MASTER

Integration factory planner and master planner at EWK

Oonk, G.

Award date:
2000

Integration Factory Planner and Master Planner at EWK

Author: Gertjan Oonk

Supervisor EWK: Dipl.-Ing. J. Heidrich

Supervisors TU/e: Dr.ir. J.C. Fransoo
Prof.dr.ir. J.C. Wortmann

Auditor TU/e: Prof.dr. A.G. de Kok

October, 2000

Abstract

This report describes a project conducted at EWK. The objective is making a design of the production control structure and the processes which constitute together this structure. Therefore workflows have been made for the various systems in order to achieve the purposes of these processes. The other objective is to optimize the quality of the Master Planner. Therefore a new method has been designed and implemented to calculate the Master Planner parameters. The results are an improvement of 6% in the plan-performance.

Acknowledgements

This report is the result of my final thesis of the course Industrial Engineering and Management Science at Eindhoven University of Technology. My final thesis concerned with how the integration between the Factory Planner and Master Planner should look like. I conducted this assignment at the company Edelstahl Witten-Krefeld (EWK) from April 2000 until October 2000.

I would like to thank EWK for giving me the opportunity to do this project at their company. As it turned out this project has been a big learning experience for me.

There are a lot of persons at the department Produktionswirtschaft (PW) I wish to thank for their support during my staying at EWK. In the first place these are the people who helped me get acquainted with the various business processes (more specific the planning processes) in my orientation period (the first two months). In no particular order I mention:

Mr. Dirkschneider
Mrs. Wilmes-Konig
Mr. Oberkandler
Mr. Bernard
Mr. Wicke
Mr. Tiedkte

Furthermore I would like to thank Mr. Kammerinke for helping me out with some technical programming matters.

Since my project was part of the bigger i2 project, I also cooperated with the i2 party. In spite of their already busy activities, they made time for me and helped me out wherever possible. For this I would like to thank them. I mention:

Mr. Roger
Mr. Bolz
Mr. Dobler

I also want to express my gratitude to the three heads of the department PW: Mr. Nase, Mr. Kay and especially my company supervisor Mr. Heidrich for his guidance and support.

My special thanks go out to Dr. ir. Fransoo at TUE for his continuous and extremely valuable support and superb guidance during this project. I also like to thank Prof. dr. ir. Wortmann, my second supervisor for his feedback. Here I also would like to thank Mrs. Schalla, a Phd student and employee at VAW which is also involved in a i2 project, for her interest and support during my project.

Besides these persons who were directly involved in the project, many other people have been of great support. I like to thank therefore also the head of the personal department: Mr. Ishorst who helped me getting around the first few days and found me a nice place to stay during my period here in Germany. Lastly I thank my parents for their emotional and technical support (the car!!!).

Summary

Original problem statement

This project was executed for EWK. EWK has its main focus on rolled and forged products manufactured in high-quality steel. Since their operational characteristics (such as high-end product variety, multi-site environment, campaign-planning, transport in hot-condition and various outsource-possibilities) result in a quite complex situation with regard to the logistic control, they started therefore the implementation of the Supply Chain Management Solution of i2 Technologies. This solution consists of several modules ranging in a hierarchy from tactical through to operational and scheduling which can support the various necessary planning-activities. Two of these modules are the Factory Planner and the Master Planner. The Factory Planner determines on which day each manufacturing operation of a given customer order should be performed on which particular resource by creating a factory-wide optimal plan. The output of the Factory Planner will then be used as an input for the more detailed scheduling (sequencing) of the manufacturing orders. The Master Planner creates a Master Plan for EWK's supply chain over a horizon of 12 months, by integrating business policies, market demand and supply chain capability into one common plan. The initial problem description with which has been started at the beginning of this project is stated as follows:

"Given the possibilities of this APS package in what way should the integration between the two modules MP and FP look like, so that EWK can control its production activities optimally?"

Systems

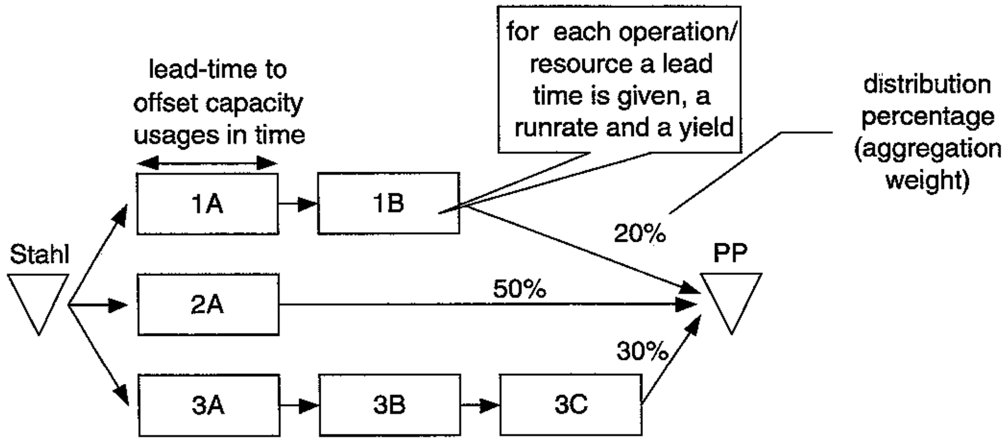
A description will be given of the most important systems. This understanding is necessary before the reader moves to the part under the header solutions. It also gives the reader an insight why the original problem statement has changed.

Master Planner:

The input for the Master Planner are the forecasts for the various planning-items (and the other flat-files as well). So what the Master Planner does is calculating for an one-year horizon the capacity reservations (in terms of the ATP-allocations per planning-item) by taking into account the main constraints of the factory (so without violating the capacities of the main production-routes) and where the objective is to minimize the deviations of the allocations from the forecasts. The Master Planner "thinks" in terms of the so-called planning-buckets (at EWK the planning-buckets are one week). Only the most important resources are modelled on this MP level. On the Factory Planner every resource has been modelled. In order to describe in more detail how things are modelled within Master Planner first two notions have to be introduced. These are the so-called planning-product and a planning-item. A planning-product is an aggregate product. This planning-product is modelled as a weighted combination of various routings. Each routing consists of a sequence of operation/resource steps. For each operation/resource step the following data are given:

1. run-rate (capacity usage)
2. yield
3. lead-time (to offset these capacity usages in time)

Furthermore each parallel routing in a PP is given a weight, the so-called distribution percentage. One could interpret this as a aggregation weight. This is illustrated below.



A planning-item has two dimensions: planning-product and market-sector (seller). The market-sector dimension is formed by the sales-department and a team of customers. For each forecast of a planning-item a priority (1 or 2) is assigned.

Demand Manager:

The Demand Manager is a database created in Microsoft Access. This DM consists of two parts and therefore serves two purposes. The first part is a GUI (Graphical User Interface) in which the forecasting can be done by Sales. The second part is that the DM creates all the relevant flat-files which are necessary as an input for the MP. Furthermore it is able to disaggregate the ATP-allocations on planning-item level (which have been calculated by the MP) to allocations on LT-level. As has been said the other part of the Demand Manager is a tool which supports the forecasting process. The forecasting is done in each sales-department on lagertype-level for a team of customers. The seller-dimension (which has been mentioned in the discussion of the MP) is formed by the sales department and team. The forecast for some planning-item is then the sum of the forecasts of those lagertypes which belong to the same seller dimension and which (when mapped to its planning-product) belong to the same planning-product. So the forecast for the planning-item (which is an aggregate product with a seller-dimension) is based on a detailed approach.

ATP-engine:

The ATP-allocations on planning-item level form the basis on which orders will be accepted and quoted. This is done by means of the so-called ATP-engine. ATP refers to the quantity available to commit to future customer orders after meeting all existing commitments. The following formula applies:

ATP = allocated-consumed (for a specific planning-item)

So this ATP logic can be used as orders are entered into the system (SAP/R3) to accept orders or not. Besides this the ATP-engine can provide realistic due-dates for those orders that are accepted.

Integration FP and MP:

Because the Master Planner and the Factory planner have an overlap in its horizon, MP has to take into account the already planned orders by FP (in able to provide realistic ATPs for the first few months, since these are used in the ATP-engine). This is done based on the netted forecast and the netted capacity logic.

Revised problem statement

Because there was already a specific solution at hand for the integration FP and MP, the following revised problem description (also related to operational control) has been made:

"For EWK it is not quite clear how should be worked with the various systems (on its own and together) and how all these systems together will fit in the conceptual production control structure. Besides that the initial outcome of the MP (in terms of the amount of forecasts satisfied) did not comply with their expectations."

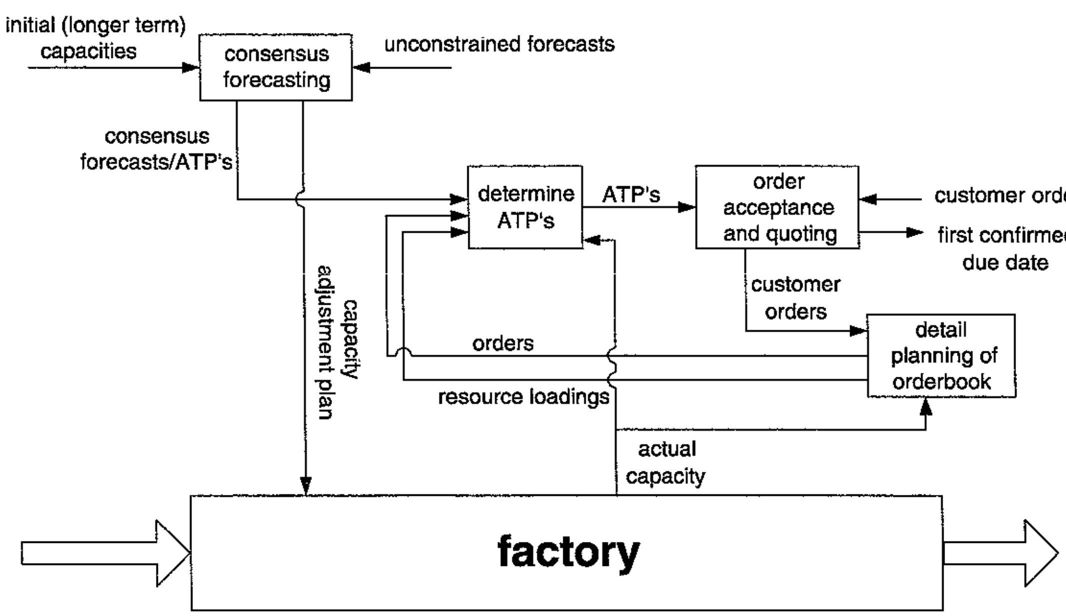
In order to tackle these problems the following task-assignments have been developed and agreed-on:

1. Developing the production control structure in terms of processes
2. Designing workflows of how to work with the various systems which support these processes
3. Improve validity of MP model

Solutions

1. Developing the production control structure in terms of processes and
2. Designing workflows of how to work with the various systems which support these processes

Pictorially the production control structure can be represented as follows. This picture tries to give a view in terms of the processes and not from a software system's perspective (because the systems only support these processes).



The first process is the so-called consensus forecasting process (CFP). This is the decision which is done least frequently. This process of making a satisfactory (what Sales likes and can sell) and capacity feasible plan is done each 3 months with a horizon of one year (a rolling horizon approach) approximately 3 months before the planning-horizon. Each month also a revision of the forecasts takes place in a meeting between Sales and PW. Inputs for this process are the initial capacities, the unconstrained forecasts and the relevant MP modelling data. One has to realize that the result (in terms of the ATPs for the PIs) of the first loop of this process can be unsatisfactory to Sales (since the input are the unconstrained forecasts). So Sales and PW should review the calculated ATP figures in the first loop and if they are unsatisfactory they should revise the forecasts. Although the initial calculation of the aggregate forecasts (in terms of PP and PI) for the MP is based on a detailed approach in the DM, it is recommended to perform the handling of the forecasts (in order to make a plan that Sales wants) on an aggregate basis in MP.

This process also drives the capacities of the various shops since this level can see the future impact of the plan on the main capacities. This is represented in the above figure by the arrow "capacity adjustment plan".

The second process determines the ATPs and passes them to the ATP-engine. These ATP figures reserve capacity for specific (aggregate) products for specific customers based on the forecasts. The granularity of these ATP figures is in weeks and the frequency with which this is done depends on the situation. Besides the consensus forecasts which form an input for this process, also the order-book in FP forms an input here. This ensures that the short-term planning-horizon of the Master Planner is synchronized and prevents either over- or under-estimating of production capacity (these feedback loops from the FP to this process can be seen as well in the above figure). Furthermore an input to this process forms the actual capacity. This is important since the actual capacity can differ from what was planned. Important here is when to update the ATP figures. Two important notions which are used here are the two terms: consistency and stability. In deciding on the frequency with which the ATP figures have to be updated a trade-off has to be made between these two notions. An update-proposal has been made which is grouped according to two criteria: time- and event-criteria. The update proposal looks as follows:

- Each month after a CFP the figures have to be updated (time)
- Furthermore an update should be done each week to synchronize the MP horizon with the horizon of the current order-book by means of netting the capacity and netting the forecast (time)
- When the actual capacity differs considerably from the planned capacity (event)

The third process uses then these ATP figures to base the order-acceptance and quoting decision on (the granularity of quoting orders is in weeks and is done each time a customer arrives). This function thus only accepts the business EWK wants: there is thus no FIFO accepting. Suppose the ATP-engine gives back that the order can not be accepted, there are various alternatives the Sales-person could consider to accept the order in some way or an other. These are respectively:

- Re-negotiate another due-date with the customer
- Use some ATP on a higher level which is shared between the various members lower in the hierarchy
- Check if there is some ATP of the same planning-product but different team within his own or other sales-department he could use
- Try to use ATP of a different planning-product
- Accept the order anyhow

The last process is the day-to-day planning of the order-book (the planning-bucket is here thus in days). The system in which the day-to-day planning of the order-book is performed is the Factory Planner

These processes (decision functions), which together form the production control structure, should result in the following business objectives:

- Higher due-date reliability and lower work-in-process
- Increased return on assets (ROA)

Next will be explained how the various processes can result in a better performance with regard to these objectives.

Since the first process provides visibility between the unconstrained forecasts on one side and the supply chain capabilities on the other, EWK is able to make a plan according to customer (market) and product priorities. So it is able to create an optimal sales-plan which has a positive impact on their profitability (thus also on their ROA). Furthermore this plan is also feasible with regard to capacity, since it takes into account the main (critical) capacities when making this plan. This creates thus the conditions for a higher due-date reliability since they do not promise more than that they are able to produce.

The second process makes sure that the actual state of the production system (which changes due to certain events like a machine-breakdown) is also taken into account in calculating the ATPs which are used at order-entry. So this results in ATPs which are as realistic as possible.

The third process makes sure that indeed the right business (according to the plan) is accepted. So there is no order-accepting based on first-come-first-served (which used to be the case). Because the ATPs form, so to say, a valve, this results in a stable flow of orders which contributes to being much better able to realize the first confirmed due-date. This thus improves the service-level realized towards the customer which is important for protecting the existing customer base (and thus the future profitability of EWK).

3. Improve validity of MP model

The importance of the validating the MP-model lies in the fact that it has a large effect on the two important performance measures: ROA and due-date reliability. The MP model forms namely the basis on which the ATP figures are calculated. These ATP figures are then used for order accepting and quoting. The amount of orders that is accepted directly influences the profitability of EWK and the quality of the quote given directly influences the due-date reliability. An analysis of how the current MP has been modelled revealed certain shortcomings. These shortcomings mainly had to do with the fact that it did not take into account the underlying variation in the run-rate and yield of the different lagertypes that belonged to some subPP (which is just the term for the aggregate product represented by a parallel routing in a PP) for some operation. Besides that the calculation of the distribution percentages was also based on a somewhat erroneous method. Therefore a new method has been proposed for calculating these three MP parameters with the purpose of getting a more accurate MP model. This method calculates the parameters based on the future forecasts per LT and the underlying variation in the run-rate and yield per LT. To test if the new method brought an improvement a one year's forecast has been planned for three different scenarios which differed from each other with regard to how the various MP-parameters had been calculated. The result was an increase in plan-performance of 6% when comparing the results of scenario (1) and (3). The explanation for the increase was that a large positive bias of the run-rate existed for those subPPs which used one of the bottleneck resources. Due to the positive bias the result was that in scenario (3) the bottleneck resources were relieved which made a further satisfaction of forecasts possible. The new method for calculating the three MP parameters results thus in a MP model with more realistic parameters, since it uses for its aggregate products an average value of the LTs underneath it. Besides that this method enables a smooth adaptation of the parameters over time if forecast-mix changes with respect to its volume and mix. This new method has also been successfully implemented in the current business practices and forms now an integral part of the Demand Manager.

Table of Contents

ABSTRACT....I

ACKNOWLEDGEMENTS....II

SUMMARY....III

TABLE OF CONTENTS....VIII

CHAPTER 1: INTRODUCTION....1

1.1: EWK....1
1.2: BACKGROUND OF THE PROBLEM AND INITIAL PROBLEM DEFINITION....1
1.3: STRUCTURE OF THE REPORT....3

CHAPTER 2: PRODUCTS, PROCESSES, ORGANIZATION AND PLANNING....4

2.1: PRODUCTS....4
2.2. PRODUCTION PROCESSES....4
2.3: ORGANIZATION....8
2.4: ORDER-PROCESSING....9
2.5. OPERATIONAL CHARACTERISTICS....10
2.6: PLANNING AT PW....11
2.6.1: Plan-auftrag and fertigungs-auftrag....11
2.6.2: Technische Auftrags Bearbeitung (1)....13
2.6.3: Kapazitäts-planung....13
2.6.4: Technische Auftrags Bearbeitung (2)....13
2.6.5: Rohstahl-planung....14

CHAPTER 3: SYSTEMS....16

3.1. MASTER PLANNER....16
3.1.1: Description....16
3.1.2: Modelling in MP....16
3.2: DEMAND MANAGER....17
3.3: ATP-ENGINE....18
3.4: INTEGRATION FP AND MP....19

CHAPTER 4: FINAL PROBLEM DESCRIPTION AND ASSIGNMENT TASKS....21

CHAPTER 5. DESIGN OF WORKFLOWS....22

5.1: CONCEPTUAL PRODUCTION CONTROL STRUCTURE AT EWK....22
5.2: CREATE CONSENSUS FORECAST....23
5.2.1: Revision of forecasts....25
5.2.2: Driving of capacities....26
5.3. DETERMINATION ATPS AND PASS TO ATP-ENGINE....27
5.4: ORDER ACCEPTING AND QUOTING....29

CHAPTER 6: QUALITY MP MODEL....33

6.1: EXPLORATION CAUSES....33
6.2: ANALYSIS CURRENT SITUATION....33
6.3: DESIGN OF A NEW METHOD....34
6.4: TESTS AND THEIR RESULTS....36

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS....42

7.1: CONCLUSIONS....42
7.2: RECOMMENDATIONS....46

APPENDIX 1: PROPERTIES AND APPLICATION AREAS OF PRODUCTS....48

APPENDIX 2: DESCRIPTION OF TECHNICAL PRODUCTION PROCESSES (1)....50

APPENDIX 3: DESCRIPTION OF TECHNICAL PRODUCTION PROCESSES (2) 58

APPENDIX 4: RESOURCE OVERVIEW OF VARIOUS SHOPS....59

APPENDIX 5: INFORMATION ABOUT LAGERTYPE....62

APPENDIX 6: BATCHING AND SCHEDULING RESTRICTIONS OF HEATS 63

APPENDIX 7: PLOTS ILLUSTRATING NETTING FORECAST LOGIC 64

APPENDIX 8: PLOTS ILLUSTRATING NETTING CAPACITY LOGIC....65

APPENDIX 9: TECHNICAL ISSUES REGARDING MAPPING....66

APPENDIX 10: DETAILED WORKFLOW OF CFP 69

APPENDIX 11: ACTIVITY AND MESSAGE DIAGRAMS AND DESCRIPTIONS....72

APPENDIX 12: RESULTS OF VARIOUS ANALYSES....75

APPENDIX 13: TIME-PHASED PROJECT 78

LIST OF ABBREVIATIONS:....79

LITERATURE AND REFERENCES USED:....80

Chapter 1: Introduction

1.1: EWK

Edelstahl Witten-Krefeld GmbH (EWK) was established in 1994. This was the result of the independent status that the division *Halbzeug / Stabstahl / Schmiedeerzeugnisse* of Thyssen Stahl AG (TST) got. However the roots of this company go even further. Figure 1 shows how EWK has been originated into its present form.

