1984).

We can stress that all approaches mentioned so far (MRP, JIT and OPT) are based only on partial insights into a few relevant aspects and do not consider all aspects of planning functions in one organisation, as it is done in Supply Chain Planning. Supply Chain Management became an issue as organisations were continously seeking to provide their products and services to customers faster, cheaper, and better than their competition. As a consequence organisations now find that it is no longer enough to only manage their own organisations. They must also be involved in the management of the network of all upstream companies that provide inputs, as well as the network of downstream companiesresponsible for delivery and after-sales service of the product to the end-customer. As key decisions in Supply Chain Management we can formulate (i2 Technologies):

- What to purchase, make and distribute when and where
- How to profitably meet projected peak seasonal demands without adding expensive capacity
- How to minimize asset deployment while retaining and attracting customers with reliable, fast service
- How to optimally use available material, capacity and suppliers for maximum profitability
- How to better trade off inventory levels and customer service for profit improvement
- How to ensure the right customers get the right products during periods of constrained supply

1.2 Advanced Planning Systems

Supply Chain Planning software generally adresses these key questions by identifying three main planning functions:

- Demand Planning
- Supply Planning
- Demand Fulfillement

Demand Planning develops a forecast of market demand by identifying market trends and predicting changes in customer preferences. Supply Planning ensures that the enterprise is prepared to meet the forecast demand by generating a supply plan into response buffers. Demand Fulfilment provides delivery committments for customer orders based on planned supply response buffers. It monitors and manages order commitments according to pre-set objectives. The planning functions of Demand Planning, Supply Planning and Demand Fulfilment describe special planning functions which form part of the overall framework of the SCM software vendor i2 Technologies, which is illustrated below:

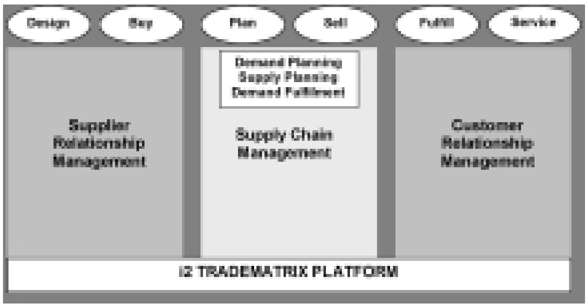

Figure 3: i2 TradeMatrix Solution Scope (Source: i2 Technologies)

A quite similar approach is described by the overall SCOR framework, which is a standard process reference model (SCOR) developed by the Supply Chain Council (SCC), an independent not-for-profit corporation, as the cross industry standard for supply chain management. The detailed planning functions in both approaches - i2 and SCOR – are identical. The only difference is the classification at a global level, as the SCOR model consists of four basic processes –plan, source, make, deliver- which define the top level processes that encompass a supply chain, and extend across all parts of the manufacturing and delivery process vendor payment. The scope is generally from immediate supplier's supplier to immediate customer's customer, in a "network of chains". The SCOR model has been used so far to configure, compare and implement supply chain network processes (Stephens, 2000). Although the SCOR model makes a distinction between Supply Chain Planning and Supply Chain Execution, we will focus mainly on the planning functions.

Figure 4: SCOR Model

As shown in the figure above, all detailed processes and decision functions which can occur in a typical supply chain, for example Sales & Operations Planning, Demand Forecasting, Supply Planning, Master Production Planning, Production Scheduling and Transportation Planning are part of the SCOR model.

In current Advanced Planning and Scheduling (APS) systems these decision functions are supported by specifically developed software tools, which are aimed at solving the single planning function under consideration. As with traditional supply chain approaches the development tools face challenges such as

- Planning tools encourage organisational disconnection (hierarchical decomposition and ordering)
- In sequential planning, Material and Capacity Requirements Planning do not concurrently consider all constraints (consistency)

By again looking back historically, for a large amount of the planning and decision functions relevant in Supply Chain Management, specific mathematical models have been formulated from a very early stage. Since 1920, Operations Research for example has been a scientific appoach which formulates mathematical models for all kinds of planning and control problems of production. Generally, in the Operations Research literature decision models for various problems of production planning and control have been formulated. But despite all the substantial theoretical developments in the area of Operations Research, however, only more recently standard software for operations planning and control become available. This standard software is based on the combination of generic OR models and methods and a powerful Graphical User Interface (GUI).

1.3 Decomposition and Planning Hierarchy in APS Systems

As already mentioned, the specific problem that such standard software has, and particularly APS systems, is that typically, the software consists of a number of interrelated, but loosely coupled modules. This results from the fact that only in a very small number of real-life situations, with limited complexity and limited uncertainty, solving a production planning problem based on a single planning model may be feasible.

We want to emphasize that this thesis is based on a specific view of what is meant by "model", and what is meant by "modeling": a "model" in our context is defined (in contrary to qualitative models in social sciences) as a quantitative model with a formal definition of variables and the relationships between variables. "Modeling" describes the process of translating a problem into a problem formulation, in terms of a quantitative model by defining objective functions and constraints.

In this context, in the majority of situations, restrictions in human cognition, mathematics, and computational power render solving the production planning and control problem as one single entity infeasible. The problem, therefore, needs to be decomposed into several sub-problems, which are generally ordered in a hierarchical manner (Bitran and Tirupati, 1993; Bertrand *et al*, 1990, Schneeweiss, 1999, Meal 1984). Accordingly, the two main problem areas in designing solutions for standard software applications are:

- How to decompose a problem into several sub-problems
- How to interrelate and hierarchically order these sub-problems

Already now in standard software applications the principle of ***decomposition*** has been recognized as a proper solution approach as one distinguishes between a mid-term planning level, where aggregate decision variables must be determined, and a short-term planning level, where detailed decision variables must be determined. Aggregation is then based both on time aggregation (hours into days, days into weeks, weeks into months) and on product and resource categories. Additionally, we can observe that current Advanced Planning and Scheduling software has adopted the concept of ***hierarchical ordering*** and ***hierarchical***

planning in the sense that in their implementations, aggregate decisions are made first and impose constraints upon more detailed decisions (Schalla *et al*, 2000; Stadtler and Kilger, 2000), in line with the more traditional approach towards hierarchical planning as introduced by Bitran and Hax (1977).

Detailed concepts for the problem of decomposition and hierarchical planning have been partly developed by Bertrand *et al.* (1990) who decompose the planning and control problem for so-called production units into a set of hierarchically related decision functions.

For special production units several researchers have elaborated the "what" of decision functions like master production plan generation, inventory management, sequencing and material requirements planning into the more explicit "how". Bertrand *et al* distinguish explicitly between problem decomposition, which they adhere to, and model decomposition. Model decomposition is used when a real-world planning and control problem is translated into a quantitative model, which in turn is decomposed into a number of subproblems. Usually the decomposition is required from a computational point of view: the model may be too big to solve or too complex to solve. Problem decomposition is based on the fact that within an organisation responsibilities for the planning function as a whole are distributed among different departments and people. Essential for this decomposition are the different kinds of decisions that must be taken based on different information, both in terms of the moment at which the information is required or is available, and in terms of the content of the information. For example people that take decisions about resource planning usually use aggregate information and consider a two-year horizon. People that take decisions about the dispatch of customer orders, use actual (real-time) information on the status of all known orders and all available resources. The latter information cannot be made available to the resource planner, since much information is in fact tacit knowledge.

In parallel Schneeweiss (1995) developed a generic framework for hierarchical decomposition, which assumes that quantitative models are used to support the planning and control of activities. Key to his approach is the use of a so-called anticipation function. In a two-level hierarchy this anticipation function is incorporated in the top-level model and represents the „expected“ future behaviour of the process at the time the base-level model is applied to take detailed decisions about the activities. In general it is still an open question whether a specific kind of anticipation, e.g. expectation is effective in case of uncertainty. What seems to be lacking in Schneeweiss' concept is the application of the anticipation concept within the base model itself, since in many cases the decisions taken are only implemented after some time. In this context it is relevant to gain insight into the impact of uncertainty in more detail than is described by Schneeweiss. Recent research of Negenman and De Kok[1998] on material coordination shows that taking expectations, only, does not capture this impact.

In view of the above it is our conclusion that the modeling of different production planning problems as part of a complete Advanced Planning and Scheduling system, including their decomposition into different levels and their hierarchical order is still a crucial problem. It is crucial since the degree and mechanism of their interaction highly influences the consistency and quality of the overall planning solution. Yet, special focus of the solution process in most APS systems is claimed to be optimality or feasibility
(see, e.g. **www.i2.com**, **www.manugistics.com**). Referring to the term feasibility we point out, that we can distinguish between the feasibility in terms of the APS system's model (e.g. i2) and the feasibility in terms of the planner. Both can be set into correlation by figure 5. Referring to the term optimality, it is assured that one can define a so-called objective function that reflects the firm's business objectives.

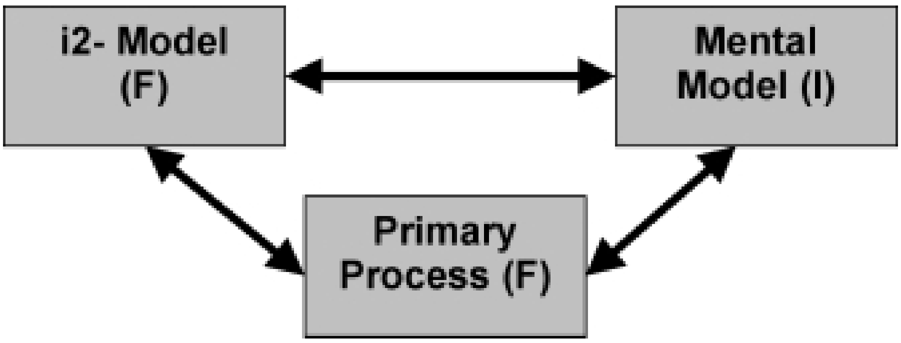

Figure 5: Feasibilities/Infeasibilities from different perspectives

The figure above shows the case, where the resulting plan is feasible (indicated as F) according to the APS system's (e.g. i2) model, but for the planner it is infeasible (indicated as I) for example because of additional rules or constraints unknown to the model. This scenario is a typical case of where a workaround needs to be introduced .

In fact more combinations are possible, such as

1. i2-model (I) / Mental model (I) / Primary Process (F)
   This is a typical example where replanning needs to be done
2. i2-model (I) / Mental model (F) / Primary Process (I)
   This is a typical example where the system is ignored by the planner
3. i2-model (F) / Mental model (I) / Primary Process (I)
   This is a typical example where a workaround needs to be started
4. i2-model (F) / Mental model (F) / Primary Process (I)
   This is a typical example where objectives cannot be realized

The best procedure appears to be that planners achieve a good and feasible solution by iteratively changing business objectives and/or priorities.
In summary, we agree in considering optimality and feasibility as being quite important aspects of a solution, but in addition we believe that consistency is of equal importance.
Another important aspect that we consider is the problem of information asymmetry. Information asymmetry basically entails the fact that when making a decision at a higher level, the amount and quality of information may be different than when the lower level decision was made (e.g. at a later time), and again different from when the actual execution of the decision takes place.

1.4 Research Questions

We hypothesize that a correct overall solution design, modeling and synchronisation of sub-problems has a big impact on the succesful implementation of standard software solutions up to the degree that in single cases the expected benefits cannot be achieved by the implementation because of incorrect design and modeling. We consider it of scientific relevance to empirically and conceptually research the use of such standard software to support the hierarchical planning and control function in a specific situation. Our main concerns are about why the modeling process in itself is difficult with respect to the structure of current APS systems. As the planning hierarchy in APS systems is hierarchically structured and most of the real life problems are of a hierarchical nature it still remains a challenging task to model hierarchical interdependencies. One of our main conclusions is that the difficulty of modeling is usually underestimated and has a big impact on the difficulties encountered in implementation. Our observations show that a number of changes in the modeling process can occur over time, if the structuring and modeling of the problem is done too quickly and with insufficient preparation. The main research questions we are dealing with in this PHD thesis are as follows:

- (RQ1) To what extent is the decomposition and hierarchical ordering of production planning problems in APS systems in agreement with theory and practice of planning and control of supply chains?
- (RQ2) To what extent is in APS systems the interaction between models at different planning levels in agreement with theory and practice of planning and control of supply chains? (Bertrand *et al.*, 1990, Schneeweiss, 1999)
- (RQ3) To what extent can modeling in APS systems ensure that the various levels of aggregation are still consistent?
- (RQ4) To what extent do APS systems incorporate the problem of information asymmetry and how can modeling help to overcome these problems?

Very closely related to the problem of decomposition (RQ1) is the problem of defining a hierarchical structure between once defined subproblems. Generally speaking, already for problem decomposition several possibilities exist, which do not exclude each other but which can be applied commonly. For example, according to the planning horizon of decisions the strategic, tactical and operational level can be distinguished. Also, a market related decomposition of the production planning problem leads to the separate planning of different product groups. Another example is the decomposition according to process oriented aspects, in which a decomposition of production into flexible production units and autonomous production areas is possible. But still, hand in hand with the decomposition goes the hierarchical ordering of the decomposed subproblems. The hierarchical ordering is of essential importance, as in general we can say that in a hierarchically structured system, the coordination of decision making processes is such that upper levels set restrictions for lower levels. We observe that in existing APS systems a decomposition and hierarchical ordering of subproblems has already been defined by the vendor. Examples for defined decision processes in i2 TradeMatrix are the processes of Available-To-Promise(ATP)-generation, Customer Order Acceptance, Due Date Quoting, Global Production Planning, Factory Planning and Scheduling, etc. For almost all of these decision processes a separate software module has been developed. Accordingly, the key question we pose in this thesis is whether the decision process structure - as defined in i2 TradeMatrix - goes in line with the existing organisational decision structure of the company under consideration. Our hypothesis is that if this is not the case, a number of modeling problems, integration problems and workflow problems might occur, which need special and detailed consideration. In the worst case we might find that the solution procedure used in the software is not related to the actual problem structure in the company.

In (RQ2) we specifically consider the degree of interaction between subproblems. Once subproblems have been defined and associated to different planning levels, an essential question is what degree of interaction is necessary between them. i2 Technologies has developed industry specific templates – as e.g. the i2 Metals Template or the i2 High Tech Template – in which functional workflows between single modules have already been defined. This was done according to the needs of a selection of representative companies in the Metals/High Tech Industries. The question we raise is whether such predefined workflows are consistent with the necessary workflows of the companies in which the systems are to be implemented. By going into more detail, the question we raise is focussed on two aspects:

- Content of information exchanged
- Frequency of information exchanged

The content and frequency of information exchanged between two modules has a big impact on the quality of the solution. In general detailed content and frequency are not predefined in templates and highly depend on the data and system's structure of each specific company. Our hypothesis is that additional add-ons might be necessary in order to get the full integration and consequently in order to get the full benefits which are to be achieved.

In (RQ3) we address the problem of consistency. It is our strong belief that besides optimality and feasibility, special consideration should also be given to consistency, as the success of the hierarchical approach depends to a large extent on the consistency between the various levels of aggregation and - additionally - on the interaction between the models at the different levels. In fact, consistency between planning levels is a requirement for the capability of APS software to generate optimal or even feasible plans. An example of an aggregation problem – and thus of a consistency problem – is the i2 TradeMatrix concept of "Planning Items". These are aggregate items that combine resource aggregation and product aggregation on the basis of similarity. The concept of "Planning Items" is a concept which has been incorporated in the i2 TradeMatrix Global Production Planning module and which needs to be consistent with the detailed product planning activities in the i2 TradeMatrix modules for mid-term planning (Factory Planner and Scheduler) (see section 5.3 for a detailed description). We believe that a correct model at the different planning levels and in general a coordinated approach can ensure that the consistency of the different solutions per module can be achieved. We want to point out that there may be several levels of consistency and each of them may represent a feasible solution for planners. Based on our observations we elaborate on the fact that the consistency and stability of solutions are highly dependent upon each other. As a first example we will describe in subsection 5.3.3. a solution approach in which two modules are only loosely connected to each other, with the consequence that this approach is characterized by low consistency between the modules but high stability for each of them. A second example is the approach which is characterized by average consistency between the modules and as well average stability. A third approach is the last extreme characterized by high consistency and low stability – an approach which in practice would probably be infeasible.

In (RQ4) we pay special attention to the concept of information asymmetry. For example, the mid-term planning **has to** use less detailed and different information than short term planning, because when medium-term planning is performed the detailed data required is not yet available. And yet the mid-term decisions should be such that the short-term decisions can be taken in line with overall operational objectives with respect to customer service, resource utilisation and capital investments. We believe that the fact that information asymmetry exists, leads to the necessity to **anticipate** at a higher level decision what may happen to the lower level decisions. In this thesis we will elaborate in section 5.3 as to whether the concept of anticipation is included as such in the i2 TradeMatrix solution approach, or whether the problem of information asymmetry is just solved by incorporating slack and frequent replanning. In general we believe that lack of anticipation will have strong consequences on the perceived quality of the model.

The principle research methology used was a single in-depth case study. Our study was an extensive multiple years, longitudinal single case. According to the features of the case study method (Yin, 1994), we developed a case study design, by focussing on the 5 components of the case study design as illustrated below:

- Formulation of Research Questions
- Formulation of Hypothesis

- Unit of Analysis
- Linking Data to Propositions
- Theory Development

Following the single case study, we conducted a series of interviews at four companies in the metals, high tech an semiconductor industry to verify our findings from the theoretical analysis and the case study.
A detailed description of our methodology is given in chapter 2.

Summarising we can say, that based on the extensive research we conducted on this theme over the last two years, our premise is that due to the modeling difficulty of APS software, good modelling skills are even more important in APS software than in traditional ERP software. We experienced that significant problems occur in understanding the structure of the supply chain planning problem, leading to many changes in model definitions during the implementation process. This empirical research should enable us to answer the scientific questions posed above. The in-depth empirical study is of scientific interest in itself, since the modeling part of the implementation process will be documented in detail.

1.5 Scope of the research

It may be surprising, but according to our observations, one of the key factors for success in APS implementation projects is correct and consistent modeling. It is even more surprising to realize that in fact little or no academic research has been published that rigorously describes and analyzes the modeling aspects in the implementation process of ERP / Advanced Planning and Scheduling Systems which greatly impact the way businesses currently operate.
One of the exceptions is the research project commissioned by the Baan Institute in 1998 (reported on in Markus and Tanis, 1999). In that study, the implementation process of an ERP system, notably the Baan system, is extensively described from an organizational change viewpoint. The authors measure ERP implementation success and relate this to the change process. The study contains many different observations and conclusions, of which we would like to mention two. The first one is that the chartering phase of the implementation process is one of the most crucial ones and usually underestimated. Secondly, many companies do not proceed with the process of improvement after they have succeeded in getting the information system ‘running’, thus preventing them from achieving

actual benefits from the system. In addition, we can observe that companies - dependent on their size - invest hundreds of thousands until millions of dollars in licensing the software, and a significant part of this is spent on hiring external consultants and making internal people available to make the implementation run smoothly (see, e.g. Bylinsky, 1999).
Not withstanding the importance of the organisational change process and any informational aspects, in this thesis we will focus only on modeling aspects of the implementation process of i2 TradeMatrix. Our main emphasis is on the process of modeling rather than describing the model in itself. The perspective from which we study APS systems, such as i2 TradeMatrix, is from the perspective of certain decision makers, such as planners, in a production planning hierarchy. We do not, however, consider any aspects of interaction between humans or any aspects of collaborative planning. Instead our focus is more on describing the formalisation of models and the associated dynamics within them. Additionally, we emphasize that it is not the complete supply chain which is examined in this thesis, but our focus is mainly on the specific i2 TradeMatrix Master Planner tool designed for tactical planning. Partially we also include observations with respect to the i2 TradeMatrix Factory Planner tool designed for operational planning. As a result of our observations, we will point out potential scope for modeling failures which could result in implementation delays and in not achieving anticipated business benefits. One important example of such a failure is the incorporation of anticipation and hierarchies in decision support systems, which is in fact a model description illustrated in chapter 5.

We are aware that there are many topics which can be related to this thesis and are also of particular interest. As we cannot put special focus on all of them we at least want to explicitly mention some selected questions of interest which have been recognized as related problem areas but which still cannot be considered in detail in this thesis:

- Organisational Aspects
- Data Structure Aspects
- Framework for implementing ERP / Advanced Planning Systems

In the following subsections we give a brief explanation of the problem areas stated above.

Organisational Aspects

In this thesis we are particularly interested in the content-side of an APS system, rather than in the organizational change process facilitating the implementation. Since we are interested in the implementation of an APS system, we will disregard the organizational change component. We argue that the organizational change component in the implementation process of an APS system is of considerably less impact than it is in an ERP system implementation. The main difference is the number of people involved. For instance, at the company we study in detail in this thesis, there are approximately 200 users of the ERP system SAP R/3 at the production site under consideration, while the planned number of users of the i2 TradeMatrix software including Demand Planner, Master Planner and Factory Planner is approximately 18 people for the entire supply chain consisting of four plants.

There are also empirical observations that the time taken for implementation of ERP systems is considerably longer than that for APS systems. For instance, at a top ten semiconductor company, i2 TradeMatrix was implemented at eighteen sites within a timeframe of one year , whereas the implementation of ERP software at a similar company has started in the early 1990's and is still not completed .

Data Stucture Aspects

Focussing on data structure aspects, we believe that although the focus of this thesis is on decision modeling, the basis for good decisions (and the basis for decision modeling) is the proper modeling structure for all data which are relevant to the decisions under consideration. In this thesis we concentrate on decisions to be made in a supply chain and analyse how different planning components can be positioned hierarchically and also how they can be integrated. Although never stated explicitly, we modeled these aggregated decisions and took as a precondition that the proper data modeling of all basic data which are needed for these decisions, is performed in the existing legacy data systems.

This is especially the case for the aggregation of information about products, which normally takes place for several material properties, without this fact being recognised in aggregation literature. Wortmann (2000) stresses that recognition of this fact would shed a different light on possibilities to aggregate as well as on the properties of aggregation rules in Production Planning and Control. Wortmann gives the following classification of materials/products and their lowest level of identification:

Discrete Products	Continous Products	Dimensioned Items	Parametrised Items (Variants)	Versions
Serialised Item	**Lowest Unit of Packaging**			

Table 1: Product Classifications

Wortmann points out that specifically from the pure material point of view, materials or products need to be classified and structured properly in any existing legacy systems. Especially with regard to information modeling a clear and predefined structure / hierarchy of materials and products helps any kind of further system development. As an example in this thesis we can consider the definition of Planning Items within the top level model of decision making. The definition of Planning Items is based firstly on a proper definition of the characteristics of end products and secondly on a clear definition of how end products can be aggregated. We are aware of the fact that both definitions are based on a clear material / product structure which needs to be available in the existing legacy systems.

In his further statements Wortmann (2000) puts special emphasis to the fact that when considering material or products in inventory (planned or actual), it can be observed that there are usually a number of quality properties relevant which are abstracted from (i.e. not taken into account) in other applications, e.g. logistics or financial applications. Some of these are described below. First of all, Wortmann makes a distinction between discrete products and (more or less) continuous products.

For discrete products, the lowest level of identification and status monitoring is the level of the individual item, the so-called serialised item. The classical example is the automotive vehicle and some of its parts. (Of course, not all discrete items are serialised: small consumer goods are usually non-serialised. However, if discrete goods are serialised, then this level is the lowest level at which distinction between different objects is maintained in an information system). If items are serialised, aggregation starts at this level, because such items are often considered identical in logistics or financial applications.

For continuous products, i.e. gasses and liquids, the lowest level of identification and status monitoring is the lowest unit of packaging (usually discrete), such as the individual vessel or bottle. The vessel or bottle may or may not become a serialised discrete item again, take for example a case of wine. (Not all continuous products are available in discrete packaging units. For example, oil and gas, water and electricity are transported towards households in continuous form. Within manufacturing plants, such a way of transportation is quite common. The lowest level of information storage is related here to the manufacturing order). Again, different packaging units are often considered as identical in logistics and financial applications, even if they are not identical from a quality perspective.

Then there are so-called dimensioned items, such as steel plate, tubes, cable, tapestry, wood, textile, paper, which have one or more dimensions from which other products are created by cutting or sawing in one or more of the dimensions. For example cable has to be treated as a dimensioned product because inventory of cable should not only identify the number of different rolls with cable, but also their length. Ten rolls of one km of a particular cable is not the same as one roll of ten km of the same cable. Yet, in many applications this difference is neglected.

Next, there are the so-called variants. Variants are parameterised items where the parameters have received a value. Apparel is a common example, where parameters such as size and color are well known for shirts, shoes and other types of products. The difference of dimensioned items and variants lies in the fact that dimensioned items can be split into smaller dimensioned items, but variants cannot be split into smaller variants. However, in many logistics and financial applications, variants are aggregated into product families by neglecting one or more parameters. (N.B. A special case of variants are configured items, where the parameter values may also influence the bill of material).

Thirdly, there is the notion of versions. Different versions of products do have different properties. In many branches of industry, the so-called form-fit-function rule applies, which states that products with the same code number should have the same form, fit and function. Therefore, versioning can be neglected from a logistics and financial point of view. From a production planning point of view, this is not correct, because there may be an engineering change in the bill-of-material or routing, and also not from a financial point of view, because there may be different costs involved.

Fourthly, the ageing of products may play a role, not only in food, but also in steel, consumer goods, plastics, books, etc., which deteriorate (or improve: wine, antiques) over time.

Finally, customer-specific (i.e. customer specified) and one-of-a-kind (i.e. producer specified) products usually are aggregated in several applications.

Summarizing, we consider the issue of a correct data structuring as a prerequisite for any proper modeling process. Yet, how data should be structured such that decision making processes can be modeled appropriately is not considered in this thesis any further.

Framework for implementing ERP / Advanced Planning Systems

Focussing on the implementation phases of ERP / Advanced Planning Systems we observed that although the interest in related enterprise systems such as sales force automation, supply chain integration and product configuration remains strong, many organisations have failed in their attempts to install ERP systems and have failed to achieve the hoped-for financial returns on their ERP investment. In this thesis our special focus is on the modeling phase of the whole implementation project, as we believe that this phase is one of the most critical ones. Nevertheless, we also believe that all phases of an implementation project are of special interest and should be considered separately. In this respect, Markus and Tanis (1999) developed a theoretical framework for analyzing, both retrospectively and prospectively, the business value of enterprise systems. In order to dicuss the reasons why companies do, or do not, adopt them, the authors describe the historical context in which enterprise systems emerged as well as the key characteristics of enterprise systems. The systems under consideration are enterprise resource planning systems (ERP), which became known as integrated software packages in which multiple functional applications shared a common database. They include some that have been developed out of the administrative side (financial / human resources) of the business (e.g. SAP and Peoplesoft), as well as some that grew from materials resource planning in manufacturing (e.g. BAAN).

The authors claim for the importance of ERP systems as a topic for Information Systems research regarding

- Financial costs and risks
- Technical issues
- Managerial issues
- IT adoption, use and impacts
- Integration

As key characteristics of enterprise systems, Markus and Tanis identify:

- Ability for integration
- Potential for configuration
- Dependency on vendors
- Effects on business process reengineering
- Adaptation of ERP to existing legacy systems and other third party applications
- Evolving functionality of ERP systems

Markus and Tanis further explore the reasons for adopting and no-adoption of ERP systems. Reasons for adopting ERP systems are for example replacing hard-to-maintain interfaces or ease technology capacity constraints as well as business reasons such as improving inefficient business processes or reducing inventory carryuing costs etc. As a main possible reason for the non-adoption of ERP systems , the lack of feature-function fit between the company's needs and the packages available in the market place is named first. A second reason is that companies that continually change their organizational structures and the resulting business models may find ERP systems unsuitable as a corporate solution.
Markus and Tanis start with describing their framework with first framing the analysis for ERP systems success. They clearly state that there is a lack of consensus and clarity about the meaning of success where information ystems are concerned. Based on their observations of ERP systems projects, they define a minimum list of success metrics as follows:

- Project Metrics
- Early Operational Metrics
- Long Term Business Results

The final fundamental framework of Markus and Tanis is based on the following phases:

- Chartering Phase
- Project Phase
- Shakedown Phase
- Onward / Upward Phase

Depending on the detailed description of each phase, there are several outcomes for each phase – one of which is the optimal outcome. The final framework is a sequence of phases, each with intermediate outcomes, which are argued to influence the final outcome, but not to determine it. An underlying theme in this framework is the role played by human knowledge and skill – and gaps in knowledge and skills- in enterprise system success.
In this thesis we do not elaborate further on the Markus and Tanis framework, as our focus is on the modeling and implementation phases of APS implementations. Nevertheless, it is our opinion that all phases described in their framework are of high importance and need special consideration in any APS implementation project.

1.6 Outline of thesis

In this chapter we have formulated the research questions that will be discussed in this study. The overall methodology used in this research is described in chapter 2. The object of study is the modeling of decision making processes in Supply Chain Planning software. Hierarchical interdependencies are the starting point for our review of hierarchical planning concepts in chapter 3. Our objective in chapter 4 is to develop a theory on anticipation in Hierarchical Production Planning. We will achieve this by giving theoretical assessments in the context of literature and by building our own constructs based on selected theoretical hierarchical planning concepts. In chapter 5 our focus is on describing the implementation process of the APS system i2 TradeMatrix at an aluminium manufacturing company called ALCO, as a case study. We will describe the i2 TradeMatrix model and the modeling approach used. In chapter 6 we will describe in detail the initial modeling phases of the implementation process. Our observations will be summarized as assessments of theory and will lead to the formulation of expected problems with respect to the further modeling phases. Those phases are described in detail in chapter 7, followed as well by theoretical assessments. We will complete our observations in chapter 8 by performing questionnaire-based interviews at companies from other industries and derive conclusions and recommendations for modeling in Advanced Planning Systems and recommendations for further research (chapter9).

Chapter 2

Methodology

In this chapter we discuss the research methodology that has been applied in order to answer the research questions formulated in chapter 1. Since our research questions relate to the use of mathematical model-based software by human decision makers, we apply both empirical research methodology, focussed on the human-system interaction aspects of the problem, and conceptual research methodology, focussed on theory-development and the use of mathematical models. The hypotheses derived fom theory development are tested by empirical research methodology.

The structure of this chapter is as follows. In section 2.1 we give a high-level overview of the research process and discuss the interrelationships between the research questions formulated in chapter 1. This motivates the research design that is discussed in detail in section 2.2.

2.1 Research Questions

For ease of reference we repeat here the research questions derived in chapter 2, by now having explicitly distinguished questions referring to theory and practice .

- (RQ1a) To what extent is the decomposition and hierarchical ordering of production planning problems in APS systems in agreement with the theory of planning and control of supply chains?
- (RQ1b) To what extent is the decomposition and hierarchical ordering of production planning problems in APS systems in agreement with the practice of planning and control of supply chains?
- (RQ2a) To what extent is in APS systems the interaction between models at different planning levels in agreement with the theory of planning and control of supply chains? (Bertrand *et al.*, 1990, Schneeweiss, 1999)
- (RQ2b) To what extent is in APS systems the interaction between models at different planning levels in agreement with the practice of planning and control of supply chains? (Bertrand *et al.*, 1990, Schneeweiss, 1999)
- (RQ3) To what extent can modeling in APS systems ensure that the various levels of

aggregation are still consistent?
- (RQ4) To what extent do APS systems incorporate the problem of information asymmetry and how can modeling help to overcome these problems?

The two strongly related research questions (RQ1a) and (RQ2a) have been the starting point for our research. The research methodology involved here has been conceptual and based on literature review. In parallel we used the strongly related research questions (RQ1b) and (RQ2b) for exploratory research based on an in-depth case study. We used the case study to test hypotheses derived from our answers to (RQ1a) and (RQ2a). The results of this research revealed that the current theories on Hierarchical Production Planning (HPP) are incomplete and (partially) incorrect. Conceptual research based on inductive reasoning lead to the enhancement of existing theories of HPP, introducing the concepts of consistency and stability in the context of Supply Chain Planning as a special case of HPP and proposing a complete typology for the anticipation concept of Schneeweiss (cf. chapter 3). Research questions (RQ3) and (RQ4) naturally followed from our conceptual research. Again we used case-study research to answer these questions. The development of various hypotheses from our research aimed at answering our research questions through conceptual research and the case study led to the development of a small-scale, yet detailed, questionnaire to seek further evidence for our research findings. Finally we used our research findings to design a process that should yield an effective and efficient implementation of APS systems as well as effective use of APS systems after implementation.

The scientific contribution and relevance of this research is twofold. Firstly, the HPP frameworks proposed by Schneeweiss and Bertrand are empirically tested with respect to hypotheses regarding model decomposition and problem decomposition, respectively. As a result of this the theory of Schneeweiss has been enhanced. Secondly, particular state-of-the-art APS software, such as i2 TradeMatrix, and its associated workflow, is tested against the frameworks mentioned above as well as its ability to cope with short-term uncertainty. The latter is of particular interest, since this should yield more insight into the effectiveness of rolling schedule approaches which are commonly used in practice in the context of supply chain planning and control.

2.2 Research Design

2.2.1 Introduction

In our research we conducted one single in depth case study in one environment relating to all research questions and questionnaire-based interviews referring to other cases in other industries. In the case of the in-depth study, our focus is on the modeling and implementation process of the i2 TradeMatrix Master Planner software. Our observations do not describe the phase of going live. We note here that the time consumed by the in-depth case study (a period of two years during the lifetime of the project) is considerable and replication in another case would be impossible. Thus, to be precise, the underlying strategy for our research is a single case, multiple years, longitudinal study, which first focusses on a single company and is then extended to other companies in the Metals and High Tech Industries. The research approach used in this thesis is depicted in Figure 6.

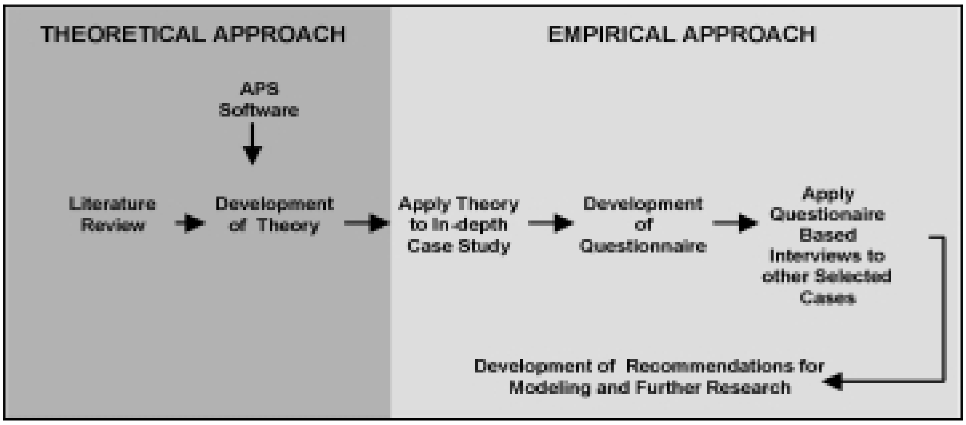

Figure 6: Research Approach

2.2.2 Review of Hierarchical Planning Systems

Our research started with investigating literature in the area of problem and model decomposition and hierarchical planning (see chapter 3). Our special focus is on the conceptual approach of Bertrand *et al* (1990) and the generic framework for hierarchical decomposition developed by Schneeweiss (1999). We investigated the literature with the objective of determining the current status of hierarchical production planning and model and problem decomposition theory and to understand different modeling approaches. In order to answer the research questions stated in chapter 1 we need to understand how decomposition , hierarchical ordering and interaction is proposed in theory of production planning and control of supply chains. We put special focus on a key aspect of the Schneeweiss approach, which is the so called anticipation function , in order to understand how consistency and stability can be achieved according to theoretical models. The aforementioned literature research is used to build a theory on anticipation in hierarchical production planning (HPP) and to extend the Schneeweiss' approach into a more general and comprehensive one.

2.2.3 Development of a theory on anticipation in HPP

In order to develop a theory on anticipation in Hierarchical Production Planning in chapter 4 we focus on the Schneeweiss' approach of anticipation. Based on his theory we develop a classification distinguishing between model anticipation and information anticipation.
As a next step we analyze the APS software TradeMatrix of i2 Technologies with special consideration of aggregation and anticipation concepts. By further applying our theoretical classification to i2's TradeMatrix APS software, we develop software specific options for anticipating lower level modules into higher level ones.

2.2.4 Case Study Methodology

In this research we have used the case study methodology. More specifically, we conducted case study research according to the approach suggested by Yin (1994). Yin's approach has been characterized as positivist by various authors, including Klein and Myers (1999). We would like to mention here two basic principles underlying Yin's approach. The first principle is that a case study should be considered as a study in itself, just like an experiment. Statistical generalization (as it is done in experiments) is not relevant for the case study as a methodology. Generalization has to be done analytically, i.e. inductively or deductively. The second principle in Yin's approach that we apply in this research is the use of ex-ante theoretical explanations of our expected findings. These explanations are based on general insights from the hierarchical planning and modeling literature. The observations that we make in the case can then later on be related to these ex-ante explanations.

There are two dominant reasons for selecting the case study methodology for this study. First, to our knowledge we are the first researchers to document in detail the modeling process in advanced planning and scheduling software. It has been a unique opportunity for academic research, since the researcher was actually involved with running an implementation project. The contributing authors have no direct interest in the results of the implementation process and act as independent and critical observers of the process. Considered in this way, this case study can be considered 'revelatory' as termed by Yin (1994, p. 41). Second, a lot of theoretical knowledge is available in the area of supply chain planning and scheduling (see, e.g., Graves *et al.* (1993) for an extensive overview), and the area of hierarchical planning (see, e.g. Bertrand *et al.* (1990) and Schneeweiss (1999)). This allows us to develop clear propositions that are well founded in theoretical insights. However, very little empirical material is available that has tested these theoretical concepts from a content perspective (rather than the organizational change perspective with the work of Markus and Tanis (1999)). The only significant results related to this area have been reported in several studies by McKay, Wiers and Crawford (see for example, Crawford and Wiers (2001) for an overview). However the focus of these studies have been on the interplay between planners and planning systems and only a single level in the planning hierarchy has been studied.

In the in-depth case study, in which the author was actively involved, the theory developed in the previous research phase has been applied, implying that we intervened in the implementation during our research. These interventions have been carefully documented and served to set the conditions for testing the development of the theory. This in-depth case study has been used to describe typical supply chain decisions and their modeling and implementation process. Special consideration is given to describing in detail the planning problems and planning requirements followed by acceptance criteria for the solution to be developed. Experiences of the planners in using the first static version of the model at the company are described. All results are used to classify modeling phases and accordingly to structure and analyse the changes performed in each phase. The defined phases are:

- Initial Requirements and Criteria Setting
- Initial Modeling
- Model Modification
- Model Extension and Advanced Requirements and Criteria Setting
- Advanced Modeling

Finally, in each phase a theoretical assessment is performed, in which both changes / structures are related to the approaches of Schneeweiss (1999) and Bertrand *et al* (1990). All results regarding the in depth case study are used as a basis for developing a questionnaire, as a basis for our small scale questionnaire-based interviews, in which detailed questions regarding modeling are formulated. Each question is related to a hypothesis, which in turn is related to our research questions in chapter 1.

The in-depth case study is discussed in detail in chapters 5, 6 and 7. A closer look at the case study conducted, reveals that within this case study , although it is a single case study, we conducted multiple data collection methods. First, there was the personal experience of the author, who was actively involved in the implementation project. Second, the author used project documentations which served as a further source of information. Third, interviews with experienced planners, being actively involved in the i2 project, took place during the whole modeling and implementation process .

The company under consideration – as a basis for our in-depth single case study - concerns an aluminium plant, called ALCO, located in Germany. ALCO was implementing i2 Technologies' i2 TradeMatrix at the beginning of this research project, standard software modules for Sales and Operations Planning and shopfloor scheduling. The implementation project at ALCO, which comprised a number of implementations of software modules for mid-term planning and short-term planning, will be used to gather detailed data about the hierarchical planning concept underlying i2 TradeMatrix and the proposed ways of working with the tool. In this thesis, we report on the first implementation phases of the supply chain planning software i2 TradeMatrix of i2 Technologies at ALCO. It is our objective to position the i2 TradeMatrix software components in the hierarchical production planning (HPP) literature, describe how the first phase of the implementation was started, and test some hypotheses on the adjustments that needed to be made on the software after the first months of operation. These hypotheses can be directly linked to the way in which these advanced planning and scheduling (APS) systems are normally configured, compared to what we may expect of hierarchical structuring in an organization based on the academic literature in the HPP domain.

Based on the conceptual analysis of the modeling process at ALCO we developed a framework for hierarchical anticipation in Advanced Planning and Scheduling Systems –

thereby extending the theory of Schneeweiss to a more generic and comprehensive approach.

2.2.5 Survey Research Methodology

First we want to emphasize that we are not performing a complete survey, but questionnaire-based interviews. The framework developed in chapter 4 was the basis for formulating hypotheses. The results from the single case study (chapters 6 and 7) have led to a number of observations which in turn were the basis for fomulating further propositions and hypotheses. Based on observations, hypotheses and results of the questionnaire–based interviews, we could derive either propositions or conclusions. By inductive reasoning and observation we have collected partial evidence for these propositions and conclusions by using the questionnaire-based interviews. This procedure is explained in detail in subsection 2.2.6.

Based on the propositions mentioned above, we have developed a questionnaire, which was designed to help understand the models and the modelling process of the APS system solution of i2 Technologies (TradeMatrix). The questionnaire provided the basis for our analysis at four other selected companies in Metals and High Tech industries, having implemented at least partially, the i2 TradeMatrix software.

We want to emphasize that the questionnaire research is not a large scale survey of companies which are successful in i2 implementations, but a detailed process-oriented one which has its focus on a few selected companies being representative for typical problem structures in their industry area. Accordingly we are not interested in a pure statistical evaluation of the outcomes but consider the outcomes as a means to support our inductive reasoning. In that sense this research is still exploratory.