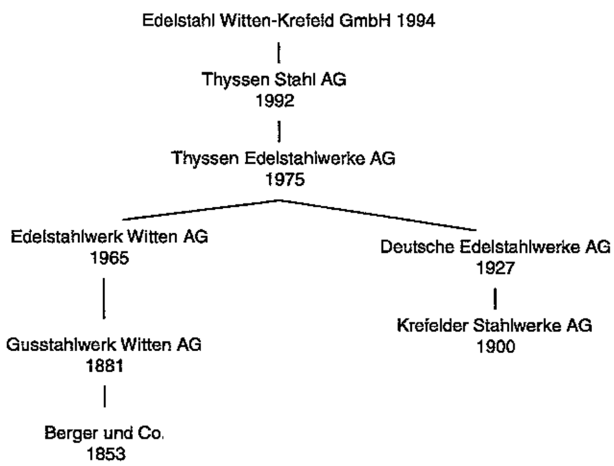


Figure 1: Historical development of EWK

EWK is a hundred percent subsidiary company of Thyssen Krupp Stahl AG. EWK has its main focus on rolled and forged products (*walz-und schmiedeerzeugnisse*) manufactured in high-quality steel (Edelstahl). EWK has 2,400 employees and generates a salesvalue of about 900 million DM. per year. EWK converts 400,000 tonnes of high-quality steel per year to satisfy 30,000 to 40,000 orders for e.g. the automobile and chemical industry. EWK has more than 20,000 customers world-wide and approximately 57 percent of the sales-volume goes direct to the customer and 43 percent to trading companies. EWK consists of three production sites located in Witten, Krefeld and Hattingen. Apart from their own sites this company has various outsourcing possibilities.

1.2: Background of the problem and initial problem definition

The operational characteristics of the supply chain at EWK (which will be discussed in section 2.4.2) result in a quite complex situation with regard to the logistic control. Some important performance measures of EWK were a through-put time of 4.5 weeks (the pure runtime of an average order is about 30 hours, so this results in ratio throughput-time:runtime of 1:25) and a due-date reliability between the 60% and 70%. EWK did not find these figures good enough and since the existing ERP system SAP/R3 did not provide the necessary planning functions, EWK searched for a new planning-tool. This new planning tool should make their supply chain more transparent and better controllable. Such a tool, they hope, will allow EWK to minimize their costs and at the same time improve their customer responsiveness. This can lead to a competitive advantage which is necessary in this time of increased competition. In October 1998 EWK started therefore the implementation of the Supply Chain Management Solution[1] of i2 Technologies.

More specific this package should enable EWK to reach the following goals:

- Improvement of the due-date reliability
- Shortening of the throughput-times (and consequently the due-dates) and as well a decrease in inventory.

[1] A general term for this kind of software is called Advanced Planning and Scheduling systems (APS)

As has being said the department Produktionswirtschaft (PW) is currently involved in the implementation of the Supply Chain Management Solution of i2. i2 Technologies, founded in 1988, has a broad set of solutions tailored to each kind of industry. One of them is the Rhythm Metals' solution. This solution is the one that i2 implements at EWK. The scope of the solution at EWK consists of the following modules (Figure 2).

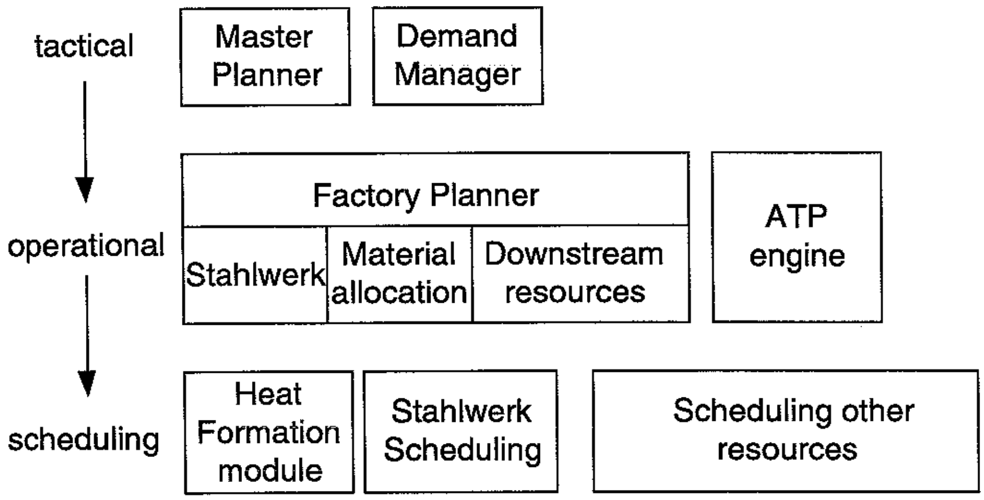


Figure 2: Overview of hierarchy various modules in i2 project

As one can see in this figure the various modules range in a hierarchy ranging from tactical through to operational and scheduling. The lowest–level decisions have shorter effectuation times[2], shorter planning horizons and are concerned with details. This hierarchy arises from differences in the effectuation times needed to execute decisions, the planning horizons for analysing and evaluating choices, and the magnitude of costs affected by the decisions [1]. For the purpose of this section it is only necessary to say roughly what the Factory Planner and Master Planner are (since this forms the subject of this report). The i2 project started with the implementation of the Factory Planner which captures all the various sites in one model. The Factory Planner determines on which day each manufacturing operation of a given customer order should be performed on which particular resource by creating a factory-wide optimal plan. The output of the Factory Planner will then be used as an input for the more detailed scheduling (sequencing) of the manufacturing orders.

One of the next steps in the i2 project is the implementation of the Master Planner. Again there will be one Master Planner covering the entire EWK supply chain. The Master Planner creates a Master Plan for EWK's supply chain over a horizon of 12 months, by integrating business policies, market demand and supply chain capability into one common plan.

However the software sold by i2 is not a solution in the sense that it needs no customization. There are many things that have to be made specific for the situation at EWK, where one of them is the question of how the integration between the FP and the MP should look like. This is a major issue within EWK. This is exactly the problem-description with which has been started at the beginning of this project.

More formally stated the initial problem-description is:

Given the possibilities of this APS package in what way should the integration between the two modules MP and FP look like, so that EWK can control its production activities optimally.

[2] Effectuation time: the difference between the point in time at which a decision is made and the point in time at which the effect of this decision on the production system is felt.

1.3: Structure of the report

Having given a short overview of EWK, an introduction into the background of the problem and the formulation of the initial problem formulation, the second chapter will give a more detailed description of EWK in terms of products it sells, production processes, organization and the planning-processes. This second chapter is divided into six sections. The first one will go more into detail about the products EWK sells. The second one will describe the site-structure and the goods flows structure. The third section is devoted to the way EWK is organized. Section 4 goes into the details of order-processing. The fifth one describes the operational characteristics to give an idea of the various difficulties that exist in planning the factory. The sixth section, lastly, will give an extensive treatise of the current way of planning. The third chapter will give a more detailed treatise of the various systems that are part of the i2 project. To have an understanding of these systems is important for chapters 5 and 6 in which the actual task-assignments are worked out. The fourth chapter reflects on the initial problem-statement and based on these considerations a revised problem-formulation including the various task-assignments is given. Chapter 5 presents the results of the first two task-assignments. In this chapter the conceptual production control structure in terms of processes is designed and for each process workflows are made of how to work with the various systems. Chapter 6 will deal with the third task-assignment and will concentrate on how to optimize and validate the quality of the MP model. Lastly in chapter 7 the conclusions are summed up and recommendations are given.

Chapter 2: Products, processes, organization and planning

The first section of this chapter will go more into detail about the products EWK sells. The second section will describe the rough routing each product follows, the site-structure and gives an overview of the goods flows that exist between these sites. The third section describes the organization of EWK. The fourth section discusses the way in which an order is processed. In section 5 the operational characteristics will be discussed which give an insight into the difficulties of planning. Section 6 will finally be devoted to the planning-processes at PW.

2.1: Products

As already mentioned EWK produces products in high-quality (*hochwertigen*) steel. These steels are characterised by particular purity and homogeneity. Tailor-made properties can be achieved by means of precise alloying and process engineering specifications with regard to melting, forming and heat treatment. These high-grade steels are categorised as follows within EWK (so-called *Werkstoffgruppe*):

- Stainless, acid and heat-resistant steels (*rost-, säure- und hitzebestandige Stähle* (RSH))
- Tool steels (*Werkzeugstähle*) including high-speed tools (*schnellstahl*)
- Engineering steels (*Edelbaustähle*) including bearing steel (*wälzlager stahl*)

EWK also produces three special kinds of products (*Sonderstähle*) which can not be categorised in one of three groups mentioned above. These are:

- FERRO TITANIT (*härtbare Hartstoffe*)
- *Dentallegierungen*
- *Schweisszusatzstoffe* (e.g. *drahtguss*)

EWK has a diverse range of products it sells. In total there are more than 40,000 different products which are sold to 20,000 customers worldwide (customers are for example from the automobile and chemical industry). All these products fall in one of the 50 main-products (*Haupt-erzeugnissen*). An important cause for this high end-product variety stems from the fact that each product can be supplied in approximately 450 different grades.

As has been argued above, EWK can supply the customer in various kind of industries with a broad range of high-grade steels. All these steelgrades can be given precisely defined properties, so they can be exactly adapted to their task or to the demands of the respective end-products. Not only can EWK supply the customer with the steel exactly tailored to its intended use, EWK also offers for example in the tool-steel range machined dies (*matrizen*) and ready-to-fit parts.

In appendix 1 a discussion of the properties and application-areas for each of the three product-categories can be found.

2.2: Production processes

Now that the background of EWK and the kind of products it makes has been discussed, this section will describe very simplified the operations each product follows and an overview of the site-structure and the goods flows between them will be given.

For each product that EWK produces, it undergoes very roughly the following steps:

- Melting (*erschmelzen*)
- Continuous casting (*strangguss*) or ingot casting (*blockguss*)
- Optional: remelting (*umschmelzen*)
- Deforming (*umformen*)
- Optional: Heat treatment (*wärmebehandlung*)
- Straightening (*zurichten/adjustieren*)
- Optional: Machining (*bearbeiten*)
- Finishing (e.g. Ultra Schall check and identity check)

First scrap steel gets melted in a furnace together with some additives. In this process the material in the furnace gets its specific grade (quality). After melting the melt can be casted in two ways: continuous cast or ingot casting. When the material is casted it gets its first form (*urformen*). To give the material even a better quality, it is possible to remelt it. The next step is to deform the cast in a certain shape (conform customer wish) (*umformen*). There are two ways to do this: rolling or forging. To give the material specific properties, it can be heat-treated in a certain way. After heat-treating the material gets straightened. To finish up the material undergoes some mechanical operations and lastly undergoes some inspections. For a more rigorous treatment of the processes the reader is referred to appendices 2 and 3.

Next, bearing these basic steps in mind the various shops at the different sites will be drawn up.

In Table 1 a listing of all the various shops sorted by its site can be found.

Table 1: Listing various shops according to site

Site	Shop
Witten	Stahlwerk (ST)
	Block-grob strasse (BG)
	Schmiedebetrieb (SB-Wi)
	Wärmebehandlungsbetriebe (Wä1 and Wä2)
	Bearbeitungsbetrieb (BBW)
	Schälbetrieb
	Zurichtungsbetriebe (Z1, Z2 and Z3)
Krefeld	Umschmelz-Stahlwerk (UST)
	Schmiedebetrieb (SB-Kr)
	Wärmebehandlungsbetriebe (WBK1 and WBK2)
	Bearbeitungsbetrieb (BBK)
	Schmiedeadjustagen (SAD1 and SAD2)
Hattingen	Vergüterei

At EWK the two terms *adjustagen* and *zurichten* have the same meaning. Moreover one has to realize that the name of the various shops does not necessarily imply that the shop merely consists of those kind of resources. For example the *zurichtungsbetriebe* in Witten and *schmiedenadjustagen* in Krefeld do not have only straightening resources, but have various other kinds of resources as well (such as finishing resources). This is also the case for the *vergüterei* in Hattingen. This is a shop complete with various hardening and finishing resources. For an overview of the various resources in each shop the reader is referred to appendix 4.

Besides these resources, EWK has various subcontractors to whom specific operations can be outsourced. Thus these specific operations require resources which EWK does not have at its disposal. The three main subcontractors can be found in Table 2:

Table 2: Important subcontractors

Company	Place	Resource
Thyssen Krupp Stahl AG	Brückhausen (stadtteil Duisburg)	Block-brammen strasse (which can roll 1.8 meter products) (blooming-slabbing mill) (B2)
Vereinigte Schmiedewerke GmbH	Hattingen	P25 (forging press) P60 (forging press)
Mannesman Röhrenwerke	Mülheim	A rolling resource which can roll 5 meter products (MRW)

In total there are more than 260 resources available that can be used to complete an order. Moreover most orders have to undergo its operations at different, geographically dispersed, sites. This multi-site-environment (including the sites of the various sub-contractors) requires therefore a careful coordination.

Figure 3 on the next page illustrates the most important goods flows that exist between the various shops at the different sites (a triangle represents a stocking-point, and a rectangle represents a shop or resource).

Some important things in this figure will be explained next:

Material is either transported in cold-condition or in hot-condition from the Stahlwerk to one of the deforming-resources (this has to do with technical peculiarities). This has consequences for the ability to stock material as unassigned material (*freie komponenten*) or not. Ninety-five percent of the melts which are produced for a deforming-operation on the BG are transported in cold-condition. So here material (this can be *blockguss, strangguss* or *umschmelzblocken*) can be stocked (see stockpoint 1). On the SX25 80% of the orders are processed in cold-condition. So here it is also possible to stock *vor-gewalzte* (on the BG) or *vor-geschmiedete* material (on the SX55) (see stockpoint 2). Orders from the ESU or LBVcan not be stocked here, since these are transported and then immediately processed in hot-condition on the SX25. However the same does not apply for the MRW and B2. For the MRW 100% and for the B2 95% is transported in hot-condition and immediately processed. So here it is not possible to stock *vor-material* Eighty percent of the orders for SB-Kr are also transported in hot-condition. For the remaining 20% it is possible to stock material (this can be *blockguss* or *strangguss*) in stockpoint 3. Here also applies that orders from the ESU or LBV can not be stocked here, since these are transported and then immediately processed in hot-condition in SB-Kr. Before the remelting shops in Krefeld also material can be stocked. This is done in stockpoint 4.

In the section about planning the function of these stocking-points as well as the *Zentral Lager* and the 2A lager will be elaborated on.

In Figure 3 one can see that material is first processed on the P33 and afterwards on the SX55. This combination that material is first *vor-geschmiedet* on the P33 and afterwards *fertig-geschmiedet* on the SX55 is called *verbund-schmieden.*

The three streams *rohblocke/rohstrang*, *unbearbeitet* and *unbehandelt* will be explained next. Depending on the requirements (wish) of the customer an order can also go directly to one of the finishing shops after deforming (see *unbehandelt*) or after heat-treatment (see *unbearbeitet*). A customer can also buy *rohblocke* or *rohstrang* (this is the name for the material after it has been casted)

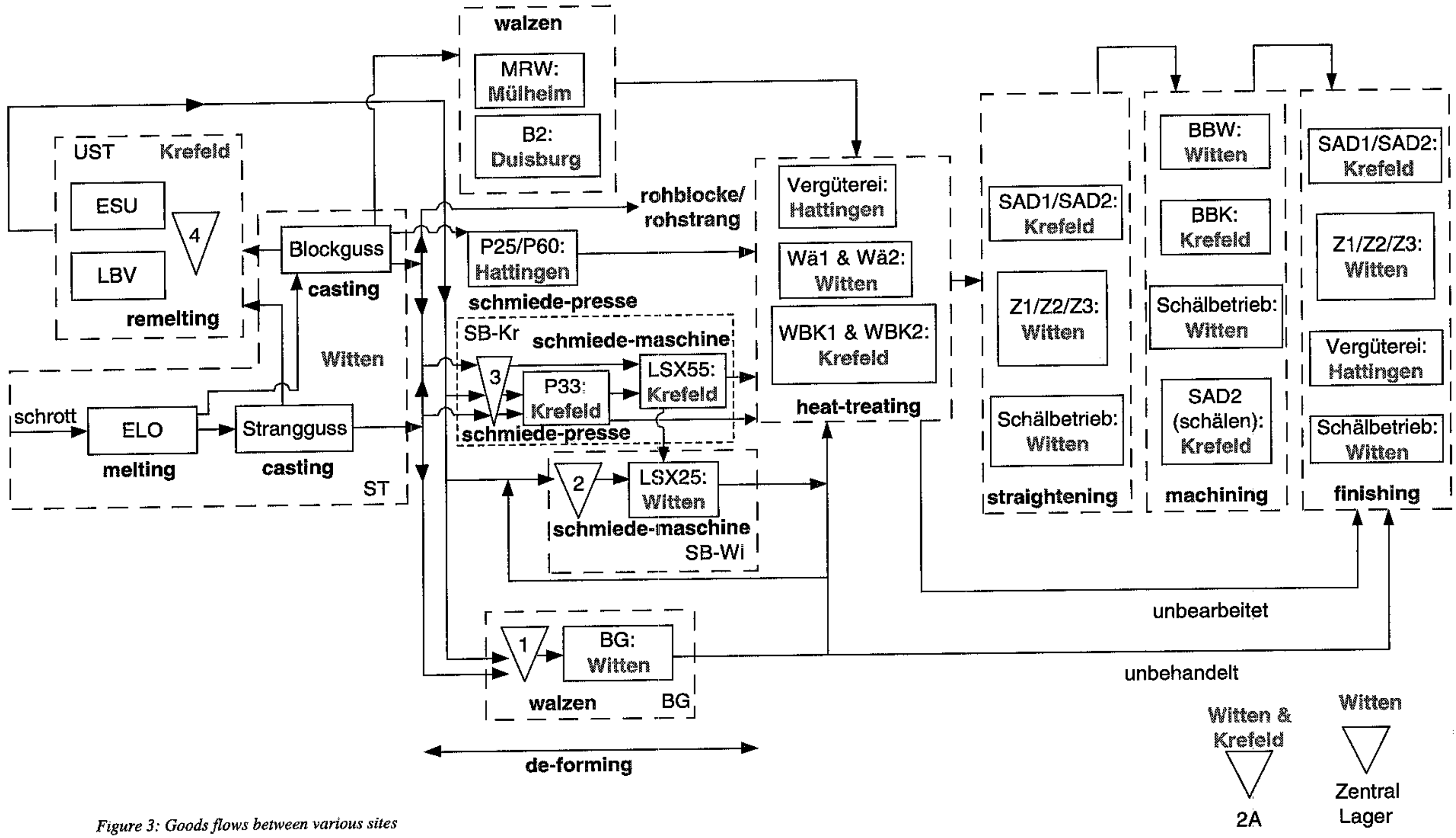


Figure 3: Goods flows between various sites

2.3: Organization

In this section the way in which EWK and Produktionswirtschaft (PW) is organized will be described. This will be done with the help of organization-diagrams. Also the responsibilities of PW and Absatz will be explained.

EWK is organized as is depicted in Figure 4:

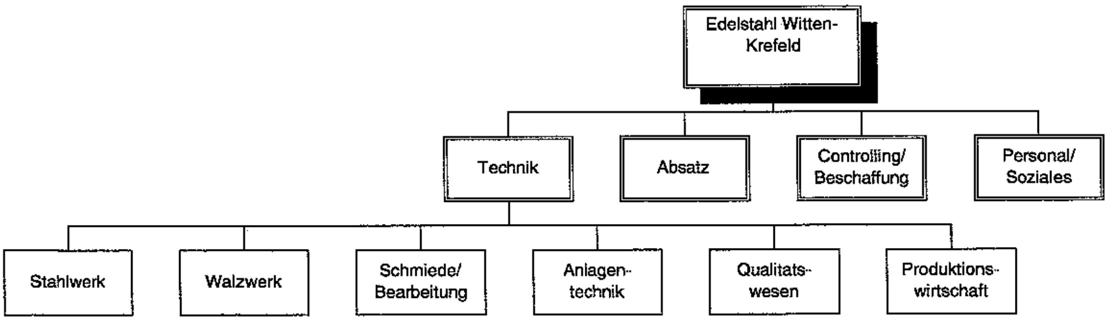


Figure 4: Organization diagram of EWK

In this diagram only the department Technik is split up into smaller organizational units. The other three are not relevant in the context of this project. The four departments: Technik, Absatz, Controlling/Beschaffung and Personal/Soziales speak almost for themselves. The responsibilities of the departments Absatz (Verkauf) and Produktionswirtschaft (PW) will be described below.