The survey research methodology underlying our questionnaire is used to capture data from different companies and is based on Forza (2002). Our survey research involves the collection of information from different companies having implemented the i2 TradeMatrix solution and finally contributes to better explain the hypotheses formulated in section 2.1. The survey research is exploratory in nature, as it is aimed at becoming familiar with HPP concepts in theory (theoretical domain) and real life (operational domain). The gained insights facilitate theory development on one hand and specification of guidelines for succesful implementations on the other hand. Precisely, our scientific enquiry comprises the following steps, based on Forza (2002):

- Development and formulation of final hypothesis and recommendations for modeling and further research
- Selection of unit of analysis (companies) and data selection method (questionnaire)
- Data collection, analysis and interpretation
- Analysis of the theoretical implications

In order to develop and formulate our hypotheses, the literature review identified important findings from earlier research. Focussing on HPP, we developed in subsection 4.2.1 a conceptual model of how we theorise the relationships among several factors identified as important to the problem. These factors are the anticipation, consistency and stability problem in HPP. Both the literature review and the in-depth case study highlighted important variables to be measured with respect to the stated hypothesis. In that sense a network of measurable variables was generated, each of them being linked to a specific hypothesis. With respect to Forza's terminology, the selection of companies is in fact the definition of the unit of analysis. In the survey research context, the unit of analysis can be defined as an individual, groups, plants, divisions, etc. In this survey our unit of analysis is defined by companies, having experience in modeling and implementing i2 TradeMatrix software. The respondent is in fact an individual, as planners , users and modelers, being sufficiently high in the organisations's hierarchy in order to answer appropriately our research questions. As a data selection method a questionnaire is used with detailed, pre-formulated questions which contribute measuring related variables. To each of the questions closely defined alternatives as possible answers are formulated. Questions have a predefined, planned sequence and serve as a basis for our interviewing activities. Data collection, analysis and interpretation is done based on personal interviews and discussions with the corresponding respondents of the organisations.

According to Forza (2002), we are aware that still a number of errors might occur in survey research, which are identified as :

- measurement error
- sampling error
- internal validity error
- statistical conclusion error

Measurement errror represents one of the most significant sources of error in survey research and indicates that one has partially or completely failed in measuring the theoretical concept. While measurement error is almost inevitable we can reduce this error by precisely formulating questions, variables and predefined possible answers. Further we conduct all interviews ouselves and take ample time to discuss questions and answers. Sampling error refers to choosing the correct subset of the entire group of people (population) to investigate.A sampling error applies when the chosen sample does not represent the whole population. We reduce sampling errors by selecting the people to be interviewed such that their role and contribution to the system's implementation is proven. We will further discuss the difficulties with selecting the companies in chapter 8. Internal validity error refers to whether an explanation is given for a certain observation, whereas other explanations are still possible. We reduce internal validity errors by first discussing during the interviews why other explanations are unlikely and by second introducing follow-up interviews with respondents in order to verify conclusions. The statistical conclusion error is not relevant for this survey, as statistical generalisation is not relevant here.

In the context of our questionnaire-based interviews and with respect to our research questions we will formulate hypotheses based on the observations we can make in the single case study. Each hypothesis will be linked to one or several measurable variables. Out of those variables we derive well formulated questions in order to measure the defined variables. All questions and some preformulated answers are part of the final questionnaire. As some hypothesis turned to be outside the focus of the questionnaire, we restricted ourselves only to those that directly add value to our research questions.
All interviews on different sites will be conducted by the author herself, supported by a team of experienced consultants.

2.2.6 Risks and Limitations

Referring to risks and limitations of our methodology, in a single case study there is always a risk that there is something particular on that specific case, which cannot be described in general terms. We reduce this risk by

- linking our observations to selected theories
- extending the case study over a longer period of time
- being physically on site
- conducting interviews

We can further reduce the risks by conducting questionnaire-based interviews with respect to other cases. Focussing on surveys, a problem we were faced with in this research was to find sufficient selected cases, in which implementation of APS software has enabled the organization to reach a certain stage of maturity, good enough for answering our questions. We reduce those additional risks by again

- linking our observations to theories
- having experienced people conducting the interviews
- having experienced people from site, who were in fact involved in the project, answering the interviews

In order to answer our research questions, we use the procedure illustrated in figure 7. Our research is based on three substantial parts:

- In-depth single case study
- Theory of Hierarchical Planning Systems
- Questionnaire-based Interviews

The single case study leads us to certain observations, which in turn are used to derive hypotheses. In addition theory is used to formulate further hypotheses. The derived hypotheses are the basis for the development of our questionnaire. Questionnaire results are used – together with observations and hypotheses - to derive either conclusions or propositions.

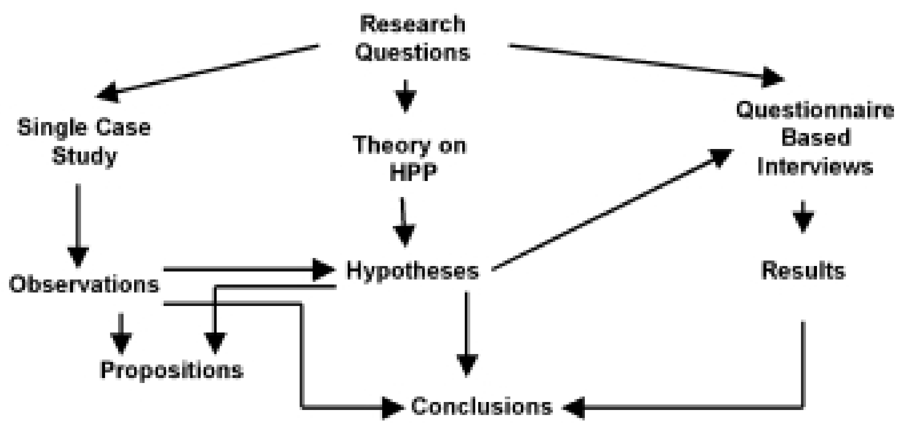

Figure 7: Procedure for Deriving Propositions and Conclusions with Respect to Research Questions

In order to derive both propositions and conclusions we first do assessments of theories after the initial modeling phases (see subsection 2.2.4) of the single case study (see sections 6.4 and 6.5). Second, in section 7.2 we formulate expected problems with respect to the model modification, model extension and advanced modeling phases (see subsection 2.2.4). Yet we are aware that we will not derive all necessary conclusions, as conclusions should be derived from the confirmation of the hypotheses by both case study and interviews. In such cases we will derive propositions instead. Propositions are derived through logical reasoning, which should be understandable to a reader, but for which further research is required to test. By finishing our study, we can claim that our results have been based on closely monitoring the implementation of i2 at a large metal company in Europe. By answering our questions other companies that have implemented or, are implementing i2 software, contributed to gaining further insight into the modelling process. The interviews' results have been used to develop recommendations for modeling decision making processes in Advanced Planning Systems.

2.2.7 Conclusions and Recommendations

The results of the single case study, the theoretical assessments and the questionnaire-based interviews are used to derive conclusions and propositions. By answering our research questions (chapter 1) we will formulate the following recommendations in chapter 9:

- Recommendations for modeling in Advanced Planning Systems
- Recommendations for further research

2.3 Summary

In the sections above we illustrated the methodology used in this research. Focussing on our research questions our methodology is based on

- a review of Hierarchical Planning Concepts (subsection 2.2.2) which is outlined in chapter 3
- a theory on anticipation in HPP (subsection 2.2.3) which is developed in chapter 4
- a single, in depth case study (subsection 2.2.4) which is illustrated in chapters 5,6,7)
- a survey research as questionnaire-based interviews (subsection 2.2.5) whose concept and results are presented in chapter 8

Our single case study methodology is based on the approach suggested by Yin (1994), whereas our survey research methodology is conducted along the guidelines of Forza (2002).

Chapter 3

Review of Hierarchical Planning Concepts

This chapter gives a review of selected hierarchical planning concepts. For better understanding, the chapter starts with a general description of what is meant by decision making processes (subsection 3.1.1), followed by an explanation of the problem of hierarchies in hierarchical planning approaches (subsection 3.1.2). Two conceptual frameworks for decision hierarchies - the framework of Schneeweiss (1999) and the approach of Bertrand *et al.* (1990) - are illustrated in sections 3.2 and 3.3.

As already stated in chapter 1.3, in this thesis we will put special focus on the term "anticipation", which has been introduced by Schneeweiss (1995) to the construct of hierarchical planning. In a two-level hierarchy, Schneeweiss defines anticipation as the top-level model incorporating the „expected" future behaviour of the process, at the time the base-level model is applied to take detailed decisions about activities. As such, we emphasize that anticipation further clarifies the concept of integration. Since hierarchical planning is about how to decompose a problem into subproblems, advanced planning is about how to use quantitative models to solve the subproblems. We want to stress that anticipation is a concept which makes clear that not only does the hierarchy play an important role in hierarchical planning, but, also the time difference in which models are applied. As such, effectuation lead time, which usually entails a difference in the information status between the top level and the base level, resulting in information asymmetry, is recognized by the anticipation concept. We claim that this aspect (in addition to hierarchy) is of high relevance for designing APS systems.

3.1 General Overview

We can observe that current Advanced Planning and Scheduling software has adopted the concept of hierarchical planning. In their implementations, aggregate decisions are made first and impose constraints upon more detailed decisions, in line with the more traditional approach towards hierarchical planning as introduced by Bitran and Hax (1977). A conceptual framework, which allows to study hierarchical phenomena from a unified point of view is given by Schneeweiss (1999). In general we can say that the planning and control of production is a complex and hierarchical problem, which needs to be decomposed into several sub-problems, which are ordered generally in a hierarchical manner (Bitran and Tirupati, 1993; Bertrand *et al.*, 1990; Schneeweiss, 1999).

Schneeweiss (1999) considers an organization as an interference of individual decision processes and states that, in order to reduce complexity, one often tries to separate complex systems into subsystems. So finally, a hierarchical structure has to be established by an initial design decision and for each of the levels certain rules of their mutual interference have to be constituted. In order to support this design decision a conceptual method is necessary which designs hierarchical structures and in particular, is capable of classifying hierarchical systems. A general framework which allows different types of hierarchical planning problems to be accomodated is constructed by Schneeweiss (1999). In particular, his framework shows the different options to structure hierarchical influences and provides a better understanding of the design process. Bertrand *et al* (1990) also stress the overwhelming importance of the design of implementable decision functions for the development of production control systems. In contrast to the framework of Schneeweiss, their hierarchical approach is more problem oriented: the complete control problem is decomposed to a number of partly hierarchically ordered sub-problems. In this chapter we will review the approaches by Schneeweiss and by Bertrand *et al.*

3.1.1 General Description of the Decision Making Process

In order to state the scope of decision making, specifically with regard to the planning decisions that we are interested in, consider the meta-model of the decision making process depicted in Figure 8.

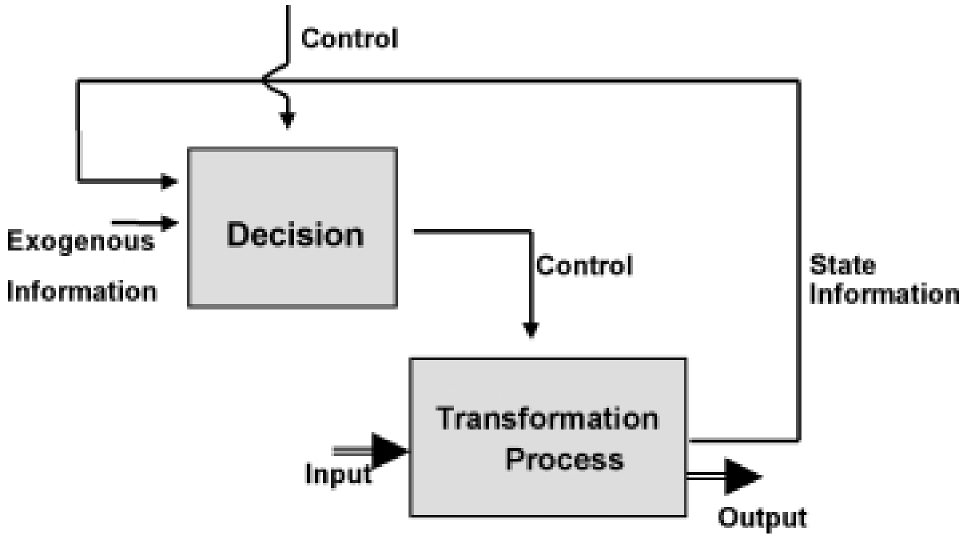

Figure 8: Meta Model of Decision Making Process

We can clearly see in the model in figure 8, that a decision depends on exogenous variables and information about activities that are influenced by the decision. The decision uses the available information to determine the value of the decision variables, which are expressed as a control upon the (physical) transformation process. The (physical) transformation process transforms input materials into output materials. Exogenous variables are in general random variables. Examples of such random variables are end-product demand, lead time of suppliers, production yields, etc.. A specific example for using the above meta model in the production planning context that we are interested in is given below.

$C_k(t)$: = amount of resource k, released at time t
$Q_i(t)$: = amount of material i, released at time t

$C_k(t)$ and $Q_i(t)$ are both decision variables and represent the outcome of the decision. $C_k(t)$ and $Q_i(t)$ are both functions which depend on the factory status and the forecast:

Ck(t) = f (state(t), forecast(t))

The factory status contains information about the actual amount of WIP and free capacity in the factory. State definitions instead can be made in a very different way. They have different definitions, for example the definition of the inventory state variable in MRP and in statistical inventory control systems.

Forecast information can be expressed as follows:

D(t): = demand in period t
D(t, t+s) = forecast of demand in period t+s, made at the beginning of period t

In terms of the meta model, D(t) and D(t, t+s) are exogenous variables, state(t) represents the state of the process after execution of activities between t-1 and t.

Table 2: Formal Description of the Meta Model in the Production Planning Context

3.1.2 The Hierarchy in Decision Making Processes

The planning and control of production is a complex and hierarchical problem, where a number of separate coordinated planning decisions are involved. In general, the problem needs to be decomposed into several sub-problems, which are ordered generally in a hierarchical manner (Bitran and Tirupati, 1993; Bertrand *et al.*, 1990; Schneeweiss, 1999).

Both Bertrand *et al.* (1990) and Meal (1984) stress that the hierarchical procedure explicitly recognizes the constraints on lower level decisions established by higher level decisions. Additionally, one of the keys to the effectiveness of the hierarchical planning approach is the simplicity of the decision making at each level. The impact of higher level decisions is generally over a longer horizon and an aggregate model is used to come to a decision. Conversely, the lowest level decisions occur over a short planning horizon and are concerned with a greater level of detail. The hierarchy is natural in the sense that long lead time decisions necessarily constrain short lead time choices. Meal (1984) summarizes the most important advantages of the hierarchical planning approach as follows:

- Reduction of complexity by definition of subproblems
- Aggregation of data at higher decision levels
- Good organizational fit
- Reduction of uncertainty by postponing decisions as long as possible

Each hierarchical level has its own characteristics and aggregation methods.
These are typically influenced by a number of factors that include the following:

- Length of planning horizon
- Level of detail of the required information and forecasts
- Scope of the planning activity
- The authority and responsibility of the manager in charge of executing the plan.

In the Operations Research literature, decision models for many problems of production planning and control have already been formulated. The problems addressed by these models include, for example, the master production plan generation, inventory management, sequencing, scheduling and material requirements planning. As stated in chapter 1, only recently has standard software for operations planning and control become available. This standard software is based on the combination of generic OR models and methods and a powerful Graphical User Interface. Typically, such software consists of a number of interrelated, but loosely coupled modules (planning components). In the context of operations planning and control one distinguishes between a mid-term planning level, where aggregate decision variables must be determined, and a short-term planning level, where detailed decision variables must be determined. Aggregation is based both on time aggregation (hours into days, days into weeks, weeks into months) and on aggregation of products and resources. Especially the time lag that exists between decisions in different layers makes consistency achievement a very difficult task. Closely coupled to consistency is the characteristic of information asymmetry, which means that the two levels do not have the same knowledge.

In chapter 4, we focus on two specific characteristics of a decision making hierarchy in operations planning, namely asymmetry of information and the use of an aggregate model at the higher decision level.

3.2 The Schneeweiss Conceptual Framework for Decision Hierarchies

The planning and control of production is a complex and hierarchical problem, consisting of a number of separate coordinated planning decisions. In a small number of real-life situations, with limited complexity and limited uncertainty, solving the problem based on a single planning model may be feasible. As described in chapter 1, in the majority of situations, restrictions in human cognition, mathematics, and computational power render solving the production planning and control problem as one single entity infeasible. The problem, therefore, needs to be decomposed into several sub-problems, which are ordered generally in a hierarchical manner (Bitran and Tirupati, 1993; Bertrand *et al.*, 1990, Schneeweiss, 1999).

As already stated in chapter 1, the focus of the solution process in models of current Advanced Planning and Scheduling Systems is claimed to be optimality or feasibility (see, for example , www.i2.com, www.manugistics.com). But besides optimality and feasibility, consideration should also be given to consistency, as the success of the hierarchical approach depends to a large extent on the consistency between the various levels of aggregation and on the interaction between the models at the different levels (Bertrand *et al.*, 1990, Schneeweiss, 1999). A significant contribution to research on hierarchical planning has been made by Schneeweiss who completed a monograph about hierarchies in distributed decision making (Schneeweiss, 1999). Earlier Schneeweiss (1995) introduced the term anticipation to the construct of hierarchical planning. Anticipation is defined as the higher level taking into account the possible reaction of the lower level to the future higher level's decision. In subsection 3.2.1 we explain in detail the conceptual framework of Schneeweiss by illustrating his understanding of an individual decision model. In subsection 3.2.2 we describe his typology for coordinating several decision processes.

3.2.1 The individual decision model

One of the key statements in Schneeweiss' approach is that even the simple individual decision process, is in fact a sequence of decision models. Each decision model *M* in this

context consists of a decision field *A*, which includes all possible decision variables, and a preference structure *C*, which includes objective functions and restrictions (M:={$C.A$}).
In describing *C* and *A*, Schneeweiss stresses 3 notions which are of particular importance.

- Aspiration levels
- Stochastic Information
- Vague expressions and hypothesis

Aspiration Levels are defined as values of a criterion that in any case the decision maker would like not to fall short to. There can be a discrepancy between the optimal value C^* of the *C* criterion and the Aspiration Level *AL*. Only if this discrepancy can be removed, the whole process can terminate and a final decision will be taken ($DISC$=$DISC(C^*, AL) \leq 0$). The decision maker will constantly need to revise his model and input parameters until the optimal value C^* satisfies at least *AL*. Alternative, after several solution cycles, the decision maker may decide to reduce *AL*. Summarizing, the individual decision process is just one link in the entire process, which has to be continued, as long as any discrepancies between aspiration levels and decision criteria exist. The stochastic information, denoted by *I*, consists of probability distribution functions (or representations of these such as mean and variance, assuming some specific type of distribution) of all random variables occurring in *M*. In a decision model vague expressions or hypothesis, denoted by *V*, might occur, which have to be made measurable. As an example consider the vague expression „in the near future the weather will be very nice". Consolidating this expression one has first to operationalize the terms „weather" and „future" by measurable attributes. Accordingly a consolidation cannot be performed without taking into account the whole situation the decision process is in. So, a Vague Hypothesis is a statement, which in a decision theoretic framework, has to be made operational, i.e. all vague expressions have to be made measurable. Obviously a consolidation cannot be performed without taking into account the whole situation the decision process is in. Symbolically, a consolidation *H* of *V* is H:=$CONV$
In summary, Criterion *C*, decision field *A*, consolidation *CON*, aspiration level *AL* and stochastic information *I* are the most important quantities which characterize a model *M*. In order to stress the fact that *M* is just one link in the entire process, Schneeweiss calls a model at stage *k* a cycle:

Z_k:=$(C_k, A_k, CON_k, AL_k, I_k)$

The whole process then has to be continued as long as a positive discrepancy still exists.Usually the process should start with risk avoiding consolidations and high aspiration levels. But still, one of the most crucial problems is the ”meta-decision-problem” of selecting the next cycle $k + 1$.

For an unbounded rational decision maker there would be no problem. All possible future cycles would be known. For bounded rationality the situation is far more restrictive. One can assume that in stage k the decision maker is able to look ahead into the near future, such that he knows at least some small part of the set of all possible future cycles. This part is called by Schneeweiss the reservoir RES_k. The reservoir is continously built up as the process proceeds, i.e. in each stage one has not only to decide which cycle should be selected, but also which cycle should be considered as candidate to enter the reservoir. In view of a bounded rational situation that cycle will be selected which leads to an improvement of the general goals the decision maker has.

3.2.2 Decision Cycles and Anticipation

Schneeweiss considers an organization as an interference of individual decision processes, which in practice are more tractable and less complex than the whole decision problem as such. The submodels used for describing these partial decision processes are kept rather simple and are coordinated by only a few controlled interfaces. The submodels are generally hierarchically arranged. Schneeweiss mainly focusses on 2 processes, the top process (PT:=$\{Z_kT$, k=1,2,...$\}$) and the base process (PB:=Z_kB, k=1,2,...$\}$).

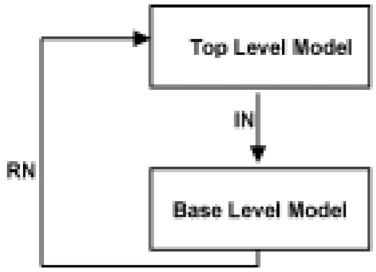

Figure 9: Interaction of Decision Processes

Coordination between these hierarchically arranged submodels is obtained by the higher level process (indicated as the top level) exerting control (by means of instructions) over the lower level process (indicated as the base level), and the lower level process giving feedback (by means of reactions) to the higher level process. Defining aspiration levels that the top level intends to reach with its decision sets the criterion for the top level.

In summary, Schneeweiss states that the top process decision ($a_kT \in A_kT$) can be used to influence all components of the base-cycle. The top-down influence is called an instruction *IN*. The base level takes this instruction and communicates a reaction *R* to the top level. In fact, taking instructions or deciding upon reactions will not be done without any knowledge of the other's decision process. Hence, before taking a top decision, the base level will be taken into account by mapping it into the top-cycle. Schneeweiss calls the result of this mapping an anticipation, denoted by *ANZT*(*ZB*). In order to derive an optimal instruction to the base level, the top level anticipates the base level decision making process and hypothetically applies different instructions as stimuli to the anticipated base level. These instructions give rise to possible reactions and result in an optimal instruction, which is finally communicated to the base level. This process of consecutive hypothetical instructions is reflected in the so-called anticipation function that describes the base level's possible reaction with respect to an instruction.

With respect to collaboration, Schneeweiss only considers vertical collaboration between levels. But referring to parallel collaboration between lower levels, he does not consider any collaborative aspects in his definition of anticipation functions, although in practice there is communication between planners at lower levels. Collaboration instead is an issue which has to be supported by appropriate tools using in most cases the advantages of INTERNET based technology. In this thesis we do not discuss any lateral collaboration on base levels.Schneeweiss stresses that in many situations the anticipation will only give a rough idea of the respective cycle. Often however, one will be able to anticipate a possible reaction of the other level with respect to a hypothetical action. Schneeweiss calls this anticipated reaction an anticipation function, denoted by *AFT*(*IN*) and *AFB*®. Hence $AF_kT(IN_k)$ represents an anticipation of the reaction R_k and $AF_kB(R_k)$ anticipates the instruction IN_{k+1}. The tandem above can now be described as follows: The top level anticipates the base level and determines a suitable instruction *IN* which is given down to the base level. The base level reacts in sending the signal *R* to the top level after having anticipated a possible future instruction *IN**. Schneeweiss concludes his framework by pointing out that not always an anticipation function exists. The four different situations he distinguishes are listed here and explained in detail in chapter 4:

- Exact explicit anticipation, in which the base model is anticipated exactly
- Approximate explicit anticipation, in which the base model and/or the anticipation function are determined only explicitly
- Implicit anticipation, in which only one part of the base model is anticipated
- Non specific anticipation, in which no function describes a possible reaction with respect to a hypothetical instruction *IN.* Instead there are only some aspects of the base model, which are taken into account at the top level.

Consequently, each decision process can be described as a cyclic process which has to be continued as long as there exists a positive discrepancy between the aspiration level of the top model and the anticipated reaction of the base model. Each decision process represents a learning process that learns from the success or failure of earlier cycles. A cycle can either be based on a hypothetical instruction and anticipation (leading to an intra-decision cycle) or a factual instruction and reaction (leading to an inter-decision cycle). This cyclic process is reflected in Figure 10.

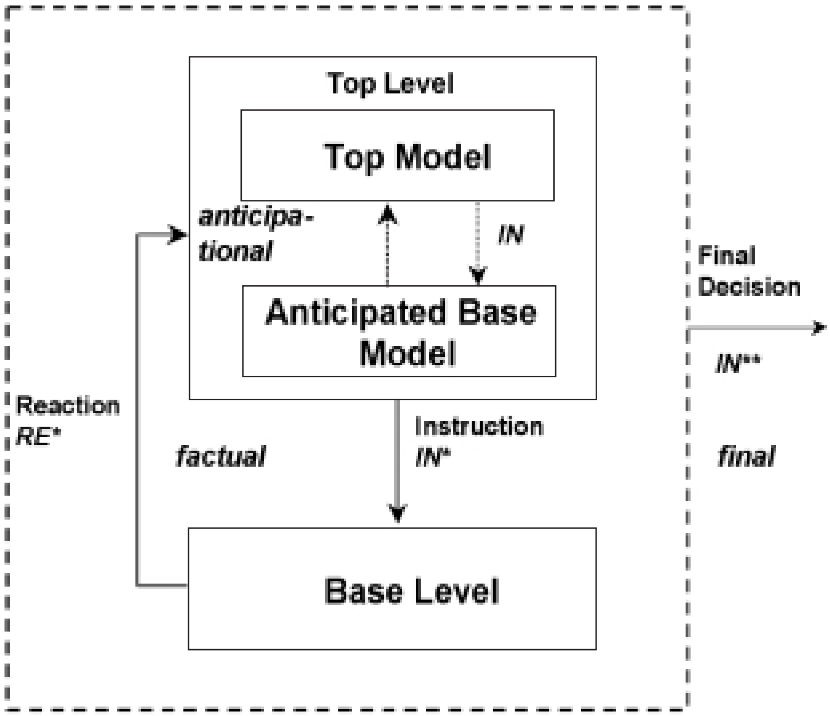

Figure 10. Decision Cycles in the Decision Hierarchy (from Schneeweiss, 1999, p. 29)

Formally, this can be described as follows (Scheeweiss, p. 39):

- **Top Level Equation**

  The top level equation can be described as a function of pure top level criteria (e.g. costs), base level criteria as expressed in the top level model, and state information (e.g. WIP, current inventory):

  $$a^{T*} = \underset{a^T \in A^T}{\arg\text{ opt}}\, E\{C^T[C^{TT}(a^T), C^{TB}(AF(IN(aT)))] | I^T_{t_0}\}$$

  The top level calculates the optimal instruction under ist stochastic information. In doing so the base cycle is taken into account by the reaction (of the last cycle) and the anticipation function.

- **Instruction**
  The instruction represents the instruction that is transferred from the top level to the base level:

  $IN{=}IN(a^T)$

The base cycle finally calculates an optimal reaction.

- **Anticipation**
  The anticipation function can be described as a function of the base level model, as it is seen at the top level, and as a function of base level decision variables, as seen at the top level. These decision variables $\hat{a}^B$ are not necessarily equal to the decision variables used in the base level a^B.

  $$AF(IN){=}\arg\operatorname{opt}_{\hat{a}^B \in \hat{A}^B_{IN*}} E\{\hat{C}^B{}_{IN}(\hat{a}^B)|\hat{I}^B{}_{IN}\}$$

- **Base Level Equation**

  $$a^{B*}{=}\arg\operatorname{opt}_{a^B \in A^B_{IN*}} E\{C^B{}_{IN^*}(a^B)|I^B{}_{IN*,t1}\}$$

The concept discussed here includes the idea of exact assumptions about lower levels. Within each cycle of a hierarchically structured decision process there is a top-down influence of the top level on the base level. Each decision made at the top level represents an instruction for the base level. This instruction influences all components of the base level cycle. The base level takes this instruction and communicates a reaction to the top level. It is important to understand the basic premise that giving instructions, or deciding upon reactions will not be done without any knowledge of the other's decision process. Yet, Schneeweiss stresses that it is essential to realize that the tandem equations do not fully describe the tandem process. There will be many decisions that depend on the overall organizational goal the decision makers try to achieve. As an example think of the anticipation $ANT_k\, T(Z_kB)$ of the base cycle by the top level. In spite of C_kT the top decision maker has still considerable freedom to select an anticipation which is not only locally optimal but which also considers future developments. Therefore, because of bounded rationality the equations above need an interaction with the decision maker. They constitute no real planning process but a mixture of planning and leadership activities.

In chapter 4 we will build our own constructs with respect to modern APS systems, based on the specific description of the hierarchical planning process by Schneeweiss, as outlined before, rather than basing ourselves on the general concepts of hierarchical planning.

3.3 The BWW problemoriented approach

Based on Meal (1984), Bertrand *et al.* (1990) find that the design of a production control system concerns the design of a comprehensive set of organizational and operational decision functions that can be implemented. Meal distinguishes three approaches to the design of production control systems: a decentralized approach, a centralized approach and a hierarchical approach. The centralized approach relies heavily on the investment in vertical information systems. The decentralized approach accepts the existence of slack and weakly coordinated self-contained tasks. The hierarchical approach is directed to the design of self-contained tasks and the creation of the right amount of slack necessary to make these tasks self-contained. Bertrand *et al.* advocate a hierarchical approach to production control: the complete control problem should be decomposed into a number of partly hierarchically ordered sub-problems. Their design is based on the following two premises:

- Each production situation is unique and it is not allowed to approach it in a one-dimensional way; thus, for each situation a specific production control system needs to be designed, using different perspectives on the problem.
- The design of a system for production control has to start with the development of a framework of decision functions, which is feasible from the organizational point of view.

They further develop three basic design principles upon which the design of a production control structure in such a unique situation should rely:

- Goods Flow Control (GFC) and Production Unit Control (PUC)
- Detailed item-oriented control and aggregate capacity oriented control
- Relationship between Production and Sales

Focussing on the distinction between Goods Flow Control (GFC) and Production Unit Control (PUC), a PU is defined as a production department which in the short term is self-contained with respect to the use of its resources and which is responsible for the production of a specific set of products from a specific set of materials and components. In that context, a Production Unit is defined by a class of PU-end-items with for each PU-end-item a class of operations with corresponing material and resource requirement. Work orders are assigned to the PU for the manufacturing of batches of PU-end-items. It is not allowed for the same work order to be produced in several PU's , nor do the authors allow any subcontracting between PU's in an ideal situation. An ideal production unit is self-contained from a manufacturing point of view (how to produce). Also from a production control point of view (when and how much to produce) the ideal production unit is self-contained, but it is constrained with respect to the amount and timing of its production. *These constraints constitute the operational constraints or operational characteristics of a production unit*. The constraints are basically generated by the limited availability of capacity and by the operation processing times required for the manufaturing of PU end-items. However, additional constraints can be generated by the way in which a production unit organizes ist production process in order to realize specific objectives. The creation of a PU requires a relatively stable environment for that unit with respect to the demand for the end-items produced by that unit. The advantage of defining and using PU's stems from the *reduction of complexity* of the control problem. In other words, the definition of one or more PU's generates a decomposition of the entire control problem into 2 or more subproblems. Accordingly, the total production control is split up into:

- Production unit control per PU
- Goods flow control, which coordinates the outputs of the PU's and which coordinates Production with Sales

Goods Flow Control releases work orders to the production units. As stated above the behavior of the PU itself is described by the so-called operational characteristics. Operational characteristics refer to variables like work order throughput times and capacity restrictions. Bertrand *et al.* (1990) stress that the dimensions and scale are not important for the definition of a production unit; what is important is that it must be possible to model the input/output behaviour of the PU in a relatively simple way. After having distinguished the PU's, the overall production control system is decomposed into production control per PU and the GFC system, that is the coordination of the various production units and the coordination of production and demand. The relationship between Goods Flow Control and Production Units is shown in the figure below:

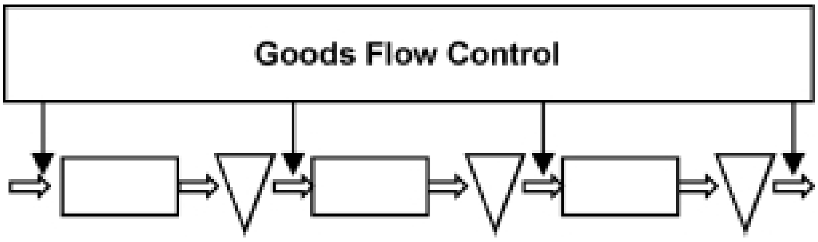

Figure 11: Relationship between GFC and PU

As stated above, according to Bertrand *et al.* (1990, page 14), the first task in designing a hierarchical control system is to distinguish PU's. Bertrand *et al.*. give 3 factors that play an important role in the question of how to select in a Bill-of-Material structure the items that must be controlled at the goods flow level (GFC items):

- Uncertainty
- Product Structure (number of components at each of the levels in the BOM structure)
- Capacity Bottlenecks (whether or not items are to be produced on capacity bottlenecks)

With respect to uncertainty Bertrand *et al.* make a distinction between *production yield uncertainty and demand uncertainty*. Items with a long lead time usually have a high demand uncertainty. So, the reliability of demand information generally decreases as the lead time increases. Nevertheless, production has to be initiated each period, and generally the amount to be produced is therefore based on a plan. Therefore, the demand uncertainty is buffered by creating some slack by means of safety stock or safety time. Bertrand *et al.* stress that the amount of production to be started for each item during a specific period may differ from the off-setted requirement of that item, generated one period earlier.For this reason, ideally all items in the product structure should be GFC-Items.However, this would create a very complex production control problem. Additionally, apart form differences in demand uncertainty, also large differences in production and delivery uncertainty will give rise to the need for specifying GFC-items. A prominent factor which leads to differences in production uncertainty is a variable yield of the manufacturing process.

With respect to product structure, in order to avoid the early issue of components needed at the final stage of an assembly process, the assembly process is often split up into a number of phases.

With respect to capacity bottlenecks, in many PU's there are one or two major bottlenecks, which are characteristic for the type of unit involved. Usually these bottlenecks contribute significantly to the value added to the products. If the bottleneck occurs as the first operation in the PU, the lead time through the PU will usually be reliable and short after the bottleneck. If the bottleneck occurs as the last operation in the PU it is wise to split up the PU into 2 parts, where the second part consists of the bottleneck capacity only. With capacity bottlenecks it is difficult to react to short term variations in volume. Therefore, after a capacity bottleneck, it should be possible to have some stock which serves to decouple the short term variations in demand from the production capacity.

Summarizing, Bertrand *et al.* introduced a distinction between control activities with a local scope (PUC) and control activities with a global scope (GFC). The authors stress that in order to realize the required delivery performance in the market, coordination of the activities of the production units is necessary. Goods Flow Control is primarily responsible for the coordination of the PU's and stock levels and for linking them to the market requirements. Production Unit Control, on the other hand is primarily responsible for accepting realistic objectives regarding capacity levels, production levels and work orders. From the point of view of Goods Flow Control, the PU's are black boxes. This implies that the internal structure of the PU's is not relevant for Goods Flow Control. Bertrand *et al.* distinguish on GFC level 2 control aspects:

- aggregate production planning (APP) and
- material coordination.

The control variables in the aggregate coordination process are the bottleneck capacity, the production budgets, the sales budget, the inventory budget, the budget for subcontracting etc. On this aggregate level they deal for example with the control of total capacity per PU. These budgets act as goals and restrictions for the detailed coordination process. In fact GFC controls the inventory levels of the PU-end-items by releasing work orders to the PU. The outputs of the APP function are an aggregate delivery plan, a capacity use plan, a capacity adjustment plan, and an aggregate inventory plan. An overview of the global goods flow control structure is given below:

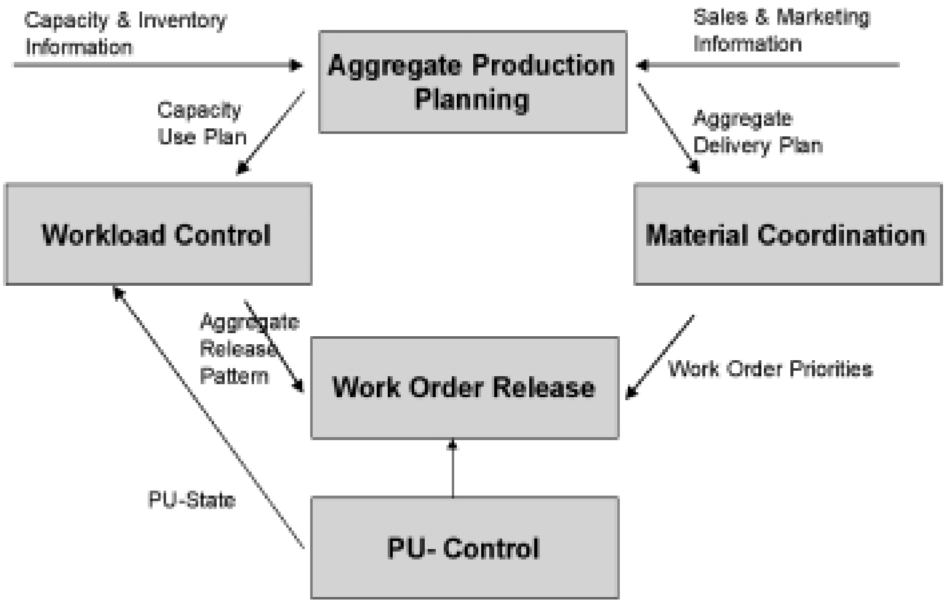

Figure 12: Goods Flow Control Structure

The aggregate delivery plan states planned deliveries for families of items over a number of future periods. The capacity use plan states the required effective capacity use in terms of hours per period over a number of future periods. The capacity adjustment plan states the adjustment of the available hours per period over a number of future periods. The aggregate inventory plan states the planned inventory for the various production stages for a number of future periods.

The control variables in the detailed coordination process (material coordination) are mainly the timing of work orders (release date and due date). In the material coordination function, priorities are determined for the release of work orders for GFC-items, where GFC items in the context of Bertrand *et al.* (1990) stock keeping units. These priorities are based on detailed demand information and on the work order throughput times. The detailed demand information is directed by the aggregate delivery plan. Actual work order releases are determined by the priorities given by material coordination and the release possibilities from the aggregate release pattern. The aggregate release pattern is determined by the capacity use plan of APP and by controlling the workload of the PU.

Focussing on the relationship between Production and Sales, GFC is defined as the coordination with respect to quantity and timing of Sales and Production. A very common situation is where at some high level of control, agreements are formulated between Sales

and Production with respect to sales, delivery conditions, reliability of sales forecasts, average inventory and WIP. Sales determines required delivery patterns for the end-items, taking into account structural agreements, but neglecting the actual possibilities of production. Production has to follow these required delivery patterns. This way of operational coordination is purely one way. Information about the state of Sales is given to Production to follow.
Focussing in the operational coordination of Sales and Production, it is based on information with respect to the state of Sales and Production. For production the state could be defined as the *set of realizable delivery patterns.* For sales the state could be defined as the *set of acceptable delivery patterns*. For production, instead of the set of possible delivery patterns, Bertrand *et al.* propose to choose underlying variables as inventories and WIP as state variables. For sales it is more difficult to find underlying state variables, because marke-ting and sales information can hardly be formalized. For sales it has to be accepted that in most cases it is not possible to find a good state definition. That means that judgement has to play an important role in the coordination process of Production and Sales. Operational coordination of Production and Sales could be reduced to finding and implementing the solution of some mathematical programming model, albeit a complex one. Operational coordination of Production and Sales is part of GFC.

In this thesis we accept the theoretical framework from Bertrand *et al* (1990) as a basis for formulating observations and hypotheses derived from the single case study.

3.4 Summary

In the sections above we explained two concepts for Hierarchical Planning: the conceptual approach of Bertrand *et al.* (1990) and the generic framework for hierarchical decomposition, developed by Schneeweiss (1999). We emphasize that the main difference is in the "what" and the "how". Bertrand *et al* (1990) describe what needs to be modeled, Schneeweiss (1999) describes how it has to be modeled. In fact we accept both approaches as good theories. In our further research we will use these concepts for different purposes in order to:

- improve theory with respect to anticipation, consistency and stability problems by relating it to Hierarchical Planning in current APS systems (chapter 4)

- structure our observations derived from the single case study (chapters 6 and 7)
- perform theoretical assessments based on the observations derived from the single case study (chapters 6 and 7)
- formulate hypotheses based on observations and theoretical assessments derived from the single case study (chapters 6 and 7)
- perform questionnaire-based interviews and describe results (chapter 8)
- make recommendations for modeling in Advanced Planning Systems and recommendations for further research (chapter 9)

Chapter 4

Hierarchical Anticipation in Advanced Planning and Scheduling Systems

In chapter 3 we gave a review of Hierarchical Planning Concepts. Our focus was first on the generic framework for hierarchical decomposition given by Schneeweiss and second on the conceptual approach of Bertrand *et al.* Considering modern Advanced Planning and Scheduling (APS) systems, the phenomenon is that they give no insight in the formal hierarchy of planning and anticipation. As stated in subsection 2.2.3 we are aiming at developing a theory on anticipation in Hierarchical Production Planning. Therefore the first purpose of this chapter is to give a theoretical assessment in the context of literature. The second purpose is to build our own constructs based on the hierarchical planning concept outlined by Schneeweiss.

In this chapter, we further analyze the Schneeweiss' concept of anticipation. We pay special attention to the concept of asymmetry; i.e. mid-term planning has to use less detailed and different information then short-term planning, because detailed data is not yet available at the time that mid-term planning decisions need to be made. And yet the mid-term decisions should be such that the short-term decisions can be taken in line with overall operational objectives with respect to customer service, resource utilization and capital investments.