Absatz is responsible for:

- The contact with the customers
- The making of offers and order-taking (and supplements (*nachträge*))
- The settlement of claims

PW is responsible for:

- The confirmation of the feasibility (*durchführbarkeit*) of orders to Sales
- The due-date confirmation for the customers
- Making of the production-programs with taking into account the instructions of Qualitätswesen
- The provision of *vor-material* with taking into account the instructions of Qualitätswesen
- The granting of *lohn-arbeit* to subcontractors (*Passive Lohnarbeit*)
- The acceptance of *lohn-arbeit* (*Aktive Lohnarbeit*)
- The planning and controlling of the production in economical sense and with respect to the timeliness
- The development and maintenance of the software-systems and the documentation of the software

Because the department where this project is done is at Produktionswirtschaft (which is a part of Technik), the organization structure of PW is depicted in Figure 5 on the next page with its various departments. To know how the organization of PW is structured is important for section 2.6 in which the planning-processes are explained.

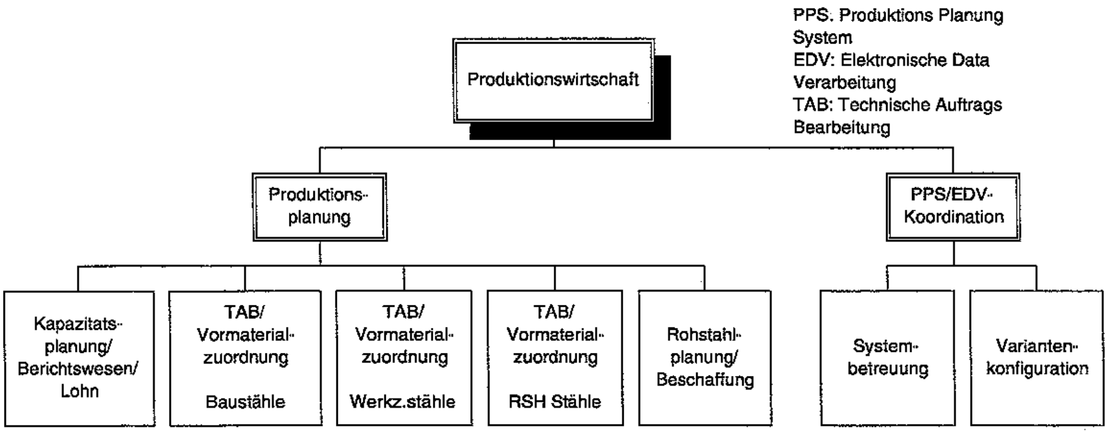


Figure 5: Organization diagram of Produktionswirtschaft

2.4: Order-processing

When a customer places its order at one of the sales-departments of EWK there are two possibilities. The first possibility is that the product he requested is on stock in the Zentral Lager. Zentral Lager has the most common items on stock. The only thing what still has to be done is sawing the product in the length the customer wishes for. Mostly the smaller customers are delivered from this Zentral Lager. At EWK these kind of orders are called *lageraufträgen*. The controlling of this stockpoint remains outside the scope of PW. The department which is responsible for this is a sub-department of Sales. When some minimum level of a certain product has been reached Zentral Lager places an order at PW. The information-system which supports this works separately from SAP. As can be seen this control-structure is make-to-stock.

The other possibility is that the order the customer places is not on stock at the Zentral Lager. This means that the *auftrag* is made to order (at EWK this is called a *strecken-auftrag*). For this situation the workflow of the order-processing is given in Figure 6:

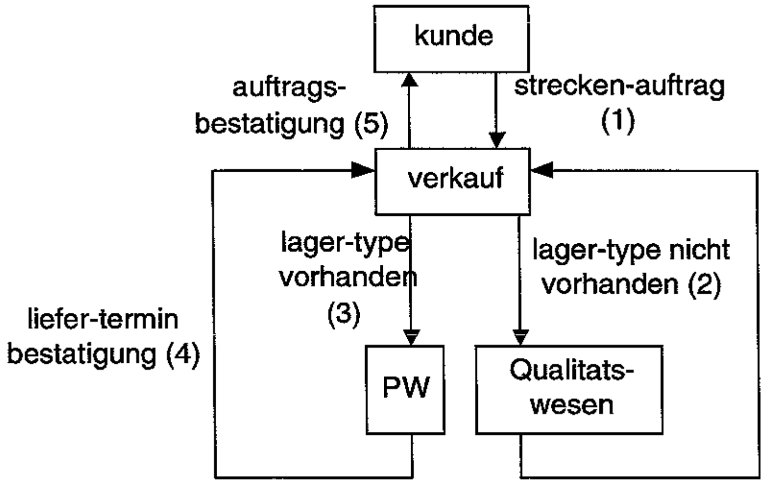


Figure 6: Workflow of order-processing for a strecken-auftrag

1) The whole process starts when a customer places an order at Verkauf. Verkauf gives each order a order-number (*Kunden-auftrag-nummer*). When the customer places orders for different products, each order for a specific product is given a position-number (*positions-nummer*). Each different product is described by a lagertype-number. One has to realize that this lager-type number is a detailed description for a customized product (tailored for a specific customer). A more detailed explanation of a lagertype can be found in appendix 5.

2) If a lagertype for this particular requirement does not exist yet the details of this order go to Qualitätswesen. Qualitätswesen checks the order on technical and qualitative details and establishes the different norms in the *merkmal-bewertung* and the way the order should be produced (routing etc.). These things are then recorded in the DV-system under a new lagertype-number (this is also called *internen Kunden-vorschrift*).

3) Verkauf checks the order on completeness and if it is corresponding with the technical specifications of the lagertype (these technical specifications of a lagertype are made by Qualitätswesen). Also the due-date for each position-number (this is the date when the customer likes to receive this product: *Kunde-wunsch-termin*) is entered. So the result of this order-taking is for each position-number the amount in kilogrammes for a particular lagertype and its due-date.

4) PW checks for each position-number of an order the feasibility of its due-date requirement. After one day (in exception cases at most two days) PW sends the first confirmed due-date for each position-number of a particular order (*erste bestätigte liefertermin*) to the responsible Sales-department. The way PW comes up with this erste *bestätigte liefertermin* and other planning-related issues will be discussed in more detail in section 2.6.

5) The sales-department receives the confirmed due-date for a particular position-number of an order and communicates this to the customer in question.

2.5: Operational characteristics

In section 2.2 the site-structure and the various shops have been discussed. This understanding is important to understand the difficulties that arise in planning the factory. This section aims at giving an insight into these aspects. As has been seen EWK produces high-grade steel products to order. This combination of make-to-order and the particular characteristics of the steel industry results in certain operational characteristics which requires careful planning. Next the most important characteristics will be mentioned and explained:

Grade-variety:
First there are more than 450 different grades. The problem here is thus to fill up a heat (melt) with orders that all require the same grade. Moreover some orders have the same grade, but are different in the sense that within this grade even tighter tolerances for one or more chemical elements apply.

Capacity-aspect:
All orders differ considerably from each other with regard to which operations they need, the amount of operations (average is approximately 10 operations), the time needed for one and the same operation. This applies for a large extent to the shops after casting. These factors result all in a competition for capacity by the different orders. So a good insight in the current resource loadings is essential.

Campaign-planning:
At the block-grob strasse one works in campaigns. This means that on this aggregate a specific rolling-group (*walzgruppe*: which can roll a certain dimension-range) is rolled for a certain time. These campaigns are necessary due to considerable change-over times (changing a calibre takes about one hour) that exist between the various calibres. The scheduling (*fein-planung*) of the various orders into one of these campaigns is as well a difficult matter.

Transport in hot-condition:
What also imposes a big hurdle in the logistic control is the fact that most of the material that has to be deformed at for example the forging shop in Krefeld has to be transported in hot-condition (*warm-übergabe*) to this shop from the Stahlwerk in Witten. This also applies for the material which has to be processed further at the MRW or B2.

Intra-site coordination:
The existence of three sites between which a large inter-dependence exists demands for a careful inter-site coordination. This is because each shop at a site does not necessarily have the same kind of resources in house.

Outsourcing:
The outsourcing capabilities have as a negative implication that they fall outside the logistic control of EWK. So this requires also careful coordination between EWK and the subcontractor.

Somewhat less important are the following:

Process uncertainties:
At average 1 of the 20 melts that are produced in the Stahlwerk does not comply with the planned specification. So it can happen that a specific quality which was aimed for in a particular heat is not met in spite of the presence of a process-control system. The reason can be for example that the scrap-group which was used was not as good sorted as it should be. Of course in this kind of industry resources are sensitive to faults and machine-breakdowns can occur. This can have a considerable impact on the flow of orders especially when such an aggregate forms a bottleneck. For example the casting in *blockguss* or *strangguss* does not always happen the way it should be or a large aggregate such as a forging press is now and then subject to a malfunctioning. The time to repair these kind of installations can take quite a long time.

Technical waiting times:
Further in for example the heat-treatment shops there are for example technical waiting-times. This means that when an order has been heat-treated it requires a certain time to cool-down before it can go to the next operation.

Batching constraints:
Heat-treatment shops are also subject to batching-constraints since one has to fill up the furnace to a certain extent to obtain a certain minimum loading.

All the foregoing issues result thus in a quite complex situation with regard to the logistic control.

2.6: Planning at PW

In this section the various planning-processes will described in more detail. This is done by describing the important planning-activities that take place in each planning department of PW (therefore the various sub-sections are organized according to these departments). Before this is done however, first two important notions will be introduced which are necessary for a good understanding of that what follows.

2.6.1: Plan-auftrag and fertigungs-auftrag

Two important notions that SAP uses are the two concepts: *plan-auftrag* and *fertigungs-auftrag*.
At EWK there are four types of *plan-auftrag/fertigungs-auftrag*:

1) a *plan-auftrag* and a *fertigungs-auftrag* for the *stahlwerk*
2) a *plan-auftrag* and a *fertigungs-auftrag* for the *umschmelz-stahlwerk*
3) a *plan-auftrag* and a *fertigungs-auftrag* for *vor-geschmiedete* or *vor-gewalzte material*
4) a *plan-auftrag* and a *fertigungs-auftrag* for a position-number of a customer-order

Plan-auftrag:
Such an order is not yet released to the shopfloor and thus only "exists" at the department PW. It contains the sequence of all the steps which are necessary for production. The starting-times for the operations are known. However these can change in the mean-time.

Fertigungs-auftrag:
A *plan-auftrag* is converted into a *fertigungs-auftrag* when material has been allocated to this order. Later this *fertigungs-auftrag* is released to the shopfloor (the precise *arbeitsvorgaben* are printed and send to the shopfloor). The timing of this releasing varies for each case.

So for a certain order one has either a *plan-auftrag* or a *fertigungs-auftrag*. When a *fertigungs-auftrag* is finished (in the first three cases) or some step of a *fertigungs-auftrag* is finished (in the last case), the status of this step is changed to "finished". This *zurückmelden* of timing and quantity of a finished step is done in the FLS (*Fertigungs Leit System*) and is just an interface to SAP.

Now these two kinds of orders have been made clear, the planning-process will be described in the remainder of this section. The basis for the sections 2.6.2 to 2.6.5 forms the following workflow (Figure 8) which will be referred to in these sections when necessary.

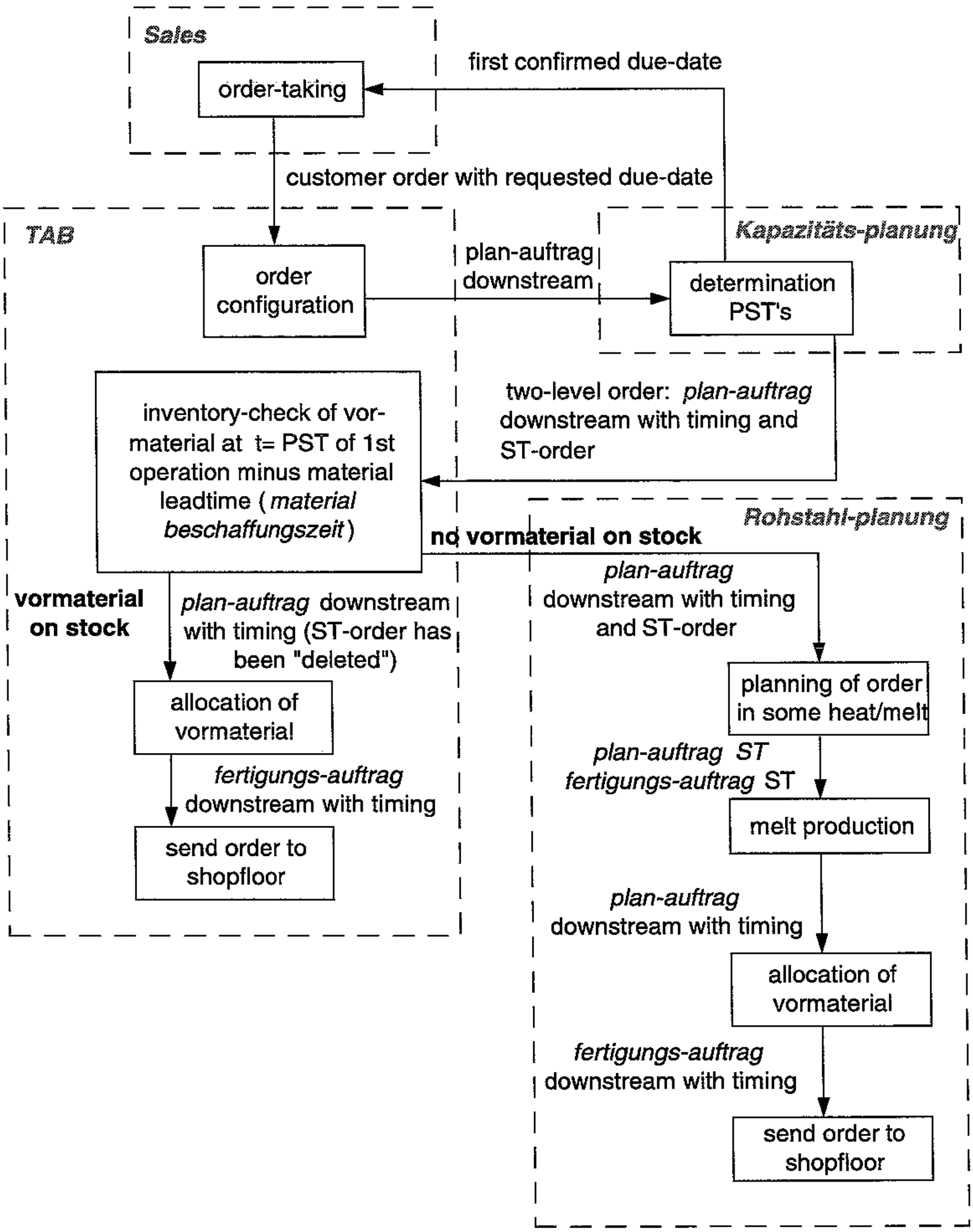


Figure 8: Workflow of planning

2.6.2: Technische Auftrags Bearbeitung (1)

As has been shown in section 2.4 the order goes from Verkauf to PW via SAP when all the commercial (*kaufmännischen*) and technical details are cleared. More specific the order goes to one of the *Technische Auftrags Bearbeitung* (TAB) departments which is responsible for this particular type of order: RSH, BS or WS.

TAB configures each position-number of a *kunden-auftrag*. Configuring means that a particular order is fully specified with regard to the routing, kind of input-material which is needed and the quantity and length of it. The result of this configuring is that a position-number of a *kunden-auftrag* is converted into a so-called *plan-auftrag*.

This *plan-auftrag* is still unconfirmed with respect to its due-date. The next step will confirm for this *plan-auftrag* a certain due-date.

2.6.3: Kapazitäts-planung

This department tries to plan the order-book in such a way that each customer-order is completed on time. This process is supported by the Factory Planner. Next the Factory Planner (what it does and how is worked with it at EWK) will be explained in more detail.

The Factory Planner, given all manufacturing orders[3], will generate a planned start time (PST) for each operation it has to undergo in the factory. This is done as follows:

Each night planning-data (which contains the latest information with regard to the status of each order in the factory) is uploaded in FP from SAP. The next morning the planning-department *Kapazitätsbelegung* makes a new plan for this day. This is done in two steps:

The FP works by first loading all of the orders on the plan as if there were infinite capacity. The infinite capacity pass identifies existing problems and allows the planners to take corrective action. At EWK they adjust the campaign planning for the BG and the *schmiede-betrieb* Krefeld.

Then the Factory Planner is run in finite capacity mode which is used to eliminate resource overloads, without creating unsatisfactory due-date performance or violating material constraints. The finite capacity pass employs a constraint-based, bi-directional propagation technique that forces changes to both upstream and downstream resources. This technique, referred to as constraint-anchored optimization (CAO), uses a global approach as opposed to a local one when resolving conflicts.

At EWK they run the FCP first for the BG and the *durchlauföfen*, then they freeze (lock) the *plan-aufträge* on these resources for a certain horizon so other *aufträge* can not push them out. After that FCP is run for all the resources. The last step is that the planner imports the unconfirmed orders and FP plans these in and the result is that each new order gets its first confirmed due-date (as can be seen in the Figure 8).

So the Factory Planner establishes for each order a PST for each operation.

Important is that the Factory Planner splits each customer-order up into two manufacturing orders (the so-called two-level order). One for the Stahlwerk (various of these Stahlwerk-orders are then grouped in a heat which is feasible because of the batching restrictions and constitute together a plan-auftrag/fertigungs-auftrag for the Stahlwerk) and one for the downstream resources. At the end of section 2.6.4 we will come back to this.

2.6.4: Technische Auftrags Bearbeitung (2)

The TAB has a list from FP for all orders sorted by the PST for the first deforming-operation and *werkstoffnummer*. For each *werkstoffnummer* there exists a so-called *material-beschaffungszeit*. This is the time-span of which one can say with some certainty that the *vor-material* can be made available. These times are based on historical data.

[3] these can be one of the orders as listed in section 2.6.1

Since not every *werkstoff-nummer* is melted as oft as other *werkstoffnummern* these times can differ from *werkstoffnummer* to *werkstoffnummer*. The *material-beschaffungszeit* can vary from approximately 20 days to 50 days. A responsibility of TAB is to assign (*zuteilen*) *vor-material* to an order. So what TAB does is looking if there is *vor-material* available for a certain order when the PST of the first operation minus the *material-beschaffungszeit* has been reached. They do this with help of an informationsystem called PROSE. PROSE is a database which contains information about all the available material which has not been allocated yet to an order. The following information is being kept in PROSE: meltnumber (*schmelznummer*), grade (*werkstoff*) and status (*anwendbarkeit*). So TAB enters the lagertype of an order (a *kunden-plan-auftrag* without a material-allocation) in PROSE and PROSE gives then all the *schmelz-nummern* back which could be used for this particular order in this quality (it filters all the possibilities). Moreover for each possibility a status for the combination material-order is given. Status green means that the material can be used without any problems. Status yellow means that there are certain restrictions in the application of the material for this order. Status red means that first consultation has to take place with Qualitätswesen before this material is used for the order. One has to realize that different status can apply for different combinations material-order. In the future this allocation of material will be done automatically by FP for about 50% of the orders.

Besides this information-source for free material that is available, there are also two stocking-points (one in Witten and one in Krefeld) which stores material that used to be allocated to a certain order but not anymore. The reason for this is that the material did not satisfy anymore the requirements of this particular order and is therefore rejected. Since it still could be used for some other order it is stored in these so-called second-choice (*zweite wahl*) stocking-points.

As can be seen in Figure 8, two things are possible when TAB searches for the right material. The first possibility is of course that the needed material is available (this can be the case because the production system is not a pure pull-system as is explained later in section 2.6.5). The Stahlwerk-order of the two-level order is "deleted" then since there is already appropriate *vor-material* available. The only thing that remains to be done is to allocate the material to the order and to convert the *plan-auftrag* in a *fertigungs-auftrag*. When there is no material available (the second possibility), TAB has to make sure that it gets produced in the Stahlwerk. The Stahlwerk-order is maintained of course then. The logic of the two-level order makes sure that no unnecessary stocks-accumulation occurs by postponing the production as much as possible. So what TAB does is sending all the orders for which the *material-beschaffungszeit* has been reached and for which the needed *vor-material* can not be satisfied from stock to Rohstahl-planung. Next will be described how Rohstahl-planung plans it melts.