We argue that anticipation is very closely related to the type of aggregation chosen in the system. As such, we distinguish between model anticipation and information anticipation. We will show that these constructs are in line with the types of anticipation that have been introduced by Schneeweiss[1], yet provide a more systematic means of analysis. Further, we apply these constructs for developing a number of alternative options for integrating two planning modules within the APS software i2 TradeMatrix (TradeMatrix is a trademark of i2 Technologies, see www.i2.com).

The remainder of the chapter is structured as follows. Section 4.1 pays explicit attention to the various types of anticipation that Schneeweiss distinguishes. In section 4.2, we present our analysis of the anticipation concept in close relation to a discussion on aggregation. We conclude this section by a classification of the various types of anticipation. In section 4.3, we apply our classification towards constructing a number of alternative options for integrating the Master Planner and Factory Planner modules within i2 TradeMatrix. We summarize section 4.3 by stating our conclusions.

[1] Whenever we refer to Schneeweiss in the remainder of the chapter, we actually refer to Schneeweiss (1999).

4.1 Hierarchical Decision Making and the Concept of Anticipation

Schneeweiss distinguishes four types of anticipation, i.e., exact explicit reactive anticipation, approximate explicit reactive anticipation, implicit reaction anticipation, and non-reactive anticipation. Since we are specifically interested in a further analysis of the concept of anticipation, and we intend to apply this to the design of an APS software hierarchy, we will now discuss these various types of anticipation in more detail.

Exact Explicit Reactive Anticipation

Under exact explicit reactive anticipation, the anticipation function matches exactly the optimization procedure the top level assumes the base level will use. The anticipation is explicit since it anticipates the actual behavior of the base level, and it is exact, since the information known to the top-level is processed exactly. The only difference between top level and base level, is that there may exist uncertainty in the system, which is only being revealed at the base level. Alternatively, exact explicit reactive anticipation is also called perfect anticipation. In order to make the differences between the various types of anticipation more explicit, we will now describe a master planning / shop floor scheduling aggregation hierarchy in terms of exact explicit reactive anticipation. The master planning / shop floor scheduling hierarchy is a general problem, as it is described in e.g. Bertrand *et al.* (1990).

Base Level Model Description		
Variables	Symbols and equations	Description
Planning horizon	$T_B \in \mathbb{N}$	Time horizon for the base level model
Planning buckets	$(t-1,t], 1 \leq t \leq T_B$	Time bucket representing a day
Items	$E = \{e_1,...e_N\}, N \in \mathbb{N}$	Set of all items, i.e. components, subassy's and end-products
Lead time	L_i	Expected Lead time of item e_i, i.e. the sum of the average processing time and the average waiting time and slack
Single resources	$K = \{k_1,...k_K\}, K \in \mathbb{N}$	Set of all single resources
Released resources	$C_j(t)$	Amount of resource k_j released at time t
Released material	$Q_i(t)$	Amount of material i released at time t
WIP	$WIP_i(t) = \sum_{s=t-L_i+1}^{t} Q_i(s)$	Cumulative orders of item i released and not yet completed at time t
Orders/forecast	$D_i(t)$	Orders or forecast for item e_i in period t
Inventory	$I_i(t+1) = I_i(t) + Q_i(t - L_i) - D_i(t)$	inventory of item i at time t, immediately before receipt of the order released at time $t - L_i + 1$

Table 3: Base Level Model Description

Top Level Model description = Base Level Model Description, except		
Variables	Symbols and equations	Description
Planning horizon	$T_T \in \mathbb{N}$	Time horizon for the top level model
Planning buckets	$(w-1, w], 1 \leq w \leq T_T$	Time bucket representing a week
Forecast	$\hat{D}_i(t)$	Forecast for item e_i in period t

Table 4: Top Level Model Description

Approximate Explicit Reactive Anticipation and Implicit Reactive Anticipation

In approximate explicit reactive anticipation, the anticipation function is explicit, but is only calculated approximately. Approximations can be made in the model, in the information status, and in the criterion that the base level is expected to use. In implicit reactive anticipation, the anticipation function considers only a part of the decision function of the base model. As a consequence, not all aspects of the base level model can be traced in the anticipation function, even as an approximation.

In our master planning / shop floor scheduling example, the top level model consists of an aggregation of the base level model by aggregating single resources into resource groups and by aggregating end products into product groups. This can be explained by the following example: Assuming that in the finite loading model (detailed base level model) there are 100 end-products, then after aggregation, in the aggregate model (aggregate base level model) there is only an aggregate number of 11 product groups. Assuming further that in the finite loading model (detailed base level model) there are 30 single resources, then after aggregation, in the aggregate model (aggregate base level model) there is only an aggregate number of 5 resource groups.

The conclusion is that starting from the top level model only a disaggregation function (a disaggregation model) makes it possible to derive the original base level model total. The description of the variables in the top and base level models is as follows under these two types of anticipation.

Base Level Model Description

Variables	Symbols and equations	Description
Planning horizon	$T \in \mathbb{N}$	Time horizon for the base level model
Planning buckets	$(t-1,t], 1 \le t \le T$	Time bucket representing a day
Items	$E = \{e_1,...e_N\}, N \in \mathbb{N}$	Set of all items, i.e. components, subassy's and end-products
Lead time	L_i	Lead time of item e_i, i.e. the sum of the average processing time and the average waiting time
Single resources	$K = \{k_1,...k_K\}, K \in \mathbb{N}$	Set of all single resources
Released resources	$C_j(t)$	Amount of resource k_j released at time t
Released material	$Q_i(t)$	Amount of material i released at time t
WIP	$WIP_i(t) = \sum_{s=t-L_i+1}^{t} Q_i(s)$	Cumulative orders of item i released and not yet completed at time t
Orders/forecast	$D_i(t)$	Orders or forecast for item e_i in period t
Inventory	$I_i(t+1) = I_i(t) + Q_i(t - L_i) - D_i(t)$	Inventory of item i at time t, immediately before receipt of the order released at time $t - L_i + 1$

Table 5: Base Level Model Description

Top Level Model description

Variables	Symbols and equations	Description
Planning horizon	$T_T \in \mathbb{N}$	Time horizon for the top level model
Planning buckets	$(w-1,w],1 \leq w \leq T_T$	Time bucket representing a week
Planning items	$P = \{p_1,...p_R\}, R \in \mathbb{N}$	Set of Planning Items, i.e. aggregate items
	$F_p : E \rightarrow P$,	Mapping process from the set E of end
	$F_p(e_i) = p_r, 1 \leq i \leq N, 1 \leq r \leq R$	products to the set P of Planning Items
Lead time	$\hat{L}_r = \max\{L_i \mid T(e_i) = p_r, 1 \leq i \leq N\}$	Lead time of Planning Item p_r ,
	$+\Delta_r$	Δ_r modelling slack time
Aggregate Resources	$\hat{K} = \{\hat{k}_i,...\hat{k}_K \in \mathbb{N}$,	set of all aggregate resources,
	$F_r : K \rightarrow \hat{K}$,	Mapping process from the set K of single
	$F_r(k_j) = \hat{k}_m, 1 \leq j \leq K, 1 \leq m \leq \hat{K}$	resources to the set $\hat{K}$ of aggregate resources
Released Aggregate Resources	$\hat{C}_r(t)$	Amount of aggregate resource $\hat{k}_m$ released at time t
Released Aggregate Material (Planning Items)	$\hat{Q}_r(t)$	Amount of Planning Item p_r released at time t
Aggregate WIP	$W\hat{I}P_i(t) = \sum_{s=t-\hat{L}_r+1}^{t} Q_r(s)$	Cumulative orders of item p_r released and not yet completed at time t
Aggregate Inventory	$\hat{I}_r(t+1)$ $= \hat{I}_{pr,T}(t) + \hat{Q}_r(t-\hat{L}_r) - \hat{D}_r(t)$	Inventory of Planning Item p_r at time t, immediately before receipt of the order released at time $t - \hat{L}_r + 1$
Aggregate Forecast	$\hat{D}_r(t)$	Forecast for Planning Item p_r in period t

Table 6: Top Level Model Description

Non-reactive Anticipation

In non-reactive anticipation, there is no specific anticipation function. The top level model contains some general features of the base level. The features are not specifically dependent on or related to the (hypothetical) instruction.

Although Schneeweiss recognizes that the four types he distinguishes are just some important examples, we will argue in the next section that there is a more systematic latent analysis under Schneeweiss's types of anticipation. This analysis will show that there is another important example of anticipation that has been neglected in the initial analysis outlined above.

4.2 Aggregated Decision Making Models and the Resulting Need for Anticipation

4.2.1 General Typology for Aggregation and Anticipation Types

Aggregation is a process for simplifying a problem by defining condensed data and decision variables. By considering different hierarchical levels and separate decision models for each level, we can formally say that the basic difference between decision models at each level is in the degree of aggregation. Aggregation achieves a reduction of data requirements and as well a reduction of model complexity, especially at the upper decision levels. According to Steven (1998) a meaningful aggregation should further be based on the following principles:

(1) the higher the hierarchical position of the planning level, the higher is the aggregation of data and decision variables
(2) aggregation should be in line with the organizational structure
(3) aggregation should take into account the solution possibilities of the subproblems, so that disaggregation errors can be avoided.

Aggregation in the concept of Schneeweiss as discussed in chapter 3 mainly focusses on the way the base model is anticipated in the top decision model, stressing his view that making decisions at upper levels will not be done without any knowledge of the lower level's decision process. Accordingly, we can define the following:

<u>Definition:</u> *Top Level Model = Anticipated Version of the Base Level + Decision Variables covering the rest of the Planning Horizon*

In this section we develop a formal classification typology of possible anticipations, which are based on the types of aggregation used. The notation follows the notation of the general Schneeweiss model, as introduced in section 3.2. In order to describe all types of possible anticipations in general, we make a first basic distinction of what types of aggregation areas we consider. Aggregation is referred to two parts of the decision making process:

- The model part
- The information part

Aggregation referring to the model part explicitly deals with complexity reduction. At the top level the decision making process is represented by an aggregate and simple model in order to reduce complexity and to distribute detailed decisions to lower planning levels. We can thus distinguish the following anticipation types with regard to the model:

1. Explicit Model: The base level model as seen in the top level is exactly the same as the original base level model:

   $$\hat{a}^B = a^B$$
   $$\hat{C}_{IN}^B = C_{IN}^B$$

2. Implicit Model: The base level model as seen in the top level is different than the original base level model:

   $$\hat{a}^B \neq a^B$$
   $$\hat{C}_{IN}^B \neq C_{IN}^B$$

Consequently, the terms explicit and implicit with regard to anticipation refer to the fact whether the top-level base model (including the criterion) is exactly the same as the base-level base model. If this is the case, we call this explicit anticipation, if this is not the case, we call this implicit anticipation. Explicit anticipation thus uses a detailed model of the base level, whereas implicit anticipation uses an aggregate model of the base level.

Aggregation referring to the information part is related to uncertainty and effectuation time. In the context of the questions related to the anticipation function, special attention regarding information is paid to the concept of information asymmetry. Information asymmetry basically entails the fact that when making a decision at a higher level, the amount and quality of information may be different from when the lower level decision is made (later), and again different from when the actual execution of the decision is taking place. The fact that information asymmetry exists, leads to the necessity to *anticipate* at a higher level decision what *may* happen at the lower levels decisions. We can thus distinguish the following anticipation types with regard to information:

1. Exact Information: The base level information as seen in the top level is exactly the same as the original base level information:

   $\hat{I}_{IN}^{B} = I_{IN}^{B}$

2. Approximate Information: The base level information as seen in the top level is different than the original base level information:

   $\hat{I}_{IN}^{B} \neq I_{IN}^{B}$

Consequently, the term exact and approximate refer to the fact whether the top level model has exact information of the base level status. Note that in most cases some time elapses between the moment at which the top level makes its decision (instruction) and the moment at which the base level makes its (final) decision. This *effectuation time* usually entails a difference in the information status between the top level and the base level, resulting in information asymmetry and – automatically – in approximate anticipation.

Taking all combinations between anticipation types referring to the modeling part and anticipation types referring to the information part, we can construct the typology represented in Table 7.

	Exact Information	*Approximate Information*
Explicit Model	$\hat{a}^{B} = a^{B}$ $\hat{C}_{IN}^{B} = C_{IN}^{B}$ $\hat{I}_{IN}^{B} = I_{IN}^{B}$	$\hat{a}^{B} = a^{B}$ $\hat{C}_{IN}^{B} = C_{IN}^{B}$ $\hat{I}_{IN}^{B} \neq I_{IN}^{B}$
Implicit Model		$\hat{a}^{B} \neq a^{B}$ $\hat{C}_{IN}^{B} \neq C_{IN}^{B}$ $\hat{I}_{IN}^{B} \neq I_{IN}^{B}$

Table 7: Anticipation typology based on information and model aggregation

Given this typology, we can distinguish three types of anticipation, based on the various types of aggregation used to construct the anticipation function as discussed above. The three types are:

1. Explicit Model / Exact Information (EE)
2. Explicit Model / Approximate Information (EA)
3. Implicit Model / Approximate Information (IA)

Note that the combination of exact information and implicit model does not make a lot of sense, since there does not seem to be a clear reason for constructing an implicit model (i.e., more aggregate than the detailed model) if exact information is available. In the following subsection we will compare the types of anticipation we have developed with the types of anticipation that have been developed by Schneeweiss.

4.2.2 Schneeweiss's anticipation types in the aggregation based anticipation typology

Table 8 shows that Schneeweiss' types of anticipation fall into two categories with regard to the type of aggregation used.

	Exact Information	*Approximate Information*
Explicit Model	• *Exact Explicit Reactive Anticipation*	
Implicit Model		• *Approximate Explicit Reactive Anticipation* • *Implicit Reactive Anticipation* • *Non-reactive Anticipation*

Table 8: Anticipation types of Schneeweiss with regard to information and model aggregation

Schneeweiss's understanding of exact explicit reactive anticipation goes in line with our classification type Explicit Model / Exact Information (EE anticipation). With regard to exact explicit reactive anticipation, Schneeweiss stresses that the base model is anticipated exactly in the top model such that the base level model is a part of the top level model. This part of the top level model is exactly identical to the base level model. The same is valid for the information part. Exactly the same information used in the base level is now used for the top level. It should be further noted that the EE anticipation only exists, if the base level information is known with full certainty. E.g. the base level model should have exact information about demand. Otherwise, this kind of anticipation does not exist. Also Schneeweiss notices this when he refers to this as “an idealized case”.

Approximate explicit reactive anticipation anticipates the whole base model approximately into the top level. Implicit reactive anticipation anticipates only a part of the base model into the top level. Both types of anticipation are covered by our Implicit Model / Approximate Information (IA anticipation), as it does not in itself distinguish between approximating the whole base model or using only a part of the base model.

Non-reactive anticipation can be considered as a special case of IA Anticipation, in which the top-level model of the base level is simply considered as “empty”.

Note that Schneeweiss does not distinguish any anticipation functions of the type EA.

4.3 Planning Hierarchy in the APS System i2 TradeMatrix

4.3.1 Introduction into the APS System i2 TradeMatrix

Current APS systems for supply chain management are focussed on optimizing activities in a supply chain such as enterprise functions from the ordering and receipt of raw materials through the manufacturing of products to the distribution and the delivery to the customer. In order to operate efficiently, it is the objective of APS systems that these functions operate in an integrated manner.

The general solution that can be found in most APS systems, is based on a hierarchical structure, consisting of three levels: Demand Planning, Master Planning, and Factory Planning. Here we adopt the terminology used by i2 Technologies with respect to their APS suite i2 TradeMatrix (see www.i2.com). At the top level in the planning hierarchy is the Demand Planner module which generates time-based forecasts per product / product group (according to historical / statistical data, market strategies, etc.). The next level is the Master

Planner module. The Master Planner module creates a Master Plan for a company's supply chain, by integrating business policies, market demand and supply chain capability into a common plan. The bottom level module is Factory Planner. Customer orders are entered into the Factory Planner order book. Factory Planner then determines on which day each manufacturing operation of a given customer order should be performed on which particular resource by creating a factory-wide "model" optimal plan. Here we want to especially remark that optimality in the mathematical sense does not exist. This is because as optimality depends on the exogenous variables as an input, information asymmetry and uncertainty in the hierarchical planning process prevent optimality in this case. Therefore we define "model optimality" as the optimal solution found for the formulated model. The output of Factory Planner can be used as an input to the more detailed scheduling (sequencing) of manufacturing orders at the shop floor level and as a basis for procurement. The scope of i2 TradeMatrix also includes an order quoting process for customer orders. The basis for the given quotes are the Available to Promise allocations (ATP) created as a result of the Master Planning process.

Figure 13 shows the various modules and their interrelationships. In this section we restrict ourselves to the levels of Master Planning and Factory Planning. The level of Demand Planning is indicated in the picture below by the specification of Forecasts per Planning Item as an input for the Master Planning process.

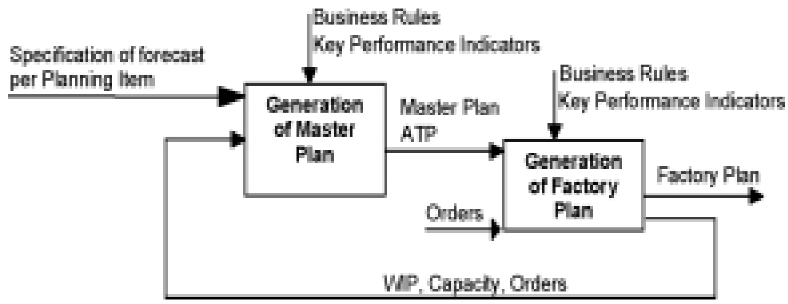

Figure 13: Overview of Planning Hierarchy in i2 TradeMatrix
(IDEF scheme methodology, see www.idef.com)

Considering this planning hierarchy, the i2 TradeMatrix solution also views the organization as a set of several decision making processes – this can simply be seen from the product definition of Master Planner (intermediate/ top level) and Factory Planner (lowest/ base level), which have been built for modeling several decision processes. Relating this to the terminology introduced above, we can associate the top level decision process with the Master Planning functionality and the base level process with the Factory Planning functionality. Further, exact explicit reactive anticipation implies that all equations from Factory Planner are part of Master Planner. Factory Planner would be totally incorporated into Master Planner. The only difference that still can exist is that the Factory Planner planning horizon is for example three months, the Master Planner planning horizon is bigger. Alternatively, the non-reactive anticipation implies that there is no feedback from the base level, so that Master Planning is solved without any knowledge of Factory Planning.

4.3.2 Basic Definitions in the i2 TradeMatrix Context

In the following subsections, we will describe three possible options for defining the anticipation function between the i2 TradeMatrix modules Master Planner and Factory Planner. The options are derived from our general typology for aggregation and anticipation types presented in subsection 4.2.1 and represent a proper integration between the 2 planning layers of Master Planner and Factory Planner. It is important to note that each of the options developed below suggests a different modeling process and use of the Master Planner tool. The options describe different possibilities to anticipate the reaction of Factory Planner into the Master Planner model. These possibilities address the anticipation of the following variables:

- Work in Process (WIP)
- Resource Capacity
- Sales Forecast

as a result from Factory Planner in the Master Planner Model.

Accordingly, our focus when constructing the options based on our classification typology will be on:

- Order Book (i.e., the orders that have already been entered into i2 TradeMatrix Factory Planner)

This piece of information may be used to net the aggregate forecast at the Master Planner level.

- Resource Loadings (as planned in i2 TradeMatrix Factory Planner)
  This information may be used to net the aggregate capacity at the Master Planner level in order to plan for the netted forecast
- Inventory and inventory projections (resulting of i2 TradeMatrix Factory Planner)
  This information may be used as a starting condition for Master Planner

In order to understand the development of the specific anticipation and aggregation options, a few basic explanations of concepts within i2 TradeMatrix are necessary.

Unassigned WIP versus Assigned WIP

Unassigned WIP includes all physical material that will remain in the supply pipeline once the current order book is fully satisfied. This can also be viewed as the “excess” production/inventory level carried in the system to satisfy potential future demand. For example, if today no further orders are taken, then there will still be some remaining inventory after the order book has been satisfied. Unassigned WIP needs primarily to be considered in Factory Planner. Assigned WIP includes all physical material to be consumed by the current order book demand. In general it can be stated that assigned WIP does not have to be considered in Master Planner, as this material is not subject of the planning procedure regarding the future. The only exception where assigned WIP needs to be considered, is when the Master Planner planning horizon is set such that the backwards calculation of operations, which refer to short term orders, determines a start operation which lies in the past. The software problem here is that any operations lying in the past have to start artificially at the beginning of the horizon. We point out that for such operations, material has been assigned already in earlier planning steps. In order to avoid that those orders are delayed because of material unavailability, Master Planner needs to be informed about assigned material in the beginning of the planning horizon. We stress that this way of modeling is only caused by internal software problems.

Capacity Load versus Free Remaining Capacity (Netted Capacity)

The capacity load in Master Planner is defined as the capacity utilization per time bucket (week) per resource. Accordingly the following definition is valid under the assumption that a plan is given:

Free Remaining Capacity per time bucket per resource	=	*Available Capacity per time bucket per resource – (capacity utilization of actual (where production has started) orders per time bucket per resource + capacity utilization of planned (where production has not started yet) orders per time bucket per resource)*

Forecast versus Net Forecast

The (sales) forecast is the unconstrained forecast per Planning Item (aggregation of physical end products, see subsection 6.5.1) per time bucket (week) as generated by the sales department. Accordingly the following definition is valid:

Net Forecast	=	*Unconstrained Forecast per Planning Item and week– (actual orders per Planning Item and week + planned orders per Planning Item and week)*

In principle the net forecast can be negative, but it should always be a positive number or zero when used as an input for Master Planner. Planned orders in this context are defined as orders which have already been accepted but for which production has not yet started.

4.3.3 Aggregation and Anticipation in i2 TradeMatrix - Development of Basic Options for Anticipating Factory Planner into Master Planner

The development of the three basic options for anticipation in i2 TradeMatrix is based on our general typology for aggregation and anticipation types and mainly depends upon which degree of Work in Process (WIP) information is uploaded form the base level into the top level.

Implicit Model Approximate Information (IA anticipation) (empty base level model)

The classification type of IA anticipation assumes its simplest form when considering the anticipated base level model as empty. In terms of the i2 TradeMatrix solution this can be interpreted as that the top level model of Master Planner is run with no WIP information, neither assigned nor unassigned, coming from the base level model of Factory Planner. Factory Planner does provide the Master Planner model with feedback regarding its status.

That means, that the problem of a changing world is dealt with by inserting slack into the Master Planner model and recalculating the model many times if status information (fed back from Factory Planner) has changed.
Figure 14 illustrates the instructions IN_k (Master Plan, ATP) and the reactions R_k (Due Date Quoting, WIP, capacity, and orders) respectively.

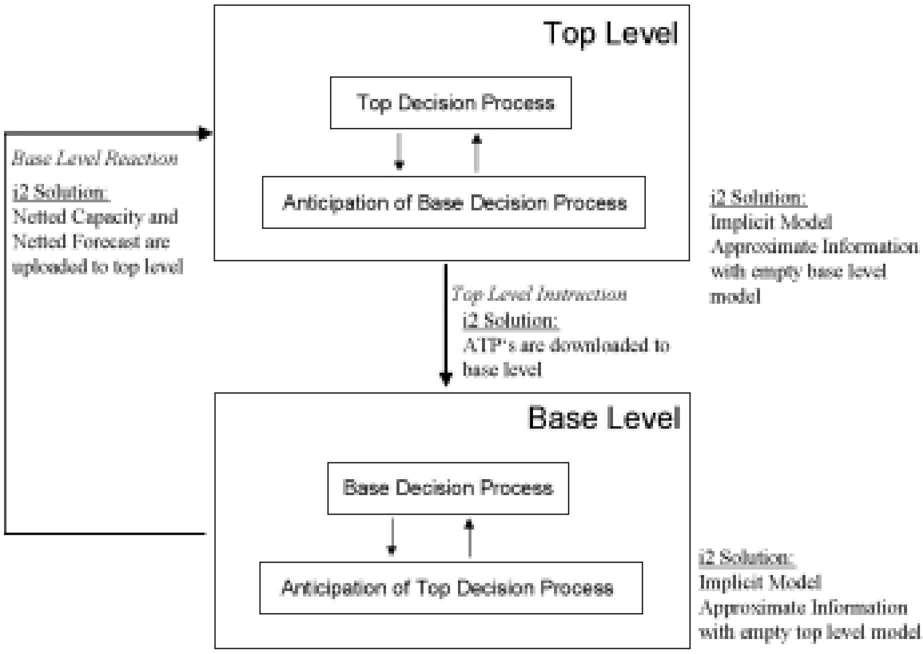

Figure 14: IA Anticipation in i2 TradeMatrix.

Summarizing, in case of IA anticipation with an empty base level model there is no anticipation of the base level into the top level and vice versa. There is only information exchanged by sending instructions and reactions as shown above. The reaction coming from the Factory Planner model (base level) only includes the specification of capacity, netted by already consumed capacity, and the specification of sales forecast, netted by already accepted orders. This option represents the most cautious approach. The top level model is started with no WIP information, neither assigned nor unassigned. Master Planner will have to use only the capacity available to fulfill the forecast demand.

The question whether unassigned WIP should be taken into consideration in Master Planner, depends in practice on two aspects:

- whether there is always a “significant” amount of unassigned material in various inventory points, which cannot be neglected, and
- whether the ERP system is able to explicitly distinguish between assigned and unassigned material.

The instruction coming from Master Planner includes the ATPs to be used for due date quoting in the Factory Planner. In this option, capacity is netted outside of Master Planner. The concept is that in a first step, free capacity per single resource has to be computed from the ERP system and associated to a Master Planner time bucket. In a second step this information has to be aggregated to the Master Planner resources. Similarly, the sales forecast is also netted outside of Master Planner. The concept is again, that in a first step, actual and planned orders, taken from the order entry system (e.g., SAP R/3), are mapped into the Master Planner Planning Items. In a second step, this amount per Planning Item and Master Planner time bucket has to be subtracted from the unconstrained forecast coming from sales. A summary of the characteristics of this option is given in Table 9 .

<table>
<tr><th>Unassigned /Assigned WIP</th><th>Capacity</th><th>Forecast</th></tr>
<tr><td rowspan="4">None</td><td>Data:
Netted Capacity (Remaining free capacity per MP bucket per MP resource)</td><td>Data:
Netted Forecast per MP Planning Item and MP bucket</td></tr>
<tr><td>Data Source:
ERP System</td><td>Data Source:
ERP system
Sales Forecasts</td></tr>
<tr><td>Data Manipulation:
• Computation of free capacity per single resource per MP bucket
• Aggregation to MP resources</td><td>Data Manipulation:
• Mapping of actual and planned orders into Planning Items
• Subtraction from the unconstrained forecast</td></tr>
<tr><td>Data Destination:
Master Planner</td><td>Data Destination:
Master Planner</td></tr>
</table>

Table 9: IA Anticipation in i2 TradeMatrix.

The advantage of IA anticipation with empty base level model is that this option is quick and simple to implement, understand, use and maintain. The disadvantage is that there is no view of real orders and their percentage of the forecast within the Master Planner model. Additionally, very crude assumptions regarding capacity may lead to significant errors. Furthermore, it is stressed that aggregated lead time used in the top level model is computed as aggregate estimates about processing times and waiting times.
However, regarding consistency and stability, it may perform very well in situations where

- A stable product mix is guaranteed
- The sales forecast is very accurate
- Processing times and capacity availability is fairly reliable and stable

Summarizing, the IA anticipation is characterized by low consistency between Master Planner and Factory Planner and high stability.

Explicit Model Approximate Information (EA anticipation)
EA anticipation can be described in i2 TradeMatrix terminology as that unassigned present WIP and assigned present WIP are loaded into the top level (Master Planner) model. Note that in this option only present WIP is considered. A representation of this option is presented in Figure 15.

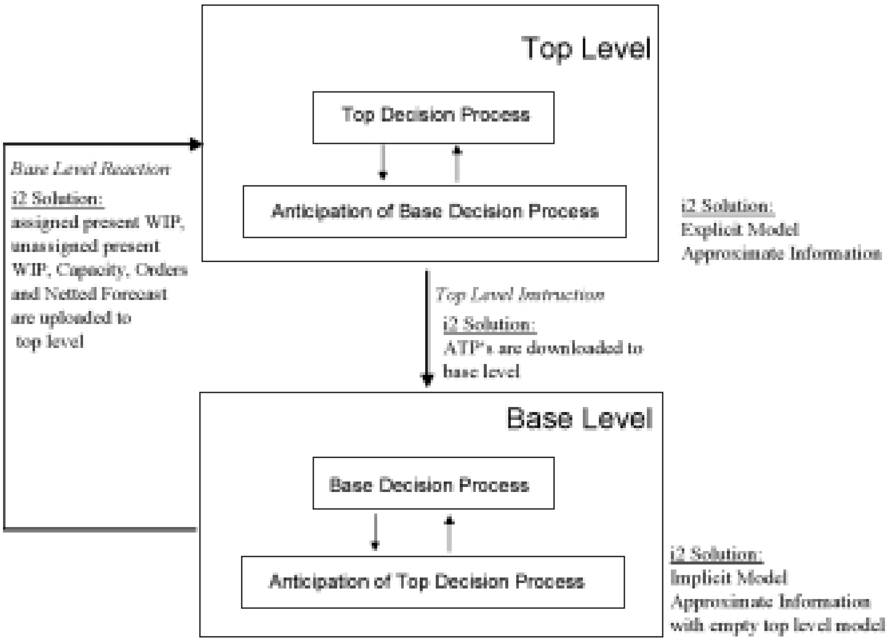

Figure 15: EA Anticipation in i2 TradeMatrix.

When using EA anticipation, unassigned present WIP and assigned present WIP is loaded into the top level (the Master Planner model). The concept is that in a first step, WIP material coming from the ERP system has to be mapped into Master Planner Planning Items. In a second step WIP material has to be located into Master Planner inventory buffers. Capacity is netted automatically in the Master Planner model. The concept is that actual and planned orders are taken out of the order entry system and mapped onto the Master Planner Planning Items. The Master Planner model thus includes actual and planned orders and capacity is netted automatically within the Master Planner model. The demand forecast is netted outside of Master Planner, comparable to IA anticipation. A summary of the characteristics of EA anticipation in i2 TradeMatrix is given in the Table 10.

Unassigned /Assigned WIP	Capacity	Forecast
Data: • Unassigned present WIP per Planning Item and Buffer • Assigned present WIP per Planning Item and Buffer Data:	Data: Actual and planned orders per MP Planning Item	Data: Netted Forecast per MP Planning Item and MP bucket
Data Source: ERP System	Data Source: ERP System	Data Source: ERP System
Data Manipulation: • Mapping of WIP material into MP Planning Items • Location of WIP material into MP inventory buffers	Data Manipulation: • Mapping of orders into MP Planning Items	Data Manipulation (Layered Planning): • Mapping of actual and planned orders into Planning Items • Subtraction from the unconstrained forecast *Data Manipulation (Simple):* • Mapping of actual and planned orders into Planning Items
Data Destination: Master Planner	Data Destination: Master Planner Capacity is netted automatically in Master Planner	*Data Destination:* Master Planner

Table 10: EA Anticipation in i2 TradeMatrix.

The advantage of EA anticipation is that in this option real orders and remaining demand can be viewed within Master Planner. The disadvantage is that the Master Planner plan may differ significantly from the Factory Planner plan.

This option is appropriate to use only if certain preconditions for consistency and stability between Master Planner and Factory Planner are assured. These preconditions are as follows:

- Lead Times as used in Factory Planner are stable
- Lead Times as used in Master Planner are computed by using the same detailed data basis as used in Factory Planner and are aggregated afterwards and added to a slack
- The sales forecast is very accurate
- Processing times and capacity availability is fairly reliable and stable
- If these preconditions can be assured, the product mix does not necessarily have to be stable.

These preconditions are actually essential, since if, for example, lead times in Factory Planner are not stable the aggregated lead times in Master Planner will not work. Processing times and capacity availability needs to be stable in order to aggregate from the detailed level. Summarizing, the EA anticipation is characterized by average consistency between Master Planner and Factory Planner and average stability.

Explicit Model Exact Information (EE anticipation)

When EE anticipation is applied to the i2 TradeMatrix product, both unassigned present and future WIP and assigned present and future WIP are loaded onto the top level (Master Planner) model. The difference with EA anticipation is that here we consider the full Factory Planner plan over the whole time horizon, including future WIP. The option is presented graphically in Figure 16.

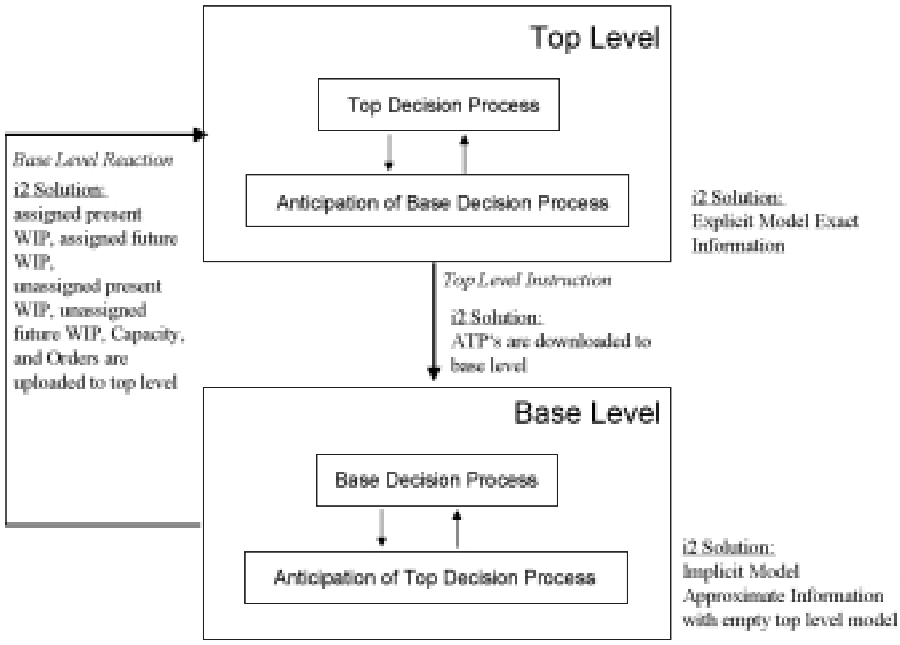

Figure 16: EE anticipation in i2 TradeMatrix

Unassigned present and future WIP and assigned present and future WIP are loaded onto the Master Planner model. The concept is that in a first step, WIP material coming directly from Factory Planner has to be mapped into Master Planner Planning Items. In a second step WIP material has to be located into Master Planner inventory buffers. Capacity is netted outside of Master Planner. Comparable to IA anticipation, the concept is that in a first step, free capacity per single resource has to be computed from Factory Planner and associated to a Master Planner time bucket. In a second step this information has to be aggregated to the Master Planner resources. The sales forecast is netted outside of Master Planner, comparable to IA anticipation. A summary of the characteristics of EE anticipation in i2 TradeMatrix is given in the Table 11.

Unassigned /Assigned WIP	Capacity	Forecast
Data: • Unassigned present and future WIP per Planning Item and Buffer • Assigned present and future WIP per Planning Item and Buffer	Data: Netted Capacity (Remaining free capacity per MP bucket per MP resource)	Data: Netted Forecast per MP Planning Item an d MP bucket
Data Source: Factory Planner	Data Source: Factory Planner	Data Source: ERP system
Data Manipulation: • Mapping of WIP material into MP Planning Items • Location of WIP material into MP inventory buffers • Conversion of FP operations into MP operations • Location of WIP to operations	Data Manipulation: • Computation of free capacity per resource • Aggregation to Master Planner resources	Data Manipulation: (Layered Planning): • Mapping of actual and planned orders into Planning Items • Subtraction from the unconstrained forecast Data Manipulation(Simple): • Mapping of actual and planned orders into Planning Items
Data Destination: Master Planner	Data Destination: Master Planner	Data Destination: Master Planner

Table 11: EE anticipation in i2 TradeMatrix

The advantage of EE anticipation is, as in option 2, that actual and planned orders can be viewed and accordingly the effect of the order book along with the forecast plan. The disadvantage of this option is that maintenance is complex and very high. Very difficult resource mapping decisions have to be made, which could also lead to crude approximations, thus hampering the value provided by more detailed FP information. The value of the information is questionable when mixing FP output with MP output.

Summarizing, using this option would theoretically be very consistent, but due to the complexity of maintenance, costs are very high. The only precondition for consistency that needs to be fulfilled is that the sales forecast is very accurate.

In total we can say that this option would in practice be infeasible, as instability would be very high. Summarizing, the EA anticipation is characterized by high consistency between Master Planner and Factory Planner and low stability.

4.3.4 Conclusions

Table 12 gives an overview of the three options we developed for Master Planner / Factory Planner integration. Obviously, there are intermediate options that can be developed, but the anticipation typology we have used demonstrates that we have discussed the dominant specific times. EE anticipation is the advanced option in the sense of full integration, which directly takes into account the reaction R_k* of the Factory Planner Model and uses it to make the anticipation (netting). EA anticipation and IA anticipation are not using the Factory Planner inputs but inputs from the ERP system in order to make the anticipation.

	Implicit Model Approximate Information (empty base level model)	Explicit Model Approximate Information	Explicit Model Exact Information
Unassigned/ Assigned WIP	none	ERP System ↓ MP	FP ↓ MP
Capacity	ERP System ↓ MP	ERP System ↓ MP	FP ↓ MP
Forecast	ERP system ↓ MP	ERP system ↓ MP	FP ↓ MP

MP Table 12: Overview of three integration concepts between MP and FP

Summarizing, in this section, we have presented a systematic analysis of the concept of anticipation in hierarchical planning. Anticipation has been considered as the function in a hierarchical planning system by which the higher level decision function anticipates the reaction of the subordinate level decision function to its instructions. Our analysis was based on two characteristics of the anticipation function, namely the degree to which it includes details of the lower level decision model, and the degree to which it contains details of the lower level information status (current and future).

We have applied our typology on designing a number of alternative integration options between two modules that can be found in many Advanced Planning and Scheduling Systems: a module which focusses on aggregate level supply chain planning (e.g., Master Planner in i2 TradeMatrix) and a module which focusses on a more detailed level of factory planning (e.g., Factory Planner in i2 TradeMatrix). This has lead to essentially three different mechanisms for integrating the two planning modules.

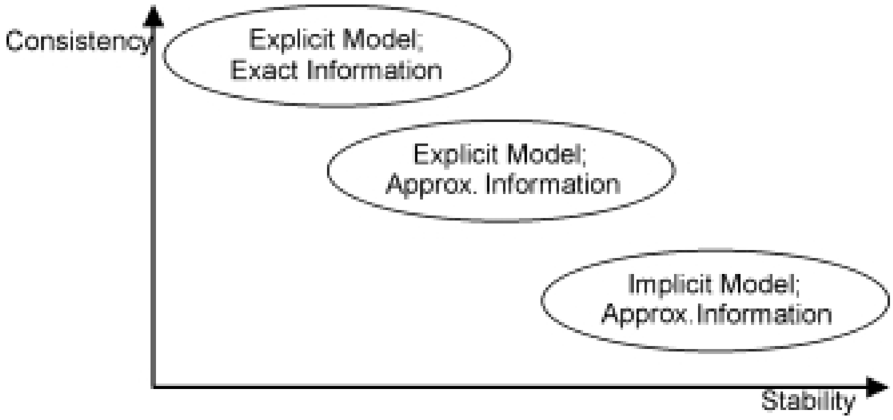

Figure 17: Trade-off between consistency and stability

Selection of the appropriate type of integration ultimately depends on the requirements with regard to consistency between the two levels and stability of the plans between consecutive period. This trade-off has been summarized in Figure 17. As such, this will depend on the specific operating characteristics of the company being represented by the planning software.

4.3.5 Other issues

We want to emphasize two further issues, which are relevant in this context, but which have not been adressed in this chapter.

- Slack Variables are not explicitly considered in the i2 TradeMatrix design

Although slack is a critical input variable in a planning system like i2 TradeMatrix, it is only implicit in its design concept. Evidently, the amount of slack needed, e.g. in time or capacity, depends on the actual production situation, but in fact slack should not be hidden in a system. The correct approach would be to have slack as an explicit variable in the design concept (Galbraith, 1973).

- Aspects of reality fit with respect to Factory Planner are not considered in the i2 TradeMatrix design

Our observation is that although databases incorporated in Factory Planner have a lot of details (e.g. variants, BOM's, etc.), Factory Planner still does not correspond to a perfect model of reality. Accordingly, as we consider the way Factory Planner is anticipated into the Master Planner model, reality should as well be anticipated into the Factory Planner model. We believe that the relationship Factory Planner/Reality is similar to the anticipation Master Planner/Factory Planner. The anticipation of reality into Factory Planner is not part of our thesis, but can be considered as another research area.

4.4 Summary

In this chapter we paied explicit attention to the concept of anticipation based on Schneeweiss. We analyzed the anticipation concept and developed a general typology for aggregation and anticipation types, by distinguishing between information aggregation and model aggregation. We gave an introduction into the APS system i2 TradeMatrix and then applied our typology towards constructing a number of alternate options for integrating the Master Planner and Factory Planner modules within the software. We will further use our typology in chapters 6 and 7 in order to structure our observations from the single case study and make theoretical assessments. Both, observations and theoretical assessments will lead to hypotheses, summarized in chapter 8.