2.6.5: Rohstahl-planung

Per day about 13 melts can be produced. Each melt weighs approximately 130 tonnes (in fact the maximum tonnage of a heat is a function of the dominant grade as well as whether the orders in a heat are to be ingot casted or continuous casted). At the *Rohstahl planung* of PW they make a planning for the melts with a horizon of 5 days. Each two days a representative of this department discusses this plan with ST. They adjust then the plan together by taking into account aspects such as possible infeasibilities, the status of progression or to possible changes that have arisen.

First those orders that are processed in hot-condition are planned in (because the melt has to be produced on the same day as when it is processed in hot-condition on the next operation). Then, based on this structure, the cold melts are planned in. This is done since cold melts are less strict with regard to timing, since they can be stocked.

Each melt is being charged with a specific *schrott-grupp* (this is sorted used steel) (which *schrott-grupp* depends on the specific *werkstoff*). In the process a sample is collected and the process-control system calculates then how much of which alloy-elements still has to be added to obtain the specific grade (these alloy-elements are much more expensive of course than the scrap). So the input for this ELO is a so-called *schrott-grupp* (scrap-group). The provision of this material is arranged by Thyssen Krupp Stahl AG in Dortmund. The availability of this input-material is in the planning never a problem. Besides *schrott-grupp* as well *legierungen* (alloys) and *schlackenbildner* (slag forming addition) form an input for the ELO (these are also guaranteed a 100% availability).

As has been mentioned, the *Rohstahl-planung* receives the orders for which not the appropriate material was available. *Rohstahl-planung* tries to plan these then in the next few days.

When forming a heat important restrictions have to be taken into account. Appendix 6 lists the most important restrictions. This grouping of orders into heats is supported by the Heat Formation module of i2.

Besides the grouping of orders into heats, the sequencing of the melts is also an important issue and is bound to certain restrictions. Some sequencing restrictions that apply are listed as well in appendix 6. For these kind of restrictions a scheduler for the different heats is planned for in the i2 project (this is called the Stahlwerk-scheduler).

The planner works as follows:

By looking at the orders for which the *material-beschaffungszeit* has been reached (condition 1) and by taking into account the various restrictions (condition 2), the planner groups and sequences the heats. Cold orders for which the *material-beschaffungszeit* has already been reached and is being planned in a certain heat, a soft link is made between the order and the melt. A hard link between such a cold order and material is only made then just before it has to start. By doing this, one remains as flexible as possible. For hot orders a hard link is made of course since these orders require immediate processing after it has been melted and thus can not be stocked.

In order to fill up a heat when that is necessary (so when there are not enough orders which fulfill these two conditions) the planner looks at other planned orders which could also be planned into this heat, but for which the *material-beschaffungszeit* has not been reached yet. For these orders also a soft link between the order and the melt is made and the material is produced to stock (stock-order). Here again holds that doing this has as advantage that flexibility is created.

When there are even no longer-term orders which could be planned in the planner has to (in order to fill up the heat) create real stock-orders which is being stocked at one of the stockingpoints (see for the various stocking-points Figure 3). This can be called a push-system. However the possibility of filling up the heat with longer-term orders is not a real push-system, since it is stock which exists in expectation of longer-term orders which already have been accepted.

Chapter 3: Systems

In the foregoing chapter the planning-processes have been discussed. The focus in this chapter was on the processes and not so much on the systems which support it. However a good understanding of the systems is important for chapters 5 and 6 in which the actual task-assignments[4] will be worked out. Therefore this chapter will give a quite detailed explanation of three systems which will be used in the future to support the planning-activities. These are respectively: Master Planner, Demand Manager and the ATP-engine. Then will be explained why an integration between FP and MP is necessary and also how this is accomplished in the i2 solution. Lastly an overview will be given of the total systems' architecture.

3.1: Master Planner

The first sub-section will explain what the Master Planner is and does and what its inputs and outputs are. Also the logic underneath the MP model and the advantages it can bring will be discussed. The second sub-section will describe exactly how the factory is modelled within MP.

3.1.1: Description

The Master Planner creates a capacity feasible production plan for a given forecast, based on defined business goals. It is a tactical plan that operates over a twelve-month horizon in weekly time-periods. The Master Plan connects sales and manufacturing by providing a unified plan.

Stated differently, the Master Planner creates a plan which Sales wants (accepting the business it wants, no FIFO accepting) and which is feasible with regard to capacity.

The input for the Master Planner are the forecasts for the various planning-items (and the other flat-files as well). The output are the so-called ATP-allocations per planning-item per planning bucket (or planning period). The ATP-allocation can be interpreted as a reservation of capacity for a certain planning-item.

The logic underneath the Master Planner is a multi-objective linear program (hierarchical layered optimization). The outcome of the MP is the result of minimizing the shorting of forecasts with priority one subject to the capacity restrictions (these are linear restrictions). Then the second objective: minimizing the shorting of forecasts with priority two is applied. This is done in such a way that the optimal solution for the previous objective can not be worsened.

So what the Master Planner does is calculating for an one-year horizon the capacity reservations (in terms of the ATP-allocations per planning-item) by taking into account the main constraints of the factory (so without violating the capacities of the main production-routes) and where the objective is to minimize the deviations of the allocations from the forecasts (first for the forecasts with priority 1 and secondly for the forecasts with priority 2). By having taken into account these restrictions with the ATP-allocations and accepting and quoting orders based on these ATP-allocations, it is expected that an order, when accepted, is much better able to realize its first confirmed due-date (the demand and production-capabilities are much more closely aligned this way). So one of the advantages the Master Planner can bring is, besides a plan Sales wants, a higher due-date reliability (percentage of the confirmed orders which is shipped on time).

3.1.2: Modelling in MP

The Master Planner "thinks" in terms of the so-called planning-buckets (at EWK the planning-buckets are one week). Only the most important (critical) resources are modelled on this MP level. An analysis has been made by EWK to determine which resources these are. At this moment approximately 50 resources are modelled on this level. On the Factory Planner every resource has been modelled. Some of them have been modelled on an aggregate level (there are approximately 250 resources modelled on this FP level). Not all resources on FP level are 1 to 1 related to the MP level.

[4] The revised problem-description and the formulation of the task-assignments will be discussed in chapter 4

In order to describe in more detail how things are modelled within Master Planner first two notions have to be introduced. These are the so-called planning-product and a planning-item.

A planning-product is an aggregate product. This planning-product is modelled as a weighted combination of various routings. Each routing consists of a sequence of operation/resource steps. For each operation/resource step the following data are given:

4. run-rate (capacity usage)
5. yield
6. lead-time (to offset these capacity usages in time)

Furthermore each parallel routing in a PP is given a weight, the so-called distribution percentage. One could interpret this as a aggregation weight. This is illustrated below.

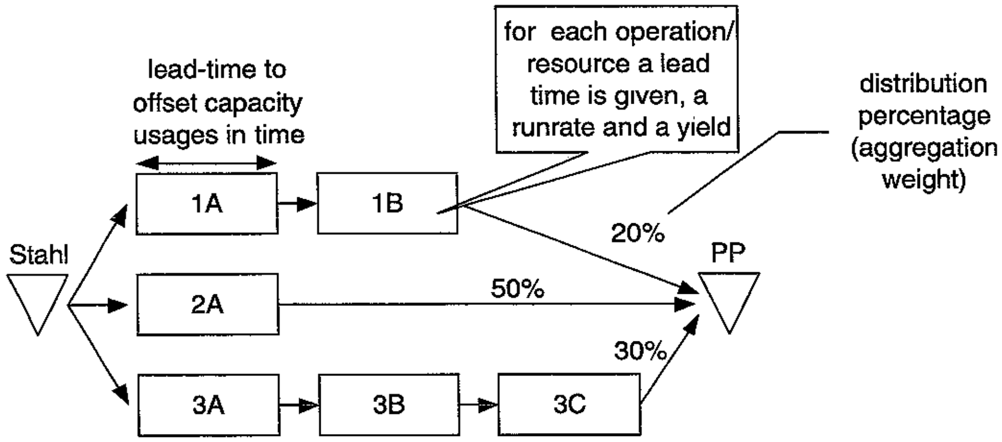


Figure 9: MP-model of production system

The specific operation is represented by a so-called *Vorlagen-schlüssel* (that is the code-number of a operation). For example V020 means rolling. With resource is meant the specific machine on which it undergoes the operation. The triangle represents a stockingpoint.

A planning-item has two dimensions: planning-product and market-sector (seller). What market-sector exactly means at EWK will be explained in more detail in the next section. For each forecast of a planning-item a priority is assigned. The priority can only be 1 or 2.

3.2: Demand Manager

The Demand Manager is a database created in Microsoft Access. This DM consists of two parts and therefore serves two purposes. The first part is a GUI (Graphical User Interface) in which the forecasting can be done by Sales. The second part is that the DM creates all the relevant flat-files which are necessary as an input for the MP. Furthermore it is able to disaggregate the ATP-allocations on planning-item level (which have been calculated by the MP) to allocations on LT-level.

In able to create these files the Demand Manager consists of several tables and several procedures which are programmed in VBA (Visual Basic for Applications). The most important information in the flat-files are the following:

- Definition of the parallel weighted routings of the planning-products in terms of the sequence of operation-steps
- For each operation in such a routing a specification of the run-rate, yield and lead-time
- For each parallel routing a distribution-percentage
- Forecasts on planning-item level per planning-bucket (which is a week)

As has been said the other part of the Demand Manager is a tool which supports the forecasting process. The forecasting is done in each sales-department on lagertype-level for a team of customers.

This looks as follows:

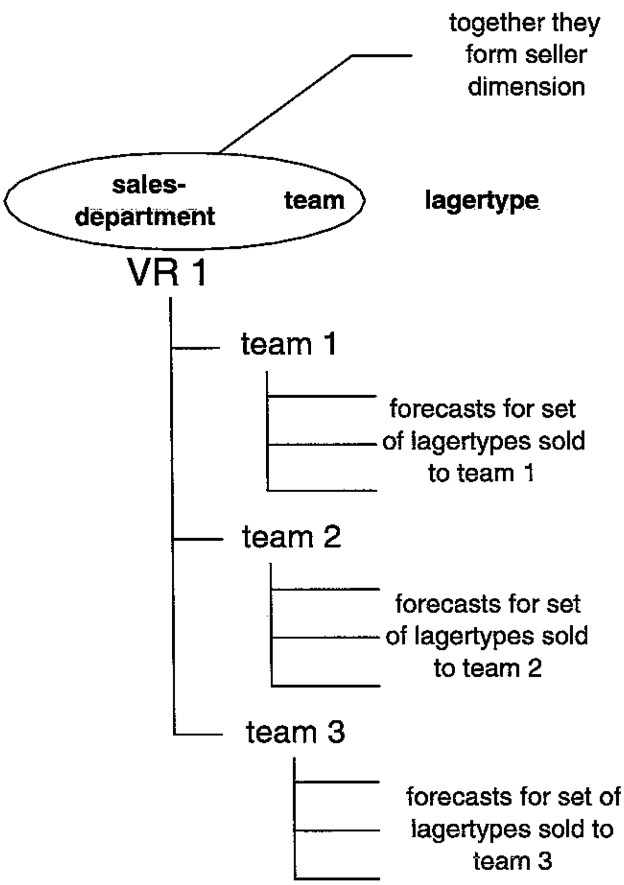


Figure 10: Structure of how forecasts are given

The seller-dimension (which has been mentioned in the discussion of the MP) is formed by the sales department and team. The forecast for some planning-item is then the sum of the forecasts of those lagertypes which belong to the same seller dimension and which (when mapped to its planning-product) belong to the same planning-product. So the forecast for the planning-item (which is an aggregate product with a seller-dimension) is based on a detailed approach.

3.3: ATP-engine

The ATP-allocations on planning-item level form the basis on which orders will be accepted and quoted. This is done by means of the so-called ATP-engine. ATP refers to the quantity available to commit to future customer orders after meeting all existing commitments. The following formula applies:

ATP = allocated-consumed (for a specific planning-item)

So this ATP logic can be used as orders are entered into the system (SAP/R3) to accept orders or not. Besides this the ATP-engine can provide realistic due-dates for those orders that are accepted.

When an order comes in at Sales, the ATP-engine checks if for this order enough ATP is available. Next an example will be presented in order to illustrate this ATP logic.

The table below shows the current ATP figures for a certain planning-item at t=3 (which were calculated on t=0).

Table 3: ATP figures

	T=1	T=2	T=3	T=4	T=5	T=6	
Allocated	20	30	100	100	50	50	
Consumed	20	30	60	0	0	0	
ATP	0	0	40	100	50	50	

Now an order comes in with a request for 40 tonnes for a lagertype (which falls into this planning-item) with a due-date of t=5. As can be seen this order can be accepted with a confirmed due-date of t=5 since the ATP figures are sufficient.

The ATP figures, after having accepted this order, look now as follows (Table 4).

Table 4: ATP figures

	T=1	T=2	T=3	T=4	T=5	T=6	
Allocated	20	30	100	100	50	50	
Consumed	20	30	60	0	40	0	
ATP	0	0	40	100	10	50	

Now suppose another order comes in with a request for 150 tonnes to be delivered at t=5. Also this order can be accepted since the cumulative ATP is 150 tonnes (the summed ATP of t=3 through to t=5) and is therefore sufficient to fulfill this order.

Since the MP modelling does not take into account the time needed for the appropriate *vor-material* to become available, a fixed leadtime is added when quoting an order.

3.4: Integration FP and MP

The reader should have an idea of how the Master Planner and Factory Planner works by now. Therefore it is now possible to discuss why there should be an integration between FP and MP and how this integration is done.

Because the Master Planner and the Factory planner have an overlap in its horizon, MP has to take into account the already planned orders by FP (in able to provide realistic ATPs for the first few months, since these are used in the ATP-engine). When the order-book is mapped as a function of time for some planning-item, one gets the following picture:

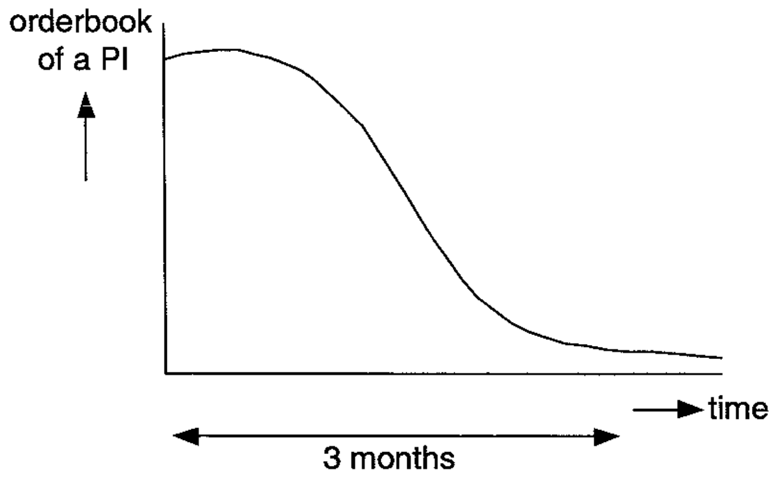


Figure 11: Order-book mapped as function of time

This is done based on the netted forecast and the netted capacity logic.

Netted forecast: The order-book in lagertypes is mapped to the order-book in planning-items (it depends on the due-date of the orders in Factory Planner in which planning bucket it falls in the Master Planner). This order-book in planning-items is then netted from the forecasts given per planning-item. This is illustrated in appendix 7.

Netted capacity: The resource loadings of the already planned orders in FP are mapped to resource loadings per planning bucket per MP resource (there are about 50 modelled resources on the MP level). In which planning-bucket the load falls depends on the PST for this operation of this specific order. These figures are then netted from the available capacity per MP resource per planning bucket. The available capacities of the various MP resources for the 12 month horizon are based on the FP resource calendars (these FP calendars are imported in MP). So this capacity netting is done in order to block-out the already consumed capacity in FP on the MP level. In appendix 8 some pictures illustrate this concept.

The result is that the netted capacity is used by the MP level to plan the netted forecast with.

Another possible part of the integration is the one of unassigned material. However since material is so diverse (big fan-out) it is impossible to take to this aspect into account on the MP-level (the technical mapping between unassigned material and planning-item is thus impossible).

Figure 12 provides the global view in terms of all the various systems and its interactions. Information about the various mappings which take place can be found in appendix 9.

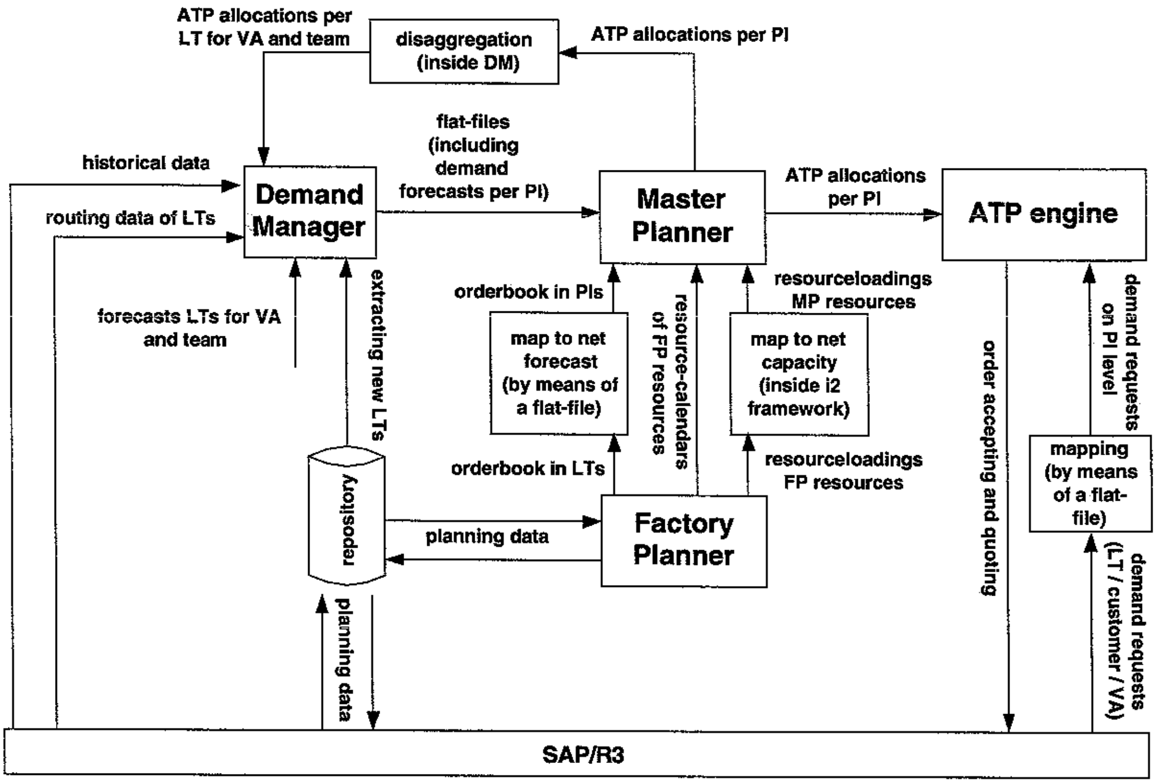


Figure 12: Systems' architecture overview

Chapter 4: Final problem description and assignment tasks

In chapter three the various systems have been described, including the total systems' architecture. One has seen in section 3.4 that there is already a solution at hand for the integration FP and MP. When one compares this to the initial problem description which is stated in section 1.2 one can see that the question of how the integration between FP and MP should look like is not that interesting anymore. Therefore was looked together with the various involved parties at other problems (related to operational control) which EWK faced in this i2 project and which would be tackled during this project. The result was that EWK wanted to have a better idea of the global picture of the production control structure and which decision functions it consists of. They felt that this was necessary because, during implementation, the focus was too much on getting the details of the systems up and running without thinking of the business processes the systems serve. This means that it was not clear to them how should be worked with the various systems in order to achieve to intended goals of the various processes. Furthermore the initial outcome of the MP (in terms of the amount of forecasts satisfied) did not comply with their expectations. Since the MP plays such an important role in the tactical planning a more thorough analysis of the underlying model in MP should be made in order to improve its validity. Consequently the problem-statement has been revised and is now stated as follows:

> For EWK it is not quite clear how should be worked with the various systems (on its own and together) and how all these systems together will fit in the conceptual production control structure.
>
> Besides that the initial outcome of the MP (in terms of the amount of forecasts satisfied) did not comply with their expectations.