Chapter 5

Implementation of i2 TradeMatrix at ALCO: Case Description

In this chapter we describe the supply chain characteristics of the case under consideration by introducing the products, the manufacturing facilities, the relevant suppliers and the service centers. We will limit the description to the general company overview, and to those details of the supply chain that are relevant to understand the remainder of the chapter. In section 5.2 we give an overview of typical decision problems in a supply chain, followed by an illustration of the current performance and perceived problems at ALCO (section 5.3). Section 5.4 gives a high level description of the i2 TradeMatrix products Demand Planner (DP), Master Planner (MP), and Factory Planner (FP), and the general solution approach of the vendor i2. More specifically, it addresses the proposed overall solution for this particular company, using the i2 TradeMatrix suite.

5.1 Supply Chain Characteristics of ALCO

As mentioned before, the study concerns the implementation of the TradeMatrix software of i2 Technologies at a European multi-billion euro revenue turnover aluminum manufacturing company that we will call ALCO. ALCO has plants and subsidiaries both in a number of European countries and outside of Europe. It offers a complete range of aluminum products, special aluminas, carbon products, silicon metal, and gallium. ALCO covers a broad range of products, including primary and secondary metal (Division "Aluminum"), rolled products (Division " Rolled Products") for the packaging markets and technical applications, flexible packaging materials (Division " Flexible Packaging") for food service and pharmaceutical uses and finished goods such as aluminum ladders and household foil (Division "Others"). ALCO also operates recycling facilities for aluminium scrap and industrial waste. In this case study, we will limit ourselves to the Division "Rolled Products". The Division "Rolled Products" is further subdivided into 4 Business Units:

- Foil (producing plain aluminum foil with variable thickness ranges for flexible packaging)
- Lithography (producing high quality aluminum strips for offset printing plates)
- Sheet & Strip (producing plain and painted strips with variable thickness ranges for automotive industries, heat exchangers etc.)

- Beverage Can (producing plain and painted strips for beverage cans)

The Division “Rolled Products” in 1997 had 2 locations, the A-plant, which is subdivided into the Business Units Foil, Lithography, Strip&Automotive and Beverage Can, and the B-plant. The B-plant is a 50% ALCO owned company and a very important supplier of input material - 65% of all input raw materials for the A-plant are supplied by the B-plant. The B-plant delivers pre-rolled raw material of a certain thickness range.

Recently, the Division “Rolled Products” acquired an additional number of rolling mills as a first step towards globalization of the companies operations. The new plants are also located in Europe. The (newly acquired) C-plant and D-plant mainly produce Sheet&Strip products, whereas about 50% of the E-plant concentrate on Foil, so the new plants are associated to the aforementioned Business Units accordingly.

This entire set of plants together with a number of significant suppliers and subcontractors form ALCO’s supply chain. The initial implementation of i2 TradeMatrix Master Planner, as will be described later, has been conducted at ALCO’s A-plant. The entire supply chain is depicted in the figure below:

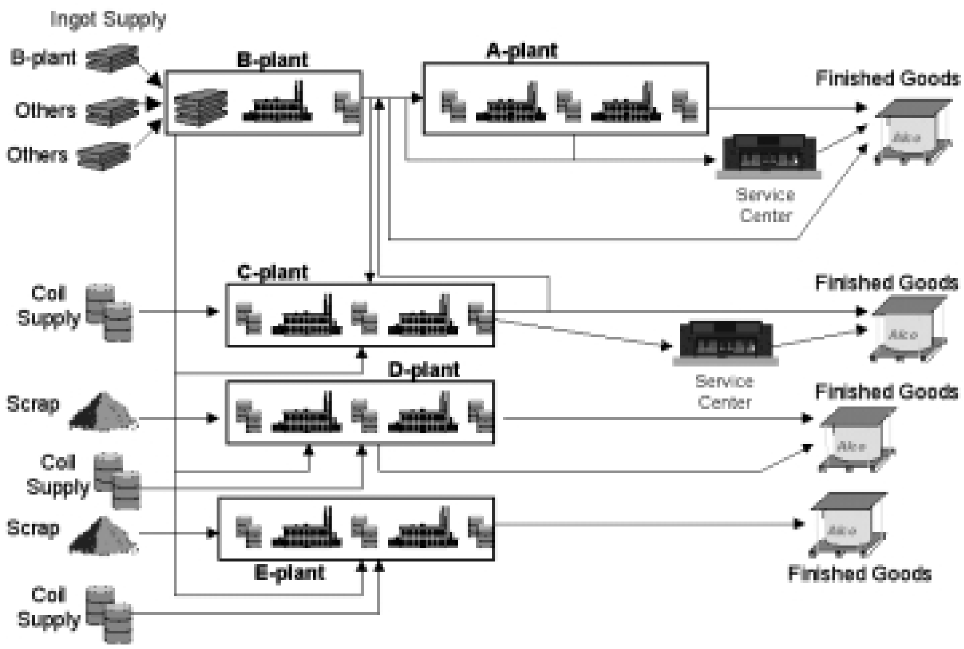

Figure 18: Supply Chain of the Rolling Division of ALCO

The material transfers shown in Figure 18 are within the scope of the planning tools being implemented.

5.2 Overview of Decisions in the Supply Chain

It is well recognized that planning is composed of a set of decisions that can be organized into a hierarchy (Meal, 1984). When a particular decision is made, it will necessarily restrict the degrees of freedom available for decisions lower in that hierarchy. Generally speaking, the entire supply chain is very complex and many decisions need to be made, varying from sourcing decisions at suppliers to detailed sequencing decisions on the rolling mills. For the purposes of discussion, planning decisions are divided into three categories: Strategic Planning, Tactical Planning and Operational Planning. Tactical planning is also known by the term Master Planning and this term will be used in the rest of the paper, in conjunction with the terminology used by the APS vendor. Operational planning is called Factory Planning by the APS vendor. The specific decisions in each category are shown in the table below.

Decision Type	Examples	Time horizon
Strategic	How much capital to invest and where to invest it, what markets to serve, what products to make, performance measures for business etc.	0-10 years
Master (Tactical)	What business to accept, what service levels to provide for standard products.	0-18 months
Operational	What date to promise an order, which material to assign to which order, which order to run on a machine.	0-3 months

Table 13: Scope of hierarchical decision types at ALCO

While acknowledging the importance of strategic planning, given the expense involved in changing strategic direction at capital intensive companies like those in the aluminum industry, it is a relatively infrequent process. The focus in this thesis therefore is on Master Planning (MP). That is to say, given assets, identified markets and products, and strategic business objectives, what is the best way to achieve the maximum return on assets? There are three fundamental ways to accomplish the goal through MP:

- Accepting the right business: business that results in the most effective use of existing assets.
- Choosing the right locations (suppliers, manufacturing possibilities, service centers, etc) to produce a particular product (when there are multiple possible sources) such that

total costs are minimized.
- Deploying the minimum level of inventory to maintain responsiveness and to guarantee a given service level

While the process of master planning can vary from company to company, the end objectives and outputs are very similar. The outputs are therefore discussed first. The process of master planning at ALCO is discussed in section 4. The principal outcome of master planning is a multi-period plan which includes the following pieces of information:

- Products to be sold, in a particular time period. This can be further divided into individual regions, sales offices, customers etc. (Allocation to markets)
- Products for which market demand exceeds production capacity (this in the long term is an input into strategic planning)
- Products to be manufactured at each facility in a particular time period (Sourcing of products)
- Labor required to produce the products (typically down to number of shifts required per week on a facility)
- Raw material and inventory required to produce the products
- Performance measures like expected level of inventory at the beginning and end of the period and the inventory trends during the period
- Performance measures like the total revenue, cost and profit for the plan

5.3 Current Performance and Perceived Problems of ALCO

Since production used to be limited to two closely related sites with a clear and fairly straightforward routing structure, supply chain planning has not developed as a function in the company until the recent acquisitions of additional sites. During the last years, positions have been created in the company for people responsible for this task. The challenge and improvement potential seems enormous, as very little coordination amongst the plants is existent. The new APS software is expected to support this decision making process. In addition, however, the new software will also replace the currently used legacy software for factory planning and two-stage tuning between the rolling mill and raw material supplier. Since planners have been executing this task for a long time, the challenge is different in this area and the management expects that breaking with some of the old planning regimes will open up new opportunities for creating more flexibility in the supply chain. As discussed above, we will limit ourselves in this paper to the modeling of the master planner function in the A-plant.

Visibility

Currently, there is no common planning tool covering the whole ALCO supply chain, incorporating both production facilities and suppliers. While local visibility at the A-plant's shop floor is very high, visibility at the planning level can be improved such that there is a uniform view of the A-plant and the B-plant in one planning system. In particular, the customer order due dates are quoted with just a rough check of the available capacity at the B-plant. As mentioned above, utilization of available capacity is very high. Consequently, timely completion of customer orders may be limited by the available capacity either at the A-plant or at the B-plant. Furthermore, it is currently very difficult to tune production planning between both sites due to the lack of insight into the available capacity. The management expects that after the i2 TradeMatrix implementation is completed, a business-wide optimal plant loading, integration between the B-plant and the A-plant, and business-wide optimized product decisions can be achieved. At the individual site, it is expected that planning can be improved through upstream and downstream visibility of constraints.

Inventory

ALCO lacks a planning tool for the management and control of inventories. Specifically, it can be observed that uncertainties often cause the problem that component inventory stockouts result in machine downtime or that the frequent ordering of wrong materials lead to high stocks. Current inventory levels are high, but availability of intermediate and finished products from inventory is low. From a systems perspective, it appears that many incorrect ordering decisions are taken; uncertainty appears to be hedged against in an incorrect manner. As to inventory management, it is expected that after the i2 TradeMatrix implementation inventory can be created as a plan and not as a result of manual planning. This can be achieved through improved coordination of materials across the supply chain and the synchronized release of materials.

Customer Service

The level of customer service is perceived to be insufficient due to incorrect lead time predictions - as planning is based on deterministic and static manufacturing lead times, which can in reality vary according to the actual capacity and material situation in the plants - and low visibility of late orders. Customer service levels vary across products and over time. For some product families, during some period of time, it may be as high as 95%, while for other products, during specific periods of time, it may be as low as 20%. The current system does not provide sufficient visibility and support to provide good lead time estimates for quoting due dates, neither does it provide the master planner with details about late orders. As for customer service, it is expected that after the i2 TradeMatrix implementation transparency of order status and delays can be achieved. It is expected that capacity and material constraints can be incorporated in the real-time due date quotation.

Planning Time:

Finally, the current system does not support rapid response. The average time taken to create a balanced sales and operating plan ranges between 3 days to 1 week of actual working time, by which time a lot of the input information may have changed and the actual value of the plan may be seriously doubted. Additionally, a significant proportion of the planners' time is spent on tasks like meetings, reports, maintaining data – tasks that prevent him from doing what-if analyses and improving the plans produced. As to planning process, it is expected that from the i2 TradeMatrix implementation a decreased planning cycle time can be achieved.

5.4 i2 TradeMatrix's Model and i2's Modeling Approach at ALCO

The supply chain of the Rolling Division at ALCO can be characterized as a set of activities which include enterprise functions from the ordering and receipt of raw materials through the manufacturing of products through the distribution and the delivery to the customer. In order to operate efficiently, it is the objective of the i2 TradeMatrix project that these functions operate in an integrated manner.

The general i2 TradeMatrix solution as presented here, is based on a hierarchical structure, consisting of three levels: Demand Planner, Master Planner, and Factory Planner. At the top level is Demand Planner which generates the forecasts per product / product group (according to historical / statistical data, market strategies, etc.). At ALCO, there will be one Demand Planner model, which generates the demand forecast associated with the ALCO supply chain. It is expected that Demand Planner would be run on a monthly basis to create a revised forecast for a rolling 24-month period.

The next level is Master Planner. The Master Planner module creates a Master Plan for the ALCO supply chain over a maximum time horizon of 24 months, by integrating business policies, market demand and supply chain capability into a common plan. There will be one Master Planner model covering the entire ALCO supply chain. It is expected that Master Planner will be run initially on a monthly basis, updating the operational plan based upon revised sales forecasts from Demand Planner, and changes in manufacturing capability and resource availability. In addition the model can also be run if needed to enable what-if analysis. The bottom level module is Factory Planner. Factory Planner determines at which time each manufacturing operation of a given customer order should be performed on which particular resource by creating a factory-wide optimal plan.

The ALCO solution comprises of four separate Factory Planner models, one for each of the production sites. It is expected that the Factory Planner model would initially be run on a daily basis. The output of Factory Planner will be used as an input to the more detailed scheduling (sequencing) of manufacturing orders at the shop floor level and as a basis for procurement. This functions are performed outside the i2 TradeMatrix solution.

The current scope of the implementation also includes the implementation of an order due week quoting process for customer orders. This process will be performed by the i2 TradeMatrix ATP model, connected to the ALCO Order Entry System. The basis for the given quotes is the Available to Promise allocations created as a result of the Master Planning process. It is planned that the ATP model will have only a single connection (or “point of entry”) to the ALCO Order entry Systems. The ATP model will operate on a daily basis, in conjunction with the Order Entry System.

5.4.1 Model and Business Process Used at ALCO

In the application at the ALCO Rolling Division, there will be one DP model, one MP model and four FP models. In this thesis, we are limiting our analysis to the MP model, which is configured to generate a feasible Master Plan for the Rolling Division supply chain with a horizon of 12-24 months. The company uses one central MP model for the entire supply chain. The MP model represents all Business Units, factories, suppliers and service centers. The most important perceived benefits of centralizing the MP model is that it

- enables to plan according to agreed business rules
- increases supply chain visibility
- allows sharing of resources between the BUs.

This decision will have a significant impact on the current business planning and organizational structure of ALCO. The main difference in the situation prior to i2 is that two main control loops are missing in the current situation:

- the control loop between Factory Planner and Master Planner which transfers WIP/Capacity/Order information, and
- the control loop between Master Planner and Demand Planner, which transfers ATP/Consumed Allocations/Orders.

In Figure 19 we show the various modules and the way they are to be implemented at the company.

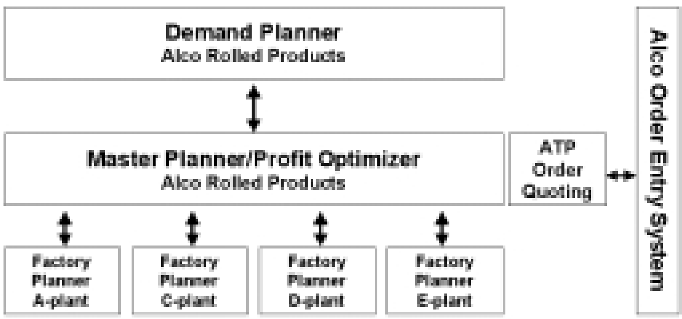

Figure 19: Implementation of i2 TradeMatrix modules at ALCO's Rolling Division

The MP model incorporates buffers (input buffer, output buffer and possibly intermediate buffers for bottleneck resources and Work in Process consideration) – both for the the B-plant supplier and the four production facilities. Buffers are part of the model in order to prevent bottlenecks from running out of material (e.g. in case of machine breakdowns), and to divide the supply chain into segments to increase delivery performance by reducing lead-time (diversity postponement (Bertrand *et al.* 1990, Lee and Billington, 1995.). For each buffer, minimum safety stock levels are defined. The Master Plan attempts to maintain these minimum safety stock levels, unless it prevents timely delivery of customer orders. For a discussion on the use of safety stock in LP-based supply chain models, we refer to De Kok and Negenman (1998) and Simchi-Levi *et al.*(2000).
The MP model only contains the most important operations and key bottleneck resources, and consequently, routings described in the model only these modeled operations and resources. A key factor in the implementation of MP is the concept of Planning Items. Planning items are aggregate representations of actual products. The aggregate grouping into Planning Items is based on products following the same process routes, consuming the same key resources, and serving the same market sectors. The number of actual products, and the variety due to customer specificity in many cases, requires definition of the aggregate representations in order to be able to construct an initial allocation of forecasts to resources and to determine the resulting available to promise. This way of aggregate modeling is in line with well-known hierarchical planning concept from the literature, such as Meal (1984), Bitran and Tirupati (1993), Bertrand *et al* (1990) and Schneeweiss (1999).

We will now briefly discuss the way in which the various business processes and models will operate under the new planning regime. The DP model will support a plant-independent sales department representing all four plants. Based on demand data an unconstrained sales forecast is generated by DP. DP supports a multi-dimensional representation of demand according to customers/geography, products and time. Committed forecasts per Planning Item are given by either the sales department itself or by using the Demand Planner module. These forecasts are entries into the Master Planner module that generates the yearly feasible plan. The result is a feasible allocation per Planning Item and week. Obviously this allocation can differ from the original sales forecasts. The consequence is that either – based on negotiations with the sales department – replanning has to be done according to modified forecast, or that the allocations are nevertheless accepted. Customer order quoting is then

based on the agreed allocations described above (using Available-to-Promise logic). In this process the specific aggregation / disaggregation procedures are a key factor to actual performance. In the initial model (BR1, see section 6.5), DP is not yet implemented, and forecast data come directly from the sales department. It is important to note that these forecast data refer either to products or to product groups. The sales department has no knowledge of the definition of Planning Items. A separate database maps the product and product group forecasts on the Planning Items for use in the MP model.
After implementation, 18 users will be involved in the use of the i2 TradeMatrix software. This number can be specified as follows:

- 7 users of Factory Planner (1 planner per Business Unit in the A-plant (4), 1 planner for each of the other plants)
- 6 users of Master Planner (Order Management Team) (1 planner for the ALCO supply chain, 1 Business Unit representative (4), 1 sales representative)
- 5 users of Demand Planner (1 planner for demand planning, 1 sales representative per Business Unit)

5.4.2 Business Objectives and Layered Planning within Master Planner

Master Planner considers various business objectives in the hierarchical planning framework. Business objectives need to be defined by the company. The business objectives define the goals of the planning process. In the metals industry, these goals could be of different types, such as:

- Increase ROA
- Decrease Inventory
- Increase tonnage shipped
- Improve customer service especially to preferred customers

Each business objective corresponds to the objective function of a linear program. The sequence of objectives forms a strict priority. When a particular business rule is applied, the previous business objective level cannot be violated; accordingly the solution for previous objectives cannot be worsened. This process continues sequentially, until all objectives have been applied. The sequence or layer of objectives is quite important and certain sequences of objectives may not make much sense. Determining the sequence of these business objectives is a crucial part of the master planning implementation (concept of layered planning) and has to be done in advance and before starting the Master Planner solution process. This does not mean that the ordering is permanent or hard-coded. The user does have some control over the sequence. Being even more precise, the user has complete control over assigning priorities to forecasted demand in order to increase the tonnage shipped. Once the user has assigned specific priorities, the solution process of Master Planning cannot be interrupted. There is no user intervention possible between the different solution steps within Master Planner.

In the first implemented model of Master Planner, the biggest and only defined objective is to satisfy demand, or in other words to increase the tonnage shipped. The goal is to satisfy the demand as much as possible either on time or through late satisfaction (which is allowed) as well as through alternate end item stocking locations if available. Demand in Master Planner generally can be classified as

- To be backlogged
- To be shorted

If a part of demand is placed in a backlog layer then in the case of capacity and/or material shortage that order would be completed late (backlogged). If a part of demand is placed in a short layer then in the case of capacity and/or material shortage that forecast would be shorted. In the current Master Planner model, unsatisfied demand is shorted.
The question that now arises is to describe how to assign priorities to specific objectives. We assume that, as already implemented, the most important objective is to satisfy demand and as such to increase the tonnage shipped. Demand in Master Planner is represented as a demand number related to a specific Planning Item and a specific time bucket (week). This statement is already a more detailed description of Figure 19, in which demand forecast input for Master Planner is shown as directly coming from Demand Planner. Planning Items within Master Planner are aggregate representations of actual products, which are additionally related to a specific market sector. Accordingly the correct input to Master Planner is a forecast number per Planning Item and week. The problem of assigning priorities to the objective of maximizing demand satisfaction now turns out to be the problem of assigning priorities (layers) to the demands per Planning Item. Obviously the most trivial solution would be to assign the same priority (e.g. Priority 1) to all Planning Items. In this specific case, all Planning Items are then equally important. In the case of a

shortage of capacity or materials, Master Planner will generate an infeasible solution, since it is very likely that there will not be enough capacity to fulfill all demand at the same time using the same resources. The solution would be infeasible since demand for a Planning Item might be shorted that belongs to a very important customer, who must be satisfied under any circumstances.

In most practical cases however differences between customer importance exist. Accordingly planners should be able to assign different priorities to different customers/market sectors and as a consequence be able to assign priorities to Planning Item demands.

5.5 Summary

In this chapter we first described the characteristics and main problems of the company on which our single case study is based, ALCO. We further gave a high level description of the i2 TradeMatrix solution approach used at ALCO. In the following chapter we will focus particularly on the MP solution approach by describing the methodology used in the MP project and the various modeling phases. We will illustrate the necessary data to build the initial MP model and the basic concepts behind the MP solution.

Chapter 6

Description of Modeling and Implementation Process at ALCO – Methodology and Initial Modeling Phases

In this chapter we start our description of the modeling and implementation process at ALCO by outlining the methodology used. In section 6.2 we give an overview of the implementation strategy in order to position our research within the time span of the implementation process. Section 6.3 describes the first modeling phase under consideration (the initial requirements and criteria setting phase) by distinguishing between observations and theoretical assessments. The second modeling phase, which actually results in a first Master Planner model (initial modeling phase), is described in section 6.4, again followed by a theoretical assessment. Section 6.5 summarizes the modeling experiences and user impressions gained after the first two modeling phases and relates them to the theory of Schneeweiss (1999) and Bertrand *et al.* (1990).

6.1 Methodology

According to our explanations in section 2.2, in this chapter we particularly consider the first implementation phase of the supply chain planning software i2 TradeMatrix (i2 Technologies) at ALCO. Our focus is on the implementation of the Master Planner module, as part of the i2 solution (see subsections 4.3.1 and section 5.4). The methodology used for describing the modeling and implementation process at ALCO is based on the description of characteristic phases of the project implementation. These phases were not set up in advance but were defined from a retrospective view of the author. Table 14 lists the phases identified and their duration within the overall project timescales .

Phases	Description	Duration	Section
1	Initial Requirements and Criteria Setting	March 1999 – April 1999	6.3
2	Initial Modeling	May 1999 – December 1999	6.4
3	Model Modification	February 2000 – April 2000	7.2
4	Model Extension and Advanced Requirements and Criteria Setting	May 2000-September 2000	7.3
5	Advanced Modeling	May 2000 – December 2000	7.4

Table 14: Phases identified for Description of Project Implementation

In our methodology each phase is structured in such a manner that observations are described, assessments to theory are explained and conclusions derived. Each phase is described from the retrospective view of the author, who was actively involved in the project. All data used to set up the model at ALCO were company specific data and gathered by the project team itself. The observations made for each phase are described in a more observatory way, whereas the assessments and conclusions are directly related to the theories under consideration and contain our own findings and evaluations. The basis for the observations reported in this chapter were the project documents that were generated during the period of observation (March 1999 – December 2000) augmented by the personal experiences and ex-post explanations of the author.

Being more specific, in the assessment sections, we will assess the modeling of the supply chain as it has been foreseen in the i2 TradeMatrix approach outlined in section 4.3. This assessment will be positioned in relation to two hierarchical planning approaches, namely the tandem process as described by Schneeweiss (1995, 1999) and the conceptual aggregation approach described by Bertrand *et al.* (1990). We have chosen specifically these two approaches since they address decision making in a hierarchical setting from an organizational point of view, an information point of view, and from the point of view of effectuation time. With respect to these points, both approaches distinguish themselves from the hierarchical planning systems developed in the US in the late seventies and early eighties, which mainly address aggregation and optimization issues (e.g. Hax and Bitran (1977), Bitran and Tirupati (1993)) and do not consider the organisational, informational and effectuation time point of view of hierarchical settings. The purpose of this assessment is to present experiences gained when designing the Master Planner model and first impressions of users from the actual implementation of the system at the company.

6.2 Overview of Implementation Strategy at ALCO

In order to make clear our time span of the study and the position of this time span in the entire implementation process, in this chapter we briefly describe the implementation strategy used at ALCO. Rather than attempting the configuration of the entire system and all software modules simultaneously (as in a “big-bang” type of approach), the implementation of the software at ALCO – and especially the implementation of Master Planner module - was done in a stepwise fashion. We will now briefly describe the idea behind this step definition and the associated benefits.

The Master Planner model development was based on the i2 Business Release methodology. A Business Release is an integrated set of changes that result in some specific business improvements, and will include one or more changes to model functionality, data, business processes and policies and performance measurement. In order to apply the Business Release Methodology to implementation projects, projects have to be subdivided into a number of defined Business Releases. Since the ultimate goal of the methodology is to reduce project implementation complexity and risk, the full functionality (and anticipated business benefits) associated with a module implementation can only be achieved after the last Business Release has been completed.

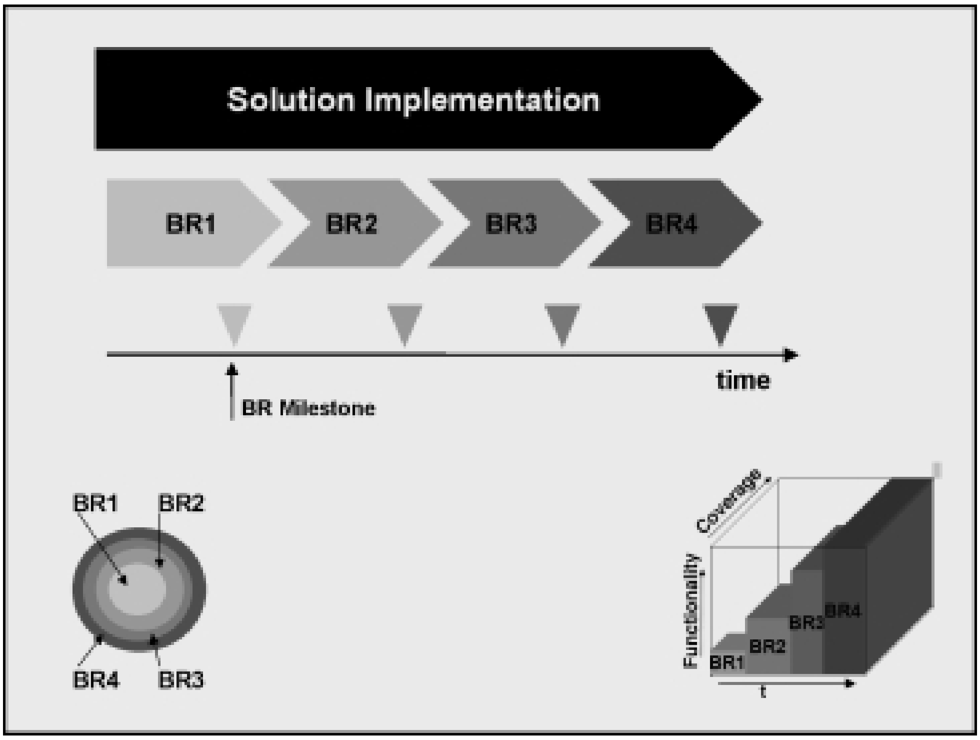

Figure 20: Business Release Methodology

According to figure 20, a Business Release can be defined by the functionality (and hence benefit) to be achieved, the coverage and the time to completion. The duration of a Business Release highly depends on the complexity which is given by the required functionality and / or the specified coverage.

Going into more detail, each Business Release can further be subdivided into work phases for ensuring a more systematic approach. For further information on the Business Release methodology we refer to **www.i2.com**. Table 15 lists all Business Releases for the Master Planner model.

6.3 Initial Requirements and Criteria Setting - Phase 1

6.3.1 Observations

This phase describes the initial requirements and criteria setting of the Master Planner project necessary for model development. Participants of this phase were the project team at ALCO and i2 Technologies. ALCO's project team consisted of planners, modelers and IT specialists.

One of the first activities in this phase was to define the Master Planner Business Releases. Table 15 below lists the Business Releases for the project under consideration and the associated objectives for the implementation of the Master Planner module.

Business Release	**Description**	**Objective**
BR 1	MP model of the A-site	Reconciliation with current operating plan
BR 2	MP model other sites	Increased supply chain visibility
BR 3	MP model refinement	More accurate ATP
BR 4	Integration MP with order entry at the A-site	Closed loop with order entry system
BR 5	Integration MP with order entry other sites	Closed loop with order entry system
BR 6	Integration MP with FPs	Closed loop with factory floor
BR 7	Introduce profit optimization functionality	Improved profit

Table 15: Business Releases of the company's APS implementation project regarding Master Planner

BR1 was aimed at developing a first model of the A-site - as described in section 5.1 - including its suppliers. The clear objective to be reached with this Business Release was to achieve reconciliation with the current operating plans. So, the model should have the capability of (at least) replacing the current planning tools used by ALCO for master planning.

BR2 had as its focus the extention of the Master Planner model developed during BR1 to include B-C-D- and E-sites as well as all service centers, as described in section 5.1. The objective of completing BR2 was to increase supply chain visibility by having

modeled all suppliers, sites and service centers into one Master Planner model.
BR3 was defined consciously with respect to any more detailed model changes which might be necessary in order to achieve a more accurate ATP. Accordingly the objective was to achieve accurate ATP's and have as such a supporting tool to enable accurate order delivery date promising by the sales force.
Thus far, BR1 to BR3 were designed to deliver a more "stand-alone" solution, which captures the current supply chain of ALCO and current planning philosophies. No integration with existing ALCO legacy order promising systems was considered yet. Therefore, BR4 and BR5 had their focus on integrating the Master Planner model with the order entry systems of the modeled sites. The objective was to achieve a closed loop between the Master Planner model and all order entry systems. Summarizing, the ultimate output of these releases was expected to be the ability for Due Week Quoting and the Available-to-Promise Engine. BR6 was aimed at integrating the Master Planner model with other i2 modules, the Factory Planner module. The Factory Planner implementation projects at each site in the supply chain were started in parallel with the Master Planner project . The objective was to achieve a closed loop integration with operational planning levels at ALCO. In BR6, different integration concepts were planned to be considered with special focus on appropriate data processes and workflows. The aim was to integrate the modules such that they finally represent one overall system for forecasting, masterplanning and factory planning. The primary business objective here was that the integration of Master Planner and Factory Planner would help ensure that the operational planning level is correctly coordinated and consistent with the tactical / strategic planning level.
BR7 aimed at incorporating so-called profit optimization functionalities into the Master Planner model. Profit Optimizer is an extension to the Master Planner model which enables the calculation of the financial impact of a plan by modeling cash inflows for the sale of products and cash outflows for the procurement of material, manufacturing performance, and distribution operations, and for carrying inventory. The main objective was to enable ALCO to make financially optimised decisions regarding product mix across its manufacturing sites.

In this research, we are interested especially in the first Business Release (BR1) of the Master Planner (MP) project. The phases under consideration are all part of BR1. As Master Planner is a tool for tactical planning, which needs to be coordinated with tools for operational planning, our expectation is that Master Planner is a good candidate for

observations related to our research questions. Inputs for the model development were the sales forecast, manufactured products and their corresponding routings, yields, resource capacities, and calendars. In BR1 there were no real orders and no work in progress considered. Outputs from the model were the forecasted production plan and the ATP allocations for a one year planning horizon. BR1 was the first occasion in the project where a constructed model would be confronted with real practice. We are interested in observing this confrontation and testing the propositions that we made with regard to this model introduction. The detailed Factory Planner (FP) implementation is not part of our research.
Before starting the development and implementation process of the i2 TradeMatrix solution, required functionalities were defined by the project team. The requirements stated can be categorized as follows:

- Global Requirements
- Specific Requirements related to the Planning Tools MP and FP
- Specific Planning Requirements
- Acceptance Criteria

Global Requirements have been formulated by ALCO's upper management board. The Specific Requirements related to the Planning Tools MP and FP have been stated by ALCO's middle management in cooperation with i2 Technologies. In addition to that, ALCO's planning department formulated further Specific Planning Requirements. The Acceptance Criteria have been stated by the planning department of ALCO. Only if the developed model after BR1 fulfills all acceptance criteria, is then the first model accepted and the Business Release can be completed successfully. The table below shows a selection of requirements which are related to our research questions.

Global Requirements	Specific Requirements related to MP / FP	Specific Planning Requirements	Acceptance Criteria
A standardised, comprehensive planning system			Capability of performing what-if-analysis
Integrated, dynamic and optimised planning processes for each manufacturing location and Business Unit	The unconstrained sales forecast is satisfied as much as possible, by having a minimum level of production for different products after which any spare capacity will be filled according to predefined product priorities		
Supply Chain Planning must enable the company to benefit from the potential synergies of having different process routings across different manufacturing sites			Planning Cycle Time within MP must be of an acceptable duration MP user interface allows for basic model changes online
Optimal Management of stock levels	Definition of material buffers within MP to prevent bottlenecks running out of material Minimum safety stock levels should be respected, but demand order satisfaction has higher priority in the planning process		
Order Quoting on a due week basis, as accurate as possible, based on strategic Master Plan		Production is planned as late as possible with the principle that backlog orders are produced first and real demand orders are produced on time If customer demand orders require more resource capacity than available in a given week, the next possible due date will be quoted	
Delivery Performance			
Transparency			Visibility of levels of load and resources in site A and in primary supplier

Table 16: Global and Initial Requirements and Criteria Setting

The requirements stated above were used in order to describe in more detail the specific expectations regarding the MP model after BR1. Accordingly, after BR1, the Master Planner model should include:

- Detailed modelling of the production site A, by taking into account that the model incorporates necessary material buffers (input buffers, output buffers, intermediate buffers for bottleneck resources and work in process consideration) and key resources
- Detailed modelling of the primary supplier source for prerolled coils, by taking into account that the model incorporates necessary material buffers (input buffers, output buffers, intermediate buffers for bottleneck resources and work in process consideration) and key resources
- Rough modeling of 3 alternate supply sources for raw material supply by taking into account just the global capacity constraints for each supplier and the business rules and priorities for supply; the model to be developed in BR1 will automatically choose the supplier to be involved for each demand order, depending on the given business rules and priorities
- Rough modelling of Service Centers by incorporating the possibility for the routings of production items to include a Service Center as an additional material processing step between the production site and delivery to the customer.
- Decision making capability, to decide at which site a particular product is produced, should be automated as much as possible. This is especially applicable to the situation where an identical product can be made at more than one production facility.

In this context it was explicitly stressed that the detailed modeling of production site A includes the definition of appropriate Planning Item decompositions. Planning Items are necessary as the Master Planner model describes the supply chain at an aggregated product level (called Planning Items), in which only the key and bottleneck resources in any production location are represented. According to subsection 4.3.1 it was stated that the forecast data needs to be mapped to each Planning Item decomposition in order to ensure the correct MP model input.

Regarding material buffers, it was explicitly stated that the first Master Planner Model after BR1 should incorporate the necessary buffers (input buffer, output buffer and eventually intermediate buffers for bottleneck resources and Work in Process consideration) – both for the primary supplier and site A. Buffers were considered as part of the model in order to, firstly, prevent bottlenecks running out of material (in case of unplanned maintenance, unplanned breakdowns or unplanned supply issues for example) and, secondly, to divide the supply chain into segments to increase delivery performance by reducing lead-time (customer specification as late as possible). This can be achieved by managing efficiently intermediate stock buffers at various levels of the supply chain. It was stated that in order to determine the minimum safety stock levels, the rule should be respected that minimum safety stock levels should not account for planned capacity shortages, planned maintenance (loaded in the model), or planned material constraints (for example known production yields already incorporated in the model). Instead, minimum safety stock levels should account for unplanned additional demand (for example, resulting from poor quality of the forecast), unplanned capacity shortages, unplanned maintenance, or unplanned material constraints (for example resulting from material rejection, during production, or unexpectedly extended supplier lead times).

Finally, the stated requirements were additionally used to exclude certain functionalities from MP BR1:

- In BR1 not all different process routing possibilities and not all material flows the supply chain of ALCO consists of are incorporated in the model.
- Detailed modelling of production sites B,C,D
- Definition of Planning Items for production sites B, C, D
- Due Date Quoting

6.3.2. Assessment

Although the overall aim was to create a Decision Support System for Supply Chain Planning, one of the objectives of Business Release I was, as described in subsection 6.3.1. the reconciliation with existing operating plans at ALCO. Reconciliation with existing operating plans meant that the plans resulting from the system should match with plans made by the planners themselves. Being more precise, it was expected that the same capacity utilisations and the same demand should be planned over time in both cases. The idea behind this was that only if the plans are in principle equal, the plans generated by the system can be accepted by planners. We can observe that few of the stated requirements can be directly linked to this objective. The direct connection we can make is the requirement that the unconstrained sales forecast should be met as much as possible and that production should be planned as late as possible. Nevertheless, at the same time the objective of reconciliation can hardly be met if not all process routing possibilities and not all material flows are modeled in the first Business Release. In addition, we emphasize that the required functionality of having the decision making capability where to produce automatized cannot be completely implemented if not all process routing possibilities are included in the decision process. Hence, a true reconciliation with current operating plans cannot really be made after BR1.

Furthermore, we observed that some of the stated requirements cannot be met at the same time. An example for this observation is that planning production as late as possible may conflict with improving delivery performance.
Referring to the Acceptance Criteria we can observe that most of the defined criteria are not very specific. Furthermore, they have no relation to the objective of achieving reconciliation with current operating plans . Only few of them are related to the requirements stated previously with regard to the expected functionalities.
As a special remark we want to state that at this stage of the project there was a common understanding that the ATP and Order Quoting process would be modeled in the Master Planner solution. In addition we want to point out that the phases as defined in section 6.1 were defined from a retroperspective view of the author and in principle are not consistent with the previously defined Business Releases (subsection 6.3.1.)

Summarizing we can state with respect to our research questions, that already in this phase – the Initial Requirements and Criteria Setting – very little formality in the process can be observed (O1). Observation O1 is stated as hypothesis H1 in chapter 8. Rules and principles of anticipation as illustrated in chapter 4 were not an issue in the initial requirements setting phase, and accordingly completely neglected. This leads us to the observation that not always (correct) anticipation types are chosen (O2). Observation O2 is as well stated as hypothesis H2 in chapter 8. Our hypotheses both contribute to research question (RQ3), in the sense that the formality followed in the modeling process will significantly impact consistency between models on different hierarchies.

Note: All observations made in subsection 6.3.2 are related to the specific i2 implementation at ALCO

6.4 Initial Modeling - Phase 2

6.4.1 Observations

This phase describes the modeling activities for developing the first Master Planner model in BR1. Participants of this phase were the project team at ALCO and modeling specialists from i2 Technologies. The initial modeling approach was based on all stated requirements and functionalities as described in section 6.3. This subsection is structured such that we explain the concepts of selected modeling areas, which are:

- Planning Item Definition
- Resource Aggregation, Bottleneck Specification, Routing Aggregation
- Processing Time and Lead Time Aggregation
- Buffer Definition
- Forecast Data Definition

Planning Item Definition

The very first step in developing the model design of the first Master Planner model, was the definition of the so-called Planning Items. As the Master Planner model considers longer-term tactical decisions, the planning processes in Master Planner are not based on detailed products (order-items) but on so-called Planning Items. Planning Items are defined formally as follows:

Definition: *A Planning Item represents an aggregated group of similar products (Planning Product) related to a particular market sector:*
Planning Item = Planning Product + Market Sector

Therefore, a Planning Item in principle is the combination between a certain Planning Product and a particular Market Sector. A Planning Product in turn is defined as a group of individual customer products which follow similar process routes and consume the same key resources to approximately the same degree during their manufacture. All individual customer products which follow similar process routes and consume the same key resources define a Planning Product or a Product Class. The key resources can be identified, for example, by analysing historical resource (machine) utilisation data for the manufacture of products. A Market Sector is defined as representing any logical group of customers, for example, a geographical region, or a particular strategic customer.

When deciding on the number of Planning Items to be used in the Master Planner model it is necessary to find the correct balance between (a) having enough detail to accurately represent the usage of resources, and (b) having too much detail which makes planning too detailed and complex (thus effectively reducing visibility). In order to define Planning Items out of individual products the following steps have been followed:

- Analysis of Master Data for defining the existing bottleneck resources by either asking production people about existing evaluations or by generating utilization graphs of all resources:
  The next step was to generate graphs of (No. of products/runtime) for all resources including both bottleneck and non bottleneck resources. Depending on the resulting data spread several runtimes have been defined accordingly. Based on the above defined runtimes the first grouping of Planning Items resulted after building all combinations of common routing and common runtime.
- Analysis of Sales Data in order to define market sectors and associated attributes (width, geography, customer type):
  Based on that the final grouping of Planning Items resulted after having built all combinations of common routing, common runtime and common market sector.
- Analysis of Actual Data:
  Any combination has been taken out, which either did not exist or had a very low manufactured tonnage.

Finally, in the MP model, which contained only one production site, the site A, all products belonging to the same Product Class / Planning Product satisfy the same constraints:

- Sellable Products
  A product is defined as belonging to a Planning Product Class only if this is a product which goes directly to the customer (sellable)
- Production on Capacity Bottlenecks
  A product is defined as belonging to a Planning Product Class only if the corresponding routing includes a capacity bottleneck
- Bottleneck Ressources
  Each product belonging to a Planning Product Class goes over the same bottleneck resources
- Lead Times
  Each product belonging to a Planning Product Class has more or less the same lead time

- Processing Time
  Each product belonging to a Planning Product Class has more or less the same processing time on capacity bottlenecks

Additionally, regarding the routings the specific finished good took at the main supplier of pre-rolled coils, modeling was done as follows : We assume that finished good A is produced in site A according to one specific production routing. We further assume that for the same finished good A there are two alternate routings at the supplier site, both having approximately the same lead time. In order to distinguish between the two supplier routings, the corresponding modeling was done such that two sepaprate finished goods A1 and A2 were defined, each of them having a specific supplier routing and the same production routing. This way of modeling is represented in figure 21.

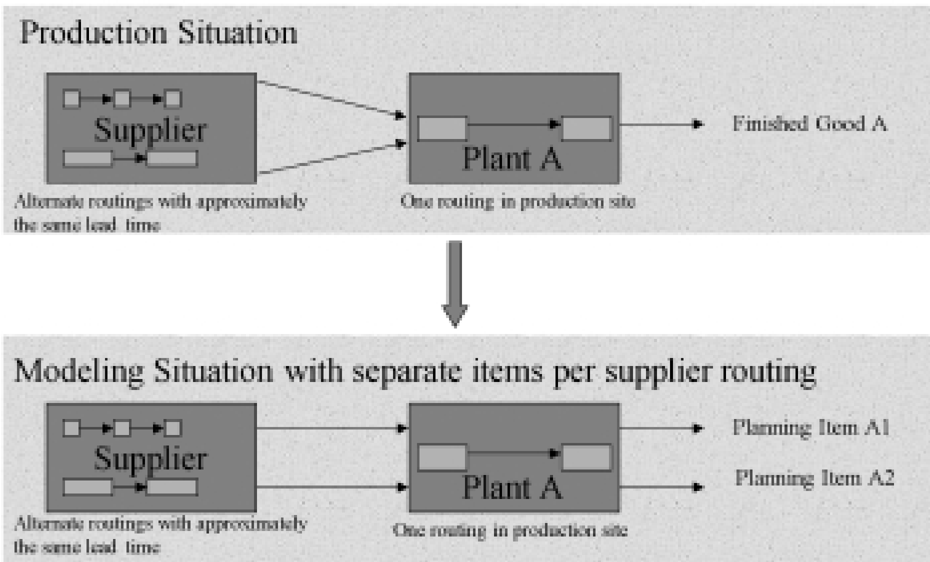

Figure 21: Modeling Situation with separate items per supplier routing

In summary, this way of modeling considered that for one finished good ex production site, there are two alternate routings at supplier site with approximately the same lead time. In order to be able to distinguish the two alternate supplier routings, two separate Planning Items were modeled for the same finished good and each having a different supplier routing.

Resource Aggregation, Bottleneck Specification, Routing Aggregation

In parallel with the definition of Planning Items goes the specification of "real" production bottleneck resources. Focussing on operations and associated resources only the most important operations and key bottleneck resources were defined in the Master Planner model. Resources and corresponding resource availability calendars reflected the available capacity per resource in weekly time buckets, by including shift systems and holidays. The process of defining aggregated resources was both a manual and theoretical process, based on the existing physical resources in the data systems. They were entered manually as aggregated resources in the system.

Processing Time and Lead Time Aggregation

Manufacturing operation and processing times as input data for Master Planner had to be inserted per operation. Processing times are needed to represent the corresponding load of an operation on a specific resource. Operation times include both material processing time and subsequent post-processing cool down time. Operation times are needed in order to plan the order backwards starting from due date. According to the aggregated operations defined previously, the calculation of aggregated operation times was again a manual process. Yields were inserted per operation and hence determined the raw material tonnage needed to satisfy the order.

Buffer Definition

Focussing on buffers and inventory policies, as stated in subsection 6.3.1, the Master Planner Model incorporated the necessary buffers (input buffer, output buffer and eventual inter-mediary buffers for bottleneck resources and Work in Process consideration) – both for the primary supplier sitesite and the production site A.. Buffers under consideration in Master Planner have been carefully defined according to the strategy of the production site regarding where to keep and control inventory.

Forecast Data Definition

Forecast data per defined Planning Item was necessary as input data for Master Planner. Forecast data came directly from the sales department. But as forecast numbers were not available at Planning Item Level, the forecast had to be mapped to the Planning Item definitions by using historical information. Again this was a manual process and data was entered in the system manually.

Final Model

The number and type of planning items in the final model for all 4 Business Units are presented in table 17:

	Finished Products ex site A	Semi-finished Products In site A	Products consumed ex supplier	Finished Products ex supplier / service center
Business Unit A	63	63	11	
Business Unit B	11	3	11	
Business Unit C	89	86	63	35
Business Unit D	78	66	14	

Table 17: Modeling with complete number of Planning Items

In Business Unit A 63 Planning Products were defined which were specified as finished goods ex site A. For each of these 63 Planning Products exactly one routing was defined for site A. The difference between the 63 Planning Products was either alloy or temper or gauge range or width range. All 63 fininshed goods could be made from just 11 supplier products.
In Business Unit B there were 11 Planning Products ex site A and 3 semi-finished products in site A. All products could be made of 11 Planning Products from the supplier.
In Business Unit C there were 89 finished products ex site A and 86 semifinished in site A. All products could be made of 63 Planning Products from the supplier. 35 planning Products reached the customer directly eihter ex supplier, ex service center or other sites.
In Business Unit D there were 78 finished products ex site A and 66 semi-finished products in site A. All products could be made of 14 Planning Products ex supplier. Figure 22 shows the number of Planning Items mapped on the supply chain structure.

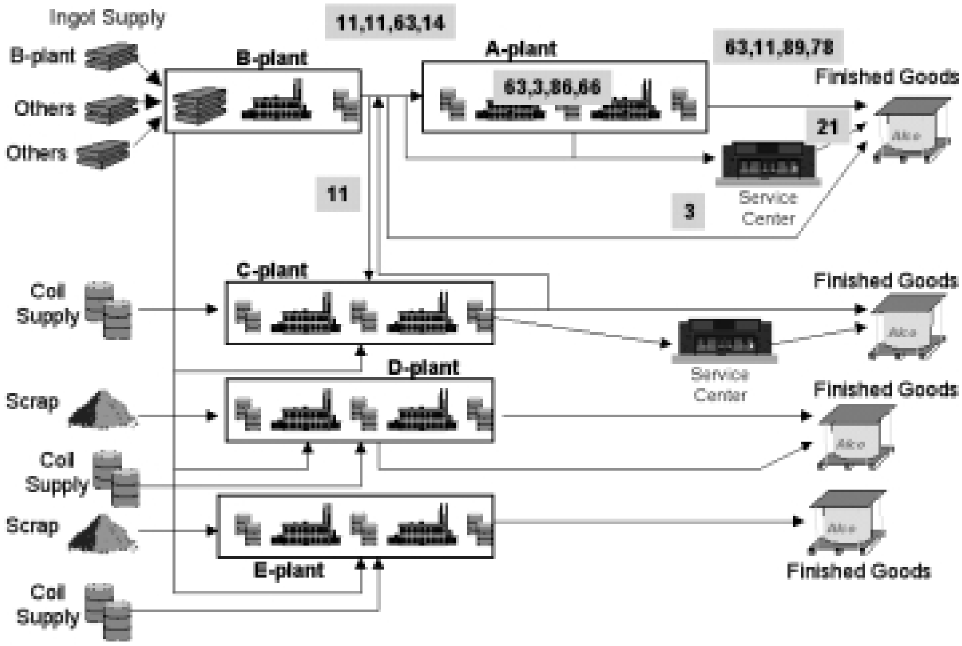

Figure 22: Illustration of Modeling with complete number of Planning Items

6.4.2 Assessment

By having completed Master Planner BR1, a first prototype model was available, which fulfilled the stated Acceptance Criteria, as defined in subsection 6.3.1. The Specific Planning Requirements shown in subsection 6.3.1. were also fulfilled. Referring to the Specific Requirements related to MP / FP the only fulfilled requirement was that the unconstrained forecast was satisified as much as possible. This could be realized by defining minimum levels of production for different products. Referring to material buffers and safety stock levels, although material buffers were defined in the Master Planner model, they were not used for inventory management or any safety stock calculations. The requirement of driving the operational planning level by MP, could not be fulfilled at this stage of the project anyway. At this stage of the project, the prototype model did not go “live” (i.e. into production usage), but was used by the key users to fully understand usage of model , the user interface, and to discover any remaining modeling errors or develop further necessary improvements to the model. One of the most interesting observations made when designing

Note: All observations made in subsection 6.4.2 are related to the specific i2 implementation at ALCO

the Master Planner model, focusses on the way business objectives are defined and the way the model is used by planners. Our observations can be summarized as follows:

- (O3) The definition of business objectives, layers and priorities needs a deep understanding of the model from the user's perspective
- (O4) Planners run the model several times and change the sequence of business objectives
- (O5) There is no user intervention in the solution process
- (O6) There is no anticipation function in the solution process
- (O7) Aspiration Levels are used as an additional layer in the sequence of business objectives
- (O8) Infinite Capacity Planning is not often used in practice
- (O9) No rules and constraints for inventory management are modeled

Furthermore, at this stage of the project, the development of Factory Planner models for the production sites A, B, C, D were still not finished, and so accordingly none of the systems under consideration went live. The purpose of this subsection is to assess the initial modeling approach to the theories of Schneeweiss (1999) and Bertrand *et al.* (1990), as described in chapter 3 .

Summarizing, our observations so far already contribute to some of our research questions. As the definition of business objectives, layers and priorities needs a deep understanding of the model from the user's perspective, which in fact was not achieved in the beginning, we can hypothesize that the complexity of the planning solution was underestimated (H3). This hypothesis can be further underlined by the fact that although material buffers and safety stock levels were defined, they were not used for inventory management. This hypothesis can be related to research question (RQ2b), stating that the interaction between models at different planning levels in APS systems is not in agreement with reality. Another hypothesis, also related to research question (RQ2b), is that no formal relationship between Master Planner and Factory Planner is considered (H4). This is due to the fact that no rules and constraints for inventory management have been modeled.
Another important observation is that the solution process developed so far does not consider any type of anticipation function in the context of Schneeweiss, as described in chapter 4, subsection 4.3.3. Since the Factory Planner models (base level models) were not developed at this point, the definition of anticipation functions was not possible anyway.

More precisely, in this stage of the project not even the IA anticipation was achieved (see subsection 4.3.3), since no netted capacity or netted forecasts were actually uploaded. This confirms our hypothesis that not always (correct) anticipation types are chosen (H2). This hypothesis can be related to research question (RQ3).
Our observation that infinite capacity planning is not often used in practice, leads us to the hypothesis that planners do tend to find workarounds to the system, that enable them to plan the way they perceive the problem, rather than following the way the model of the system expects them to work (H5). This hypothesis can be related again to research question (RQ2b).

Further on in this section we will justify our observation that the creation of aggregate inventoy plans (O13) and work order releases (O14) is not really a control task in Master Planner. Hence, our observation will be that the Master Planner functionality only covers one part of the GFC function (O12) (Bertrand *et al.* (1990). This leads us to the hypothesis that in the i2 solution there is no explicit material coordination between Master Planner and Factory Planner (H6), and in fact there is no formal relationship in terms of instructions / constraints between Master Planner and Factory Planner (H4). These hypotheses contribute to research question (RQ2a). We will further show that planning items in the i2 context, as compared with GFC items, are more detailed from the capacity point of view and less detailed from the material point of view (O15). This leads us to the hypothesis that there is a mismatch between the solution procedures and the problem structure (H7). This hypothesis can be related to research question (RQ1a).

Initial Modeling in the context of Schneeweiss
The centralized Master Planning Model as described in section 4.3 can be seen according to Schneeweiss (1995, 1999) as one individual decision process M, characterized by a decision field A and a preference structure or criterion C, as described in section 3.2.
Considering the Schneeweiss approach our observations, which are formulated here as propositions, as they are derived from theory are explained in detail below:

- (O7)/(P1) the i2 TradeMatrix solution treats aspiration levels as business rules
- (O10)/(P2) the i2 TradeMatrix solution does not recognize stochastic information
- (O11)/(P3) the i2 TradeMatrix solution cannot capture vague statements

Referring to the first proposition, Aspiration Levels in the i2 TradeMatrix solution of a centralized Master Planning Model can be expressed by business rules / business objectives which have to be fulfilled. As an example consider the criterion *C* as one of maximizing demand satisfaction according to predefined forecasts. The Aspiration Level *AL* is defined as the minimum production level that has to be fulfilled in any case. Note that the software does not recognize this aspiration level as such. Therefore, although Aspiration Levels in the Schneeweiss theory are not considered as constraints, in terms of the software it can only be entered as a constraint, possibly finding infeasibility. The second way of dealing with Aspiration Levels is to define an objective function in the first step, e.g. max demand, without knowing the optimum solution *C**. It is up to the judgement of the planner to assess whether *AL* has been met if his aspiration level is higher than *C** and to play with objective functions and constraints such that he meets *AL*. Mathematically, this can be explained as follows: According to the software, the mathematical model to be solved can be formulated as

$$Min\ f(x)$$
$$s.th.\ g(x) <= b$$

This can either result in infeasibility or in a feasible, optimal solution x*, such that

$$g(x^*) <= b$$

If Aspiration Levels are set as

$$f\sim(x) >= AL^*,$$

planners should check whether

$$f\sim(x^*) >= AL^*.$$

If $f\sim(x^*) < AL^*$, in real life planners would e.g. rearrange orders which already might have been scheduled. Summarising, the result can either be finding a optimal solution x~ by human intervention with

$f(x\sim) > AL^*$,
or define a new Aspiration Level $AL\sim$ *with* $AL\sim < AL^*$.

Furthermore, Schneeweiss indicates one of the most difficult decisions that the decision maker faces is to select the next cycle of decision making (see chapter 3). As it looks, the i2 TradeMatrix model and software does not support selecting alternative strategies (scenarios). In the business process (workflow) that supports i2 TradeMatrix this has been captured by suggesting that the planner first runs the model with infinite capacity before running the model under capacity constraints.

Referring to the second proposition, the i2 TradeMatrix solution does not explicitly take into account stochastic information. The underlying optimization model is typically a deterministic mathematical model, involving multiple constraints and some objective function. Uncertainty is dealt with implicitly in three distinct ways:

- Estimating (i.e. forecasting) exogenous random variables, such as future demands
- Introduction of slack parameters such as safety stocks and excess capacity, which are incorporated into constraints and/or the objective function
- Replanning as incorporated in a rolling schedule approach

An essential flaw in such an approach is that it is not recognized that the mere fact that demand, lead times and other exogenous variables are random variables implies that structures of optimal planning strategies are likely to differ significantly from the strategies that result from the combination of a rolling schedule approach and deterministic optimization. For a deeper insight into this phenomenon we refer to Blackburn and Millen[1982], Lawrence[1997] and Negenman[1998].

Referring to the third proposition and as Schneeweiss indicated, any formal system will have difficulties capturing vague hypotheses. As a vague hypothesis consider performance indicators, like ”improve delivery performance”. Performance Indicators in principle can be inserted in the model either as part of the objective function or as an additional constraint. But we have to point out that some Performance Indicators cannot be formulated since they cannot be made measurable. In general, there is the problem that Performance Indicators need to be made specific (for example, what is meant by “delivery performance”) and need to be made measurable (for example, what is meant by "improving"). Further, vague measures such as schedule stability may need to be made explicit.

Initial Modeling in the Context of Bertrand

Considering the BWW approach, our observations regarding the i2 TradeMatrix solutions are manyfold and are explained in detail below:

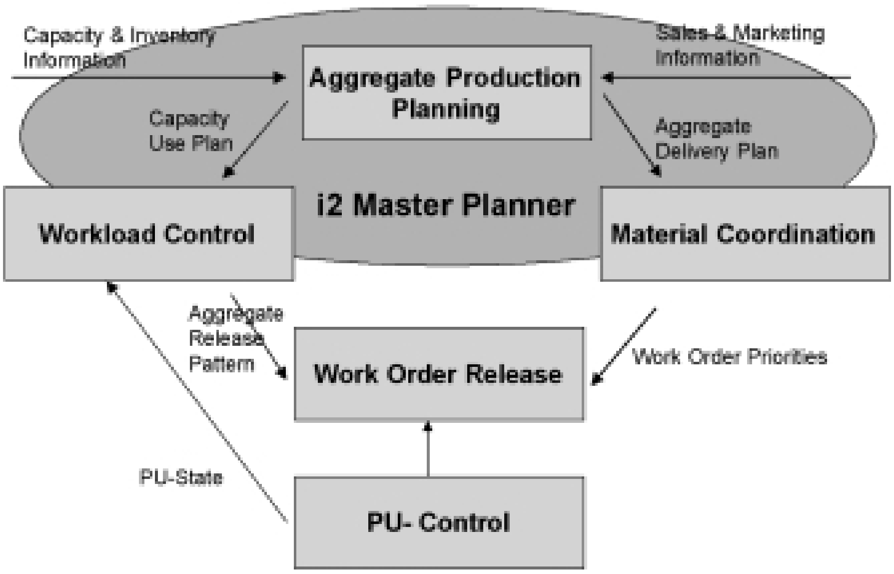

Figure 23: Master Planner Function in comparison to the BWW Approach

- (O12) Master Planner functionality only covers a part of the GFC function
- (O13) There is a difficulty in achieving aggregate inventory plans in Master Planner
- (O14) Work Order Release is not considered as a control task at Master Planner
- (O15) Planning Items in the i2 context – as compared with GFC items – are more detailed from the capacity point of view and less detailed from the material point of view

Referring to the first observation (O12), in the i2 TradeMatrix solution at ALCO, a distinction between GFC and PUC can as well be observed. Yet the main difference is that in terms of i2 the GFC function is in fact both, the Master Planner function as well as the Factory Planner functionality. The Master Planner function only covers a part of the GFC function, as shown in the figure above. According to Bertrand, the APP level forms the connection with the higher levels of control in the production organisation, where integration of the various control aspects of the organisation (sales, logistics, finance, personnel, etc) takes place. This part in fact goes in line with the Master Planner functionality, which is designed for long term tactical production planning by taking into account restrictions from all other parts of the organisation. The connection to sales in the i2 Master Planner planning solution is modeled via the entry of forecasts per Planning Product. The connection to finance in the i2 Master Planenr planning solution is modeled via profit optimisation functionality, which is an extension to the Master Planner model enabling the calculation of the financial impact of a plan by modeling cash inflows for the sale of products and cash outflows for the procurement of material, manufacturing performance, and distribution operations, and for carrying inventory. This can be seen as a basis for making financially optimised decisions regarding product mix across all manufacturing sites. The connection to personnel in the i2 Master Planner planning solution is modeled via the entry of working shift patterns.

Repeating the outputs of Master Planner we can formulate:

- Infinite capacity plan/finite capacity plan
- Aggregate inventory plan
- ATP per Planning Item and time bucket
- Ability to compare alternative scenarios

The finite capacity plan is comparable with the BWW's aggregate delivery plan, which for families of items states the planned deliveries over a number of future periods. The finite capacity plan is also comparable with the BWW's capacity use plan, which for selected capacity types states the required effective use in terms of hours per period over a number of future periods. Referring to our second observation (O13), the aggregate inventory plan can in principle be compared with BWW's aggregate inventory plan, in which the planned inventory for the various production stages is specified, for a number of future periods. Yet it has to be pointed out, that there is a main difficulty in achieving an aggregate inventory plan in the i2 Master Planner solution. Referring to subsection 6.3.1., in the Global Requirements and Specific Requirements related to MP / FP, material coordination functionalities were defined, which cannot just be solved by the Master Planner model. The main reason is because Master Planner is not designed to be modeled on a detailed material level. Instead, there are three possibilities to model this in Master Planner:

- Master planning is modeled at a Detailed Planning Item Level, which matches with the stock materials.
- Master planning is modeled at an Item Level which corresponds to real physical material and can be located higher in the supply chain
- Master planning is modeled at an Aggregated Item Level which does not correspond to any real physical materials

Within the Master Planner BR1 model, the third possibility was chosen and modeling was done at an aggregated Planning Item level, which does not correspond to physical materials. This decision had – from a retroperspective point of view – a big impact upon where and in which module safety stock checks could be performed. Since safety stock checks can only be performed at the level of material for which stocks need to be considered, and this level can differ from the Planning Item definitions, again there are three options:

- Master planning is modeled at a detailed item level
  When this option is chosen safety stocks can be considered at the same detailed item level
- Master planning is modeled at an Item Level higher in the supply chain
  (but physically existent);
  When this option is chosen safety stocks can be considered at the same Item Level higher in the supply chain
- Master planning is modeled at an aggregated item level
  When this option is chosen, it is still true that safety stocks always need to be considered at a detailed item level

Sunce the BR1 model was modeled at an aggregated item level it is quite obvious that the initial functionality of safety stock control in Master Planner was not solvable any more. We can conclude that, as the functionality of managing stock levels is not part of the Master Planner functionality, it has to be solved in a different way. The project team obviously had high level discussions about the available Master Planner functions, but without going into details.

Referring to our third observation (O14), the main difference between the BWW approach and the i2 Master Planner planning solution is that the material coordination function is, in fact, not solvable in Master Planner but has to be extended to other i2 modules like Factory Planner or Inventory Planner. Hand in hand with this conclusion goes the fact that workload control also cannot be performed just in the Master Planner module but in other lower level modules. Therefore, one can say that the hierarchy as it is described by BWW is quite different from the hierarchy proposed by i2. In the i2 planning solution there is no guarantee that there is consistency in the overall planning solution. Instead the necessary planning functionalities are in i2 solution decomposed without any clearly designed links which might indicate a design error in the software system.This design error in turn may have severe consequences on a company's organisational fit. As main decision functions are split, the unavoidable redefinition of people's tasks might turn into problems.

Nevertheless there was a difference in how the i2 solution was perceived by the project team and how the i2 solution can be designed in reality. The i2 TradeMatrix solution, as it was perceived at this time by the project team, was designed such that the output of the Master Planning function directly controls the operational Factory Planner, as shown in the figure 24. As illustrated above this is not possible because of the lack of material coordination functionality within Master Planner. Accordingly, additional systems need to take over this missing functionality, such that the figure below is in fact much more complicated. More precisely, here we have a classical example where perception does not equal reality.

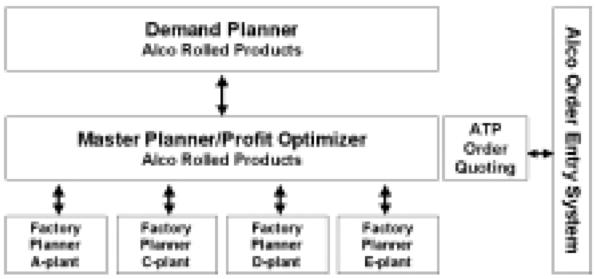

Figure 24: Perception of i2 TradeMatrix solution

We can emphasize that work order release is not considered as a control task at the Master Planner level, but rather this is left to Factory Planner which needs to solve the workload problem and report back any lead time problems that may result. Inherently this means that the i2 TradeMatrix solution assumes more flexibility in the interaction between Master Planner and Factory Planner rather than the rather strict top-down hierarchy assumed in Bertrand's approach. This issue will however not be discussed in this section, as we focus on Master Planner functionality. Finally, with regard to the relation between production and sales, in the i2 TradeMatrix solution this is very clear and one-way: demand is a constraint that needs to be fulfilled. Any flexibility in the demand is therefore not used in the design of the decision process.

Referring to our fourth observation (O15), the key design issue at ALCO was to define and select Planning Items. In the supply chain, detailed operations had been grouped into a small number of PUs. Using these aggregate operations, the complexity of the production control decision problem had been decreased. We emphasize that in the i2 implementation, the PU's are not completely seen as black boxes, since machine loading and capacity usage is completely transparent at the Master Planner level. GFC items in the i2 solution have been defined based on uncertainties in demand and production after each of the PUs. We emphasize that the inventory levels at these buffers are not explicitly controlled but are based on anticipated uncertainties in demand and production. Any inventory actually resulting in these buffers is therefore a consequence of uncertainties rather than a controlled inventory present to deal with future uncertainties. In summary we can say, that in the i2 context GFC items are more detailed from the capacity point of view and less detailed from the material point of view.

6.4.3 Conclusions

The analysis of the proposed model in the i2 TradeMatrix solution in the context of the supply chain control approaches proposed by Schneeweiss (1999) and Bertrand *et al.* (1990) shows that we may expect some problem when these models are implemented in a "live" production environment and handed over to the planners. We are in a very unique research setting in that we can exactly observe the first contact of the planners with the models that were developed and the software that represents the model. Note that the planners did not have any equivalent software prior to being confronted with the i2 TradeMatrix software and the model described above. We summarize our main observations as follows:

Note: All observations made in subsection 6.4.3 are related to the specific i2 implementation at ALCO

- (O16) the complexity of the planning solution and the degree of integration was underestimated
- (O17) stated requirements were not consistent
- (O18) partial implementation of the model was not possible
- (O19) no anticipation functions were defined

Referring to the first observation (O16), we can state that when starting the project the complexity of the planning solution and the degree of integration needed between the i2 modules was underestimated. An example for that is the fact that when global requirements (see section 6.3.1.) for the i2 TradeMatrix project were formulated, it was never specifically stated, that in order to fulfill these requirements it is quite obvious that the specific tools of Master Planning and Factory Planning have to be synchronized and operate in an aggregated manner. More precisely, the logical consequence of this is that the Operational Planning at the factory level should be driven by the strategic Master Plan. Additionally, in order to achieve business goals, such as "improving delivery performance", one important prerequisite is that order quoting is accurate and synchronized with capacity constrained finite planning. This observation confirms hypothesis (H3).

Referring to the second observation (O17), the requirements stated at the beginning of the project were not always consistent. An example for this observation is that the requirement of the planning department that "order splitting is not feasible", is in contradiction with the business goal of "reducing delivery time" and is a restriction on the available functionalities of the system. The requirement of the planning department that "production should be planned as late as possible" could in a rolling schedule approach result in a loss of production capacity. This observation confirms hypothesis (H1).

Referring to the third observation (O18), the definition of Business Releases was done such, that an immediate part implementation would have been difficult. Especially going live with BR1, which did not include all material flows, would cause problems, unless not included material is guaranteed to be available.

Referring to the fourth observation (O19), obviously there was a need for defining anticipation functions (see subsection 4.3.3), since the Master Planner model did not consider work order release as a task, nor did it achieve any inventory plans. Yet, no anticipation functions were defined in phase 1. Going live with BR1 would again cause problems with respect to consistency and stability aspects. This observation confirms hypothesis (H2).

We can summarize that in general one underestimates difficulties and overestimates functionalities in Master Planner. Furthermore we can observe a lack of good understanding of BWW-type decomposition of planning.

One of the major problems in implementing the model, however, was the accuracy of available data. If business objectives have not been defined very clearly, if Planning Items have not been defined in a correct way, if not all necessary constraints have been considered, or if resources have not been defined at the correct level of detail, then the resulting model may not represent planning reality and therefore be wrong. We will not address the issue of wrong data, as this is not part of the research question in this section.

6.5 Modeling Experiences and User Impressions after Phase 1&2 Related to Theory

6.5.1 Modeling Experiences and User Impressions Related to the Work of Schneeweiss

Considering the Schneeweiss approach our observations are as follows, which are explained in detail below:

- (O20) choosing the next cycle of decision making corresponds to selecting a sequence of business objectives
- (O5) planners cannot interfere in the solution process
- (O21) there is a difference in the proposed vendor-workflow and the workflow used in reality
- for model input we can state:
  - (O10) Probability distributions (or representations of these) of random variables are not comprised
  - (O22) Model input is very often based on direct input historical data rather than using historical data for estimating future data
  - (O23) Targets for improvement are not part of the model

Referring to the first observation O20, in order to relate Master Planner modeling aspects to the concept of Schneeweiss, we can state that Master Planner business objectives correspond to the preference structure or criterion C of an individual decision process. Especially demand satisfaction – as a criterion C **-** is one of the most crucial objectives in the current Master Planner model. The indication of Schneeweiss, that the most difficult decision that the decision maker faces is to select the next cycle of decision making, corresponds to the very difficult task of selecting a sequence of business objectives. Indeed the definition of layers and priorities has to be done very carefully in Master Planner and requires a very deep understanding of the model from the user's perspective. Accordingly this goes in line with observation (O3). If business objective definition and priority setting is done carelessly, the resulting solution will most probably be infeasible. The best procedure, however, seems to be one in which planners achieve a good and feasible solution by iteratively changing business objectives and/or priorities. In principle this should be supported by i2 TradeMatrix's ability to compare alternative scenarios, which is a basic requirement for

Note: All observations made in section 6.5 are related to the specific i2 implementation at ALCO doing plan modifications. But as stated in subsection 6.4.2 this ability is not really available. As this observation goes in line with (O3), we can relate it to hypothesis (H3). Referring to the second observation (O5), the Master Planner solution process consists of a number of linear programs, solved sequentially with a specific objective function. As described in subsection 5.4.2 each business objective and priority layer within the Master Planner model corresponds to the objective function of a linear program. For planners it is not possible to interfere in this solution process. So, once having set the whole sequence of business objectives, the solution process seems to be like a black box from the planner's point of view. Relating this kind of solution process to the Schneeweiss's methodology, we can observe that – in addition to planners not being able to intervene - there is also no anticipation between the solution steps. Each linear program is solved separately, without anticipating the outcome of the next level. Now it becomes clear that, in order to succeed, this kind of solution process requires a consistent method for defining business objectives and layers of priority. Using aspiration levels as another priority layer within the sequence of business objectives does not make things easier. Considering the aspiration level concept of Schneeweiss, in the first Master Planner model prototype the Aspiration Level AL corresponds to a constraint, e.g., setting a minimum production level (e.g. 80 %). In the first Master Planner prototype this was entered as a direct constraint into the system and used by the model as an additional layer to the already defined sequence of business objectives. This observation has already been stated in section 6.5.2.

Referring to the third observation (O21), we consider the use of infinite and finite capacity planning. The vendor-developed workflow suggests using both infinite and finite capacity plans in a sequential manner. The main reason for this is that dependent on the specific demand data particular capacity overloads might be resolved manually, while one deliberately does not adjust the available capacities or demand requirements as defined in the model. In reality however, we could observe a difference to the proposed workflow. By observing the planner's general procedure to check whether a Master Plan is feasible or not, we can conclude that:

1. Planners first run a finite capacity plan without modifications
2. Planners then check whether demand is late according to the finite capacity plan
3. In case of demand being shorted (i.e. not being fulfilled) the planner either changes the minimum production levels or even directly reduces the total initial forecast amount.

This procedure implies that planners prefer to start with a finite capacity plan rather than with an infinite capacity plan. This observation can also be underlined by the fact that users – in order to check whether a plan is feasible or not – first check capacity utilization and shorted forecasts. Even if it seems that reducing forecasts is the only possible way to reach a high capacity utilization, this reduction is preferred by the planners and must be discussed with the sales department and production. Summarizing, therefore, if, for example, the first thing that planners check is the shorted forecast and, if they do not want to reduce the forecast in order to get a feasible plan, they should have a very clear idea of how to select the layers and sequences of business objectives accordingly. This goes hand in hand with the fact the business objectives should be defined differently depending on whether a finite capacity plan is used or an infinite capacity plan. This observation can be related to observation (O8) in subsection 6.5.2.

Referring to the fourth observation (O10), we focus on the way specific parts of the model input are generated. An example of a situation where probability functions are useful is the specification of future demand. However, in the current Master Planner model, future demand is not entered as stochastic information but as a point estimate, based on historical data. As already discussed above uncertainty is expected to be dealt with in an iterative manner, using a rolling schedule approach and obviously not according to Schneeweiss's suggestion that uncertainty needs to be dealt with by anticipating the lower level behavior at the higher level.
Another example of a situation where model input is mainly based on historical data – rather than on vague hypothesis - is the computation of processing times per Planning Item and resource. In the current Master Planner model prototype the computation is very strongly based on past performance and not on future expectations. This observation indeed leads us again to Schneeweiss, indicating that any formal system will have difficulties capturing vague statements (P3). If we relate vague statements to performance indicators, like "improve delivery performance", these statements have to be made specific and measurable. Formulating them as a target for improvement, they could indirectly be used in the model itself by representing the basis for model input computations like processing times, etc. For the moment this is not part of the Master Planner model prototype.

6.5.2 Modeling Experiences Related to the Work of Bertrand et al.

Considering the approach of Bertrand *et al.* (1990) our observations are as follows, and are explained in detail below:

- (O24) The solution technique of the model is not related to the logical structure of the problem to be solved.

The most obvious example where it becomes evident that the solution technique of the model is not related to the logical structure of the problem is the way in which Master Planner Planning Items are defined and selected. In the supply chain, detailed manufacturing operations have been grouped into a small number of Production Units. Master Planner Planning Items have then been defined based on uncertainties in demand and production after each of the Production Units. So far this way of defining and selecting Planning Items corresponds to the approach suggested by Bertrand *et al.* regarding the selection of Production Units and Goods Flow Control Items. But after having designed a model like this, we observed that the question occurred of how to present this model to planners and people? We observed that planners had difficulties in getting a clear and simple picture of all Planning Items and their interconnections defined throughout the supply chain. The picture delivered by the model structure itself was also confusing. Planners were not immediately aware of the ultimate effects of changes. For example, the impact of a change in a finished goods Planning Item on other intermediate and raw material Planning Items in the supply chain. Therefore, a second model development was necessary illustrating the connections and interdependencies between raw material items, intermediate items, and finished goods items in the supply chain. This observation confirms hypothesis (H7) that there is a mismatch between the solution procedure and the problem structure.

6.6 Summary

We started this chapter by outlining our methodology and by giving an overview of the implementation strategy used at ALCO. Our main focus in this chapter was the description of 2 modeling phases:

- The initial requirements and criteria setting phase
- The initial modeling phase

Based on the observations made in each phase, we performed theoretical assessments with respect to the theory of Schneeweiss (1999) and Bertrand *et al.* (1990) and clearly linked the observations to hypotheses and research questions. In the following chapter 7 we will describe the remaining modeling phases of the implementation process (see subsection 2.2.4) and complete our observations. Again we will link the observations to hypotheses and research questions. A table listing all observations, hypotheses, propositions and conclusions can be found in chapter 8.

Chapter 7

Description of Modeling and Implementation Process at ALCO – Expected Problems and Revised & Advanced Modeling Phases

In chapter 6 we described two modeling phases of the i2 implementation process at ALCO. The derived observations could be related to hypotheses and research questions. In section 7.1 we list those observations which refer to theory and are relevant for the next modeling phases and formulate them as expected problems. Further on, in this chapter we will describe the remaining modeling phases, as there are the phases of

- Model modification (section 7.2)
- Model extension and advanced requirements and criteria setting (section 7.3)
- Advanced modeling (section 7.4)

7.1 Expected Problems

The expected problems formulated in the next sub-sections are distinguished between observations based on the theory of Schneeweiss (1999) and the theory of Bertrand *et al.* (1990).

7.1.1 Expected Problems Related to the Work of Schneeweiss

For reasons of better understanding we summarize below the main observations and conclusions drawn after Phase 1 & 2 which can directly be related to Schneeweiss (chapter 8). After each observation we illustrate expected problems with respect to the next modeling phases:

- (O6) There is no anticipation function in the i2 Master Planner solution process. As a consequence we expect inconsistencies and instabilities in the overall i2 planning solution, especially between Master Planner and Factory Planner or even between Master Planner and Demand Planner (Demand Planner is not considered in this thesis). We expect that these inconsistencies will be avoided by additional tests and corrections outside the system. Our findings will contribute to research question

(RQ2a), (RQ2b) and (RQ3).

- (O7) Aspiration Levels are used as an additional layer in the sequence of business objectives of the i2 Master Planner solution. As a consequence we expect that the workflow that is used to achieve a balanced and feasible plan will be more complex, as detailed evaluations and tests regarding feasibilities/infeasibilities will be necessary. The conclusion would be that the modeling process could be improved to better use the tools that are provided by the APS vendors. We define this as a new hypothesis (H8). Our findings will contribute to research question (RQ4).
- (O20) Choosing the next cycle of decision making corresponds to selecting a sequence of business objectives. As a consequence we expect that there will be difficulties in achieving an optimal solution with respect to the correct setting and sequencing of business objectives. As planners will iteratively need to change business objectives and priorities (as they cannot interfere in the solution process), the ability to compare alternative scenarios in the short term becomes crucial. We expect a mismatch between solution procedure and problem structure (H7), which in reality is solved by workarounds and additional models. Our findings will contribute to research questions (RQ1a) (RQ1b).

7.1.2 Expected Problems Related to the Work of Bertrand

For reasons of better understanding we repeat and summarize the main observations and conclusions drawn after Phase 1 & 2 which can directly be related to Bertrand:

- (O12) (O14) The i2 Master Planner functionality only covers a part of the GFC function as Work Order Release is not considered as a control task at i2 Master Planner. As a consequence we expect that some other information systems will have to deal with those functions. Yet, if the functions are not integrated in the overall system's design we expect problems in consistency (H2). We have to emphasize that this hypothesis cannot be confirmed in this chapter, but only in the questionnaire-based interview results. We assume that the complexity of the planning solution will increase and as such the integration between i2 modules and other systems. Our findings will contribute to research questions (RQ2a) and (RQ2b) .
- (O13) (O15) There is a difficulty in achieving aggregate inventory plans in i2 Master

Planner, as Planning Items in the i2 context – as compared with GFC items – are more detailed from the capacity point of view and less detailed from the material point of view. As a consequence we expect difficulties in managing inventories within Master Planner. The main reason is because Master Planner is not designed to be modeled on a detailed material level.

7.2 Model Modification (Revised Model) - Phase 3

7.2.1 Observations

The Model Modification Phase followed immediately after the Initial Modeling Phase. The main participants were the ALCO project team and consultants from i2 Technologies. The main repair work which followed immediately after BR1 was the redesign of the Planning Item definition for site A. Key users of the Master Planner model realized that the modeled number of Planning Items was too high to be handled and maintained. Besides the pure quantitative issue, it became quite clear that it was difficult to generate a sales forecast for some of the Planning Items. Therefore the second modeling design for Master Planner Planning Items took additionally into account the further two criteria:

- Demand Uncertainty (Reliability of Demand Information). A product should be defined as belonging to a Planning Product class only if the demand uncertainty is very low
- Total number of Planning Items Modeling was based on the principle design change of introducing a fixed split percentage:

As described in subsection 6.4.1 the real production situation at ALCO was such that focussing on the primary supplier site, the same finished good could have alternate supplier routings with approximately the same lead time. As illustrated in figure 25 below, additionally the situation might also occur in which alternate supplier routing with different lead times are possible. In situations like this, finished good items have to be defined as two different items, as shown in figure 25.

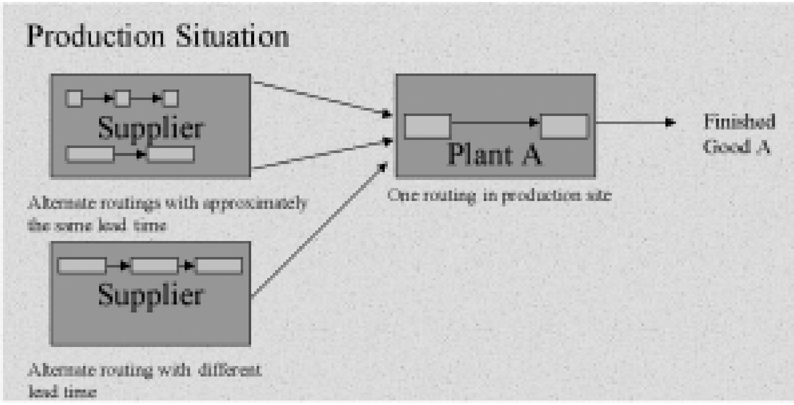

Figure 25: Production Situation at ALCO

In order to reduce the final number of Planning Items, the project team decided to model these cases with a fixed percentage associated with the selection of alternate routings with the same lead time. This meant for example , that 80% of one Planning Item would always be planned according to the supplier routing "a" and 20% of the same Planning Item would always be planned according to the supplier routing "b", as shown in figure 26.

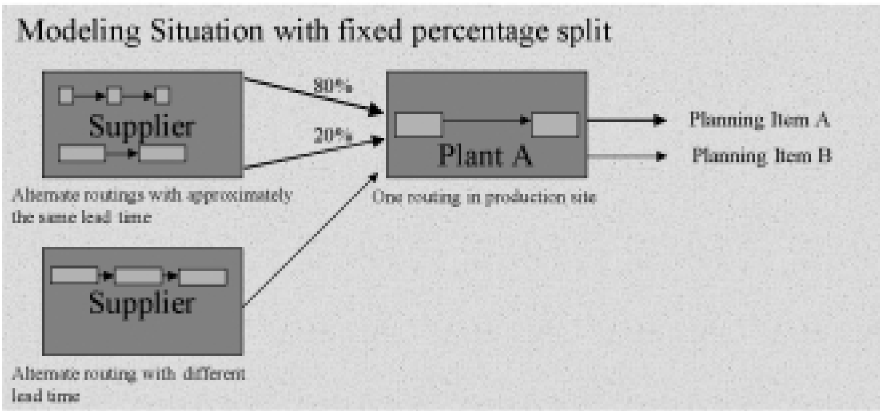

Figure 26: Modeling Situation with fixed split percentage

By this way of modeling the original number of 63 Planning Items for Business Unit A was firstly reduced to 26, by not considering items with zero demand (demand uncertainty), and secondly significantly reduced to 6 by modeling the fixed split percentage. Yet, the disadvantage of this solution was that this method of modeling may result in suboptimal plans, since the percentage of 80% to 20 % for selecting specific routings at the supplier site was fixed for every plan. Accordingly, even if, for example, from a capacity point of view it would have been better to choose a 70% to 30% rule, the model would not choose this possibility. But despite this fact, this modeling solution was preferred by the users, who claimed that the 80/20 rule is the rule that fits in the majority of cases. Planners were aware of the fact that this modeling could result in sub-optimal plans, but in order to reduce the number of Planning Items, they rather preferred to have more human intervention in achieving an optimal solution.

7.2.2 Assessment

The model modifications performed in Phase 3 were focussed on reducing the final number of Planning Items. These modifications were mainly changes in the model structure in order to achieve a higher degree of simplicity. The changes were based on selected aggregation procedures, which were agreed by the project team. The two main reasons for reducing the final number of Planning Items were:

- reduction of complexity
- making changes to solutions more understandable

In order to reduce complexity the first activity was that the final number of Planning Items was significantly reduced for at least one Business Unit from 26 to 6 by introducing the fixed split percentage modeling. The point we want to emphasize here is that obviously planners prefer a quite simple model to deal with, even if that requires more human intervention to find a feasible and optimal solution. In order to make changes to solutions more understandable, an additional Microsoft Excel-based tool was built, in which all Planning Items including finished goods items, semi-finished goods items and consumed supplier items were represented in such a manner that all interrelationships between items could easily be recognized. Referring back to the expected problems formulated in subsection 7.1.1, we can state that giving planners better control on the model, as it is done here by reducing complexity, makes the task of choosing the next cycle of decision making easier (O20).