In order to tackle these problems the following task-assignments have been developed and agreed on by the various parties:

1. **Developing the production control structure in terms of processes:**
   First a design of the conceptual production control structure will be made. Therefore the main processes (decision functions) which together constitute this production control structure will be identified and explained. Furthermore will be explained how these three processes will help in achieving important business objectives. All this will be treated in section 5.1.
2. **Designing workflows of how to work with the various systems which support these processes:**
   For three of the four identified processes in the first task-assignment designs will be made of how to work with the various systems (in order to achieve the intended purposes of the processes). These three processes are respectively create consensus forecast, get ATPs from MP and pass over to ATP-engine, order accepting and due-date quoting. These differ from each other with respect to the frequency with which the process is done, its planning horizon and the bucket size of the horizon. For each process the following will be done:
   - Describe process
   - Describe workflow
   - Describe dataflows

   Where possible various alternatives are investigated and are evaluated on its advantages and disadvantages (pro's and con's). The results of this will be presented in sections 5.2 through to 5.4.
3. **Improve validity of MP model:**
   Since the MP calculates the ATP-allocations which form the basis for order-accepting and quoting, and thus directly influences the profitability of EWK and due-date reliability, it is very important that the underlying model in MP should be validated. This third task-assignment is set out in chapter 6.

Chapter 5: Design of workflows

This chapter will describe the results of the two first task-assignments which have been defined in the previous chapter. The first section is devoted to developing the production control structure (conform first task-assignment) and the last three sections will present the results of how to work with the various systems in order to achieve the goals of the various processes (conform second task-assignment).

5.1: Conceptual production control structure at EWK

As already mentioned this section will present an overview of the production control structure in terms of the various processes (decision functions) which take place. First will be explained what is meant with production control and with a production control structure by citing a concise definition. Bertrand, Wortmann and Wijngaard [2] defined production control as the coordination of supply and production activities in manufacturing systems to achieve specific delivery flexibility and delivery reliability at minimum cost. A production control structure contains the decision functions used for this coordination and the relations between these decision functions. Pictorially the production control structure is represented in Figure 13. This picture tries to give a view in terms of the processes and not from a software system's perspective (because the systems only support these processes[5]).

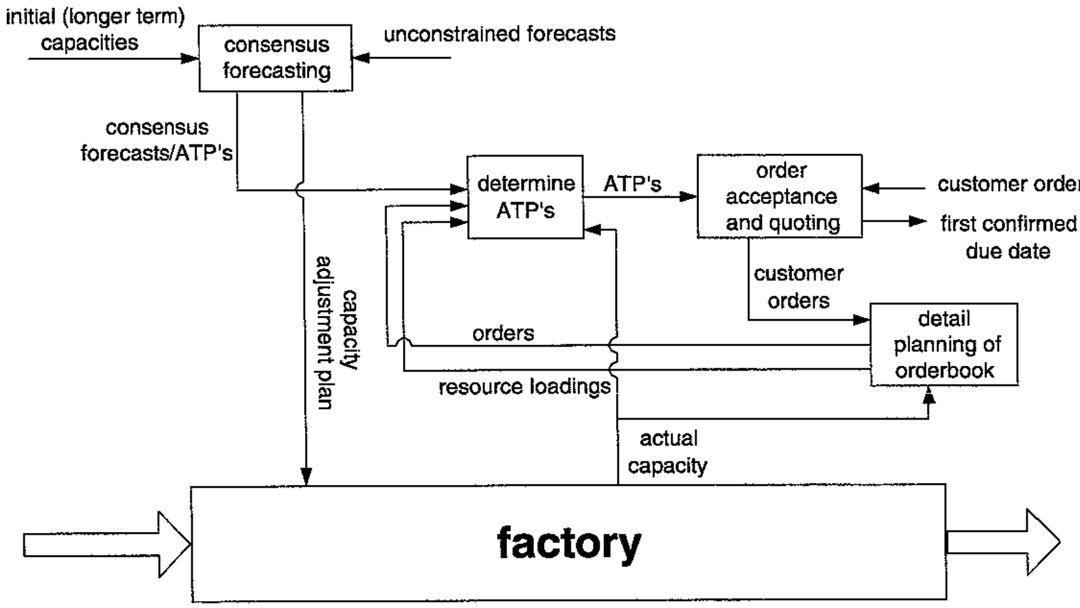


Figure 13: Conceptual production control structure

The first process is the so-called consensus forecasting process (CFP). This is the decision which is done least frequently. The result of this process is an agreement between Sales and Production on what and when to sell and to whom. So this is a plan what Sales likes and can sell and which is feasible with regard to capacity. This process is done each month with a horizon of one year (the planning-bucket is here in months). This process also drives the capacities of the various shops since this level can see the future impact of the plan on the main capacities. This is represented in Figure 13 by the arrow "capacity adjustment plan".

The second process determines the ATPs and passes them to the ATP-engine. These ATP figures reserve capacity for specific (aggregate) products for specific customers based on the forecasts. The granularity of these ATP figures is in weeks and the frequency with which this is done depends on the situation. Besides the consensus forecasts which form an input for this process, also the order-book in FP forms an input here. This ensures that the short-term planning-horizon of the Master Planner is synchronized and prevents either over- or under-estimating of production capacity (these feedback loops from the FP to this process can be seen as well in Figure 13). How this is accomplished

[5] A global picture of the various systems which support this process is illustrated in Figure 12

technically speaking has been discussed in section 3.4. Furthermore an input to this process forms the actual capacity. This is important since the actual capacity can differ from what was planned and if this is the case an update of the ATP figures should occur. Section 5.3 will elaborate further on this updating-issue.

The third process uses then these ATP figures to base the order-acceptance and quoting decision on (the granularity of quoting orders is in weeks and is done each time a customer arrives). This function thus only accepts the business EWK wants: there is thus no FIFO accepting.

The last process is the day-to-day planning of the order-book (the planning-bucket is here thus in days). The system in which the day-to-day planning of the order-book is performed is the Factory Planner

These processes (decision functions), which together form the production control structure, should result in the following business objectives:

- Higher due-date reliability and lower work-in-process
- Increased return on assets (ROA)

Next will be explained how the various processes can result in a better performance with regard to these objectives.

Since the first process provides visibility between the unconstrained forecasts on one side and the supply chain capabilities on the other, EWK is able to make a plan according to customer (market) and product priorities. So it is able to create an optimal sales-plan which has a positive impact on their profitability (thus also on their ROA). Furthermore this plan is also feasible with regard to capacity, since it takes into account the main (critical) capacities when making this plan. This creates thus the conditions for a higher due-date reliability since they do not promise more than that they are able to produce.

The second process makes sure that the actual state of the production system (which changes due to certain events like a machine-breakdown) is also taken into account in calculating the ATPs which are used at order-entry. So this results in ATPs which are as realistic as possible.

The third process makes sure that indeed the right business (according to the plan) is accepted. So there is no order-accepting based on first-come-first-served (which used to be the case). Because the ATPs form, so to say, a valve, this results in a stable flow of orders which contributes to being much better able to realize the first confirmed due-date. This thus improves the service-level realized towards the customer which is important for protecting the existing customer base (and thus the future profitability of EWK).

Next these three processes will be described in more detail. This will be done with help of workflows and dataflows.

5.2: Create consensus forecast

This process of making a satisfactory (what Sales likes and can sell) and capacity feasible plan is done each 3 months with a horizon of one year (a rolling horizon approach) approximately 3 months before the planning-horizon. Inputs for this process are the initial capacities (initial since actually this process should drive the capacities on the FP-level; section 5.2.2 will elaborate on this aspect), the unconstrained forecasts and the relevant MP modelling data. Each month also a revision of the forecasts takes place in a meeting between Sales and PW.

The systems which supports this process are the Master Planner and the Demand Manager. What the Master Planner and Demand Manager do and how they work, have already been described in chapter 3.

In Figure 14 a workflow is presented which depicts step by step the various activities which have to be performed in this process.

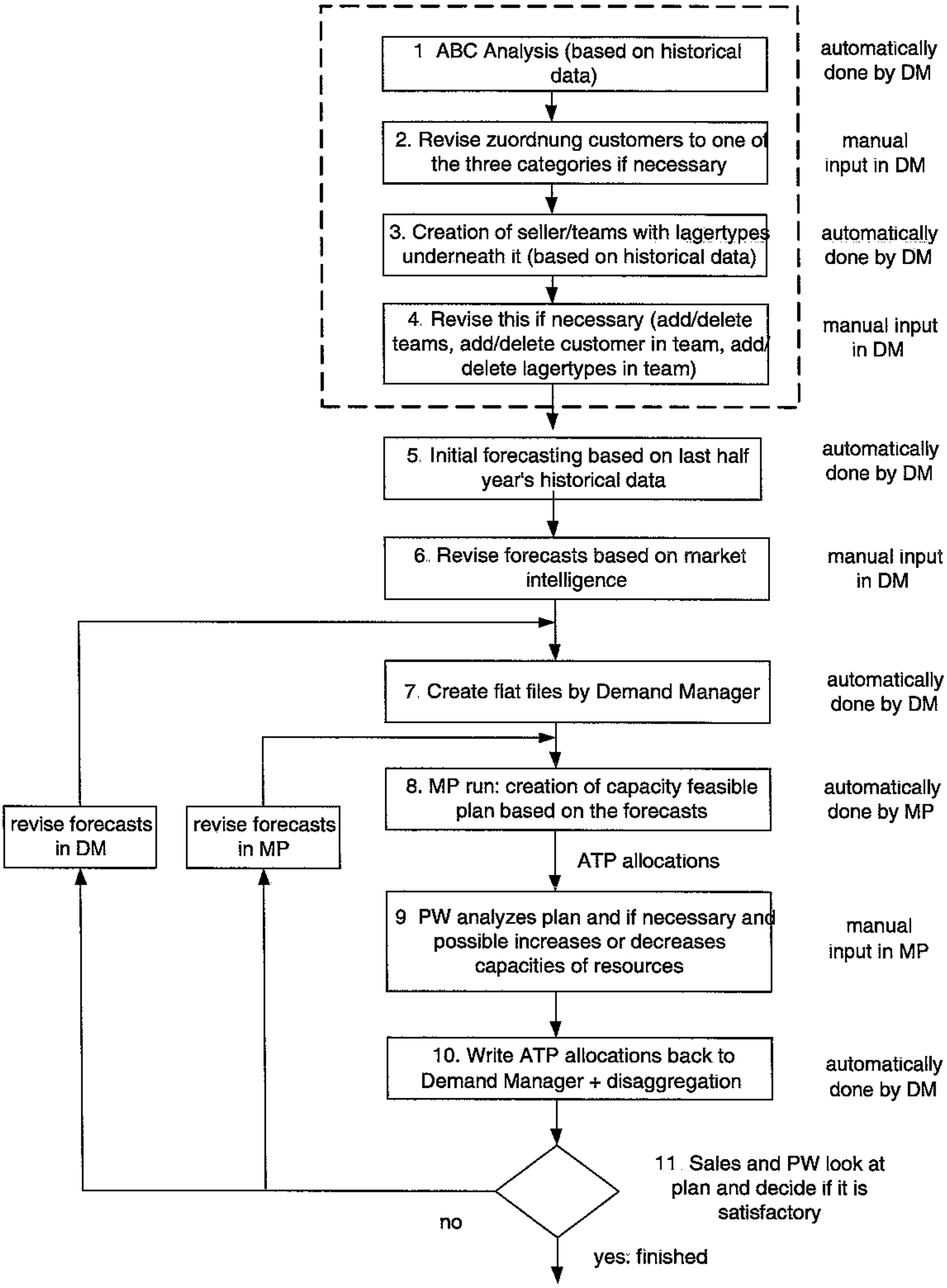


Figure 14: Workflow consensus forecasting process

A comprehensive description of each step in this workflow can be found in appendix 10. As well dataflows (in the form of Activity and Message Diagrams) can be found in appendix 11. This section will concentrate only on the most important issues. These are respectively how forecasts should be revised and the notion of the "driving capacities function" of this process.

5.2.1: Revision of forecasts

As already mentioned the result of this process should be a plan which Sales likes, can and is commited to to sell. However one has to realize that the result (in terms of the ATPs for the PIs) of the first loop of this process can be unsatisfactory to Sales (since the input are the unconstrained forecasts). So Sales and PW should review the calculated ATP figures in the first loop and if they are unsatisfactory they should revise the forecasts. This process of revising the forecasts in order to create a consensus forecast can be illustrated by means of the following picture (Figure 15).

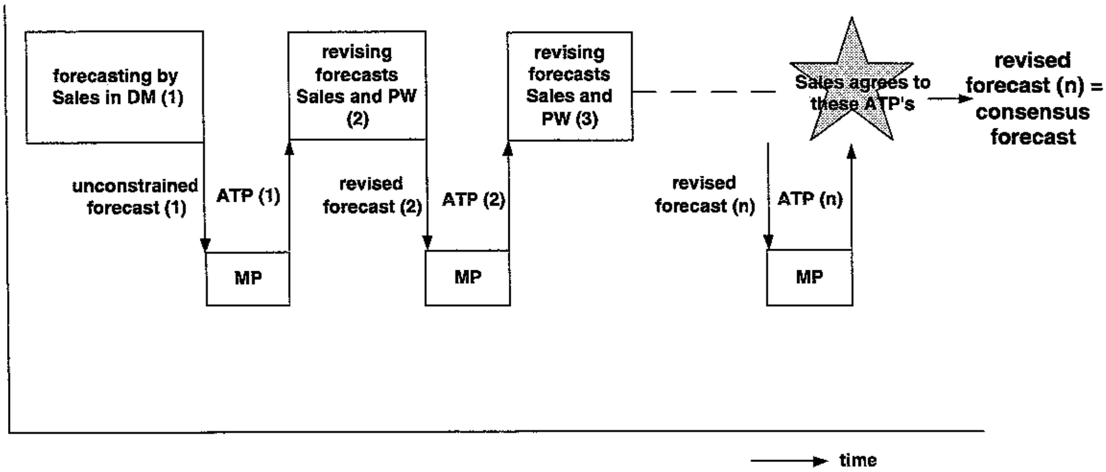


Figure 15: Process of creating a plan which Sales likes and can sell

Various alternatives are possible to revise the forecasts. These alternatives are explained next together with each its advantages and disadvantages. Lastly a recommendation is given for the most suitable way of working.

First alternative on how to revise the forecasts in Demand Manager:

After disaggregation Sales can compare for each lagertype underneath a seller what the ATP is compared with the forecast for each monthly bucket. When the ATP for a certain lagertype underneath a seller is not enough and Sales wants to increase its ATP, the only option is to increase its forecasts. However the lagertype with increased forecast, will only get more ATP after the MP run, if forecasts have been decreased for other lagertypes which fall into the same planning-product as the LT for which the forecasts have been increased (in order to free up capacity for this planning-product). The difficulty here is however that Sales thinks in terms of lagertypes and does not have an idea of the notion planning-product. Even if Sales has this notion (e.g. when the system supports this by giving the user an overview of which LTs fall into which PPs) this way of revising forecasts is very time consuming since there are more than 20,000 lagertypes for which there are forecasts (too much detail).

Second alternative on how to revise the forecasts in Demand Manager:

An other alternative which the DM supports is to compare the total allocation a seller got with the total forecasts which have been given for this seller. On this seller level it is then possible to revise the forecasts when this is desirable. However one has to realize that when changing the forecasts on this level, the effect of this on the ATP is difficult to anticipate/estimate. So smart revising of forecasts (in order to create plan which Sales wants) on seller level is difficult, since all lagertypes underneath a seller fall within different planning-products. The effect of revising this way on the ATP is therefore difficult to judge.

Third alternative on how to revise the forecasts in MP:

Revising of forecasts can be done on planning-product level within MP. So the handling of the forecasts is then done on an aggregate basis.

When this is desirable, EWK can decrease the forecasts for one planning-product and increase it for an other planning-product in order to shift the allocations between the two PPs. This has its intended result on the ATPs when these two planning-products share the same kind of bottleneck resource.

Fourth alternative on how to revise the forecasts in MP:

Revising of forecasts could also be done on planning-item level within the MP. Sales and PW can re-allocate the ATPs within a planning-product between the different market-sectors when this is desirable. This results then in different ATP figures for the different market-sectors within the planning-product.

Recommendation:

One has seen that the initial calculation of the aggregate forecasts (in terms of PP and PI) for the MP are based on a detailed approach in the DM. However it is recommended to perform the handling of the forecasts (in order to make a plan that Sales wants) on an aggregate basis. So this is a combination of the third and fourth alternative. This approach is the most logical/natural thing to do, since the ATP engine works also in terms of aggregate products. So why go into more detail when revising the forecasts? Another advantage is that less systems are involved in this process which make things easier. This process of revising should be done in a structured meeting between PW and Sales. Such a meeting between Sales and PW is very important, since this provides from both sites the appropriate know-how to make these kind of decisions/trade-offs. Moreover doing it this way, will result in a knowledge-transfer between these two functional areas (for example Sales gets a better idea of what a planning-product implies in the "Sales-world").

5.2.2: Driving of capacities

One can see in Figure 12 that the resource-calendars of the MP resources are imported from FP. This could give the false suggestion that these capacity availabilities remain fixed during this process. However one of the key-benefits of this process is overlooked then. Namely this key-benefit is that the result of the consensus forecasting process should drive the capacities of the various shops since this process can "see" the future impact of the plan on the main capacities. So the decision to increase or decrease capacities (since there is some flexibility in adjusting the capacities for the various shops on the short-term) is the result of this process. Output of this process could also be used as an input into planning of more strategic nature (which deals with the more longer-term decisions e.g. investing in new machines). So the importing of the calendars is only done to give the Master Planner an initial value of the capacities to work with.

What has been argued above is also reflected in step 9 of the designed workflow in Figure 14. This step says "PW analyses plan and if necessary and possible increases or decreases capacities of resources". So if some planning-products have too little allocated capacity (result of their forecast shorting), PW should look if it is possible to increase the available capacities for some resources in order to take away this shortage. PW can perform then several what-if scenarios to see what the result of this modifying is on the ATPs.

It is recommended to perform this step on planning-product level. The advantage to perform it on PP-level is that the whole process is more transparent, since the PPs directly influence the capacity consumed by the forecasts (the view is then on somewhat less than 50 variables). Planning-items will multiply this figure with approximately four. Because this step deals with capacities the specific breaking-up in planning-items is here not that important.

One has to note that in this process the Factory Planner is not accounted for, since these kind of decisions deal with issues on the somewhat longer term (longer effectuation times), so the short-term is here not of interest. In the second process the ATP figures are calculated which form the basis for order-accepting. Since the order-accepting decision is taken each day the short-term state (order-book of FP) should thus be taken into account. However the basis for these figures are the results of the first process. This second process will be described in section 5.3.

5.3: Determination ATPs and pass to ATP-engine

An issue here is when to update these ATP figures. This is important because this process determines the ATPs which are used at order-entry. Since the decisions taken at order-entry (the decisions whether or not to accept an order and if accepted quoting an order) are actually being felt by the production system (here the result of all the preceding processes is materialized) and thus determine the state of the production system, the ATPs used here should reflect as realistic as possible of what EWK is capable of making. In this section first the possible causes which could lead to an update are investigated and explained. Lastly a proposal will be given on when to update the figures and how this could be supported.

Three possible reasons for updating the figures are (this can be seen in Figure 13 when one looks at the different input-arrows):

1. revision of forecasts
2. actual capacity is structurally different than planned for
3. changed order-book

Before these 3 causes are explained in more detail, first something has to be told about two terms which will be used in this discussion. These are the terms stability and consistency. With stability is meant more specific the stability in the ATP figures and with consistency the consistency between the FP-level, MP-level and consensus forecasting process (CFP). The stability-aspect is important because these figures are used in the order-accepting and quoting process. The maximum frequency of updating is of course one day (since the FP also works based on planning-data which are extracted from SAP each night). Suppose the updating is done each day (so the MP-run is done based on the latest status of each of three above described inputs and then passed to the ATP-engine). Of course the MP-level is then very consistent (at least as much as is technically possible within the i2 solution) with the FP-level and CFP. However the question is what the effect of the updating-frequency is on the stability of the ATP figures (this remains to be seen). Next will be explained why instability in the ATP figures is not really a desirable situation.

When there is a large instability, this can result in quite some confusion at Sales. Suppose for example a customer places an order and there is not enough ATP for it and thus the customer has to be sold "no". The day after another customer places an order (which falls in the same PI and with the same due-date as the order which was placed by the customer the previous day) and "suddenly" there is enough ATP for it, so it can be accepted. So this is of course from the viewpoint of the customer an awkward situation and for the sales-person also not a stable basis to work with.

The first possibility will be explained next. Revision/updating of the forecasts takes place each month in a meeting between Sales and PW. When the quality of the forecasts (quality in terms of the uncertainty of the forecast) is drawn as a function of time, one gets the following picture:

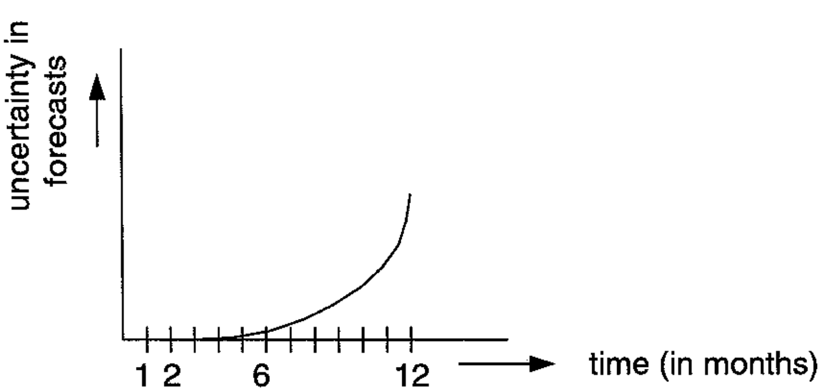


Figure 16: Uncertainty in forecasts as a function of the time-window

As one can see the quality of the forecasts for a horizon of 3 to 6 months is fairly good. After that period of time the quality decreases dramatically. So therefore this revision of forecasts is necessary.

One can argue that based on the quality of these forecasts, this revision of forecasts also results in a real difference in forecasts of the order-mix (in terms of different forecasts for planning-items). Therefore updating the ATP figures, after the revision, seems like a good thing to do.

The second possibility for updating the ATP figures, is also important, and this is when the actual capacity differs than what was planned for. The feedback-loop to this process can be seen in Figure 13.

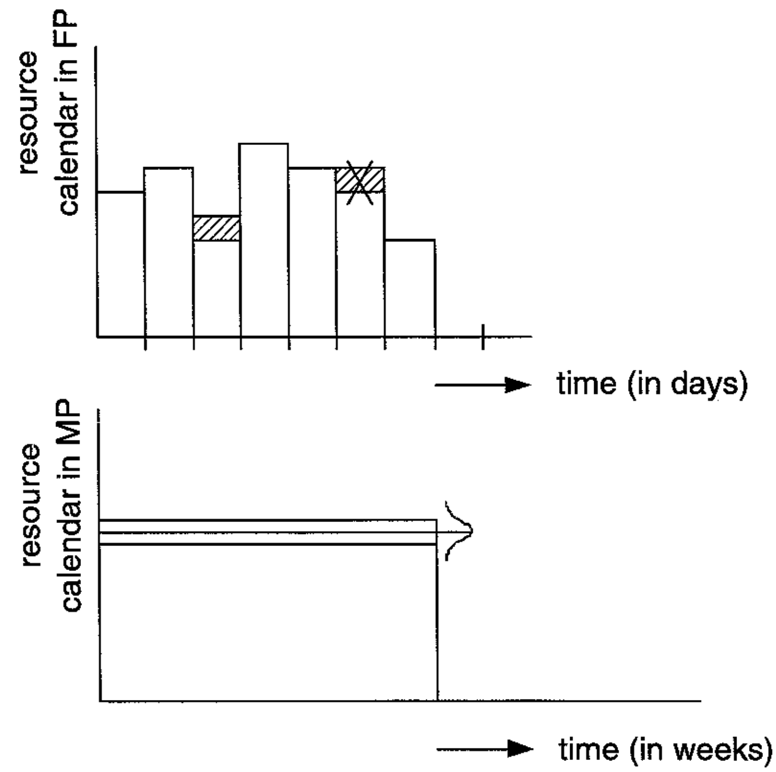


Figure 17: Illustration of capacity availabilities in FP and MP

One can ask if adding or removing a shift should result in an updating of the ATP figures. In the first picture of Figure 17 it is decided to add a shift at t=3. At t=6 is decided to remove a shift. Adding a shift at t=3 results in a larger available capacity on MP-level (when one updates). But at t=6, the available capacity is again just as large as it was. So the average capacity per week (on the MP-level) has not changed because of this. Updating these figures each time a shift is added or removed makes sure the FP and the MP are very consistent with each other, but the effect of it on the stability of the ATP figures has to be tested. So this is a trade-off between stability and consistency. What is important is that the average capacity is the same as was planned for (the changes in the day-to-day capacity is thus not that important). So if the average capacity which was planned for is going to be really different from the actual capacity (so a structural difference), an updating of the ATP figures is necessary. If this is not the case an update is not necessary. This first case can happen for example when a machine break-down occurs and results in a large down-time of the resource. Of course the ATP figures, should be updated then. An estimation should be made of the amount of down-time and this should be reflected in the resource calendar on the MP-level. When this happens an ad-hoc updating has to be done.

The third cause are the day-to-day changes in the order-book. However this does not necessarily imply that updating of the figures also should be done each day. The effect of the day-to-day changes in the order-book on the stability of the ATP figures must be tested, to give a good recommendation for the frequency of updating. However it is expected that an update (by means of netting the capacity and the netting the forecast in MP with the FP order-book) once a week will result in a good trade-off between the stability in the ATP figures and the consistency between the FP and MP-level.

To conclude this discussion a proposal and recommendation is given for the frequency of updating. Criteria for updating the figures can be divided into two categories. These are so-called time- and event-criteria.

The time-criteria apply in this case to when the forecasts change as a result of the CFP. So this means that an update is done each month after a CFP. Furthermore an update should be done to synchronize the MP horizon with the horizon of the current order-book by means of netting the capacity and netting the forecast. It is expected that once a week will suffice. The event-criteria refer to the case that certain events make it necessary to do an update. This happens thus when the actual capacity changes considerably from the planned capacity. A tool which could be of help when an update should be triggered is illustrated in Figure 18.

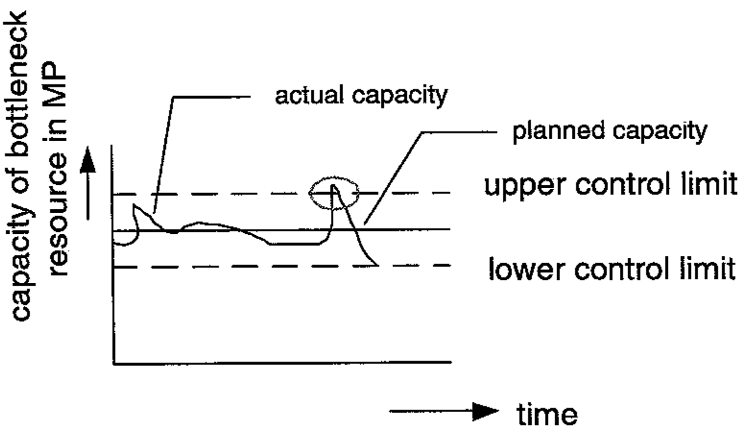


Figure 18: Tool for triggering updates in case of certain events

When the actual capacity crosses one of the control limits, one could speak of a structural difference (e.g. a machine breakdown) and consequently an updating should occur. When the actual capacity remains inside the limits, one could speak of a non-structural difference (day-to-day variations, but average stays the same) and therefore an update is not necessary.

In appendix 11 a dataflow in the form of a Activity and Message Diagram of this process can be found.

5.4: Order accepting and quoting

Given the ATP-allocations which form the output of the second process, these allocations are then used at order-entry to base its order-acceptance and quoting decision on. When an order comes in and there is enough ATP for it, it is merely a routine question. However if there is not enough ATP for it, what can be done then? This section will therefore identify the various steps a Sales-person can undertake when trying to find enough ATP for it. Lastly the proposed solution by i2 in the form of its ATP-engine will be discussed and some critical remarks will be given.

Figure 19 on the next page provides the rough framework of the possible steps.

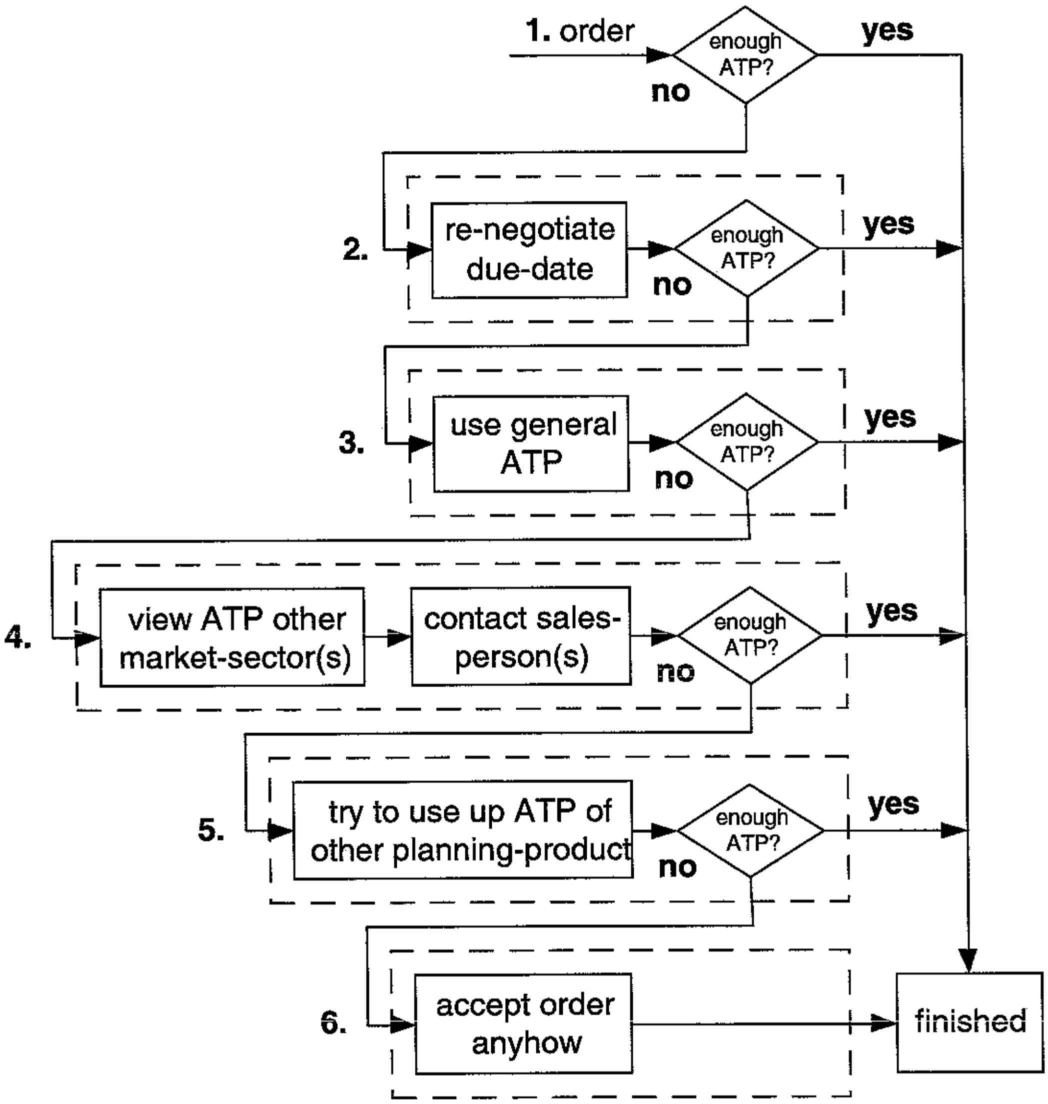


Figure 19: Possible steps in order to find sufficient ATP

Next each step in this workflow is (see the indices in the picture and the text below) explained in more detail.

1. Customer places its order by some form of medium (telephone/fax/email etc.) at one of the sales-departments (*verkaufs-abteilung*). This order constitutes a certain amount for a certain lagertype and requested due-date for a specific customer. The salesperson enters the necessary information into SAP and the ATP-engine gives a signal back whether or not enough ATP is available to satisfy this order completely on time. When there is enough ATP the order is accepted and confirmed for this amount and due-date. So when there is enough ATP for an order, everything is just as normal and the order-entry process is merely a routine question. However suppose the ATP-engine gives back that the order can not be accepted (so it can not be satisfied completely on time since there is not enough ATP). What could be done then? There are then various alternatives the Sales-person could consider to accept the order in some way or an other.

2. One of them is to re-negotiate another due-date with the customer. The due-date the sales-person is aiming for should be then of course that due-date for which enough cumulated ATP is available. It is then up to the customer if this new due-date is okay with him. In this context it is also possible to split up the order in various sub-orders each with an other due-date. It is not sure if this type of order-handling lies in the business-policies of EWK or the other party.

3. Another option could be for the sales-person to use some ATP on a higher level which is shared between the various members lower in the hierarchy. So this is a general ATP which can be used for all orders which are handled by one of its members. This hierarchy can be illustrated by means of the following picture:

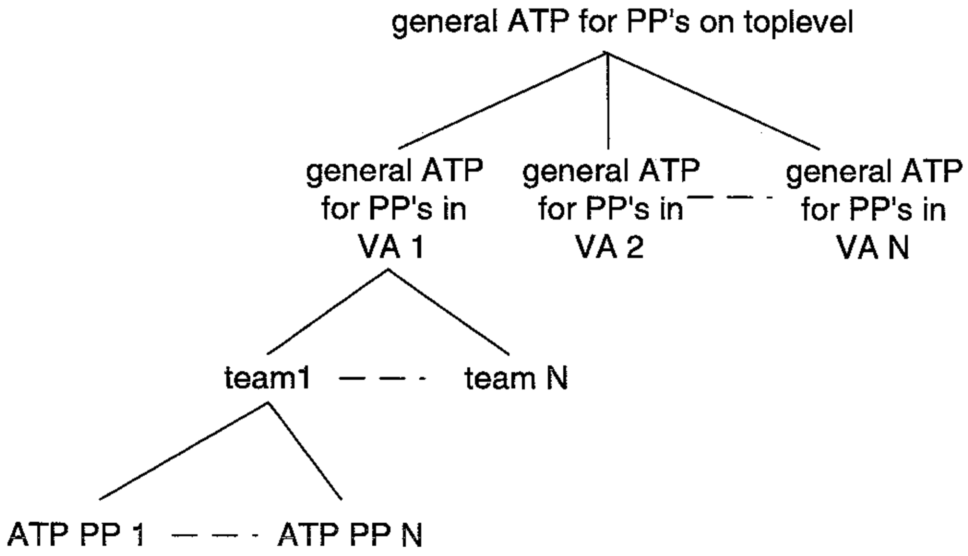


Figure 20: ATP-hierarchy

4. If this previous option does not work out, the salesperson could check if (this should be supported by the system in the sense that it can give such a view on the ATP figures) there is some ATP of the same planning-product but different team within his sales-department he could use. This "borrowing" could be of course also done from various teams as long as the total is enough to satisfy this order. Also ATP could be used for this specific planning-product from another sales-department. Of course the responsible sales-person of this other market-sector has to be contacted if this is allowed or not. This depends for example on the expectations of future orders in this planning-product/market-sector category. If this sales-person allows him/her to use some of his ATP, then there is no problem. However suppose he/she does not allow this, and the other still persists in using some of his ATP, then the two involved persons should step to their superior (the superior of the *verkaufs-abteilung* in question) to discuss this. Their superior should make the decision then. When this issue of using ATPs plays between two different *verkaufs-abteilungen*, this decision should be made on an even higher level in the organization.

5. If the sales-person, after considering the above options, still is not able to find enough ATP, he could try to use ATP of a different planning-product. However he should contact PW about this to find a suitable planning-product which has a quite similar capacity-structure and ideally one which shares the same bottleneck resource.

6. As a last option of resort, it could be possible to accept the order anyway (e.g. when it is a very important customer). So it should be possible to override the system. However it has to be defined who the authority has to do so in this situation. In this case also PW should be contacted to discuss whether this can be done or not. So one has to look what the impact is of this decision on the other, already accepted, orders. One should realize that accepting an order although there is not enough ATP for it should be an exception rather than a rule because otherwise the whole idea behind the ATP concept is lost.

Having mentioned and explained these various steps, now the way the ATP-engine deals with these steps in the case of not enough ATP will be explained. The ATP-engine provides most of the above mentioned functionalities. However the ATP-engine can only be run in two modes: full automatic and completely manual. Doing it completely manual has as disadvantage that it is too time-consuming, since the goal is to give the customer an immediate (real-time due-date quoting) answer on his request (in terms of if the order can be accepted and if so with which due-date). The advantage is of course that the user has complete control over the outcome of the process when considering the various possibilities.

When performing it full automatic, the advantage is that the ATP-engine gives within seconds the outcome by performing the various steps in some pre-programmed way. However an important drawback is that the user has no control over the process. One has to realize that the outcome of the ATP-engine can have its effect across the organizational boundaries of Sales (e.g. by "stealing" ATP of a team in another sales-department). Since each organizational unit at Sales has also separated responsibilities, this is an unwanted side-effect of doing it completely automatic. Bertrand [2] confirms this by saying that the design of a production control structure has to start with the development of a framework of organizable decision functions. Important here is the term organizable which means that responsibilities and decision-authorities should coincide. So therefore it is important that the user has some control over this process. Therefore a middle way would be better. A solution would be to let the user interact with the system by having a view (visibility) on the possibilities and so the system assists the sales-person in making a decision (decision support system). This way the sales-person is more flexible in making its decision and he or she remains in control over the outcome. Furthermore the responsiveness in giving a quote to the customer will also be fairly reasonable in this setting.

In appendix 11 a dataflow in the form of a Activity and Message Diagram of this process can be found.

Chapter 6: Quality MP model

As already mentioned in chapter 4 this chapter focuses on the quality of the MP model. First it will be shown why this is so important by relating it to two important performance measures. Next the current situation with regard to how the MP has been modelled will be discussed. Since this analysis reveals certain shortcomings a new method for calculating 3 MP parameters is designed. Also the performance of this new method will be compared to the old method by performing several tests.

6.1: Exploration causes

The intended advantage of the implementation of the MP depends on several factors. In Figure 21 an overview of the various factors which affect the 2 performance measures: due-date reliability and ROA is given.

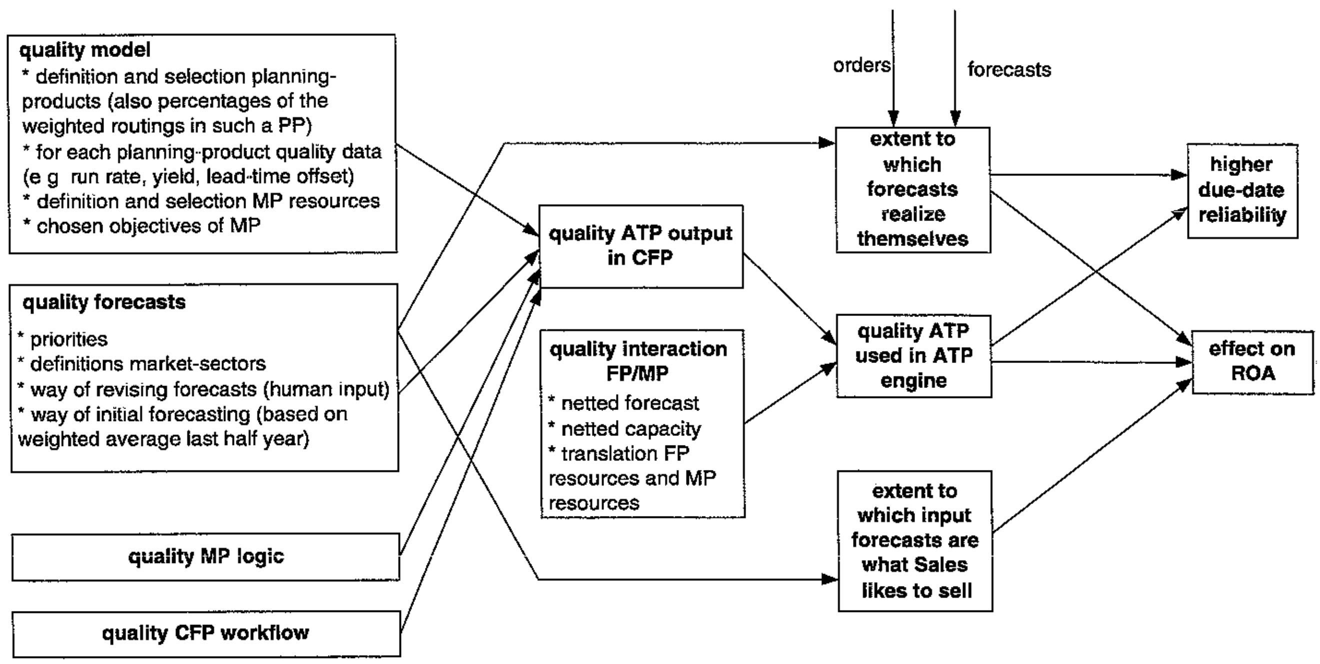


Figure 21: Overview various causes which affect ROA and due-date reliability

The two most important factors on which the intended advantage of implementing the MP depends are the quality of the forecasts and the MP model itself. The reason that it is so important that the forecasts should be quite accurate is of course that otherwise reserved capacity (in terms of the ATP figures) remains unused. Next will be explained why it is so important that the underlying MP model should be quite accurate. The MP model forms the basis on which the ATP figures are calculated. These ATP figures are then used for order accepting and quoting. The amount of orders that is accepted directly influences the profitability of EWK and the quality of the quote given directly influences the due-date reliability. This chapter focuses however only on optimizing and validating the quality of the MP model because it is expected that on this aspect the most improvements can be gained (because not much can be done about the forecasting accuracy).