7.2.3 Conclusions

In summary we can say, that having a quite low number of Planning Items makes it easier to understand the effects of changing Business Rules and other constraints. The main reason for this is because possible outcomes and effects only have to be related to a few interrelated Planning Items.

Note: All observations made in subsection 7.2.2 are related to the specific i2 implementation at ALCO

7.3 Model Extension and Advanced Requirements and Criteria Setting - Phase 4

7.3.1 Observations

This phase can be split into two parts: The Model Extension part and the Advanced Requirements and Criteria Setting part. The Model Extension part was mainly based on a completely separate project, called “Reengineering Business Processes”, which was established after it was realized by ALCO that there were still open questions regarding not the stand-alone, but the integrated planning solution of i2.

Open questions additionally resulted from a new implementation of SAP/R3 with which the i2 planning solution would have to be integrated. Participants of the Model Extension part were the project team of the “Reengineering Business Processes” project, which consisted partly of the project members of the Master Planner project and partly of sales managers, purchasing managers and planners from all sites A, B, C, D considered in the supply chain. All participants were employees from ALCO. i2 Technologies was not involved. The Advanced Requirements and Criteria Setting part was done in close cooperation with the Model Extension part. Participants were the Master Planner project team and consultants from i2 Technologies. The Model Extension part included the following changes, which will be explained in detail:

- Definition of separate Planning Items in Master Planner for products using materials with high lead times. This relates back to our observations (O13) and (O15) that Planning items are more detailed from the capacity point of view and less detailed from the material point of view. This fact can lead to difficulties in achieving aggregate inventory plans. The observations will contribute to hypothesis (H6), that there is no explicit material coordination between Master Planner and Factory Planner and to hypothesis (H7), that there is a mismatch between solution procedure and problem structure.
- Definition of site specific Planning Items in Master Planner and specification of how to handle the decision of site where to produce a specific Planning Item. This relates back to our observation (O14) that Work Order Release is not a control task in Master Planner. Hence, this task needs to be solved in other modules/systems.The observation will contribute as well to hypothesis (H6) that there is no explicit material coordination between Master Planner and Factory Planner and to (H7), that there is a mismatch between solution procedure and problem structure.

- Definition of a seller structure in ATP / Demand Fulfilment engine. This relates back to our observation (O12) that Master Planner only covers a part of the GFC function. According to the BWW approach, we expect that detailed sales structures are modeled outside of Master Planner.
- ATP date is the basis for customer due date / Master Planner and Factory Planner consolidation. This relates back to our hypothesis (H4), that there is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner.
- Solving the Material Coordination problem. This relates back again to our observations (O13) and (O15).

Definition of separate Planning Items in Master Planner for products using materials with high lead times

In the context of this project, it became obvious that in some cases the calculated due week might still not be correct. This was especially true for those cases, in which certain end products needed specific auxiliary materials (such as special papers and laquers) in their production process, having a very long lead time (e.g. 12 weeks). As this lead time is in fact longer than the manufacturing lead times, these products needed to be associated to separately defined Planning Items. This very important consideration was communicated to the Master Planner project team and consequently led to a correction in the models.

Definition of site specific Planning Items in Master Planner and specification of how to handle the decision of where to produce specific Planning Items

During the development phase of BR1 of Master Planner, the decision was made to define Planning Items according to the site where they are produced. Although BR1 was only focussing at site A and accordingly Planning Items for site B had to be defined in a later Business Release, this decision ultimately had impact on the way Planning Items at site A were defined: a Planning Item which in principle could be produced either in site A or site B, was defined as two separate items rather than as one item with alternate routings. Accordingly, another additional criteria for defining Planning Items became valid:

- *Producing Site*

  Each product belonging to a Planning Product Class is manufactured in the same site

This definition meant that if the same product can theoretically be produced in two different sites, two separate planning products are defined. Furthermore, in the project "Reengineering Business Processes", sales people stressed their wish that they would prefer to make the decision about where to produce a product, themselves. As a consequence, regarding the modeling of site specific planning products, the decision concerning which site to produce was decided to be done by sales people via site specific Planning Items, and definitely not automated within Master Planner or the ATP / Demand Fulfilment engine.

Definition of a seller structure in the ATP/Demand Fulfilment engine

The Master Planner model as developed in BR1 did not include a concrete customer/ product/seller structure. Instead, the market sector was completely neglected, since otherwise first their total number would have been exploded and second they would not be global enough to get forecasted. Yet, the project team realized that it was still essential to define Planning Items according to the given seller structure, as a basis for Due Week Quoting. The decision was made to model the complete seller structure within the ATP / Demand Fulfilment engine.

ATP date as the basis for customer due date / Master Planner and Factory Planner consolidation

In the context of the project "Reengineering Business Processes", the decision was made that the ATP date is the basis for announcing the first due date to the customer. Of course this date needed to be reliable in the sense that all actual dates further calculated by Factory Planner do not deviate significantly from each other. In order to ensure that the ATP date does not deviate significantly from the Factory Planner date, two performance indicators habe been defined. These performance indicators needed to be consistently measured in both Factory Planner and Master Planner. By doing this the project team wanted to ensure that necessary improvements in both systems are recognized in time. The defined performance indicators and their way of measuring are shown in figures 27 and 28.

Definition KPI 1:
Deviation of the initial scheduling results in Master Planner and Factory Planner

Master Planner and Factory Planner are both systems which are involved in the delivery date calculation. In order to get indications about necessary corrections or improvements concerning both systems, it is senseful to compare their scheduling results.

The deviation between the calculated delivery date FP and the ATP-Date MP at the moment of initial scheduling in Factory Planner is measured. Comparisons of the scheduling results FP with the ATP-Date MP at later points in time are not senseful, because only the initial scheduling result of FP is comparable to the ATP-Date.

The comparison can only take place in the unit ‚week‘ (the unit of MP). Thus, the FP-date has to be converted into the depending calendar week.

Only the absolute value of the deviation as well as the corresponding number (with respect to the absolute value) of deviations, without any restrictions or interpretations, are determined here.

Boundary values for the jugdement of the results of the report have to be defined. For example:
- absolute value of tolerated deviation (e.g. 1 week)
- percentage of tolerated number of deviations (e.g. 10 % of total number)

Formula/Calculation:

per order: [Delivery Date-FP (converted in week)] minus [ATP Date-MP] =,
Deviation in number of weeks‘

summation:
- select all orders in one period
- sort all orders according to ‚Deviation in number of weeks‘
- determine number of orders per ‚Deviation in number of weeks‘
- determine percentage of total number of orders per, Deviation in number of weeks‘
- presentation of the determined values in suitable manner

result: Number of deviations in numbers and percentage including the distribution per absolute value of deviation

Basis (time / period): **Unit of Measurement:** **Frequency of Measurement:**

Figure 27: Definition and Measurement of KPI 1

Definition of KPI 2:
Deviation of Lead Time / Capacity Usage in Master Planner and Factory Planner

In order to measure consistency between Master Planner and Factory Planner it is senseful to compare how Lead Time and Capacity Usage is defined in Master Planner and Factory Planner. Consistency between both systems can only be achieved if it can be assured that the Lead Times and Capacity Usage is computed on the same data basis.

The following definitions should be valid:

Lead Time for an End Product (Factory Planner) = Processing Time + Technological Cool Down Time + Average Waiting Time
Lead Time for a Planning Item (Master Planner) = Maximum value of Lead Times of all end products belonging to the Planning Item + Slack

We want to measure the deviation between the Lead Times / Capacity Usage for certain materials as used in Factory Planner and the Lead Times / Capacity Usage for the corresponding Planning Items in Master Planner.

In order to have a correct measurement the following steps need to be performed:

- specify which Materials belong to the Planning Item under consideration
- specify the Lead Times per Material as used in Factory Planner for all Materials belonging to the Planning Item
- Specify the MIN/MAX values of the Lead Times of all Materials considered, by neglecting divergent values (Ausreißer)
- Specify the Lead Time for the corresponding Planning Item according to the definition given above
- Specify the deviation between both Lead Times

Formula/Calculation:
per Planning Item:- Define all Materials which belong to the Planning Item

per Material: - Compute all Lead Times according to the Formula
Lead Time Material = Processing Time + Technological Cool Down Time + Average Waiting Time

all Materials: - Compute the MIN/MAX values for Lead Times Material

per Planning Item: - Compute the Lead Time according to the formula:
Maximum value of Lead Times of all Materials belonging to the Planning Item + Slack

Deviation: - Lead Time Planning Item - max
(all Lead Times of all Materials belonging to the Planning Item)

Basis (time / period): Unit of Measurement: Frequency of Measurement:

Figure 28: Definition and Measurement of KPI 2

Material Coordination
The project team decided that the optimal management of stock levels should be done within the ERP system.

Next to the Model Extension part there was in this phase also the Advanced Requirements and Criteria Setting part, which is illustrated in detail below.

Advanced Requirements Setting and Definition of Acceptance Criteria
We want to point out that this part was actually the preparation of BR4, as described in subsection 6.3.1. – with one difference. The project team realized, that the Order Quoting functionality could not be done in the Master Planner model. The main reason for this was, that relating the Planning Products defined so far to Market Sectors – as necessary for Due Week Quoting – would have exploded the final number of items in Master Planner. Accordingly, BR4 was redefined in the sense that in BR4 developing the ATP / Demand Fulfilment engine which facilitates the Due Week Quoting process was the main issue.
For describing the advanced requirements and acceptance criteria, we use the same table form at table 18 as we did in subsection 6.3.1. The advanced requirements can as well be subdivided into global requirements, specific requirements related to MP/FP, and specific planning requirements. The term "advanced" is just used to distinguish between phase 4 and phase 1 of the modeling process. requirements have been defined by the Master Planner project team at ALCO in close cooperation with i2 Technologies.

Global Requirements	Specific Requirements related to MP / FP	Specific Planning Requirements	Acceptance Criteria
A standardised, comprehensive planning system	**Definition of Seller Structure in ATP / DF engine, as a basis for Due Week Quoting**	**Development of ATP / DF engine for Due Week Quoting, based on predefined Business Rules**	Capability of performing what-if-analysis **Interface and Online connection between MP and ATP / DF engine**
Integrated, dynamic and optimised planning processes for each manufacturing location and Business Unit	The unconstrained sales forecast is satisfied as much as possible, by having a minimum level of production for different products after which any spare capacity will be filled according to predefined product priorities		
Supply Chain Planning must enable the company to benefit from the potential synergies of having different process routings across different manufacturing sites			Planning Cycle Time within MP must be of an acceptable duration MP user interface allows for basic model changes online
Optimal Management of stock levels	Definition of material buffers within MP to prevent bottlenecks running out of material Minimum safety stock levels should be respected, but demand order satisfaction has higher priority in the planning process		
Order Quoting on a due week basis, as accurate as possible, based on strategic Master Plan		Production is planned as late as possible with the principle that backlog orders are produced first and real demand orders are produced on time If customer demand orders require more resource capacity than available in a given week, the next possible due date will be quoted. Availability of a manual process on an individual order-by-order-process	**ATP allocation basd on a predefined seller strcuture Automatic** **Expiration of ATP's**
Delivery Performance			
Transparency			Visibility of levels of load and resources in site A and in primary supplier

Table 18: Advanced Requirements and Criteria Setting

The bold marked requirements and acceptance criteria have been added and mainly refer to the development of the Due Week Quoting Process. The italics marked requirements have been deleted, in the sense that the optimal management of stock levels is not covered by the i2 solution any longer. Instead, it was decided that this functionality should be solved by the SAP/R3 system. Also excluded was the functionality of having an automatized decision process for deciding where to produce certain products.

7.3.2 Assessment

The following assessments are subdivided into assessments regarding changes in model structure and assessments regarding changes in functionality allocation and refer to the Model Extension part and to the Requirements Setting and Acceptance Criteria part.

Changes in Model Structure (Model Extension)

The following changes can be associated to changes in Model Structure and refer to the Model Extension part:

- Long Lead Time Planning Items
- Separate site specific Planning Items
- Definition of seller structure in ATP engine

The observations we make are:

- (O25) Modeling is not conform with the original planning functionality
- (O26) Defining the seller structure in the ATP engine makes the workflow more complicated

Referring to the long lead time Planning Items we want to stress that this way of modeling was unavoidable in order to have a reliable Due Week Quoting. The project team was quite aware of this fact and decided to include long lead time Planning Items, although – as a consequence - again the total number of Planning Items would increase. The reference to our expected problems is outlined in subsection 7.3.1

Referring to separate site specific Planning Items, the decision in BR1 to model two separate site specific planning products for alternate manufacturing sites was made intuitively. Nevertheless, it had a big impact on whether the final decision of where to produce a product could be automated or not. The stated planned functionality in BR1 was

Note: All observations made in subsection 7.3.2 are related to the specific i2 implementation at ALCO

to automate this decision process as much as possible within the ATP engine (see subsection 6.3.1.). But in order to make this possible, a model of only one planning product with alternate routings would have been necessary – a fact which was neglected in BR1. As a consequence, by having defined site specific planning products, and accordingly by having site specific ATP's, the decision process of where to produce a certain product now mainly had to be done by humans. A positive aspect of this fact was that sales people were supporting the manual decision process anyway. In summary, this way of modeling did not conform to the original planning functionality (O25) as described in subsection 6.3.1, and can be related to hypothesis (H3), that the complexity of the planning solution is usually underestimated. Additionally, this way of modeling had as a consequence, that additional information about where to produce which products was necessary from the SAP/R3 system. Another important consequence was that the workflow became even more complicated, as several ATP checks had to performed, one for each site specific planning product. The important aspect here is that there was a change in the Requirements Setting. This observation (O24) that the solution technique of the model is not related to the logical structure of the problem to be solved, again confirms the hypothesis that there is a mismatch between solution procedures and problem structure (H7) – a reason why workarounds and additional models are used. This hypothesis contributes to research question (RQ1b). The reference to our expected problems is outlined in subsection 7.3.1.

Referring to the definition of a detailed seller structure within the ATP / Demand Fulfilment engine, we want to stress that on one hand this decision had as a first consequence not to increase the final number of Planning Items in MP, but on the other hand had as a second consequence that again the workflow is becoming more complicated. The reason for this complication is the fact that the constrained forecast per Planning Product as computed by Master Planner has to be given to the ATP / Demand Fulfilment engine, where it has further to be split into the percentages of the predefined seller structure, and where it really corresponds to the definition of a Planning Item. It can be summarized that the main functionality, namely the generation of ATP's was for a large part realized outside of Master Planner, within the ATP/Demand Fulfillement engine. Our observation that defining the seller structure in the ATP/Demand Fulfilment engine makes the workflow more complicated (O26) leads us to the hypothesis (H9) that the generation of ATP's on a detailed basis, is for a large part realized outside of Master Planner. We emphasize that this is a generic solution approach proposed by many APS companies. This hypothesis contributes to research question (RQ1a) and (RQ1b). The reference to our expected problems is outlined in subsection 7.3.1

Changes in Functionality Allocation (Model Extension)
The following changes can be associated to changes in Functionality Allocation and still refer to the Model Extension part:

- ATP date is the basis for customer due date / MP and FP consolidation (Aggregate Delivery Plan of BWW)

The observations we make are:

- (O27) The perceived solution was not conform with reality
- (O28) Consistency between systems was tried to be achieved by defining Performance Indicators
- (O29) ATP as the only link between Master Planner and Factory Planner is not sufficient
- (O30) Work Order Release Function is not covered by any i2 modules

We can state that the major observed issue in phase 4 was the decision that the ATP date is the basis for customer due dates. This decision was communicated to the Master Planner and Factory Planner project teams. Realisation mainly happened in the Master Planner team. The Factory Planner team was additionally responsible to keep on track with the performance indicators illustrated in chapter 7.3.1. With this decision consistency issues actually came up. Referring to chapter 4, our observation here is that instead of defining anticipation functions in the top level model, external links serve as a means to achieve consistency. This observation (O29) confirms the hypothesis that there is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner (H4). This hypothesis is related to the research quetsions (RQ2a) and (RQ2b). The reference to our expected problems is outlined in subsection 7.3.1. The project team was aware of the fact that MP and FP models needed consolidation. Accordingly, the definition of two Performance Indicators actually meant adding a feedback loop to the system. Again we observe that instead of defining anticipation functions, anticipation is replaced by feedback. It was at this point in time that the project team actually realized that the perceived solution as described in subsection 6.4.1 was in reality not true (O27). Figure 29 illustrates the weak points of this design.

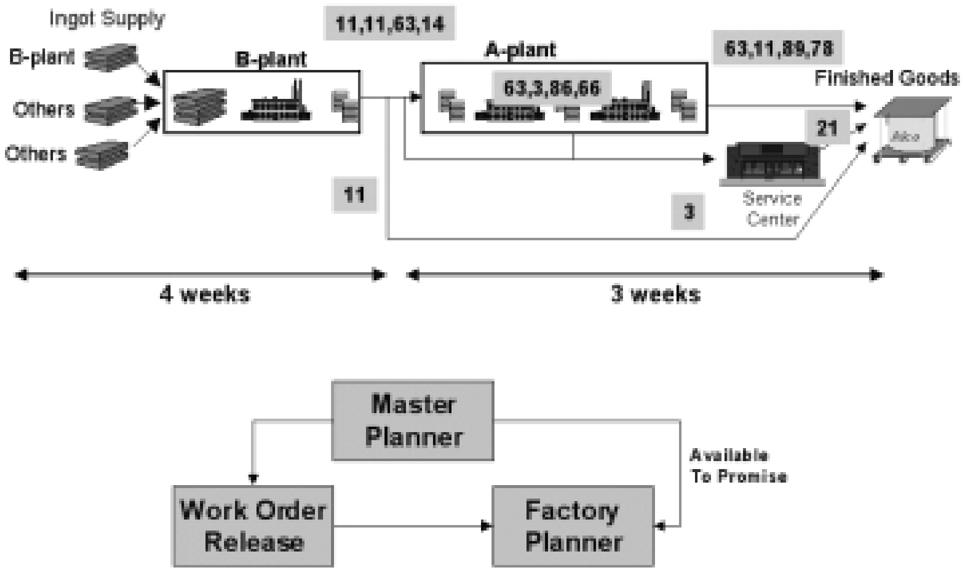

Figure 29: Perceived Solution

In the chosen solution, the Available-To-Promise is the only link between Master Planner and Factory Planner. As suppliers and production site A are modeled in the Master Planner model, the ATP capacities for Due Week Quoting actually represent all supplier and manufacturing capabilities necessary for computing reliable delivery times. This may be sufficient for serving incoming orders with a delivery time shorter than 3 weeks. In order to cover incoming orders with a delivery time larger than 3 weeks, the necessary supplier production orders have to be generated just based on forecasts.

Furthermore, the Work Order Release functionality is not covered by any i2 module (O30), but by the ERP system instead. This observations confirms the hypothesis that there is no explicit material coordination between Master Planner and Factory Planner (H6) and contributes to research questions (RQ2a) and (RQ2b).

Changes in Requirements Setting and in Definition of Acceptance Criteria

Referring to the changes in Requirements Setting and Definition of Acceptance Criteria we want to emphasize that they are twofold. Some Requirements and Acceptance Criteria have been added, others have been removed. The excluded criteria refer to the automatized decision process of where to produce certain products, and to the optimal management of safety stocks. The added criteria refer to the development of the ATP / DF engine and the Due Week Quoting process. The observations that we draw are:

- (O31) Excluding the optimal management of stock levels from the requirements list did not solve the problem
- (O32) Shifting the optimal management of stock levels in the ERP system has as a consequence that Master Planner and ERP systems are not operating on the same constraints and hence there is no control of the solutions gained.

These observations again confirm the hypothesis that there is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner (H4) and that there is no explicit material coordination between Master Planner and Factory Planner (H6). These hypothesis contribute to research question (RQ2a) .

As elaborated in subsection 6.4.2. the optimal management of stock levels in Master Planner might result in a very difficult task, as Master Planner operates on an aggregated level of items, called Planning Items, which are not physically really existing materials. Accordingly, Planning Items cannot really be put in stock, since they are aggregated items. Hence, this is an example where aggregation has caused a significant problem. Hence, despite the fact that in principle Master Planner has the functionality to control safety stock levels and is as well able to generate necessary replenishment orders by programming additional add-ons, there is still the remaining prerequisite which implies that Master Planner has to be modeled on physically existing item levels. The only way out of this dilemma – except for re-modeling the prototype – seemed to be the additional usage of the i2 module Inventory Planner, which is designed for safety stock control and generation of replenishment orders. It is important to mention at this very point in time that the usage of Inventory Planner was not seriously considered. Instead, the optimal management of stock levels was excluded as a requirement for the Master Planner module . The project team made the assumption that the management of stock levels had to be dealt with later. Yet, this was not specifically adressed as a modeling issue. An option of how the optimal management of stock levels can be solved outside of Master Planner and by using other i2 software solutions is shown below:

Figure 30: Decision Hierarchy for Make-to-Stock without ERP

The solution approach described in figure 30 above, foresees that the optimal management of stock levels is done in the Inventory Planner module. The approach is such that the corresponding Factory Planner Module at the site chosen, plans the order. In the case that the complete order is manufactured in one and the same site, Factory Planner transforms the order into a production order and sends the production order to the shop floor system. If we further assume that the site receiving the production order, is site B. In case that site B needs prematerial from Site A, the Factory Planner module at site B would have to calculate (backwards calculation) the delivery time for prematerial from site A. A corresponding order would then have to be sent to site A.

7.3.3 Conclusions

Whether having an ATP as the only link between Master Planner, Factory Planner and ERP systems really is sufficient, seems questionnable. As illustrated in section 4.2., according to Schneeweiss, anticipation concepts are functions in hierarchical planning systems by which the higher level decision anticipates the reaction of the subordinate level decision function subsection 6.4.1 was in reality not true (O27). Figure 29 illustrates the weak points of this design.

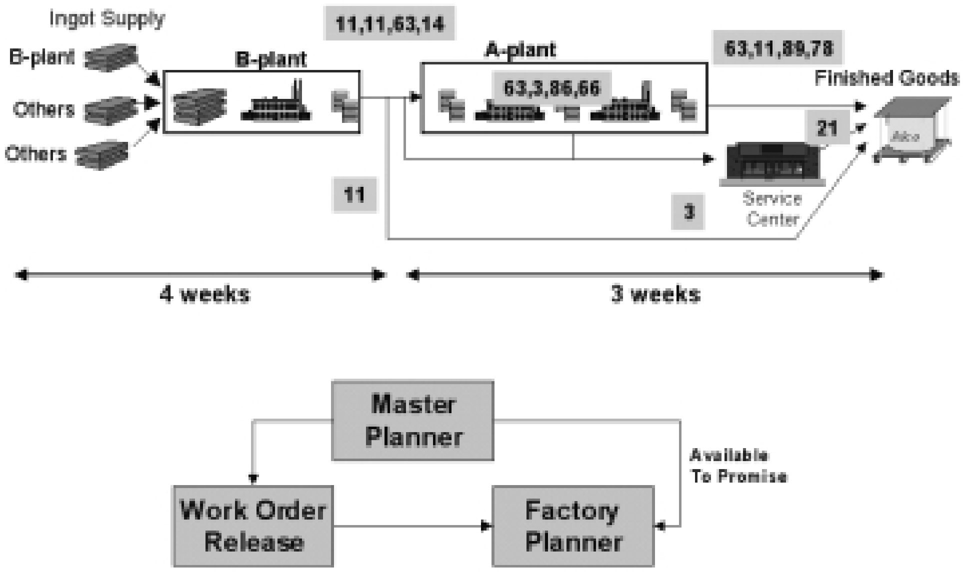

Figure 29: Perceived Solution

In the chosen solution, the Available-To-Promise is the only link between Master Planner and Factory Planner. As suppliers and production site A are modeled in the Master Planner model, the ATP capacities for Due Week Quoting actually represent all supplier and manufacturing capabilities necessary for computing reliable delivery times. This may be sufficient for serving incoming orders with a delivery time shorter than 3 weeks. In order to cover incoming orders with a delivery time larger than 3 weeks, the necessary supplier production orders have to be generated just based on forecasts.

Furthermore, the Work Order Release functionality is not covered by any i2 module (O30), but by the ERP system instead. This observations confirms the hypothesis that there is no explicit material coordination between Master Planner and Factory Planner (H6) and contributes to research questions (RQ2a) and (RQ2b).

Changes in Requirements Setting and in Definition of Acceptance Criteria

Referring to the changes in Requirements Setting and Definition of Acceptance Criteria we want to emphasize that they are twofold. Some Requirements and Acceptance Criteria have been added, others have been removed. The excluded criteria refer to the automatized decision process of where to produce certain products, and to the optimal management of safety stocks. The added criteria refer to the development of the ATP / DF engine and the Due Week Quoting process. The observations that we draw are:

- (O31) Excluding the optimal management of stock levels from the requirements list did not solve the problem
- (O32) Shifting the optimal management of stock levels in the ERP system has as a consequence that Master Planner and ERP systems are not operating on the same constraints and hence there is no control of the solutions gained.

These observations again confirm the hypothesis that there is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner (H4) and that there is no explicit material coordination between Master Planner and Factory Planner (H6). These hypothesis contribute to research question (RQ2a) .

As elaborated in subsection 6.4.2. the optimal management of stock levels in Master Planner might result in a very difficult task, as Master Planner operates on an aggregated level of items, called Planning Items, which are not physically really existing materials. Accordingly, Planning Items cannot really be put in stock, since they are aggregated items. Hence, this is an example where aggregation has caused a significant problem. Hence, despite the fact that in principle Master Planner has the functionality to control safety stock levels and is as well able to generate necessary replenishment orders by programming additional add-ons, there is still the remaining prerequisite which implies that Master Planner has to be modeled on physically existing item levels. The only way out of this dilemma – except for re-modeling the prototype – seemed to be the additional usage of the i2 module Inventory Planner, which is designed for safety stock control and generation of replenishment orders. It is important to mention at this very point in time that the usage of Inventory Planner was not seriously considered. Instead, the optimal management of stock levels was excluded as a requirement for the Master Planner module . The project team made the assumption that the management of stock levels had to be dealt with later. Yet, this was not specifically adressed as a modeling issue. An option of how the optimal management of stock levels can be solved outside of Master Planner and by using other i2 software solutions is shown below:

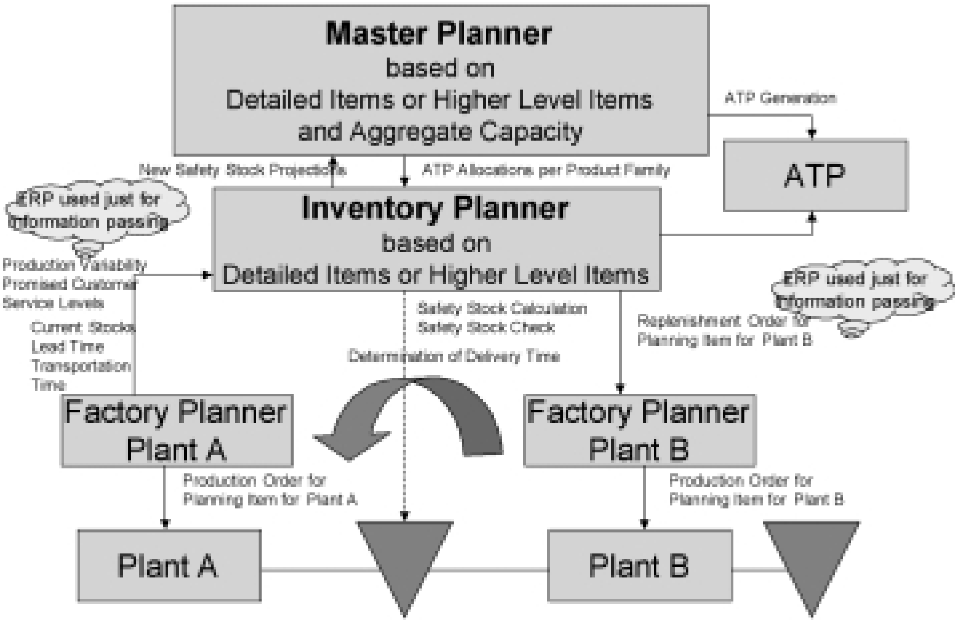

Figure 30: Decision Hierarchy for Make-to-Stock without ERP

The solution approach described in figure 30 above, foresees that the optimal management of stock levels is done in the Inventory Planner module. The approach is such that the corresponding Factory Planner Module at the site chosen, plans the order. In the case that the complete order is manufactured in one and the same site, Factory Planner transforms the order into a production order and sends the production order to the shop floor system. If we further assume that the site receiving the production order, is site B. In case that site B needs prematerial from Site A, the Factory Planner module at site B would have to calculate (backwards calculation) the delivery time for prematerial from site A. A corresponding order would then have to be sent to site A.

7.3.3 Conclusions

Whether having an ATP as the only link between Master Planner, Factory Planner and ERP systems really is sufficient, seems questionnable. As illustrated in section 4.2., according to Schneeweiss, anticipation concepts are functions in hierarchical planning systems by which the higher level decision anticipates the reaction of the subordinate level decision function

to its instructions.In the proposed solution approach just having the ATP as a link between systems does not make the anticipation complete. Consequently the consistency and stability of plans are not ensured.This confirms out hypotheses (H4) that there is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner. Additionally it confirms out hypothesis (H7) that there is a mismatch between solution procedure and problem structure.
Focussing on the BWW approach the Work Order Release Function is missing in the Master Planner design concept. Additionally, the Material Coordination Function has not been taken into account, when designing the solution concept. This again confirms hypotheses (H4) and (H7), and as well (H6) that there is no explicit material coordination between Master Planner and Factory Planner.
Inherently we can summarize that the i2 TradeMatrix solution assumes more flexibility in terms of solution design in the interaction between Master Planner and Factory Planner than the rather strict top-down hierarchy assumed in Bertrand's approach. The big danger in this flexibility is that the solution architecture which is to be designed in each project might not be designed correctly. Inconsistency and instability issues might turn out to be the critical issues in solution design.

7.4 Advanced Modeling – Phase 5

7.4.1 Observations

The Advanced Modeling phase focussed on the developed of the ATP / DF engine and the development of the Due Week Quoting process. Participants were the Master Planner project team at ALCO and consultants from i2 Technologies.

As described in subsection 6.4.1 in the BR1 Master Planner model "Market Sector" of a Planning Item was almost neglected. The definition was mainly concerned on the "Planning Product" part of the definition. Rather than remodeling BR1 according to the complete definition of a Planning Item, the project team decided to define the detailed customer/product/seller structure outside of Master Planner, in the so called ATP/Demand Fulfillment Engine. The selected solution is shown in table 19. As a first step, for all Planning Products within Master Planner the expected forecast on a global customer / market sector level was given by the sales department. The calculations were done in tonnage per year.

	Customer / Market Sector A	Customer / Market Sector B
Planning Product 1	15000	23000
Planning Product 2	6500	13000
Planning Product 3	1500	800

Table 19: Yearly Sales Plan (Aggregated Form)

The second step in the solution approach now is, given that as an input for Master Planner, to calculate at this level the constrained forecast in Master Planner. Our assumption is that there is enough capacity available to fulfill the complete forecast. Accordingly, the same numbers now have to be passed to the ATP / Demand Fulfillment Engine.
There the constrained forecast numbers have to be split into more detailed reservations which are the basis for Due Week Quoting. The way this splitting is done depends on the degree of detail the seller strcuture is represented in the DF engine. The degree of detail chosen at ALCO is shown below, according to which the complete sales structure as it was necessary for Due Week Quoting was modeled in DF. Figure 31 explains the splitting for Planning Product 1 and Customer / Market Sector B.

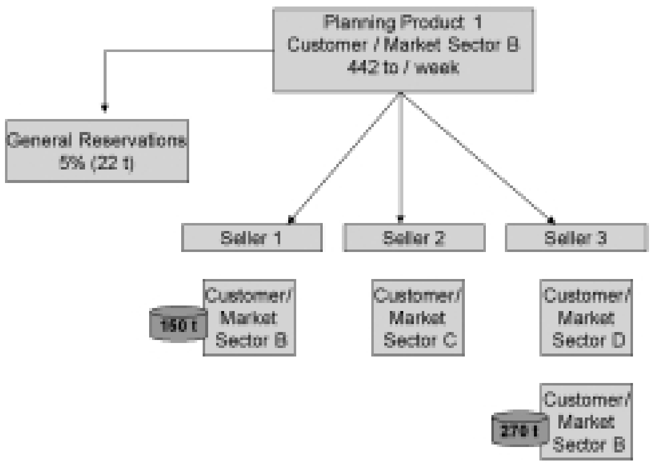

Figure 31: Splitting of Constrained Forecast in DF engine (Disaggregation)

In figure 31 it becomes evident that the original tonnage of 442 to per week is split up into 22 to per week as a reserve for unforeseen occasions, 150 to per week are associated to seller 1 and 270 to are associated to seller 2.

Summarizing, at this point in time, another additional criteria for defining Planning Items in their complete sense became valid:

- *Demand Uncertainty (Reliability of Demand Information)*
  A product should be defined as belonging to a Planning Product Class only if the demand uncertainty is very low
- *Market sector*
  Each product belonging to a Planning Item Class belongs to the equivalent Planning Product Class and has the same market sector.

Referring to the concrete process of Order Quoting, as a first step Business Rules were defined by the project team which will have to be applied to the either manual or automatic order quoting process.
A general distinction was made, according to whether a manual order quoting process is necessary for individual order-by-order processes, or whether an automatic batch program can be used for all such orders which do not require an immediate response.

7.4.2 Assessment

Having stated the rules for Due Week Quoting, they give insight into an important part of the order quoting functionality, as they show how ATP's are really used. The usage of this functionality is an indication of the quality of the Master Planner planning process and of the quality of the forecasts. Unfortunately it will always be hard to separate it, so one can always state that the forecast accuracy should be improved.
The Due Week Quoting solution confirms the hypothesis that the generation of ATP's on a detailed basis is for a large part realized outside of the Master Planner functionality (H9). This hypothesis contributes to our research qeustions (RQ1a) and (RQ1b).

7.4.3 Conclusions

The development of a detailed seller structure outside of Master Planner, as a basis for Due Week Quoting, is a solution design which has been adopted by many APS software companies. It reduces complexity within Master Planner but has as a consequence that the overall workflow and the integration between systems becomes more complicated.

Note: All observations made in subsection 7.4.2 are related to the specific i2 implementation at ALCO

7.5 Summary

So far we have addressed the modeling of the supply chain planning process in the APS software i2 TradeMatrix (chapters 6 and 7). We compared the model that was built for an aluminum company with the theoretical concepts on model building and aggregation provided by Schneeweiss (1999) and Bertrand *et al.* (1990). The description shows that many of the theoretical premises have not been used in building the actual model in the software. In addition we have made some observations about the use of the system by the planners. Many of the observations we made could be linked explicitly to the theoretical analysis of the models. The main observations about the model are related to the lack of anticipation at the various levels in the decision process (linked to Schneeweiss's theory). Note that we only considered the Master Planning process in a static situation, and even there we observed these deficiencies. We expect that, when additional research will be done on the hierarchy in the decision process, taking into account the dynamics of planning, this lack of anticipation will have even stronger consequences on the perceived quality of the model. Another main observation is that the solution procedure used in the software is not related to the problem structure (linked to Bertrand's theory). In various places, this leads to incomprehensible sequences in the decision process, and the use of models in an unforeseen way.

We want to emphasize that our observations are based on what we call theory-driven observations based on a single case study. Over the last thirty years, a considerable body of un-validated knowledge has been generated in Operations Management and Operations Research. In this study, we link some of published theory on Operations to observations in practice. The observations are made based on the theory, and its validity is claimed because of the theoretical concepts being there.

It is obvious that this is only the initial establishment of research questions related to the topic addressed here. It is clear that a next step will have to be to observe the system once the dynamics are introduced into operation. It is nevertheless remarkable that we are already able to make this set of observations based on the static situation we studied.

In chapter 8 we will focus on questionnaire-based interviews at other companies in order to further study our observations and hypotheses stated so far. We use the results to derive either propositions or conclusions, as stated in chapter 2.

Chapter 8

Questionnaire-Based Interviews

In the previous chapters, some observations and hypotheses have been generated based on a theoretical analysis of the APS tool we have been studying in chapter4 and an in-depth lonigtudinal case study of the implementation of i2 at ALCO. In this chapter we first give an overview of all stated observations and hypotheses gained so far. In section 8.2 we illustrated the interview methodology used. Section 8.3 summarizes our research questions and relates them to the stated hypotheses. The in detail discussion of each hypothesis, followed by interview results is conducted in section 8.3. Based on the methodology outlined in chapter 2, we either derive propositions or conclusions with respect to our research questions.

8.1 Overview of Observations and Hypotheses

In this section we summarize all observations and hypotheses stated so far. All observations confirming specific hypotheses are listed in subsection 8.1.1. We emphasize that some observations do not lead to any hypotheses and hence are not considered any further. We list those observations separately in subsection 8.1.2. Other observations in fact lead directly to propositions without being associated to any hypotheses. Those observations are listed separately in subsection 8.1.3.

8.1.1 Observations related to Hypotheses

The observations and hypotheses listed below represent a summary of all observations and hypotheses derived in our research. In table 20 we relate each observation to a hypothesis by printing an “x” in the associated matrix field.

Note: We want to explicitly state that all conclusions and propositions derived in this chapter are based on interview results from additional sites. Furthermore, they are only related to the implementation of i2 TradeMatrix. We speculate that our conclusions and propositions are generic ones, as i2 TradeMatrix is currently market leader in APS systems.

Observations	Hypotheses
(O1) There is very little formality in the modeling process	(H1) There is little formality in the modeling process of APS systems implementations
(O2) Not always correct anticipation types are chosen	(H2) Depending on the degree of consistency and stability not always correct anticipation types are chosen
(O3) The definition of business objecives, layers and priorities needs a deep understanding from the user	(H3) The complexity of the planning solution and the degree of integration needed is underestimated
(O6) There is no anticipation function in the solution process	(H4) There is no direct formal relationship in terms of instructions/constraints between MP/FP
(O8) Infinite Capacity Planning is not often used in practice	(H5) Planners do tend to find workarounds to the system
(O9) No rules and constraints for inventory management are modeled	(H6) There is no explicit material coordination between Master Planner and Factory Planner
(O12) Master Planner only covers part of the GFC function	(H7) Mismatch between the solution procedures and the problem structure are the main causes for concern
(O13) In Master Planner is a difficulty in achieving aggregate inventory plans	(H8) The modeling process can be improved to better use the tools that are provided by the APS vendors
(O14) Work Order Release is not a control task in Master Planner	(H9) The generation of ATP on a detailed basis is for a large part realized outside of the Master Planner functionality
(O15) In Master Planner Planning Items are more detailed from a capacity point of view and less detailed from a material point of view	
(O16) The complexity of the planning solution and the degree of integration was underestimated	
(O17) Stated requirements were not consistent	
(O19) No anticipation functions were defined	
(O20) Choosing the next cycle of decision making equals to selecting a sequence of business objectives	
(O21) There is a difference in the proposed vendor workflow and the workflow used in reality	
(O24) The solution technique of the model is not related to the logical structure of the problem to be solved	
(O25) Modeling is not conform with the original planning functionality	
(O26) Defining the seller struture in the ATP / Demand Fulfilment engine makes the workflow more complicated	
(O29) ATP as the only link between Master Planner and Factory Planner is not sufficient	
(O30) work order release function is not covered by any i2 modules	
(O31) Excluding the optimal management of stock levels from the requirements list did not solve the problem	
(O32) Shifting the optimal management of stock levels in the ERP system has as a consequence that Master Planner and ERP systems are not operating on the same constraints	

Table 20: Observations and Hypotheses

The following table relates all observations to hypotheses.

	(H1)	(H2)	(H3)	(H4)	(H5)	(H6)	(H7)	(H8)	(H9)
(O1)	x								
(O2)		x							
(O3)			x						
(O6)		x							
(O8)					x				
(O9)				x					
(O12)						x			
(O13)						x			
(O14)						x			
(O15)							x		
(O16)			x						
(O17)	x								
(O19)		x							
(O20)			x						
(O21)					x				
(O24)							x		
(O25)			x						
(O26)									x
(O29)				x					
(O31)				x					
(O30)						x			
(O32)				x					

Table 21: Observations related to Hypotheses

8.1.2 Observations not leading to Hypotheses

The following observations do not lead to any hypotheses and are not considered any further in this thesis. The reason is that we are not certain whether necessary data to confirm the hypotheses can be found. Nevertheless we consider those observations useful for further research:

- (O4) Planners run the model several times and change the sequence of business objectives
- (O5) There is no user intervention in the solution process
- (O18) Partial Implementation of the model was not possible
- (O22) Model input is very often based on direct input historical data rather than using historical data for estimataing future data
- (O23) Targets for improvement are not part of the model
- (O27) The perceived solution was not conform to reality
- (O28) Consistency between systems was tried to be achieved by defining Performance Indicators

8.1.3 Observations leading directly to Propositions

The following observations are not related to any hypotheses, as they directly lead to propositions. The reason why is that those observation are evident as such, so there is no necessity for testing. By logical reasoning we bring those observations into propositions.

(O7) / (P1) Aspiration levels are used as additional layers in the sequence of business objectives
(O10) / (P2) i2 TradeMatrix does not recognize stochastic infromation
(O11) / (P3) i2 TradeMatrix cannot capture vague statements

8.2 Interview Methodology

In order to check whether some of the theoretical insights from chapter 4 and the practical insights form chapters 6 and 7 can be observed on a wider scale in industrial practice, it has been our intention to conduct a survey. The original idea was to have a relatively small scale survey, based on extensive on-site interviews conducted by us as researchers and assisted by experienced implementation consultants.