6.2: Analysis current situation

This section will describe the way in which the definition of the planning-products has been made and how the various parameters for such a PP have been obtained.

First EWK determined which resources are the critical ones. With critical is meant those resources that, based on their experience in the past, form a bottleneck in the production flow. Then the definition of the planning-products were built based on an analysis of the routing-structure of EWK's main products.

After that a SAP extraction of the exact routings of all the various specific end-products (represented by its lagertype) was done. Then for each lagertype the routing-steps which uses a MP-resource were filtered to determine in which parallel routing of a PP it belonged. Next for each operation in such a parallel routing a run-rate, yield and leadtime was given. The run-rate and yield for such a operation was based on the values of a , in their view, representative lagertype (the so-called Hauptlagertype (HLT)). The leadtimes (to offset the capacity usages in time) that have been given were all one week. The percentages for the weights of the different routings within a planning-product have been determined by dividing the amount of lagertypes which fall in a certain parallel routing by the total amount of lagertypes which belong to this planning- product.

So the used MP parameters: run-rate and yield are based solely on one LT. However the lagertypes in some parallel routing do not necessarily have all the same value for these parameters. Said even stronger there is quite some variation with regard to yield and run-rate between these lagertypes (in appendix 12 frequency diagrams can be found which illustrate this variation). This is thus a flaw since this weighted routing within a PP actually represents an aggregate product (further in this document, this will be called a sub-planning-product). Therefore in section 6.3 a design of a new method on how to calculate the MP-parameters is made.

6.3: Design of a new method

In this section a new method will be designed on how to calculate the MP parameters: run-rate, yield and distribution percentage.

As already mentioned in section 6.2 the current method of obtaining the MP parameters of the different operations in the routing of a subPP is inaccurate since there is quite some variation with regard to yield and run-rate between the lagertypes which fall in a subPP. What is also important to note is that the forecasts for the different lagertypes which belong to some sub-planning-product differ with regard to its amount. These two aspects should thus be taken into account when calculating the value for the MP parameter. The solution would be to make the MP modelling data dependent on the forecasts given per lagertype. The calculation of the MP parameters can then be based on some form of a forecast-weighted approach. Then these parameters have been tuned as accurate as possible (since it is a function of the future forecasts per LT and the underlying variation in the run-rate and yield per LT). The result is thus that each time a MP-run is done (the forecasts have changed then of course with regard to its mix and volume), the MP parameters are adjusted accordingly.

Also the current method of establishing the distribution percentage is not really an ideal solution. The amount of lagertypes says of course nothing about the volume with which it is produced. It would be therefore better to calculate these values based on the total forecasts in tonnes for all the LTs which fall in a subPP divided by the total forecasts in tonnes for all the LTs which fall in this PP.

When the three parameters are calculated according to the above described logic, it is expected that the result is a much more realistic MP model, since it uses much more accurate MP parameters when planning the forecasts.

The assumption one makes here of course, is that the run-rate and yield data for each LT which has been extracted from SAP are accurate. Besides that the forecasts given should also be quite good (at least their mutual proportions, since the forecasts are used to weight the MP parameters).

Next the equations which are used in establishing these values are presented (note: with subPP we mean the aggregate product which follows a parallel routing within a PP).

i = index for PP
j = index for subPP in PP_i
k = index for lagertype
l = index for resource in $subPP_{ij}$ of PP_i

A_{ij} = set of LTs which fall in $subPP_{ij}$ of PP_i
B_i = set of LTs which fall in PP_i

h_k = forecast in kg's of LT k per year

x_{kl} = run-rate of LT k (minutes/kg) on resource l

$\overline{x}_{ijl}$ = average run-rate (minutes/kg) of $subPP_{ij}$ in PP_i on resource l

σ^x_{ijl} = standard deviation run-rate (minutes/kg) of $subPP_{ij}$ in PP_i on resource l

$$\overline{x}_{ijl} = \frac{\sum_{k \in A_{ij}} (h_k * x_{kl})}{\sum_{k \in A_{ij}} h_k} \qquad (1)$$

$$\sigma^x_{ijl} = \sqrt{\frac{\sum_{k \in A_{ij}} (h_k * (x_{kl} - \overline{x}_{ijl})^2)}{\sum_{k \in A_{ij}} h_k}} \qquad (2)$$

y_{kl} = yield of LT k on resource l

$\overline{y}_{ijl}$ = average yield of $subPP_{ij}$ in PP_i on resource l

σ^y_{ijl} = standard deviation yield of $subPP_{ij}$ in PP_i on resource l

$$\overline{y}_{ijl} = \frac{\sum_{k \in A_{ij}} (h_k * y_{kl})}{\sum_{k \in A_{ij}} h_k} \qquad (3)$$

$$\sigma^y_{ijl} = \sqrt{\frac{\sum_{k \in A_{ij}} (h_k * (y_{kl} - \overline{y}_{ijl})^2)}{\sum_{k \in A_{ij}} h_k}} \qquad (4)$$

p_{ij} = distribution percentage of $subPP_{ij}$ in PP_i

$$p_{ij} = \frac{\sum_{k \in A_{ij}} h_k}{\sum_{k \in B_i} h_k} * 100 \qquad (5)$$

So when one illustrates this procedure in the broader context of the FP and MP model, one gets the following picture (Figure 22):

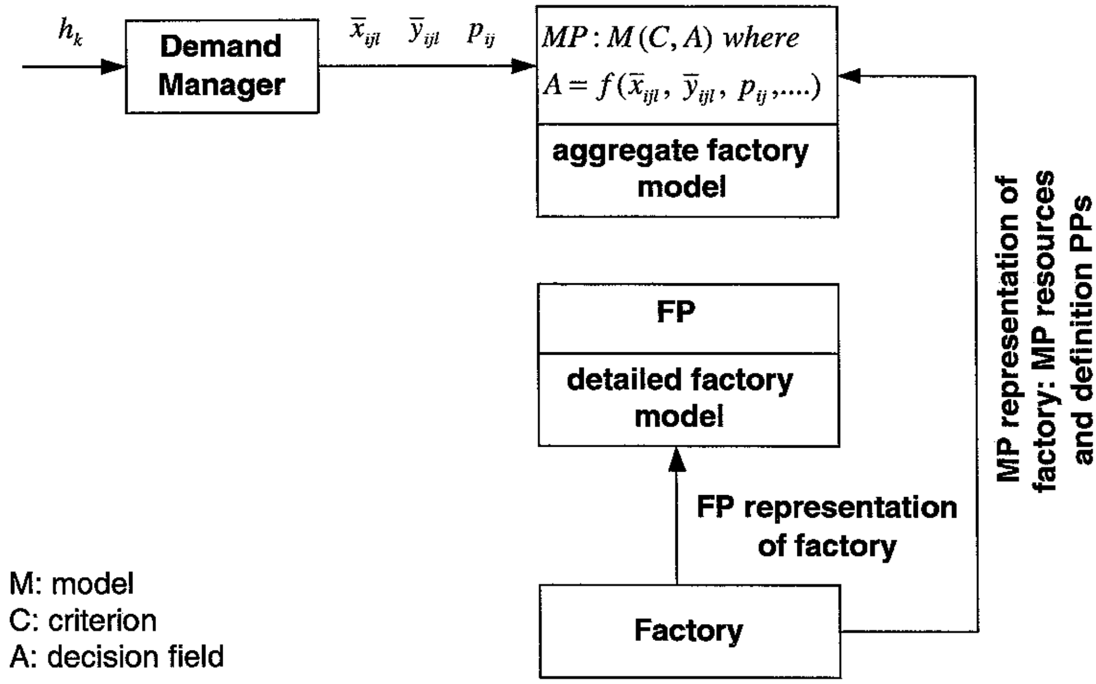


Figure 22: Second interpretation of interaction between FP and MP

This figure illustrates a second interpretation of interaction between FP and MP (as compared to the one of synchronizing the MP-horizon with the FP). This will be explained next. The MP model is, as one has seen, an aggregate representation of the factory. The model consists of a criterion and a decision field. The criterion is minimizing the shorting of the forecasts. The decision field is the solution-space which is formed by the various constraints with as its parameters the MP modelling data. It is important that the decisions made at the aggregate level (the ATPs which the MP calculates and which ultimately impacts the decision making in FP) create feasible conditions for decision making at the detailed level. In order to achieve this we adopted the idea of Schneeweiss [3] that the aggregate decision making level should anticipate on relevant characteristics of the detailed decision making level. In our case this is accomplished by making the MP parameters dependent on the forecasts given (calculating MP parameters this way tries thus to anticipate as good as possible of what the real situation is going to be in FP). The described approach in this section which we will call: *Forecast-based, with regard to its mix and volume, tuning of MP parameters in aggregate supply-chain modelling in industries with high end-product variety* will contribute to creating these feasible conditions by making the MP decision field dependent on the forecasts given. So in this sense this approach forms an interaction between FP and MP as well.

6.4: Tests and their results

This section will show what the effect is on the plan-performance for three different scenarios. Also the results will be interpreted. First the test-framework will be presented and is illustrated below.

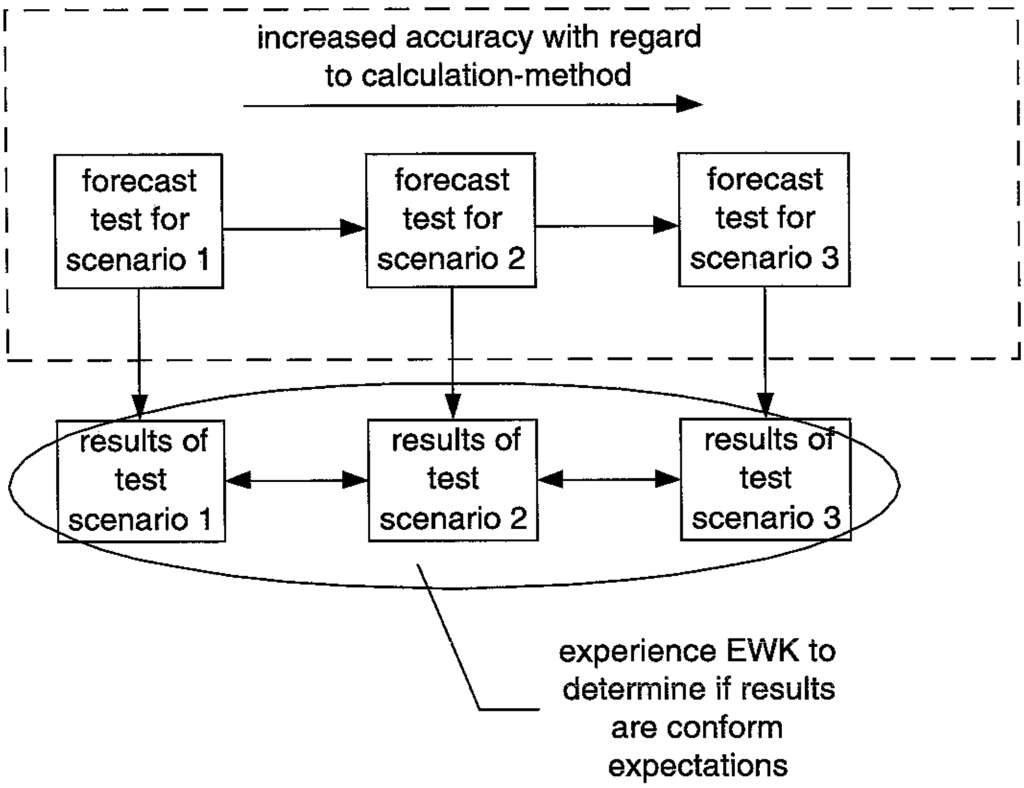


Figure 23: Test-framework

The basis is a one year's forecast. EWK makes then an educated guess to which extent they can produce these forecasts based on their experience. Then this one year's forecast is planned in the Master Planner and one looks if the plan (especially the plan-performance: this means how much of the forecast is satisfied in terms of ATP) is conform EWK's expectations. For convenience this test is in this report further referenced as the forecast-test. This forecast-test will be done for three different scenarios which differ from each other in the way how the parameters are calculated. The conditions of the three different scenarios are described in Table 5.

Table 5: Conditions different scenarios in forecast-test

Scenario (1)	Distribution-percentages based on amount lagertypes underneath sub-planning-product (as in old situation)
	Run-rate of different operation-steps for sub-planning-product based on run-rate of HLT (as in old situation)
	Yield of different operation-steps for sub-planning-product based on yield of HLT (as in old situation)
Scenario (2)	Distribution-percentages based on forecast quantities (in kg's) (conform equation 5)
	Run-rate of different operation-steps for sub-planning-product based on run-rate of HLT (as in old situation)
	Yield of different operation-steps for sub-planning-product based on yield of HLT (as in old situation)
Scenario (3)	Distribution-percentages based on forecast quantities (in kg's) (conform equation 5)
	Run-rate of different operation-steps for sub-planning-product based on weighted run-rate (conform equation 1)
	Yield of different operation-steps for sub-planning-product based on weighted yield (conform equation 3)

The conditions of scenario (1) correspond thus to the existing situation (this is called the old situation as well) as is described in section 6.2. One can look now if the plan-performance of the more accurate MP models in scenario (2) and (3) are more closely matched to EWK's expectations. So the basis to compare the different scenarios is the experience of EWK.

In Table 6 a summary of the results for the different scenarios can be found. Also within each scenario a distinction is made between the results of the plan run in Finite Capacity Mode (FCP) and run in Infinite Capacity Mode (ICP). One would expect that in Infinite Capacity Mode all the forecasts can be satisfied, since there is infinite capacity. However this is not true, since the first weeks of the planning-horizon forecasts for a planning-product can not be satisfied because of its lead-time. Therefore it is better to compare the different scenarios based on its satisfaction percentage which is defined as follows:

satisfaction-percentage = total allocated FCP/total allocated ICP (6)

Table 6: Test-results scenario (1)

	Scenario (1)	
	ICP	**FCP**
Forecasts priority 1	311248200	311248200
Forecasts priority 2	69392250	69392250
Total forecasts	380640450	380640450
Allocated priority 1	279823400	254735400
Allocated priority 2	61226970	20314630
Total allocated	341050370	275050030
Satisfaction-percentage	80.6	

The hypothesis is that the newly proposed method of calculating the MP-parameters results in more realistic ATP figures. Since EWK's total year-production is approximately 400,000 tonnes, it is expected that the results of scenario (2) will show an increase in ATP-allocations and in scenario (3) an even higher plan-performance. To test this hypothesis, the forecast-test has been done for scenario (2) and (3) respectively. The results can be found in Table 7.

Table 7: Test-results scenarios (2) and (3)

	Scenario (2)		Scenario (3)	
	ICP	**FCP**	**ICP**	**FCP**
Forecasts priority 1	311248200	311248200	311248200	311248200
Forecasts priority 2	69392250	69392250	69392250	69392250
Total forecasts	380640450	380640450	380640450	380640450
Allocated priority 1	279940800	267386100	279940800	273862400
Allocated priority 2	61241940	18286020	61241940	21222180
Total allocated	341182740	285672120	341182740	295084580
Satisfaction-percentage	83.7		86.5	

The satisfaction-percentages for each of the three scenarios are respectively for scenario (1), (2) and (3) 80.6%, 83.7% and 86.5%. This is thus a total increase in performance of almost 6%. As can be concluded from these figures, the hypothesis of a higher plan-performance has been confirmed. One of the advantages of the implementation of the MP is a higher due-date reliability. However this advantage comes for a price of course, since the MP works actually as a sort work-load control by having a regulated order-acceptance function. So it can not be expected that each MP-run a 100% of the forecasts can be satisfied, since this depends to a large extent on the specific order-mix.

Now will be looked in more detail at the reasons for the increase in plan-performance. Differences in the plan-performance between scenario (1) and (2) can only be only due to the newly proposed method for calculating the distribution-percentages. This new approach for calculating the distribution-percentage makes of course much more sense than the old one and will result thus in a more accurate MP model which is used for planning the forecasts. More accurate does not necessarily imply that it will also result in a better plan-performance. However since EWK, based on its experience, expected an improvement, the model in scenario (2) should result in a better performance as well (because the model uses a more realistic distribution percentage). Indeed this expectation is confirmed because scenario (2) shows us an increase in allocations of about 11,000 tonnes when compared to scenario (1).

Comparing scenarios (2) and (3) shows us an increase of approximately 9,500 tonnes. Because the effect of the distribution-percentage does not play a role here (since as well in scenario (2) as (3) these values have been calculated conform equation (5)) this enables us now to find the specific cause for the observed improvement here. One has to realize that an increase in plan-performance can only then be realized in scenario (3) if the bottle-neck resources which exist in scenario (2) have been relieved since further satisfaction of forecasts is constrained by these resources. This can only be then when for these bottleneck resources "false" MP-parameters have been used in the sense that a strong positive bias[6] exists between the "old" used run-rate and the new way of calculating the run-rate and/or a strong negative bias exists between the "old" used yield and the new way of calculating the yield. When large coefficients of variations exist for the run-rate (yield) for the various operations, there is also a high probability that a high bias in the run-rate (yield) exists. This is due to the fact that when one picks one item at random from a certain set of items for which there is a large cv in its parameter, there is a high probability that the one you picked is not equal to the mean of the population. Therefore an analysis of the coefficients of variation[7] for all the resources/operations in the routing of the subPP has been made and this shows that for the run-rate these values range between 0 and 0.9 and for the yield between 0 and 0.2. Frequency diagrams for these coefficients of variation and biases can be found in appendix 12. From this can be concluded that the yield will not be a significant source which can explain the differences found between the two scenarios. But the run-rate, however, can explain these differences. In order to show that overall a strong positive bias exists in the run-rate for all the subPPs which uses one of the bottleneck-resources (which exist in scenario (2)) a frequency diagram has been made which is depicted in Figure 24.

[6] bias of run-rate (yield) is defined as the difference between run-rate (yield) HLT and the average run-rate (yield) as calculated conform equation 1 (3)

[7] coefficient of variation in run-rate (yield) is defined as the standard-deviation conform equation (2) (conform equation (4)) divided by its average conform equation (1) (conform equation (3))

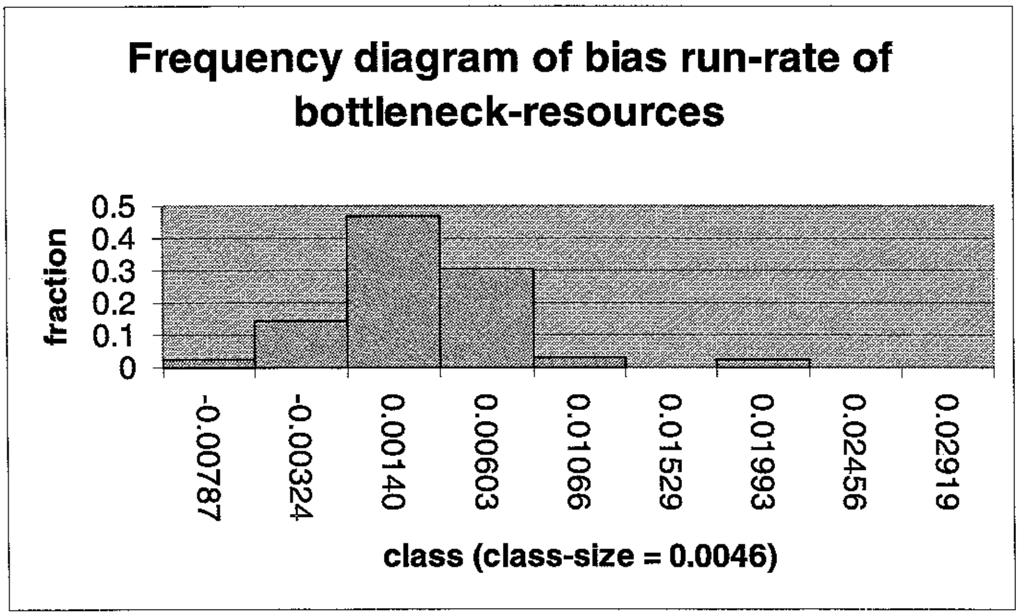


Figure 24: Frequency diagram of bias run-rate for all subPPs which uses bottleneck resources

83% of the subPPs which uses one of the bottleneck resources has a positive bias (which means that in the old situation a too high run-rate as MP-parameter was used). The average bias is equal to 0.0028 minutes per kilogramme.