It turned out to be very difficult to gain access to companies that had sufficiently progressed within their implementation such that actual experience with them running the APS software could be recorded. We therefore were able to only identify and get support and time from four companies:

a) **A top 10 international semiconductor manufacturing company (High Tech)** The implementation process included Master Planner and Demand Planner. Planning complexity was the main reason for selecting the i2 software, and the adaptability to all requirements, like customer demand, efficiency, standardisation, service. At the time the interview was done there was already some experience in using the i2 Master Planner module.

b) A top 3 international consumer electronics company (Mainstream Electronics Equipment)

The implementation process included Master Planner and Demand Planner. The Master Planner model consisted of 3 factories, 2 distribution centers and 15 sales organisations. Planning complexity and customer lead time reliability were the main reasons for selecting the i2 software. At the time the interview was done, the first Business Release of Master Planner was not finished yet. There was no experience yet in using the system.

c)A european speciality steel mill (Metals)

The implementation process included Master Planner, Factory Planner, Demand Fulfilment, Material Allocator and Heat Formation. Up to 10 own and external plants were modeled in one Factory Planner. Planning complexity was the main reason for selecting the i2 software. The complexity is characterized by high end product variety, multi-site environment, campaign planning, transports in hot condition, various outsource possibilities. At the time the interview was done Factory Planner was life but Master Planner was not yet live. Accordingly there was no experience yet in using the Master Planner module.

d) A semiconductors company

The implementation process included Master Planner, Factory Planner, Demand Fulfilment and Demand Planner. Planning complexity was the main reason for selecting the i2 software. At the time the interview was done, Demand Planner was already in use, Master Planner had been in use for about 9 months.

The small number of companies does not allow us to conduct any statistical analysis on the data, as the variance in the observations would undoubtedly be too high for any significant and generalizable conclusions. As a consequence, in this chapter we will discuss the results in a more qualitative way. We used highly structured questionnaires to conduct the interviews. The hypotheses we defined for constructing the questionnaire can be directly related to the research questions defined in chapter 1. For each hypothesis one or several variables were identified which are to be measured in order to verify the hypothesis stated. Measurement is done by evaluating answers to pre-formulated questions.

8.3 Research Questions and Related Hypothesis

For ease of reference we repeat here the research questions defined in chapter 1. We separate the research questions according to their reference either to theory (RQ1a, RQ2a) or to practice (RQ1b, RQ2b) (see section 2.1) .

As the total number of variables which measure the stated hypothesis exceeded the focus of the questionnaire, we restricted ourselves only to those variables that directly add value to the main purpose of this questionnaire. The relationhip between the research questions stated in section 2.1 and the hypothesis used in our questionnaire are stated below:

- (RQ1a) (RQ1b) To what extent is the decomposition and hierarchical ordering of production planning problems in APS systems in agreement with theory and practice of planning and control of supply chains?
  - *(H7) Mismatch between the solution procedures and the problem structure are the main causes for concern –therefore workarounds and additional models are used*
  - *(H9) The generation of Available-To-Promise (ATP) on a detailed basis is for a large part realized outside of the Master Planning Functionality of APS systems*

- (RQ2a) (RQ2b) To what extent is in APS systems the interaction between models at different planning levels in agreement with theory and practice of planning and control of supply chains? (Bertrand *et al.*, 1990, Schneeweiss, 1999)
  - *(H3) The complexity of the planning solution and the degree of integration needed between the i2 modules is underestimated*
  - *(H4) There is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner*
  - *(H6) There is no explicit material coordination between Master Planner and Factory Planner*
  - *(H5) Planners do tend to find workarounds to the system that enable them to plan the way they perceive the problem, rather than the model of the system expects them to work*

- (RQ3) To what extent can modeling in APS systems ensure that the various levels of aggregation are still consistent?
  - *(H1) There is little formality in the modeling process of APS systems implementations*
  - *(H2) Depending on the degree of consistency and stability to be achieved not always the correct anticipation types are chosen*

- (RQ4) To what extent do APS systems incorporate the problem of information asymmetry and how can modeling help to overcome these problems?
  - *(H8) The modeling process can be improved to better use the tools that are provided by the APS vendors*

8.4 Discussion of Hypothesis and Results

In this section we discuss the results of our questionnaire-based interviews with respect to the stated hypotheses. We list all hypotheses in an sequence and draw either conclusions or propositions.

(H1) There is little formality in the modelling process of APS systems implementations
According to our observations in the in-depth case study in chapters 6 and 7, we can state that a number of model updates was planned for during the implementation process. In this context we define as formality that the model is generated by strictly following certain modeling steps in a sequence. We believe that the required formality can be ensured by clearly and explicitly defining mutually relating requirements and business rules. In chapter 6 we made the observation that the definition of business objectives, layers and priorities needs a deep understanding of the model from the user's perspective (O3) (subsection 6.4.2). The in-depth case study showed that stated requirements were not always consistent (O17).We are interested in whether the following steps were taken in a sequence:

- Development of a scope document, which defines in detail the scope of the system to be implemented and the expected benefits which are to be achieved after implementation
- Definition of Business Requirements and association to the planning tools being implemented
- Formal Description and Sequencing of Business Rules
- Specification of functionalities to be available after each Business Release
- Formal Description of all planning items to be considered in modeling
- Clear definition of data source for input data

The results of the interview showed that all companies had in the beginning of their implementation projects no clear idea what modeling is about. It took all of them a long time to understand modeling issues. In one case a period of nearly 8 months was necessary

in order to understand why and how a certain modeling should be made. Referring to the formal steps to be taken in advance of modeling, three of the four companies clearly defined a scope document. Referring to business requirements two of the four companies were able to relate business requirements and functionalities to i2 modules, whereas the remaining two companies spent a long time (nearly 9 months) formulating business requirements and functionalities in a written format. Referring to business rules, three of the four companies were able to define and prioritize business rules in order to start the modeling process – followed by sessions correcting these rules. The remaining company had interpretation problems in understanding the modules and in formulating the business rules appropriately. All companies very formally defined the Planning Items to be considered. Actually this was no surprise since Planning Items are part of the data structure necessary to build the model. Therefore, all data specific issues are formally defined, if people involved are compelled to do so. Planning Items in all companies were defined according to a common routing and common run times. In two of the four companies data requirements and data sources were very clear, in the remaining two companies data sources were completely unclear, as there were lots of interfaces to other systems.
Based on these results we cannot confirm hypothesis H1. Based on earlier evidence from the case study these results from the interview we formulate the following proposition:
Even if people are aware of the necessary formal process, the partial tasks are difficult to achieve. A long time is necessary before the modeling process in itself can be started. In this time preparatory steps as to create a common understanding about modeling, business requirements and rules, required functionalities and data sources are crucial.

(H2) If low consistency and high stability is achievable then the IA anticipation should be chosen as the solution. If average consistency and average stability is achievable, then the EA anticipation should be chosen as the solution. If high consistency and low stability is achievable, then the EE anticipation seems to be the right solution, but would in practice be infeasible.
According to chapter 4 our terminology used three types of anticipation: the IA anticipation, the EA anticipation and the EE anticipation. All types of anticipation distinguish between the anticipation type referring to the model part and the anticipation type referring to the information part. The IA anticipation describes an Implicit Model anticipation and an Approximate Information anticipation. The EA anticipation describes an Explicit Model

anticipation and an Exact Information anticipation. Translating this into the i2 terminology, the three anticipation types can be described as different possibilities to anticipate the reaction of Factory Planner into the Master Planner model. These possibilities adress the anticipation of the variables Work In Process, Resource Capacity and Sales Forecast.

The interview results show that different solution designs have been chosen. One of four companies chose the IA anticipation, although the stability of product mix was lower than 10% and the sales forecast was not accurate. Only processing times and capacity availability were fairly stable. The second company as well chose the IA anticipation, but product mix and sales forecast were not stable at all. Again only processing times and capacity availability were fairly stable. The third company chose the EA anticipation although sales forecast was not stable. Stability was seen only in product mix, processing times and capacity availability. The fourth company as well chose the EA anticipation although sales forecast accuracy, processing time stability and stability of capacity availability was not given. Only product mix was quite stable.

Summarizing, in our interviews we posed questions about accuracy and stability of product mix, sales forecast, processing times and capacity availability. We have to emphasize that the answers received only reflect what people thought to be stable and accurate. Each company implemented a certain anticipation type – but whether this choice was correct can only be shown by measuring performance. We have to admit that we completely relied on people’s perception. In fact, people in practice do not have a well defined concept for accuracy and stability. Hence, given the results, the questions we posed in this respect were not precise enough. Stability and Accuracy should have been formalized. We conclude that this is a subject for further research.

(H3) The complexity of the planning solution and the degree of integration needed between the i2 modules is underestimated

Our observations in the in-depth case study show that when starting the project the complexity of the planning solution and the degree of integration needed between the i2 modules was underestimated (O16) (subsection 6.5.2).When global requirements for the project implementation were formulated, it was not stated specifically that in order to fulfill these requirements for example, that Master Planning and Factory Planning tools have to be synchronized and operate in an integrated manner. Being more precise, the logical consequence of this is that the operational planning at factory level should be driven by the strategic Master Plan. Additionally, in order to achieve business goals, such as improving delivery performance, one important component is that order quoting is accurate and synchronized with capacity constrained finite planning. We are interested in the number of transfers between applications in the planning workflow, the average number of i2 modules involved in a single planning decision and the degree of underestimation related to the number of changes in the model.

The results of the interview showed that in all companies several system interfaces were implemented. These were interfaces to legacy systems and ERP systems both for planning purposes and for retrieving data. Three of the four companies used additional interfaces to other i2 modules and third party vendors. By taking as an example the decision of where to produce a certain product, interview results made different solution designs obvious. Two of the four companies made the decision by using only one i2 module. One company used three i2 modules and the remaining company made this decision outside of the i2 solution. The changes and additions which have been performed to the initial i2 solution until the final stage was reached differed from company to company, according to interview results. Two of the four companies did not perform many changes. One company performed a lot of changes during time, pointing out the main problem of people having difficulties in understanding the modeling. The last company added functionalities over time without having achieved a satisfactory integration between modules.

These results consequently confirm our hypothesis H3. The results lead us to the following conclusion:
The planning solution proposed by i2 is a complex one. The main risks in the implementation process are to make people understand the overall solution design and the way of modeling in each module. This has enormous consequences on the solution design to be developed and accordingly to the complexity of the final solution. The degree of integration between i2 modules is crucial as planning decisions might depend on the planning results of more than one module.

(H4) There is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner
In chapters 4, 6 and 7 we have discussed the anticipatory relationships between Master Planner and Factory Planner in i2's Tradematrix solution. We could observe that actual

status information may be fed back from FP to MP if so designed in the actual implementation. Further, we have demonstrated that the only top-down link between MP and FP is through the Available-To-Promise (ATP) / Demand Fulfilment engine (O29). The Master Planner in fact determines a plan based on aggregate modeling, which determines the ATP. The ATP / Demand Fulfilment engine conducts the order acceptance and due date setting functions, while after that the accepted orders, with their due dates are scheduled in FP completely independent from any earlier decisions at the MP level. As a consequence, any capacity smoothing or other planning activities at the MP level have no impact on the actual operation and performance may be much worse than it would be if some aggregate decisions taken earlier would be taken into account (in Bertrand *et al.*'s terms these would pertain to e.g., the aggregate capacity plan and the aggregate inventory plan). We are therefore interested whether this lack of integration between MP and FP is compensated by some manual planning activities.

The results of the interview indicate that this is not done. The three companies that were not yet live with the system obviously could not answer this question, but did not indicate to expect any problems with this, whereas the other remaining company indicated that this was not part of the formal workflow. However, they do indicate that a check takes place on consistency, but the FP results in this case are used to check the MP feasibility.

This information does not give any indication that our hypothesis needs to be rejected. Given the results of the analysis in chapter 4, the results of the in-depth case study in chapters 6 and 7, and the results of the interviews, we are confident in stating the following conclusion:

As there is no direct and formal top-down relationship between Master Planner and Factory Planner, this prevents adequate anticipation by the Master Planner and will lead to considerable inconsistencies between the Master Planner outcome (ATP –ie what is expected to be available) and the Factory Planner outcome (actual schedule – ie what is scheduled to be available).

(H5) Planners do tend to find workarounds to the system that enable them to plan the way they perceive the problem, rather than the way the model of the system expects them to work
One of our observations in the in-depth case study in chapter 6 was that there was a difference in the proposed vendor-workflow and the workflow used in practice (O21). The

vendor developed workflow suggests e.g. using both, infinite and finite capacity plans sequentially. Planners in practice preferred to start with a finite capacity plan rather than with an infinite capacity plan.

We are interested in measuring the consistency between the actual workflow and the initially defined workflow. Accordingly we are interested in observing which workflow is used in order to achieve a balanced plan. We are further interested in the changes made in order to achieve a feasible solution.

The interview results show that two of four companies were not yet in the position to give a statement about the used workflow. The remaining two companies defined as a workflow the following steps: infinite capacity run, finite capacity run, changes. Referring to changes made in order to achieve a feasible plan, two companies could not answer that question. The remaining two companies considered forecast changes and capacity modifications. All changes were discussed with the departments involved.

We have no evidence that the hypothesis needs to be rejected. Additionally, we do not have a strong conclusion either.

(H6) There is no explicit material coordination between Master Planner and Factory Planner

In the in-depth case study in chapters 6 and 7 we observed (subsection 6.4.2 and subsection 7.3.1) that the Master Planner functionality only covers one part of the Goods Flow Control function(O12), the APP level which forms the connection with the higher levels of control in the production organisation, where integration of the various control aspects of the organisation (sales, logistics, finance, personnel, etc) takes place. We observed that Work Order Release is not considered as a control task at Master Planner (O14).

Since Master Planner operates at an aggregated level of items, which are not physically existing materials, the management of stock levels for real physical materials is quite difficult and implies a matching procedure between planning items and real physical materials. An alternative is to shift the modeling of safety stocks and the generation of replenishment orders into other i2 modules as e.g. Inventory Planner . We are interested in the location (systemwise) of determination of time-phase work orders releasing materials from work orders.

The interview results show that different solution designs were used in each company. One company determined the safety stock norm outside of Master Planner, and performed safety stock management within Master Planner. The second company performed safety stock management by using Factory Planner and the additional i2 module Material Allocator. The third company used Factory Planner in addition to Master Planner. The fourth company did not consider safety stock management at all. In all three companies performing safety stock management additional legacy systems / ERP systems were used in order to keep all relevant Master Data and inventory numbers.

The results lead us to the following conclusion:
The material coordination between Master Planner and Factory Planner is not explicit. In the actual implementation at ALCO it may be included in various implicit ways. Accordingly, several solution designs are possible, including additional i2 modules. The consequences are a complex solution, several system interfaces and a complex workflow.

(H7) Mismatch between the solution procedures and the problem structure are the main causes for concern – therefore workarounds and additional models are used.
In chapter 6 dealing with the in-depth case study and in section 6.5 about Modeling Experiences and User Impressions we observed that the way in which Planning Items were defined in the Master Planner model was too confusing to support planners in their daily life. The picture delivered by the model structure did not facilitate the necessary transparency regarding effects of changes, or effects on intermediate and raw material items. This in principle goes in line with our observation in section 6.5 that the complexity of the planning solution usually is underestimated (O16). We are interested whether a mismatch between the solution procedure and the problem structure is compensated by additional reports to review data, by additional calculations outside the i2 system or by additional mapping procedures for aggregating/disaggregating data. In addition to that we are interested in what kind of data (model structure, input data, objective functions) are considered to be changeable during the workflow, as this is another indicator for the degree of mismatch.

The results of the interview show that the mismatch between the solution procedure and the problem structure is indeed compensated by additional reports. Three companies pointed out that they either implemented additional reporting tools or that they built reports by themselves. One company could not answer that question as the tool was not used yet in that degree. All companies in general said that the transparency regarding the results is very poor and that reports take very long to run. It was common agreement that the i2 problem window was difficult to understand in itself. All companies used diverse aggregation / disaggregation rules in the overall solution process, which were either done manually or automatically in the i2 modules themselves or in external applications. Referring to desired changes in data, three companies considered the model structure as fixed. The fourth company was interested in changing the underlying objective functions. Three companies were interested in changing input data, as process data, forecast data, lead times or even safety stock data. One company did not consider changing input data as crucial.

This information leads us to the following conclusion:
A mismatch between the solution procedure and the problem structure is compensated by additional reports to review data , by additional calculations outside the i2 system and by additional mapping procedures for aggregating/disaggregating data. We conclude that in the i2 TradeMatrix software considered there is insufficient transparency, inadequate reporting and problem solving support. In addition run times of the software considered are too long for scenario-based planning.

(H8) The modeling process can be improved to better use the tools that are provided by the APS vendors
As described in chapter 1 there is a difference between the feasibility in terms of the i2 model and the feasibility in terms of the planner. This difference has a big impact on how and by which iterative procedures planners can achieve a good and feasible solution. From the planners point of view we are interested in the perception of the quality of i2 plans, in the kind of acceptable model simplifications, in the kind of still acceptable infeasibilities in a plan and in the kind of feasibility criteria.

Referring to the perception of quality of plans, interview results show that two of four companies could not answer that questions as the experience was not gained yet. The third company stated that the plans were mostly correct. The fourth company stated that plans were not generated automatically, but always needed to be checked regarding feasibility for production and a lot of work was necessary in advance to create somehow acceptable plans.

We have no evidence that the hypothesis needs to be rejected. Additionally, we do not have a strong conclusion either.

(H9) The generation of ATP's on a detailed basis is for a large part realized outside of Master Planner, within the ATP/Demand Fulfillment engine

In the in-depth case study described in chapters 6 and 7 we made the observation that the main motivation to define a detailed seller structure within the ATP engine was reduction of complexity in Master Planner (compare (O26)). Market Sectors were almost neglected in Master Planner, as other wise the total number of Planning Items in Master Planner would have been exploded and second they would not be global enough to get forecasted. But it was still essential that there are Planning items defined according to the given seller structure, as a basis for Due Week Quoting.Accordingly, the constrained forecast per Planning Product as computed in Master Planner is transferred to the ATP engine, where it has further to be split into the percentages of the predefined seller structure. In subsection 7.3.2 we made the observation that defining the seller structure in the ATP engine will make the workflow more complicated (O26). We are interested to observe the level of ATP detail in Master Planner, in which tool a detailed seller structure is defined and the effects on the planning worklow.

The interview results show that all companies did not model a detailed seller structure in Master Planner – instead it was modeled e.g. in modules for Order Acceptance. All companies used aggregation / disaggregation rules to first translate forecasts for sales purposes to forecasts for planning purposes and to second split the constrained forecast into the detailed seller structure.

The results lead us to the following conclusion:

Because of complexity reasons the modeling of detailed seller structures in a proper representative of APS software, like i2 TradeMatrix, is not seen as a task of Master Planning. Consequently it is not performed insight the Master Planner module but rather in additional modules outside of Master Planner. Nevertheless this has as a consequence that the planning workflow is more complicated as additional disaggregation procedures are to be performed. But at this point in time we emphasize that this is a design concept followed explicitly by most APS system vendors.

8.5 Speculating on some observations

In this chapter, we have discussed, in a rigorous manner, the observations from the case study and the results from the interview and linked them, wherever possible to propositions and conclusions. During the entire project, we have however made additional observations that have been included in the various descriptions of the studies, but which we have not been able to develop into propositions and conclusions. We do however have strong thoughts and ideas, supported by some intuitive reasoning, following these observations, that have considerable relevance for the practice of modeling and implementing APS systems.
In this section, we will briefly address three of these issues, namely:

- The underestimation of the modeling process
- Hierarchical positioning of more-or-less independent modules
- The omnipresence of planner-driven workarounds once systems have been implemented

These topics are all strongly related and included in our research. Coming back to the issue of our research, our focus was the modeling process itself. We could observe that in general the modeling process is underestimated. But why? Our speculation is that the modeling skills required for a succesful implementation process are a combination of an academic OR/OM education and practical modeling experiences. Such a combination of skills is quite rare and not available sufficiently to support the multitude of current APS implementations. If a team of specialists combines the two types of skills in an APS system implementation project, two different kinds of people have to work and communicate together, although - in the metaphorical sense - they speak a different language. Accordingly, this reflects a communication problem caused by a partial incompatibility of methods used in practice when conducting the actual modeling process and theoretical methodologies used in Operations Research. Being more precise, we expect that the methods used in practice cannot be deduced without further evidence from the methodologies known in science. Some methods used in practice are based on theories, some not, and although theory exists, it is not used. For example, the framework developed by Bertrand *et al.* (1990) has been tested in a multitude of student's and consulting projects, where it provided its validity, yet implementation of APS and ERP systems is still based on the MRP II framework of which clear deficiencies have been reported on in the literature. Another issue is the modules of APS systems themselves. These modules are typically based on deterministic mathematical programming models. This implies that uncertainty is not inherently taken into account. This in itself has a considerable impact on the actual quality of the solutions proposed, since these are in principle non-optimal (de Kok/Fransoo, 2002). On top of that each module incorporates a specific model in isolation, with the implicit assumption that a collection of partial solutions create an overall solution. In practice this is not the case, hence people have to create an overall consistent solution or, as is the case mostly, ignore the various inconsistencies and face the resulting problems at shop floor level. This implies that at local shopfloor level many decisions must be taken relating to lacking materials and resources that are likely to be inconsistent with overall objectives.

Another issue is the hypothesis that planners do tend to find workarounds to the system that enable them to plan the way they perceive the problem, rather than the way the model of the system expects them to work. We speculate that in practice, since planners are not firm with the theories and concepts of modern APS systems, people have difficulties in understanding how these systems work. Accordingly they stick to what they know and to the methods they have used in the past. The consequence is that they try to use the systems in the way they are familiar with, which implies that the model's underlying strategy is not used and accordingly cannot lead to the expected benefits. Additionally, we observed that the overall solution consistency between modules is not very good. So, regardless of how people work, modules need to be coordinated. This, in many cases leads to workarounds, especially by taking into account that any model will not cover reality as it is covered in the planner's mind.

Note that the above reasoning is very speculative, since support to these statements can only be given by measuring performance along several dimensions. More precisely, we state that overall performance depends on the right modeling choices. For example, choosing the correct anticipation types depends on the measurement of consistency and stability. Another example is the modeling choice of using ATP as the only link between MP and FP, which depends on the measurement of data accuracy and data uncertainty between MP and FP. To-date such performance measurement programs have not been implemented.

Chapter 9

Conclusions and Recommendations

The focus of this thesis was the theoretical and empirical assessment of i2 TradeMatrix with respect to the modeling of decision making processes. Here, i2 TradeMatrix represents the currently available software for Master Planning. The theoretical part of our research included a review of hierarchical planning systems (chapter 3) (Bertrand *et al*, 1990; Schneeweiss, 1999) revealing that current theories on Hierarchical Production Planning are incomplete and (partially) incorrect. Based on the conceptual framework of Schneeweiss (1999), we developed a theory on anticipation, introducing the concepts of consistency and stability in the context of Supply Chain Planning as a special case of HPP and proposing a complete typology for the anticipation concept of Schneeweiss (cf. chapter 3). The framework developed (chapter 4) was the basis for formulating a number of initial hypotheses in our research. We applied our theory on the in-depth case study, implying that we intervened in the implementation during our research. These interventions have been carefully documented and served to set the conditions for testing the development of the theory. More precisely, we used the in-depth case study (chapter 5) to describe the modeling and implementation process of the APS software i2 TradeMatrix in an aluminum company, called ALCO. The results (chapters 6 and 7) have led to a number of observations which in turn were the basis for fomulating further propositions and hypotheses. All results and theoretical assessments performed in our research were used for developing a questionnaire, as a basis for small scale questionnaire-based interviews, in which detailed questions regarding modeling were formulated. We conducted our interviews at selected industrial companies from the Metals and High Tech sector, which had basic experiences in implementing the i2TradeMatrix software. Based on observations, hypotheses and results of the questionnaire–based interviews, we could derive either propositions or conclusions with respect to our research questions (chapter 1).

9.1 Answers to Research Questions

In this section we formulate the answers to our research questions, outlined in chapter 1. For ease of reference we repeat the research questions and refer to the detailed explanation of each question in section 1.4.

- (RQ1a) (RQ1b)To what extent is the decomposition and hierarchical ordering of production planning problems in APS systems in agreement with the theory and practice of planning and control of supply chains?

  As outlined in section 1.4, this research question puts special focus on the decomposition and hierarchical ordering of subproblems in current APS systems, as it is already defined by their vendors. Examples for predefined decision processes in i2 TradeMatrix are the processes of ATP-generation, Due Week Quoting, Global Production Planning, Factory Planning and Scheduling. As illustrated in section 1.4 for almost each of these decision processes a separate software module has been developed – which leaded us to the question whether this decision process structure goes in line with the theory and practice of planning and control of supply chains. We based our research on the conceptual frameworks for hierarchical production planning of Schneeweiss (1999) and Bertrand *et al.* (1990).
  The following hypotheses have been related to these research questions (chapter 8):
  (H7) Mismatch between the solution procedures and the problem structure are the main causes for concern – therefore workarounds and additional models are used.
  (H9) The generation of ATP's on a detailed basis is for a large part realized outside of Master Planner, within the ATP/Demand Fulfillment engine.
  Referring to hypothesis (H7), in subsection 6.5.2 we made the observation that the solution technique of the developed i2 model was not related to the logical structure of the problem to be solved(O24). Main reason was the definition and selection of Planning Items in Master Planner (see (O15)), as the picture delivered by the model structure itself was too confusing for planners. With respect to (H7), in chapter 8 we draw the conclusion that a mismatch between the solution procedure and the problem structure is indeed compensated by additional reports to review data, by additional calculations outside the i2 system and by additional mapping procedures for aggregating /disaggregating data. Especially mapping procedures are necessary in i2 TradeMatrix because of the extensive decomposition of decision problems and their interdepencies.

Referring to hypothesis (H9), in subsection 7.3.2 we pointed out that the detailed generation of ATP's outside of Master Planner is a generic solution approach proposed by many APS companies, as well by i2 TradeMatrix. Yet, we emphasized that defining the seller structure in the ATP/Demand Fulfilment engine makes the workflow more complicated (O26). With respect to (H9), in chapter 8 we draw the conclusion that, because of complexity reasons the modeling of a detailed ATP seller structure was not performed in the Master Planner module but rather in the additional i2 module called Demand Fulfilment. Nevertheless this had as a consequence that the planning workflow was more complicated as additional disaggregation procedures had to be performed. We emphasized that this was a design concept followed explicitly by most APS system vendors.

In order to answer our research question we can state that the decomposition and hierarchical ordering of production planning problems in the APS software i2 TradeMatrix in practice causes difficulties in using the software. These difficulties are mainly related to workarounds and the development of additional models, reports and calculations. Additionally, specific decompositions lead in practice to more complicated workflows.

- (RQ2a) (RQ2b) To what extent is in APS systems the interaction between models at different planning levels in agreement with the theory and practice of planning and control of supply chains? (Bertrand *et al.*, 1990, Schneeweiss, 1999)

  According to section 1.4 this research question deals with the interaction between predefined subproblems. We stated that i2 Technologies developed industry specific templates in which functional workflows between single modules have already been defined, based on the specific needs of representative companies in the Metals/High Tech Industry. We raised the question whether the predefined workflow is consistent with the necessary workflow of the companies in which the systems were to be implemented.

  The following hypotheses have been related to these research questions (chapter 8):

  (H3) The complexity of the planning solution and the degree of integration needed between the i2 modules is underestimated

  (H4) There is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner

  (H6) There is no explicit material coordination between Master Planner and Factory Planner

(H5) Planners do tend to find workarounds to the system that enable them to plan the way they perceive the problem, rather than the model of the system expects them to work

Referring to hypothesis (H3) we indeed observed in the in-depth case study that when starting the project the complexity of the planning solution and the degree of integration needed between the i2 modules was underestimated (O16) (subsection 6.5.2). Observations which led to this hypothesis were e.g. (O3), stating that business objectives, layers and priorities cannot be defined without a deep understanding of the user, and (O20), stating that selecting a sequence of business objectives indeed is related to choosing the next cycle of decision making. With respect to (H3), in chapter 8 we draw the conclusion that the planning solution proposed by i2 is a complex one. The main risks in the implementation process were to make people understand the overall solution design and the way of modeling in each module. This had enormous consequences on the solution design to be developed and accordingly to the complexity of the final solution. The degree of integration between i2 modules is crucial as planning decisions might depend on the planning results of more than one module.

Referring to hypothesis (H4) we observed (subsection 6.4.2) that no constraints for inventory management were modeled in the Initial Modeling Phase (O9). Even shifting the optimal management of stock levels in the ERP system had as a consequence that Master Planner and ERP were not operating on the same constraints. We further observed that the ATP as the only link between Master Planner and Factory Planner was not sufficient. With respect to (H4), in chapter 8 we made the conclusion that, as there is no direct and formal top-down relationship between Master Planner and Factory Planner, this prevents adequate anticipation by the Master Planner and will lead to considerable inconsistencies between the Master Planner outcome (ATP –ie what is expected to be available) and the Factory Planner outcome (actual schedule – ie what is scheduled to be available). Referring to hypothesis (H6) we observed in the i2 TradeMatrix solution a distinction between GFC and PUC. In terms of i2 the GFC function is implemented through combination of Master Planner and Factory Planner functionality. The Master Planner function only covers a part of the GFC function (subsection 6.4.2). Master Planner in fact does not cover neither material coordination nor work order release. With respect to hypothesis (H6), in chapter 8 we made the conclusion that the material coordination between Master Planner and Factory Planner is not explicit. In the actual implementation at ALCO it could be included in various implicit ways. Accordingly, several solution designs were possible, including additional i2 modules.

The consequences are a complex solution, several system interfaces and a complex workflow.

Referring to hypothesis (H5) we observed in the in-depth case study that there was a difference in the proposed vendor-workflow and the workflow used in practice(O21). The vendor developed workflow suggests e.g. using both, infinite and finite capacity plans sequentially. Planners in practice preferred to start with a finite capacity plan rather than with an infinite capacity plan. With respect to hypothesis (H5), in chapter 8 we had no evidence that the hypothesis needs to be rejected. Additionally, we did not have a strong conclusion either.

In order to answer our research questions, our main conclusion is that within i2 TradeMatrix there is big flexibility in designing the interaction between models at different planning levels. With respect to practice, this in reality leads todifficulties in understanding the solution design and has as a consequence that the degree of integration between i2 modules might not be sufficient. With respect to theory, we conclude that, in contrast to the theories of Schneeweiss (1999) and Bertrand *et al*. (1990), in i2 TradeMatrix there are no explicit rules / indications defined for the interaction of modules at different levels. As an example we can state there is no direct and formal relationship between Master Planner and Factory Planner, which might lead to considerable inconsistencies in the overall solution. Instead, i2 considers interaction implicitly which might lead to complex solution designs, several system interfaces and complex workflows.

- (RQ3) To what extent can modeling in APS systems ensure that the various levels of aggregation are still consistent?

As illustrated in section 1.4, this research question adresses the problem of consistency between various levels of aggregation and the interaction of models at different levels. We stressed that consistency between planning levels is a requirement for the capability of SCP software to generate optimal or even feasible plans. Furthermore, we elaborated that consistency and stability of solutions are highly dependent from each other (chapter 4). It was our belief that a correct model at different planning levels and in general a coordinated approach can ensure that the consistency of solution designs can be achieved.

The following hypotheses have been related to this research question (chapter 8):
(H1) There is little formality in the modelling process of APS systems implementations
(H2) If low consistency and high stability is achievable then the IA anticipation should be chosen as the solution. If average consistency and average stability is achievable, then the EA anticipation should be chosen as the solution. If high consistency and low stability is achievable, then the EE anticipation seems to be the right solution, but would in practice be infeasible.
Referring to hypothesis (H1) in subsection 6.3.2 we observed very little formality in the modeling process (O1). More precise, in subsection 6.4.3 we stated that, the requirements defined in the beginning of the implementation project at ALCO were not always consistent (O17). An example for this observation was that the requirement of the planning department that order splitting is not feasible, was in contrast to the business goal of reducing delivery time and was a restriction to the available functionalities of the system. With respect to hypothesis (H1), in chapter 8 we formulated the proposition that even if people are aware of the necessary formality process, the partial tasks are difficult to achieve. A long time is necessary before the modeling process in itself can be started. In this time preparatory steps as to create a common understanding about modeling, business requirements and rules, required functionalities and data sources are crucial.
Referring to hypothesis (H2), in subsections 6.3.2 and 7.1.1 we observed that in the Initial Modeling Phase of our case study, no anticipation types have been chosen (O2) (O6). With respect to hypothesis (H2), in chapter 8 we formulated the correct choice of anticipation types depending on consistency and stability issues as a matter for further research.
In order to answer our research question, we conclude that the creation of a common understanding about modeling and required functionalities is a preparatory and crucial step before any modeling process can start. In this context, the choice of correct anticipation types, based on the consistency and stability issues to be achieved is still an open question. As we stated based on our results (chapter 8), the questions we posed in this respect were not precise enough. We recommend to formalize stability and accuracy and submit this subject for further research.

- (RQ4) To what extent do APS systems incorporate the problem of information asymmetry and how can modeling help to overcome these problems?

As outlined in section 1.4, this research question pays special attention to the concept of information asymmetry, with the sense that e.g. the mid term planning has to use less detailed and different information then the short term planning. It was our belief that the fact that information asymmetry exists, leads to the necessity to anticipate at a higher level decision what may happen to the lower level decisions.

The following hypothesis has been related to this research question (chapter 8):

(H8) The modeling process can be improved to better use the tools that are provided by the APS vendors.

Referring to hypothesis (H8), in chapter 8 we had no evidence that the hypothesis needs to be rejected. Additionally, we did not have a strong conclusion either.

In order to answer research question (RQ4) we can say, that in i2 TradeMatrix there is no implicit anticipation concepts designed. Hence, we conclude that those systems do not consider the problem of information asymmetry.

9.2 Recommendations

In this section we formulate the recommendations based on our research. We can distinguish between recommendations for modeling in Advanced Planning Systems and recommendations for further research.

9.2.1 Recommendations for Modeling in Advanced Planning Systems

Recommendations for modeling are derived from our conclusions. In fact they show the discrepancies between current modeling in Advanced Planning Systems (As-Is-Situation) and the way modeling should be performed (Should-Be-Situation) based on our findings. Our research results describe the transformation process from As-Is to Should-Be.

As-Is-Situation	Should-Be-Situation	Transformation Process based on research results
Decomposition and Hierarchical Ordering of Production Planning Problems (RQ1) The decomposition and hierarchical ordering of production planning problems in the APS software i2 TradeMatrix in practice causes difficulties in using the software. These difficulties are mainly related to workarounds and the development of additional models, reports and calculations. Additionally, specific decompositions lead in practice to more complicated workflows.	**Decomposition and Hierarchical Ordering of Production Planning Problems** The decomposition and hierarchical ordering of production planning problems should not only be based on criteria for easier modeling, but should reflect a good balance between the modeling approach and the use of the model in practice.	**Decomposition and Hierarchical Ordering of Production Planning Problems** Before starting the modeling process, modelers and users should spend sufficient time to understand the planning problem in itself. This is the basic requirement for generating a solution design which is related to the logical structure of the real problem. When considering problem decompositions for ease of modeling, modelers and users together should estimate the consequences with respect to additional models, calculations and resulting workflows. This estimation should lead to the final decision, acceptable by both modelers and users.
Interaction between models at different planning levels (RQ2 Within i2 TradeMatrix is a big flexibility in designing the interaction between models at different planning levels. With respect to practice, this in reality leads to difficulties in understanding the solution design and has as a consequence that the degree of integration between i2 modules might not be sufficient. With respect to theory, in contrast to the theories of Schneeweiss (1999) and Bertrand *et al.* (1990), in i2 TradeMatrix there are no explicit rules / indications defined for the interaction of modules at different levels. As a example we can state there is no direct and formal relationship between Master Planner and Factory Planner, which might lead to considerable inconsistencies in the overall solution. Instead, i2 considers interaction implicitly which might lead to complex solution designs , several system interfaces and complex workflows.	**Interaction between models at different planning levels** Within i2 TradeMatrix there should be an explicit formal relationship between modules at different planning levels. This is especially true for Master Planner and Factory Planner, where relationships should be formulated in terms of instructions and constraints.	**Interaction between models at different planning levels)** i2 TradeMatrix is characterized by the complexity of its planning solution. In order to interact between modules at different planning levels, we propose to explicitly formulate the links between Master Planner and Factory Planner. Special consideration should be put on the functions of Material Coordination and Work Order Release.

9.2.2 Recommendations for Further Research

Recommendations for further research result in all those cases in which we could not derive strong conclusions.

- A longitudinal study on performance using a large scale survey
  In some of the hypotheses derived from our concepts we assumed that overall performance depends on the right modeling choices. In order to verify these hypotheses a measurement program over time has to be defined. Based on this measurement program different companies can be tested and compared.
- Development of guidelines for the choice of correct anticipation types, based on the consistency and stability issues to be achieved
  In order to measure performance with respect to consistency and stability we recommend to formalize stability and accuracy as a first step in further research. Guidelines should be developed, based on which each company can choose the anticipation type which fits best into its environment.
- Need for numerical studies detailing out HPP concepts to test concrete modeling choices
  Different modeling choices (e.g. a) use ATP as the only link between MP/FP and b) anticipate FP into MP) should be compared by using a discrete event simulation environment to simulate the specific real life environment where the software is used.
- Development of guidelines for modeling to support both modelers and users
  As modeling in itself is a very complex task in i2 TradeMatrix, guidelines should be formulated which support the modeling process in i2 implementations. Examples are:

  - guidelines for developing Planning Items
  - guidelines for integration between Master Planner and Factory Planner
  - guidelines for integration between models at different planning levels, e.g. with respect to the functionality of material coordination
  - guidelines for deciding which modules should be used for which planning problem with respect to decomposition problems and complexity of workflow

References

(1) Bertrand, J.W.M., J.C. Wortmann, and J.Wijngaard (1990) *Production Control: A Structural and Design Oriented Approach*, Amsterdam: Elsevier.

(2) Bitran, G.R., and D. Tirupati (1993) Hierarchical Production Planning. In: S.C. Graves, A.H.G. Rinnooy Kan, and P.H. Zipkin (Eds.) *Logistics of Production and Inventory*, Amsterdam: North Holland, 523-568.

(3) Bitran, G.R., and A.C. Hax (1977) On the Design of Hierarchical Production Planning Systems, *Decision Sciences* 8(1): 28-55.

(4) Blackburn, J., and R. Millen (1982) Improved Heuristics for Multi-Stage Requirements Planning Systems, *Management Science* 28: 44-56.

(5) Bylinski, G. (1999), The Challenges Move in on ERP, *Fortune*, 140(10): 306C.

(6) De Kok, A.G., and J.C. Fransoo (2002) Supply Chain Operations: Comparing Planning Concepts. In: S.C. Graves and A.G. De Kok, *Supply Chain Management*, Amsterdam: North Holland, in press.

(7) Forza, C. (2002) Survey Research in Operations Management, *International Journal of Operations and Production Management*, in press.

(8) Crawford, S., and V.Wiers (2001) From Anecdotes to Theory: A Review of Existing Knowledge on Human Factors of Planning and Scheduling. In: B. MacCarthy and J.Wilson, *Human Performance in Planning and Scheduling*, London: Taylor & Francis, 15-43.

(9) Galbraith,J. (1973) *Designing Complex Organizations*, Massachusetts: Addison-Wesley Publishing Company.

(10) Goldratt, E.M., and J. Cox (1984) *The Goal: Excellence in Manufacturing*, Croton-on-Hudson: North River Press.

(11) Graves, S.C., A.H.G. Rinnooy Kan, and P.H. Zipkin (Eds.) (1993) *Logistics of Production and Inventory*, Amsterdam: North Holland.

(12) Handfield, R.B., and E.L. Nichols Jr. (1999) *Introduction to Supply Chain Management*, Upper Saddle River: Prentice Hall.

(13) i2 Technologies (1999), www.i2.com

(14) Klein, H.K., and M.D. Myers (1999) A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems, *MIS Quarterly* 23 (1): 67-88.

(15) Lawrence, S.R. (1997) Heuristic, Optimal, Static, and Dynamic Schedules When Processing Times Are Uncertain, *Journal of Operations Management* 15(1): 71-82.

(16) Lee, H.L., and C. Billington (1995), The Evolution of Supply-Chain-Management Models and Practice at Hewlett-Packard, *Interfaces*, 25(5), 42-63.

(17) Markus, M.L., and C. Tanis (1999) The Enterprise Systems Experience - From Adoption to Success. In: R.W.Zmud (Ed.) *Framing the Domains of IT Management: Projecting the Future through the Past*, Cincinnati: Pinnaflex Educational Resources.

(18) Meal, H.C. (1984) Putting Production Decisions Where They Belong, *Harvard Business Review* 62(2) 102-111.

(19) Negenman, E.G., C.A.J. Hurkens, A.G. De Kok, and J.K. Lenstra (1998) Linear Programming Models for Production Planning, *Working Paper* TM/LBS/9811., Eindhoven: Technische Universiteit Eindhoven.

(20) Schalla, A.J., J.C. Fransoo, and A.G. De Kok (2000) Aggregate Supply Chain Modeling in Advanced Planning and Scheduling Software – An Empirical Study, *Working Paper* TM/LBS/00-05, Eindhoven: Technische Universiteit Eindhoven.

(21) Schneeweiss, C (1999) *Hierarchies in Distributed Decision Making* , Berlin: Springer.

(22) Schneeweiss, C. (1995) Hierarchical Structures in Organisations: A Conceptual Framework, *European Journal of Operations Research* 86(1) 4-21.

(23) Schonberger, R.J. (1982) *Japanese Manufacturing Techniques*, New York: Free Press.

(24) Simchi-Levi, D., P. Kaminsky, and E. Simchi-Levi (2000) *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*, London: Irwin McGraw.Hill.

(25) Stadtler, H., and C. Kilger (Eds.) (2000) *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies,* Berlin: Springer.

(26) Stephens, S. (2000) *Supply Chain Council & Supply Chain Operations Reference Model Overview*, Supply Chain Council Inc., www.supply-chain.org

(27) Steven, M. (1998), *Produktionstheorie*, Gabler Verlag.

(28) Vollmann, T.E., W.L. Berry, and D.C. Whybark (1984) *Manufacturing Planning and Control Systems*, Homewood: Dow Jones-Irwin.

(29) Wortmann, J.C., D.R. Muntslag, and P.J.M. Timmermans (Eds.) (1997) *Customer-driven Manufacturing*, London: Chapman & Hall.

(30) Yin, R.K. (1994) *Case Study Research: Design and Methods*, London: Sage, 1994.

Appendix A

Hypothesis and Assignment of Measurable Variables and Formulated Questions

In Appendix A we give an overview of the hypothesis considered, related to measurable variables and formulated questions. The questions can be found in the detailed questionnaiere in Appendix B.

(H1) There is little formality in the modelling process of APS systems implementations

(V4) Variable to be measured:
Degree of Formality of Modelling Process

(Q48a-V4) Give your definition of modeling
(Q48b-V4) Did you know what modelling was about?
(Q49-V4) Before starting the technical modelling process, did you clearly define the scope of the system to be implemented and the benefits to be achieved?
(Q50-V4) Before starting the modelling process, did you clearly define the Business Requirements?
(Q51-V4) Before starting the modelling process, did you formally describe all functionalities to be available after each Business Release?
(Q52-V4) Before starting the modelling process, did you formally describe all important Business Rules of your company?
(Q53-V4) Before starting the modelling process, did you put priorities to all Business Rules?
(Q54a-V4) Before starting the modelling process, did you formally define all Planning Items to be considered within the Master Planner model?
(Q54b-V4) Before starting the modelling process, did you formally define the resource structure to be considered within the Master Planner model?
(Q54c-V4) Before starting the modelling process, did you formally define the lead times to be considered within the Master Planner model?
(Q54d-V4) Before starting the modelling process, did you formally define the processing times to be considered within the Master Planner model?

(Q55-V4) Before starting the modelling process, did you formally define where all necessary input data should come from?

(H2) If low consistency and high stability is achievable then the IA anticipation should be chosen as the solution. If average consistency and average stability is achievable, then the EA anticipation should be chosen as the solution. If high consistency and low stability is achievable, then the EE anticipation seems to be the right solution, but would in practice be infeasible.

(V13) Variable to be measured:
Match of anticipation used and expectations regarding consistency and stability
(V14) Variable to be measured:
Degree of stability in demand
(V15) Variable to be measured:
Degree of stability of primary process (Processing times)
(V16) Variable to be measured:
Predictability of detailed demand

(Q79-V14) What is stability in your product mix?
(Q80-V16) How accurate is your sales forecast?
(Q81-V15) Are processing times and capacity availability fairly reliable and stable?
(Q82-V13) How do you integrate Work In Process into the Master Planner model? (Keep in mind that there are three options, especially regarding present and future WIP)
(Q83-V13) How do you integrate netted capacity (actual free capacity per MP bucket and MP resource) into the Master Planner model?
(Q84-V13) How do you integrate netted forecast (actual orders and planned orders per planning item and week substracted from the unconstrained forecast per planning item and week) into the Master Planner model?
(Q85-V15) Are lead times as used in Factory Planner stable?

(H3) The complexity of the planning solution and the degree of integration needed between the i2 modules is underestimated

(V6) Variable to be measured:
Degree of complexity of the planning solution (number of transfers between applications in the planning workflow, e.g. EXCEL/i2/ERP/EXCEL..etc)
(V7) Variable to be measured:
Degree of integration between i2 modules (average number of i2 modules involved in a single planning decision)
(V8) Variable to be measured:
Degree of underestimation, related to the number of changes in the model

(Q61-V6) In the planning workflow how many system interfaces are involved?
(Q62-V6) What is required to generate the Master Planner Flow Quantities per routing and operation?
(Q63-V7) (Q63-V9) Do you check the results of Factory Planner with the due dates given to the customer, based on ATP?
(Q64-V7) How many different modules/systems are involved in deciding where to produce a certain product?
(Q66-V8) How many changes and additions have been performed to the initial i2 solution until the final stage was reached?
(Q67-V8) Did you change the way the decision of where to produce a certain product should be made during the modeling phase?

(H4) There is no direct (formal) relationship in terms of instructions / constraints between Master Planner and Factory Planner

(V9) Variable to be measured:
Degree of formal (constraint) relationships between Master Planner and Factory Planner

(Q63-V7) (Q63-V9) Do you check the results of Factory Planner with the due dates given to the customer, based on ATP?
(Q68-V7) /Q68-V9) Do you use the Master Planner plan to check the Factory Planner plan?

(H5) Planners do tend to find workarounds to the system that enable them to plan the way they perceive the problem, rather than the model of the system expects them to work

(V25) Variable to be measured:
Consistency between actual workflow and initially defined workflow

(Q104-V25) Which workflow do you use in order to come to a balanced plan?
(Q106-V25) When you do an infinite capacity run and you see that capacity utilisation is > 100 %, do you decide to modify capacity and why?
(Q107-V25) When you do an infinite capacity run and you see that capacity utilisation is > 100 %, do you decide to modify forecast and why?
(Q108-V25) Do you discuss the changes you do in capacity and forecast with other departments like sales, production, etc?
(Q109-V25) What input data and how do you change in order to achieve the solution you want?

(H6) There is no explicit material coordination between Master Planner and Factory Planner

(V12) Variable to be measured:
Location (systemwise) of determination of time-phase workorders releasing materials from inventory (where is the actual release of material done?)

(Q73-V12) In which i2 modules have you decided to manage stock levels?
(Q74-V12) At which level did you model planning items in Master Planner : on detailed item level, on item level which corresponds to real material higher in the supply chain, or on aggregated item level?
(Q75-V12) Which other systems do you use in order to manage stock levels
(Q76-V12) Where are replenishment orders generated?
(Q77-V12) Which modules determine the due date of work orders?
(Q78-V12) By defining planning items for Master Planner did you take into account exceptionally long lead times? e.g. products which use special auxiliary materials and hence have a longer lead time?

(H7) Mismatch between the solution procedures and the problem structure are the main causes for concern – therefore workarounds and additional models are used.

(V3) Variable to be measured:
Degree of Mismatch

(Q39-V3) Do you need additional reports to review the Master Planner database - after having inserted all input data?
(Q40-V3) How do you translate forecasts for marketing and sales purposes to forecasts for planning purposes? Do you use any aggregation rules? What factors (aspects) determine these aggregation rules?
(Q41-V3) Which detailed information level did you use to define the Resource Calendars ?
(Q42-V3) What kind of calculations or data are you using outside of the i2 system?
(Q43-V3) What kind of input data and why would you like to be able to change?
(Q44-V3) What kind of data effecting the model structure would you like to be able to change?
(Q45-V3) Which alternate objective functions would you like to be able to vary?
(Q46-V3) What were the reasons for selecting the chosen software? Try to explain and structure your original problem
(Q47-V3) Why do you think that the chosen software fits best into your company's requirements?

(H8) The modeling process can be improved to better use the tools that are provided by the APS vendors

(V20) Variable to be measured:
Degree of adherence to i2 plans
(V21) Variable to be measured:
Degree of perceived correctness to i2 plans
(Q94-V20) What kind of i2-model simplifications do you accept?
(Q96-V21) How do you perceive the quality of the plans from i2?
(Q97-V20) After having designed the model, what business policies and how do you change in order to achieve the solution you want?

(Q98-V20) (Q98-V21) After having designed the model, what kind of infeasibilities in a plan would you accept?
(Q99-V21) When you review the balanced plan, when is this plan for you feasible?
(Q100-V21) In what respect differ the i2 plans from that what you expect?

(H9) The generation of ATP's on a detailed basis is for a large part realized outside of Master Planner, within the ATP/Demand Fulfillment engine

(V11) Variable to be measured:
Level of ATP detail in Master Planner

(Q71-V11) By defining Planning Items in Master Planner did you define them as well according to the final market secors?
(Q72-V11) In which tool have you defined a detailed seller structure for due week quoting?
(Q40-V11) How do you translate forecasts for marketing and sales purposes to forecasts for planning purposes? Do you use any aggregation rules? What factors (aspects) determine these aggregation rules?

Appendix B

Questionnaire

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer
Introductory Questions					
	Industrial Sector				
	Q1	Describe the industrial sector your company is operating in			
	Customer Order Decoupling Point				
	Q3	Indicate locations of CODP. BuyToStock/BuyToOrder/CustomerToOrder?			
	Q4	Does it vary by product and/or customer?Indicate each in terms of percentage products, turnover, customers			**1-Products** __________% **2-Turnover** __________% **3-Customers** __________%
	Manufacturing and Distribution Model				
	Q5	How many factories?			
	Q6	Where are they located?			
	Q7	Are there any capacity issues at factories?			
	Q8	Is there any capacity balancing between factories? *If no please skip Q9-Q12*			
	Q9	Are there any business-rules around allocating demand to factories/mfg. lines?			

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer
	Q12	What levels of organisation are involved in dealing with cross-factory balancing? (organisational structure)			
	Q13	Are there any outsourcing partners?			
	Q14	How many DCs (Distribution Centres)?			
	Q15	Where are they located?			
	Q16	Do they have multiple factories feeding them? If so, why?			1- Upstream capacity issues; 2- Split sourcing rules; 3- Other
	Q17	Is there inventory balancing across DCs?			
	Supply Chain Control				
	Q20	Are there any flexible contracts?			
	Q21	What is the nature of these flexible contracts?			

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q22	Is there a VMI (Vendor Managed Inventory) relationship?							
	Q23	Are there any fulfillment-related agreements on service levels, etc.?							
	Q24	Are there any other service contracts?							
	Q25	Is supply chain control centralised or decentralised?							
	Q26	Is there a central control department for mid term planning?							
Fulfillement Model									
	Q27	How would you describe customer lead times ?			1-Fixed	2-Variable			
	Q28	What is the length of customer lead times?			1-min Length ________	2-max L+H147Length ________			
	Q29	What is the driver of the difference in lead times?			1-Customer	2-Product	3-Resource Load	4-Other	
	Q30	What kinds of service level contracts exist?							

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer
	Q31	Can an order be met from more than one location?			
	Information Systems				
	Q33	Do you use any ERP systems?			
	Q34	Do you use any legacy systems?			
	Q35	Do you use other decision support software?			
	Q36	Do you use any forecasting software?			
Chartering Phase					
Modeling Phase					
	Selection of Software				
	Q46-V3	What were the reasons for selecting the chosen software? Try to explain and structure your original problem	V3	Degree of Mismatch	**1-Planning Complexity** / **2-Resource Usage** / **3-Customer Lead Time Reduction** / **4-Customer Lead Time Reliability** / **5-Reduction of Inventory Capital**
	Q47-V3	Why do you think that the chosen software fits best into your company's requirements?	V3	Degree of Mismatch	
	Preparatory Steps for Modeling Process				
	Q48a-V4	Give your definition of modeling	V4	Degree of Formality of Modeling Process	

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q48b-V4	I knew very well what modelling was about	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q49-V4	Before starting the modeling process, I very clearly defined the scope of the system to be implemented and the benefits to be achieved	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q50-V4	Before starting the modelling process, I very clearly defined the Business Requirements (Benefits, Functionalities)	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q52-V4	Before starting the modelling process, I very formally described all important Business Rules of my company	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q53-V4	Before starting the modelling process, I put priorities to all Business Rules	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q51-V4	Before starting the modelling process, I very formally described all functionalities to be available after each Business Release	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q54a-V4	Before starting the modelling process, I very formally defined all Planning Items to be considered within the Master Planner model	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q54b-V4	Before starting the modelling process, I very formally defined the resource structure to be considered within the Master Planner model	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q54c-V4	Before starting the modelling process, I very formally defined the lead times to be considered within the Master Planner model	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q54d-V4	Before starting the modelling process, I very formally defined the processing times to be considered within the Master Planner model	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q55-V4	Before starting the modelling process, I very formally defined where all necessary input data should come from	V4	Degree of Formality of Modeling Process	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
Modeling Process		***Planning Items***							
	Q69-V10	I often changed the number of planning items until I reached the final solution stage. Explain why	V10	Number of changes and additions regarding the definition of Planning Items	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q70-V10	I am very confident with the number of items I have right now. Explain why	V10	Number of changes and additions regarding the definition of Planning Items	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q71-V11	By defining Planning Items in Master Planner I defined them as well according to the final market sectors	V11	Level of ATP detail in Master Planner	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q72-V11	In which tool have you defined a detailed seller structure for due week quoting?	V11	Level of ATP detail in Master Planner	1-Master Planner	2-Demand Fulfillment	3-Demand Planner	4-Other	
	Q78-V12	By defining planning items for Master Planner did you take into account exceptionally long lead times? e.g. products which use special auxiliary materials and hence have a longer lead time	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
		Master Planner/DWQ							
	Q74-V12	At which level did you model planning items in Master Planner ?(where in the item hierarchy from physical to aggregate?)	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-Agregated item level	2-Items up to the CODP	3-Items beyond the CODP	4-Other	
	Q77-V12	Which modules determine the due date of work orders?	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-i2 Master Planner	2-i2 Factory Planner	3-i2 Demand Fulfillment	4-ERP System	5-Other Applications

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q82-V13	How do you integrate Work In Process into the Master Planner model? Describe	V13	Match of anticipation used and expectations regarding consistency and stability	1-Not at all	2-By mapping WIP material into MP Planning Items and locate into Inventory Buffers	3-Other		
	Q83-V13	How do you integrate netted capacity (actual free capacity per MP bucket and MP resource) into the Master Planner model?	V13	Match of anticipation used and expectations regarding consistency and stability	1-Not at all	2-By computing free capacity per single resource and aggregating to MP resource	3-Automatically in Master Planner by mapping orders into MP Planning Items	4-Other	
	Q84-V13	How do you integrate netted forecast (actual orders and planned orders per planning item and week substracted from the unconstrained forecast per planning item and week) into the Master Planner model?	V13	Match of anticipation used and expectations regarding consistency and stability	1-Not at all	2-By mapping actual and planned orders into Planning Items and substract from the unconstrained forecast	3-Other		
		Inventory Management							
	Q73-V12	In which i2 modules have you decided to manage stock levels?	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-Master Planner	2-Inventory Planner	3-Factory Planner	4-Other i2 modules	5-None
	Q75-V12	Which other systems do you use in order to manage stock levels	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-Legacy System	2-ERP System	3-Other Appplications		
	Q76-V12	Where are replenishment orders generated?	V12	Location (systemwise) of determination of time phase workorders releasing materials from inventory (where is the actual release of material done?)	1-i2 Master Planner	2-i2 Factory Planner	3- Inventory Planner	4-ERP System	5-Other i2 Modules or other Appplications
		Solution Development							
	Q66-V8	I performed many changes and additions to the initial i2 solution until the final stage was reached?	V8	Degree of underestimation, related to the number of changes in the model	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q67-V8	I often changed the way the decision of where to produce a certain product should be made during the modeling phase	V8	Degree of underestimation, related to the number of changes in the model	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Quality, Generation and Change of Model Input Data								
	Q40-V3	How do you translate forecasts for marketing and sales purposes to forecasts for planning purposes?	V3, V11	Degree of Mismatch	1-Not necessary, as both forecasts are on the same level	2-Manually, by using aggregation /disaggregation rules and historical data	3-Automatically, by using aggregation /disaggregation rules and historical data	4-Other	

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q41-V3	What did you change since the end of the implementation project?	V3	Degree of Mismatch	1-Yearly holiday calendar	2-Shift systems	3-Maintenance Calendar	4-Other	
	Q42-V3	What kind of calculations or data are you using outside of the i2 system?	V3	Degree of Mismatch	1-Calculations to compute processing times	2-Calculations to compute lead times	3-Calculations to compute resource availability	4-Calculations to compute the forecast per Planning Item	5-Other
	Q43-V3	What kind of input data and why would you like to be able to change during the workflow?(interactive plannng mode)	V3	Degree of Mismatch	1-Product Data	2-Process Data	3-Lead Times / Processing Times	4-Forecast Data	5-Other
	Q62-V6	What is required to generate the Master Planner Flow Quantities per routing and operation?	V6	Degree of complexity of the planning solution					
	Q79-V14	What is stability in your product mix?	V14	Degree of stability in demand		Typical Fluctuation around the mean usage			
					Bottleneck Resources	< 5 %	> 5 % and < 10 %	> 10 %	
					Bottleneck Materials	< 5 %	> 5 % and < 10 %	> 10 %	
	Q80-V16	My sales forecast is very accurate	V16	Predictability of detailed demand	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q81-V15	Processing times and capacity availability is fairly reliable and stable	V15	Degree of stability of primary process (Processing Times)	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q85-V15	Lead times as used in Factory Planner are very stable	V15	Degree of stability of primary process (Processing Times)	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5+J88-Strongly Agree
	Change of Model Structure Data								
	Q44-V3	What kind of data effecting the model structure would you like to be able to change?	V3	Degree of Mismatch	1-Planning Items	2-Buffers	3-Resource Structure	4-Objective Functions	5-Other

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q45-V3	Which alternate objective functions would you like to be able to vary?	V3	Degree of Mismatch	1-Maximimze Resource Utilisation	2-Minimize Throughput Time	3-Minimize capital tied up in inventory	4-Maximize demand satisfaction	5-Other
	Reporting								
	Q39-V3	I need additional reports to review the Master Planner database - after having inserted all input data - give some examples	V3	Degree of Mismatch	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Systems Interfaces								
	Q61-V6	In the planning workflow how many system interfaces are involved?	V6	Degree of complexity of the planning solution	1-Interface to Legacy Systems	2-Interface to ERP Systems	3-Interface to other i2 modules	4-Interface to Applications from third-party vendors	5-Other
	Q64-V7	How many different modules/systems are involved in deciding where to produce a certain product?	V7	Degree of integration between i2 modules(average number of i2 modules involved in a single planning decision)	1-Legacy System	2-ERP System	3-one i2 module	4-several i2 modules	5-Other Appplications
			V9	Degree of formal (constraint) relationships between Master Planner and Factory Planner					
After Implementation Phase									
	Model Changes after Implementation								
	Q102-V22	What did you change since the end of the implementation project?	V22	Degree of model changes after implementation					
	Q103a-V22	Can you give an indication of the percentages of model changes shortly after the implementation, e.g. changes in Planning Items, resources, routings etc ?	V22	Degree of model changes after implementation	1-Planning Items ________%	2-Buffers ________%	3-Ressource Structure ________%	4-Objective Functions ________%	5-Other ________%
	Q103b-V22	Do you think that changes were done because of continuous improvements or because of failures?Please indicate percentages.	V22	Degree of model changes after implementation	1-Planning Items improv.____% failures.____%	2-Buffers improv.____% failures.____%	3-Ressource Structure improv.____% failures.____%	4-Objective Functions improv.____% failures.____%	5-Other improv.____% failures.____%
	Planning Workflow								
	MP / FP Integration								

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q63-V7, Q63-V9	I always check the results of Factory Planner with the due dates given to the customer, based on ATP	V7, V9	Degree of integration between i2 modules(average number of i2 modules involved in a single planning decision)	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
	Q68-V7	I always use the Master Planner Plan to check the Factory Planner plan	V7,V9	Degree of integration between i2 modules(average number of i2 modules involved in a single planning decision)	1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
		Workflow							
	Q104-V25	Which workflow do you use in order to come to a balanced plan?	V25	Consistency between actual workflow and initially defined workflow					
	Q105-V25	At what time in this workflow do you do an infinite capacity run?	V25	Consistency between actual workflow and initially defined workflow					
	Q106-V25	When you do an infinite capacity run and you see that capacity utilisation is > 100 % , do you decide to modify capacity and why?	V25	Consistency between actual workflow and initially defined workflow					
	Q107-V25	When you do an infinite capacity run and you see that capacity utilisation is > 100 % , do you decide to modify forecast and why?	V25	Consistency between actual workflow and initially defined workflow					
	Q108-V25	Do you discuss the changes you do in capacity and forecast with other departments like sales, production, etc?	V25	Consistency between actual workflow and initially defined workflow					
		Achieving a feasible plan							
	Q109-V25	What input data and how do you change in order to achieve the solution you want?	V25	Consistency between actual workflow and initially defined workflow	1-Product Data	2-Process Data	3-Lead Times / Processing Times	4-Forecast Data	5-Other
	Q94-V20	What kind of i2-model simplifications do you accept?	V20	Degree of adherence to i2 plans					

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
	Q96-V21	How do you perceive the quality of the plans from i2?	V21	Degree of perceived correctness to i2 plans	1-Always need substantial modification	2-Mostly need modification	3-Mostly are correct	4-Always are correct	
	Q97-V20	After having designed the model, what business policies and how do you change in order to achieve the solution you want?	V20	Degree of adherence to i2 plans					
	Q98-V20, Q98-V21	After having designed the model, what kind of infeasibilities in a plan would you accept?	V20, V21	Degree of adherence to i2 plans	1-Resource over utilisation	2-Material over utilisation	3-Sales plan is not met	4-Other	
	Q99-V21	When you review the balanced plan , when is this plan for you feasible?	V21	Degree of perceived correctness to i2 plans					
	Q100-V21	In what respect differ the i2 plans from that what you expect?	V21	Degree of perceived correctness to i2 plans	1-Planned Allocations ________%	2-Shorted Forecasts ________%	3-Planned Inventories ________%	4-Capacity Usage ________%	5-Other ________%
Achieving a feasible plan									
	Q101-V22	Who in your company is responsible for maintaining the system after implementation?	V22	Degree of model changes after implementation					
Expectations and Outcomes									
		The outcome of system implementation was conform with our initial expectations			1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
		It took not very long until we got truly useful results			1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree
		The users have done an audit / comparison for verifying the quality of the modeling process			1-Strongly Disagree	2-Disagree	3-Do not mind	4-Agree	5-Strongly Agree

Implementation Phase	Question Number	Question Text	Variable Number	Variable Text	Answer				
		Users are now really using the tool since___			1-< 3 months	2-< 6 months	3-< 9 months	4-< 12 months	5-> 12 months
		What parts of the planning process are now better than before?			1- Demand Forecasting	2-Master Planning	3-Due Date Quoting	4-Operational Planning/Sequencing	5-other
		What parts of the planning process are about the same as before?			1- Demand Forecasting	2-Master Planning	3-Due Date Quoting	4-Operational Planning/Sequencing	5-other
		What parts of the planning process are worse than before?			1- Demand Forecasting	2-Master Planning	3-Due Date Quoting	4-Operational Planning/Sequencing	5-other

Samenvatting

In dit proefschrift wordt het modelleren van besluitvormingsprocessen in Supply Chain Planning (SCP) Software besproken. Onder Supply Chain Planning (SCP) verstaan we alle planningactiviteiten die verband houden met de goederenstroom en -transformatie vanaf de inkoop van grondstof tot en met de verkoop aan de eindgebruiker, alsook de ermee samenhangende informatiestromen. In de huidige ERP/APS systemen worden de belangrijkste beslissingen in Supply Chain Planning ondersteund door specifieke beslissingsondersteunende functionaliteiten, waardoor het in principe mogelijk wordt om alle binnen een onderneming te nemen planningsbeslissingen binnen één systeem te ondersteunen. Een groot aantal van dergelijke functionaliteiten is gebaseerd op specifieke mathematische modellen die ontwikkeld zijn op het gebied van Operations Research. Zulke standaardsoftware heeft nog steeds één probleem in het bijzonder en dat is dat de software typisch bestaat uit een aantal afzonderlijke en in wezen "zwakgekoppelde" modules. De integratie tussen deze modules wordt meestal gestalte gegeven doordat alle modules gebruikmaken van dezelfde database. De huidige "zwakke koppeling" wordt veroorzaakt door het feit dat slechts in een klein aantal reële situaties, met beperkte complexiteit en onzekerheid, het oplossen van het planningsprobleem gebaseerd op één, werkelijk geïntegreerd, wiskundig model uitvoerbaar lijkt. Daarbij dient te worden opgemerkt dat het a a-priori onjuist is te veronderstellen dat alle op te lossen planningsproblemen moeten worden gekoppeld middels de ondersteuning met software gebaseerd op één geïntegreerd mathematisch model. De twee belangrijkste probleemgebieden in het ontwerpen van oplossingen voor standaard softwareapplicaties zijn daarom:

- hoe het probleem in verschillende subproblemen onder te verdelen
- het verband te leggen tussen en het hiërarchisch ordenen van dergelijke subproblemen.

Volgens onze bevindingen is één van de belangrijkste factoren voor het succesvol implementeren van projecten het correct en consistent modelleren van de te ondersteunen besluitvormingsprocessen. Tot op heden zijn er weinig publicaties die de modelleringaspecten in het implementatieproces van ERP/APS systemen (die een belangrijke invloed hebben op de manier waarop een bedrijf opereert) op een wetenschappelijk verantwoorde wijze beschrijven en analyseren. In dit proefschrift hebben we de relatie tussen typische softwarecomponenten onderzocht, waarbij we met name het fenomeen "anticipatie" hebben bestudeerd. In de context van hiërarchische besluitvorming wordt onder anticipatie verstaan, dat een hoger planningsniveau bij het nemen van een beslissing rekening houdt met mogelijke toekomstige beslissingen (reacties) van een lager planningsniveau. Meer specifiek, in een tweeniveaus hiërarchie wordt een zogenaamde anticipatiefunctie opgenomen in het "top-level" model, waarbij deze anticipatiefunctie het "verwachte" toekomstige gedrag van het proces beschrijft op het tijdstip dat het "base-level model" wordt gebruikt om gedetailleerde beslissingen over acties te nemen.

De belangrijkste vraagstellingen waar we ons in dit onderzoek mee bezig hebben gehouden, zijn die vragen die beslissen tot op welke hoogte de decompositie van een planningprobleem in diverse subproblemen en de onderlinge samenhang en hiërarchische ordening van deze subproblemen – zoals wordt gedaan in de huidige APS-systemen – in overeenstemming zijn met de theorie en praktijk van planning en beheersing van supply chains. Sterk gerelateerde onderzoeksvragen zijn die vragen die nagaan tot op welke hoogte modelleren in APS-systemen kan verzekeren dat de verschillende aggregatieniveaus nog steeds consistent zijn, en tot op welke hoogte APS-systemen de problemen van informatieasymmetrie meenemen. Informatieasymmetrie beschrijft het probleem dat op een hoger hiërarchisch niveau, bijvoorbeeld middellange termijnplanning, minder gedetailleerde en andere informatie beschikbaar is dan op een lager hiërarchisch niveau, bijvoorbeeld korte termijnplanning. Dit wordt met name veroorzaakt door het feit dat beslissingen op een hiërarchisch hoger niveau eerder worden genomen dan beslissingen op een lager hiërarchisch niveau. Het probleem wat dan voorligt is dat de middellange termijnbeslissingen zodanig moeten worden genomen dat de korte termijnbeslissingen genomen kunnen worden in overeenstemming met vooraf gedefinieerde doelstellingen met betrekking tot klantenservice, gebruik van productiemiddelen en kapitaalinvesteringen.

Het belangrijkste doel van dit proefschrift is geweest om te onderzoeken of het anticipatieconcept als zodanig is opgenomen in APS-systeembenaderingen. Daaraan gerelateerd is onderzocht of het probleem van informatieasymmetrie simpelweg opgelost wordt door het inbouwen van speling en regelmatige herplanning. Het doel is om een anticipatietheorie binnen de context van Hiërarchische Productie Planning (HPP) te ontwikkelen door onderscheid te maken tussen modelanticipatie en informatieanticipatie. We hebben de inzichten verkregen uit deze theorie toegepast en van daaruit hebben we gedetailleerde observaties binnen een enkelvoudige gevalstudie gedaan. Deze observaties zijn gebruikt om hypothesen te formuleren die vervolgens zijn getoetst middels een beperkt aantal diepgaande interviews aan de hand van een gestructureerde vragenlijst. Op basis van de uitkomsten van dit onderzoek hebben we een aantal conclusies getrokken en aanbevelingen voor verder onderzoek afgeleid. Het proefschrift is opgebouwd als volgt. In hoofdstuk 3 is literatuuronderzoek gedaan op het gebied van hiërarchische-productieplanning. De conceptuele aanpak van Bertrand *et al.* (1990) en het generieke raamwerk voor hiërarchische decompositie van Schneeweiss (1990) waren de theoretische benaderingen die het uitgangspunt waren voor ons onderzoek.

In hoofdstuk 4 is de theorie van Schneeweiss, betreffende anticipatietypen uitgebreid tot een generieke typologie. Hierbij maken we onderscheid tussen modelanticipatie en informatieanticipatie. Deze typologie is toegepast op i2's TradeMatrix APS software. We hebben geconcludeerd dat onze classificatie zeer nuttig is bij het construeren van voor het probleem van de integratie van de beschouwde planning(software)componenten. We beargumenteren dat bij de keuze van een anticipatiefuncties een afweging gemaakt moet worden tussen de vereiste consistentie tussen de twee betrokken componenten op een specifiek tijdstip en de vereiste stabiliteit van het plan in opeenvolgende perioden.

Hoofdstukken 5, 6 en 7 beschrijven een gevalstudie, waarbij de auteur actief betrokken was en die gebruikt is om de voor het geïntegreerd plannen van de goederenstroom binnen een bedrijf typerende beslissingen te beschrijven en het modellering- en softwareimplementatieproces dat nodig is om deze wijze van plannen te ondersteunen. De resultaten zijn gebruikt om de modelleerfasen te classificeren en zodoende de veranderingen gedaan in iedere fase te structureren en analyseren. De gedefinieerde modelleerfasen waren Initial Requirements & Criteria Setting, Initial Modeling, Model Modification, Advanced Requirements and Criteria Setting en Advanced Modeling. In hoofdstuk 5 is speciale aandacht gegeven aan het weergeven van de supply chain karakteristieken van het onderhavige bedrijf door de producten te introduceren, de fabricagefaciliteiten, de relevante leveranciers en de service centers. We beschrijven in detail de planningproblemen en de daaruit voortvloeiende eisen waaraan planningssoftware moet voldoen voor deze specifieke gevalstudie waarbij gebruik gemaakt is van de i2 TradeMatrix suite. In hoofdstuk 6 worden de "Initial Requirements & Criteria Setting-fase en de "Initial Modeling"-fase beschreven. De hierbij gemaakte keuzes worden beoordeeld aan de hand van de theoretische concepten van Bertrand *et al* (1990) en Schneeweiss (1999). In hoofdstuk 7 formuleren we op basis van deze beoordelingen een aantal te verwachten problemen voor verder modelleerfases. Op basis van deze uitgesproken verwachtingen worden de fasen "Model Modification, Advanced Requirements" en "Criteria Setting" en "Advanced Modeling" nader bestudeerd.

Hoofdstuk 8 beschrijft het ontwikkelen van een enquête, waarin gedetailleerde vragen over het modelleren binnen APS software. De enquête is ingevuld door bedrijven van verschillende industriële sectoren die tenminste een deel van de i2 TradeMatrix software geïmplementeerd hebben.

In hoofdstuk 9 zijn de onderzoeksresultaten, gebaseerd op de gegeven antwoorden, toegepast om ofwel conclusies ofwel aanbevelingen te verkrijgen gerelateerd aan ons onderzoeksgebied. We maken onderscheid tussen aanbevelingen voor modelleren in Advanced Planning Systems en aanbevelingen voor verder onderzoek.

Summary

This thesis discusses the modeling of decision making processes in Supply Chain Planning (SCP) Software. We define Supply Chain Planning (SCP) as all planning activities associated with the flow and transformation of goods from the raw materials stage through to the end user, as well as the associated information flows.

In current ERP/APS systems, key decisions in Supply Chain Planning are supported by implementation tools specifically developed to solve the single planning function that is under consideration. A large number of such tools are based on specific mathematical models which have been formulated within the area of Operations Research. One particular problem that such standard software still has is that typically the software consists of a number of inter-related, but loosely coupled, modules. This results from the fact that only in a very small number of real-life situations, with limited complexity and limited uncertainty, is solving a production planning problem based on a single planning model likely to be feasible. Therefore, two main problem areas in designing solutions for standard software applications are:

- How to decompose a problem into several subproblems
- How to inter-relate and hierarchically order such sub-problems

According to our observations, one of the key factors for success in implementation projects is correct and consistent modeling of decision making processes. But in fact, little or no academic research has been published that rigorously describes and analyzes the modeling aspects in the implementation process of ERP/APS systems (which have a significant impact on the way a business operates). In this thesis we have analysed the relationship between typical software components, focusing on anticipation. Anticipation is defined as the model at a higher planning level taking into account the possible reaction of the lower level to the future higher level's decision. More precisely, in a two-level hierarchy the anticipation function is incorporated in the top-level model and represents the "expected" future behaviour of the process at the time the base-level model is applied to take detailed decisions about the activities.

The main questions dealt with in this research are those of determining to what extent the decomposition of a planning problem into several sub-problems and the interrelation and hierarchical ordering of these sub-problems - as it is done in current APS systems - is in

agreement with theory and practice of planning and control of supply chains. Strongly related research questions are those of analysing to what extent modeling in APS systems can ensure that the various levels of aggregation are still consistent, and to what extend APS systems incorporate the problem of information asymmetry. Information asymmetry describes the problem that, for example, mid-term planning has to use less detailed and different information then short-term planning, because detailed data is not yet available at the time that mid-term planning decisions need to be made. Yet, the mid-term decisions should be such that the short-term decisions can be taken in line with overall operational objectives with respect to customer service, resource utilisation and capital investments.

The main objective in this thesis has been to elaborate as to whether the concept of anticipation is included as such in APS system approaches, or whether the problem of information asymmetry is just solved by incorporating slack and frequent replanning. The objective has been to build a theory of anticipation in Hierarchical Production Planning (HPP) by distinguishing between model anticipation and information anticipation. We applied the insights gained from this theory to fomulate observations resulting from a single case study. The results have further been used to formulate hypotheses and to derive conclusions and propositions related to questionnaire-based interviews.

For the thesis the following structure was chosen:

In chapter 3, literature has been investigated in the areas of decomposition and hierarchical planning. The conceptual approach of Bertrand *et al* (1990) and the generic framework for hierarchical decomposition of Schneeweiss (1999) were the theoretical approaches our research was focussing on.

In chapter 4, based on the planning hierarchy as defined in the APS system i2 TradeMatrix, the theory of Schneeweiss, regarding anticipation types, has been extended into a more general and comprehensive appoach. We developed a classification distinguishing between model anticipation and information anticipation, and applied our classification to i2's TradeMatrix APS software. We concluded that our classification is very helpful in constructing alternative integration options between the considered planning components, making the characteristics of the various options explicit. Also, we concluded that by selecting between the various anticipation functions, a trade-off will need to be made between the required consistency between the two levels involved and the required stability of the plan in consecutive periods.

Chapters 5, 6 and 7 describe an in-depth case study, in which the author was actively involved and which was used to describe typical supply chain decisions and their modeling

and implementation process. Results have been used to classify modeling phases and thus to structure and analyse the changes performed in each phase. The defined modeling phases were Initial Requirements & Criteria Setting, Initial Modeling, Model Modification, Advanced Requirements and Criteria Setting, Advanced Modeling. In chapter 5, special consideration has been given to describing the supply chain characteristics of the company under consideration by introducing the products, the manufacturing facilities, the relevant suppliers and the service centers. We describe in detail the planning problems and planning requirements at the specific case, followed by the proposed overall solution using the i2 TradeMatrix suite. Chapter 6 describes the Initial Requirements & Criteria Setting phase and the Initial Modeling phase by distinguishing between observations and theoretical assessments related to the approaches of Bertrand *et al* (1990) and Schneeweiss (1999).
We summarize the modeling experiences and user impressions gained after the first two modeling phases and relate them to the theory of Schneeweiss (1999) and Bertrand *et al.* (1990). In chapter 7 we formulate observations gained so far as expected problems for further modeling phases. Based on those expectations, the phases Model Modification, Advanced Requirements and Criteria Setting and Advanced Modeling are described.
In chapter 8, the resulting observations of the in-depth case study were the basis for developing a questionnaire, in which detailed questions regarding modeling were formulated. We give an overview of all stated observations and hypotheses gained so far, followed by a discussion of each hypothesis. Finally, each question formulated in the questionnaire, has been related to a hypothesis, which in turn were related to our research questions. The questionnaire was answered by a representative selection of companies from different industry sectors having implemented – at least partially – the i2 TradeMatrix software.
In chapter 9, based on the answers given, the survey's results have been used to either derive conclusions or propositions related to our research topic. We further formulate recommendations based on our research. We distinguish between recommendations for modeling in Advanced Planning Systems and recommendations for further research.

Curriculum Vitae

Anastasia Juliane Zoryk-Schalla, born Roumeliotis, was born in Aachen, Germany, in 1961. In 1988 she graduated as a mathematician/economist at the "Rheinisch-Westfälische-Technische Hochschule", (RWTH), in Aachen, Germany. In the same year she joined the "Bremer Institut für Betriebstechnik und angewandte Arbeitswissenschaft", (BIBA), in Bremen, Germany as a scientific researcher. Her main responsibilities were project acquisition, project management and the development of conceptual solutions for the European Community Projects ESPRIT 3143 and BRITE 3406.

In 1990 Zoryk-Schalla joined the department of Information Technology of a European multi-billion euro revenue turnover aluminum manufacturing company. As a project manager she was responsible for projects in the area of trim opimisation and computer-based scheduling and sequencing through the use of simulation tools. One of her further areas of responsibility was the analysis and comparison of current APS software packages for integrating production planning, demand planning and strategic planning into a single planning system.

In 1999 she was assigned as a project manager to the Central Commercial Management of the company. She was responsible for the conceptual design for i2 TradeMatrix Master Planner and the conceptual data integration to i2 TradeMatrix Demand Planner and Factory Planner. In 2000 Zoryk-Schalla was responsible for the management of Business Process Reengineering for all planning processes by taking into account the integration of the i2 planning solution with SAP R/3. In the last part of the year she was assigned overall responsibility for all running i2 projects (i2 TradeMatrix Demand Planner, i2 TradeMatrix Master Planner and i2 TradeMatrix Factory Planner), of the plant specific implementations of Shop Floor Systems and plant specific implementations of Expert Systems for Master Data Generation in four european plants.

In 2001 Zoryk-Schalla joined PriceWaterhouseCoopers and is currently advising customers from metals and high tech industries in the area of supply chain management.

Since 1998, in parallel to her industrial activities, Zoryk-Schalla was a Ph.D. student at Eindhoven University of Technology .

IX

The process of structuring a task with the help of associated task attributes is the essential characteristic of human group decision making in one-of-a-kind production
(A.J. Schalla: "Decisional Aspects of Computer and Human Integrated Manufacturing", Bremen Institute for Industrial Technologies and Applied Work Science, 1990).

X

Science and industry pretend to communicate – what they are missing is a common language.

XI

We do not know what makes a factory work. We understand a part and try to improve that part and leave the rest to a more complex environment and hope that it will work.

XII

Putting it in Aristotelian words: While science focusses on the principle of "causa efficiens", practice tends to prefer the "causa finalis".

XIII

The main thing is to keep the main thing the main thing.

Propositions

accompanying the Ph.D. thesis

Modeling of Decision Making Processes in Supply Chain Planning Software

a theoretical and empirical assessment of i2 TradeMatrix

by

Anastasia Juliane Zoryk-Schalla

Eindhoven, October, 2001

I

Current theories on Hierarchical Production Planning do not include the dynamic aspect of the planning and execution process as they lack the concepts of consistency and stability in the context of Supply Chain Planning as a special case of HPP (Chapter 4 of this Thesis).

II

The current way of decomposition and hierarchical ordering of production planning problems in APS software leads in practice to the use of workarounds, the development of additional models, reports and calculations, and hence to more complicated workflows (Chapter 8 of this Thesis).

III

Within current APS software, the "advantage" of flexibility in designing the interaction between models at different planning levels, in practice leads to difficulties in understanding the solution design and consequently to insufficient integration concepts (Chapter 8 of this Thesis).

IV

Current APS software does not include explicit rules / indications for the interaction between modules at different planning levels, which leads to considerable inconsistencies in the overall solution design (Chapter 8 of this Thesis).

V

The choice of correct anticipation types, based on consistency and stability issues to be achieved, is underestimated in practice (Chapter 8 of this Thesis).

VI

In a daily planning and scheduling situation, in which each machine has its own complex sequencing rules, a coordinated planning approach, considering the time-dependent availability of materials, is the basis for reducing inventory and throughput times
(A.J. Schalla: "Schneller Fertigungstest realisiert tagesgenaue Planung", VDI-Nachrichten, 1994 Jahrgang 48, Nr.10).

VII

The use of simulation tools for daily planning and scheduling has the advantage that in the short term due dates can be calculated. The disadvantage is that changes to the sequencing rules cannot be practically implemented. As a consequence due dates are still wrong (A.J. Schalla: "Täglich geplant", Arbeitsvorbereitung, 1995, Vol. 1, page 20-23).

VIII

In the sheet metal components industry, integration of design and production preparation processes with the production planning and production control systems can be achieved by incorporating the concepts of "feature-based design", adaptation of independent system modules and event-driven message and error handling at shop floor level. This gives better results than the purely independent optimization of each subfunction.
(A.J. Schalla, P.C. Knackfuß, B.E. Hirsch: "Integration of CAD/Cam and production control in sheet metal manufacturing - an application area of operations research", Production Planning & Control, 1991, Vol.2, No.2, page 96-101)