In order to demonstrate (numerically) what the potential is for the extra forecasts in tonnes which can be satisfied an upperbound has been calculated to show the effect of the adjusted run-rate figures. This upperbound calculates for all the subPPs which uses a bottleneck-resource (defined by having a utilization factor of 100%) the bias of the run-rate times its total forecasted amount divided by its average run-rate (according to equation 1) and sums this up. In equation-form this looks as follows:

C: set of bottleneck-resources
D_l: set of subPPs that uses bottleneck resource l
E: set of LTs which fall in $subPP_{ij}$

$$upperbound = \sum_{l \in C} \sum_{ij \in D_l} \frac{bias\ of\ run-rate_{ijl} \cdot \sum_{k \in E} h_k}{\bar{x}_{ijl}} \qquad (7)$$

The result of this calculation is a value of 32,000 tonnes for this upperbound. However the total increase in allocations when comparing scenario (2) and (3) is approximately 9,500 tonnes. The cause for this difference lies of course in the fact that up- or down-stream resources in the routings of these subPPs can become bottlenecks when the allocations increase and therefore the potential for the increase in tonnes can not be fully reached (especially when in scenario (2) resources existed with e.g. a utilization factor of e.g. 95% since these have not been taken into account in the calculation of the upperbound).

Another observation which can be made from the results is that the priority 1 forecasts increase much more than the priority 2 forecasts when one compares the results of the scenarios. This is of course due to the logic behind MP which is a hierarchical layered optimization procedure. The outcome of the MP is the result of minimizing the shorting of forecasts with priority one subject to the capacity restrictions (these are linear restrictions). Then the second objective: minimizing the shorting of forecasts with priority two is applied. This is done in such a way that the optimal solution for the previous objective can not be worsened. So when capacity comes available when moving from scenario (1) to (3) (because of more accurate MP parameters) it will try first to satisfy the forecasts with priority 1 with the capacity which has become available.

To conclude this section, one has seen that plan-performance has improved significantly (in terms of a higher satisfaction-percentage), which is conform EWK expectations. This newly proposed method will thus generate in this case also 6% of extra revenues (since average sales-value is 900 million DM this increase of 6% is approximately equal to 54 million DM.). An analysis has shown that the improvement in satisfaction-percentage is due to the positive bias in the capacity figures that existed for the bottleneck resources which made a further satisfaction of forecasts possible in scenario (3). The reason for this bias can not be related to some specific cause and is thus the result of pure coincidence. However one has to realize that in this case plan-performance has improved, but it could also have been the case that for another forecast-mix, a negative bias existed which thus resulted in a worse plan-performance. But this way of calculating the MP parameters is always more accurate and that is most important. Furthermore plan-performance can even improve further by increasing critical capacities by using the flexibility that is present in the production system to increase capacities on the short-term. The main points of this chapter are thus that the new method results in a MP model with more realistic parameters, since it uses for its aggregate products an average value of the LTs underneath it. Besides that this method enables a smooth adaptation of the parameters over time if forecast-mix changes with respect to its volume and mix. This new method has also been successfully implemented in the current business practices and forms now an integral part of the Demand Manager (more specific the various equations have been implemented as procedures in the Visual Basic for Applications Environment of the Access database).

Chapter 7: Conclusions and recommendations

This first section of this chapter will summarize the main conclusions of chapters 5 and 6. This section will make an assessment about the i2 systems in general. Lastly some recommendations will be made in section 7.2.

7.1: Conclusions

The following revised problem-description formed the starting-point for the design-phase of this project:

> For EWK it is not quite clear how should be worked with the various systems (on its own and together) and how all these systems together will fit in the conceptual production control structure.
>
> Besides that the initial outcome of the MP (in terms of the amount of forecasts satisfied) did not comply with their expectations.

The first part of the problem-description led to the following two task-assignments:

1. Developing the production control structure in terms of processes
2. Designing workflows of how to work with the various systems which support these processes

The result of the first task-assignment is summarized in Figure 13 which shows the various processes (decision functions) and the relations between them. Together it constitutes the production control structure. These identified processes are respectively create consensus forecast, get ATPs from MP and pass over to ATP-engine, order accepting and due-date quoting. It has also been explained how these processes will help in achieving the various business objectives.

The result of the second task-assignment was a design of how to work with the various systems in order to reach the purposes of the identified processes. Where possible advantages and disadvantages of various alternatives have been discussed and recommendations for the most suitable way of working have been made and motivated.

The first process is the one of creating a plan which Sales likes and can sell and is feasible with respect to capacity. After a general description of this process and an overview of the various activities in this process by means of a workflow, the rest of the discussion focused on two aspects of this process. These were respectively how to revise the forecasts in order to create a plan which Sales likes and wants to sell and the "driving capacities function" of this process. For the first aspect it has been made clear that the best way of working is to revise the forecasts in MP (either on planning-product level to shift the allocations between planning-products or on planning-item level to shift the allocations between the different market-sectors) since the ATP-engine also works on planning-item level and therefore it is not necessary to perform the handling of the forecasts in the same amount of detail as how the initial forecasts have been given. The second aspect discussed and explained the role of this process in the capacity adaptation. The output of this process could be used for the short-term capacity adaptation as well as for the capacity adaptation on the longer term.

The second process is the one of determining the ATPs and pass them over to the ATP-engine. It mainly dealt with the question when to update the ATP figures. Three different causes have been identified and explained which could lead to an update. Two important notions which have been used in this discussion were the two terms: consistency and stability. In deciding on the frequency with which the ATP figures have to be updated a trade-off has to be made between these two notions. An update-proposal has been given grouped according to two criteria: time- and event-criteria. The update proposal is that each month after a CFP the figures have to be updated (time). Furthermore each week an update should occur to synchronize the MP horizon with the current order-book (time) and when the actual capacity differs considerably from the planned capacity (event). This last could be supported by means of a technique which triggers an update after some specific upper- or lower-limit has been exceeded.

The third process is the one of order-accepting and quoting. The steps which the Sales-person could consider in the case that in first instance not enough ATP is available to satisfy a particular order were identified. These various steps have been put in a framework and explained in more detail. Lastly a critical remark about the way the ATP-engine works has been made. This critical remark has to do with the fact that the ATP-engine is not really an organizable decision function because its outcome (when run fully automated) can have its effect on other organizational units at Sales. This is of course an unwanted side-effect because each sales-department has separated responsibilities. So decisions at some organizational unit which affects other departments should not be automatically taken without the explicit approval of this other organizational unit.

Summarizing the production control structure has been given shape by having identified and explained the key-processes and the relations between them. For each process has been explained the purposes it serves and how it helps in achieving the various business objectives. Furthermore has been motivated how should be worked with the various systems in order to achieve the intended purposes. The result is thus that EWK has now a much better understanding how to work with the various systems because it has been related to the processes it serves. Therefore the first part of the revised problem description has been satisfactory solved.

The second part of the problem-description led to the task-assignment of validating the quality of the MP-model. First has been argued why it is so important that the quality of the MP-model should be validated by relating it to the two important performance measures: ROA and due-date reliability. An analysis of how the current MP has been modelled revealed certain shortcomings. These shortcomings mainly had to do with the fact that it did not take into account the underlying variation in the run-rate and yield of the different lagertypes that belonged to some subPP for some operation. Besides that the calculation of the distribution percentages was also based on a somewhat erroneous method. Therefore a new method has been proposed for calculating these three MP parameters with the purpose of getting a more accurate MP model. These were respectively: the run-rate for each operation in the routing of a subPP, the yield for each operation in the routing of a subPP and the distribution-percentage of the subPP in a PP. The method for calculating these parameters can be found in equations 1 through to 5. Then the so-called forecast-tests were performed for three different scenarios which differed from each other with regard to how the various MP-parameters had been calculated. The result was an increase in plan-performance of 6% when comparing the results of scenario (1) and (3) (this was also conform the expectations). Then an interpretation of the results was given by looking at the specific cause for the increase. The explanation for the increase was that a large positive bias of the run-rate existed for those subPPs which used one of the bottleneck resources. Due to the positive bias the result was that in scenario (3) the bottleneck resources were relieved which made a further satisfaction of forecasts possible. The new methods for calculating the three MP parameters resulted thus in a more valid MP model. One could say therefore that the second part of the revised problem-description has been adequately tackled.

Now that the main conclusions have been summarized and the extent to which the revised problem-description has been solved, an assessment will be made about the way the i2 systems try to tackle production control problems in relation to the hierarchical production concept of Bertrand [2,11].

Bertrand advocates a hierarchical approach to production control: the complete control problem should be decomposed to a number of partly hierarchically ordered sub-problems. Bertrand states the production control problem as follows. Given certain consistent objectives regarding customer delivery performance and manufacturing costs, how should we:

1. accept customer orders
2. place production and procurement orders
3. vary the capacity
4. allocate available capacity to manufacturing steps

They distinguish the following basic aspects to be considered in the design of a production control structure:

- The distinction between goods flow control and production unit control
- The distinction between detailed, item-oriented control and aggregate, capacity-oriented control
- The relationship between Production and Sales

The first thing to do in designing a control structure is the selection of goods flow controlled items (GFC-items). Three factors are of major importance for the selection of the GFC-items in a product structure:

- uncertainty (yield uncertainty/demand uncertainty)
- product structure (lotsize restrictions/convergence)
- capacity inflexibility (bottleneck)

After this has been done the following step is defining the so-called production units (PU). A production unit refers to a production department which on 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. By having selected the GFC-items, the definition of PUs in a particular situation has already been determined to a large extent.

The next step is designing the goods flow control (GFC) structure. GFC takes care of the mutual coordination of the PUs.

So the total production control problem is split up into:

- Production unit control per production unit
- Goods flow control, which coordinates the outputs of the production units and which coordinates Production with Sales.

Pictorially we can represent this decomposition into PU and GFC as follows:

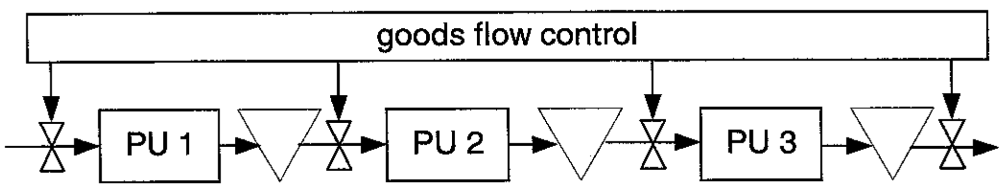


Figure 25: Decomposition PU and GFC

On the goods flow control level, we can distinguish two control aspects. First there is the coordination of flows and levels, measured in aggregate terms. This is also called the Aggregate Production Planning (APP). The control variables in the APP are the bottleneck capacity, the production budgets, the inventory budgets etc. These budgets act as goals and restrictions for the detailed coordination. Second there is the detailed coordination, referring to the individual product items. The control variables herein are mainly the timing of workorders (Material Coordination). The interface between these two levels consist of workload control and workorder release. For a more elaborate discussion on these last two functions see [2]. Pictorially this is represented as follows:

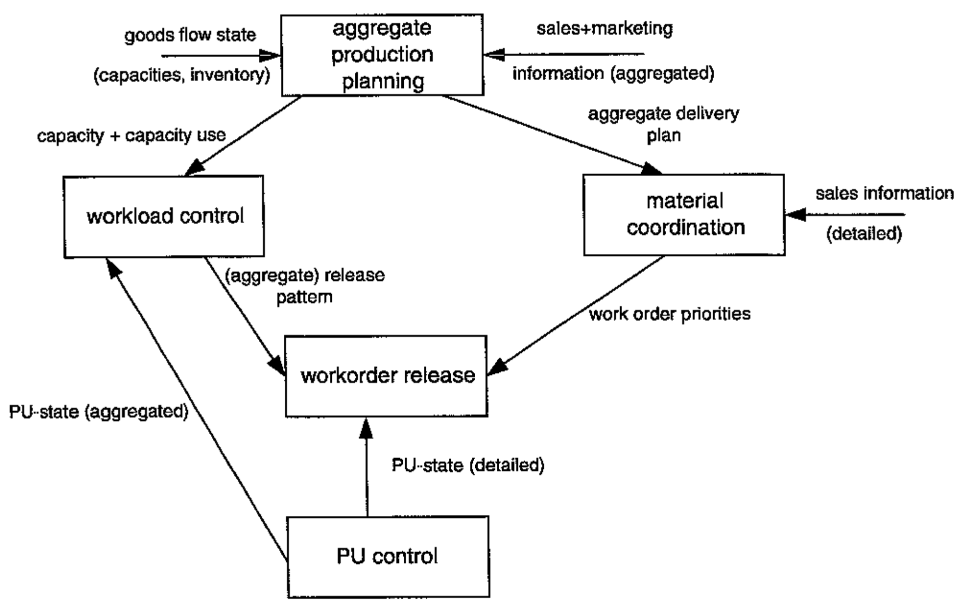


Figure 26: Goods flow control structure

The basic control variable which constitutes the interface between production unit control and goods flow control is the release of new workorders to the PU. As soon as a workorder is completed, the products are delivered to a goods flow controlled stockpoint,

The behaviour of a production unit as part of the goods flow, is described by the so-called operational characteristics. Operational constraints are for example:

- pace (time) } technical
- volume } economical: utilization factor, minimum lotsize
- flexibility
- reliability
- batching constraints: constraints in terms of prescribed batchsizes of workorders to be released or transferred
- sequence constraints: constraints on the sequence or combination of workorders
- workload constraints: constraints on the workload of the PU
- capacity constraints: constraints on the possibility to adjust the available capacity of the PU

The operational constraints are in fact structural agreements which should be made on a high organizational level. For goods flow control, the model states that, within certain limits, the loading of the PU should be stable (environmental stability). For production unit control, the model states that certain workorder throughput times should be realized. What is important is that it must be possible to model the input/output behaviour of the PU in a relatively simple way without neglecting a too large part of the potential flexibility of the PU. The internal structure of the PUs is not relevant (PUs can be considered as black boxes) for goods flow control. Only for those variables which determine the operational constraints, goods flow control must know the internal state.

The advantage of defining and using production units in a production system stems from the reduction of complexity of the control problem. Firstly consider the PU-control problem: the problem of how to achieve the agreed performance, given specific environmental conditions. Secondly there is the remaining problem of how to realize for each PU the agreed environmental conditions, and to realize the overall production control objectives (especially the delivery performance and the flexibility to the market) at the same time. This has to be accounted for by goods flow control.

Now that the theoretical concepts in the design of a production control structure according to Bertrand have been made clear, some comparisons between this approach and the i2 approach will be made which enable us to identify some of the shortcomings in the i2 solution.

At EWK no formal production units are distinguished. The Factory Planner considers actually the whole supply chain as one production unit. However in aggregate production planning (which is performed by the Master Planner) it is very important that one clearly defines the production units and its operational characteristics. So a good insight into what can be realized in each production unit is needed. This means that aggregate production planning uses a certain model of the PU (characterized by its operational characteristics: e.g. certain workorder throughput times that can be realized given specific environmental conditions) to base its decisions on. The absence of these production units explains the difficulty for EWK in finding the normative lead-times for the various MP operations in the aggregate supply chain model of the Master Planner.

As one has seen the Master Planner is used for three purposes. The first purpose is to create a plan which Sales can and likes to sell and which is feasible with regard to capacity. This is thus the i2 solution for the design-aspect: *the relationship between Production and Sales*. The second purpose is that it is used to drive the capacities of the various shops. This function can be seen as well in Figure 26. The third purpose is that the output of the Master Planner is used to base the order-acceptance and quoting decision on.

The fact that the order-acceptance and quoting decision is based on forecasts is a bit awkward since one deals here with a make-to-order environment. There are several disadvantages. One disadvantage is that forecasts are never 100% reliable (moreover the Master Planner can only deal with point estimates (forecast of mean)). The other is that you lose decision freedom since you already commit on what to accept and what not. It is better to take this decision (which orders to accept and if it is accepted which due-date it is given) when the customer actually "comes". This is also called postponement. There are two main reasons for making decisions at the latest possible moment. First at an early moment not all information may be available to make a decision (in our case: since ATP-allocations are based on forecasts). Second all kinds of events may occur that make it necessary to revise decisions made in an earlier stage, but before the actual effectuation. A better approach would be to base the order-acceptance function on some capacity loading logic. Capacity loading is a reservation that ensures that future resource allocation decisions remain feasible. It provides essential information required for future order acceptance decisions. It provides insight into the expected capacity available by the production system over time. If capacity loading decisions are made on an aggregate basis, the sensitivity for events affecting the production system may be small.

In the i2 solution the output of the Master Planner function directly controls the operational Factory Planner in terms of the ATP-allocations. These ATP-allocations are used at order-entry and ultimately determine the order-mix on the shop-floor. These ATP-allocations form the only interaction between FP and MP and can be seen as a simple workload-control function. Since no distinction is made between PUs (because the complete production system is modelled in one central Factory Planner) it is difficult for the aggregate production planning to take into account the most important characteristics of the PU when making important decisions such as order-acceptance and quoting. Consequently this prevents more sophisticated tools in the APP domain from being used.

7.2: Recommendations

Recommendation regarding modelled lead-time data in MP:

One has seen that the actual MP modelling data makes for this parameter a very rough estimation by giving each operation a leadtime of 1 week. This parameter could be tuned of course much more accurate (however the granularity of the lead-times in MP is in weeks) and should be based on the estimated queue-time and minimum queue-time which is used as an input-parameter in the FP. Let us first therefore elaborate somewhat more on these two notions. Minimum queue-time is used in FP as a hard constraint and has to do with e.g. technical waiting-times which can not be compressed. Estimated queue-time however is a time-representation of target work-in-process (WIP) in front of a resource. These times create thus in front of a resource a queue of orders so that a specific resource will not run out of orders. The FP uses this estimated queue time as a soft constraint. When e.g. the FP notices that an order will not meet its due-date (because of whatever reason) it can try to compress the estimated queue-time on one of its up- or down-stream resources. After this tuning has been done a test that checks these lead-time data could look as follows: Suppose ATP figures have been calculated, based on a one year's forecast. A possible test is to enter an arbitrary, imaginary order which falls in some PP. See which due-date can be given based on the ATP figures. Next the order is entered into FP. The FP will calculate then a PET (*Fertigstellungs-termin*) of the order. So the due-date quoted based on the ATP figures can be compared then with the PET the FP calculated to see whether or not there are big differences.

Recommendation regarding implementation Demand Manager as forecasting-tool at Sales:

The key-determinant for the success of any user-system interface are the users who have to work with the systems. It is possible to just give them a manual and say: "Okay here is the manual, and you have to work like this". But the chance exist that the users do not like how the system is working (e.g. too much work or too complex) and therefore do not make an effort which can result in a poor system's performance. This can result that the whole system does not achieve its intended purpose. A test which can be done (to prevent the above described scenario) is to give the actual users a manual (in order to prepare themselves) and afterwards they have to work with the DM by themselves without any other support. An independent person observes these persons and writes down important things he sees. After the users have worked with the system, feedback from the users by means of a question-list is obtained by the observer. Having collected this feedback, structural improvements can be made by redesigning the system so the users' needs are met. So the keyword in the above description is user-involvement.

Recommendation regarding data-maintenance:

All the various systems generate a lot of data. All this data of course is not a goal in itself but should be used in a meaningfull manner in order to support the planning-processes. However the enormous amount of data which is produced and shifted between the various systems over time could lead to the case that over time the various data-sets are confused with one another which thus results in the wrong things being done. To give an example one has seen that the output of the CFP process should drive the capacities on the shop-floor level. However because this data is generated some months before the actual capacity adaptation is effectuated, it is important that this data is recorded somewhere in a careful manner. So it is recommended to make sure that the various data-sets are maintained and stored properly (e.g. by means of a time-stamp).

Recommendation regarding implementation Master Planner:

The MP project comprises of two BR's (business releases). The goal of the first BR1 is to have a working and usable architecture in which the consensus forecasting can be done. The second BR is the installation of the ATP-engine which forms the basis for order-entry and accepting. This means also a working integration between FP and MP in able to take the short-term horizon into account at order-entry. However that fact that the MP model has been validated on its quality (as part of BR1) does not imply that it also will work successfully in the business practices. The ultimate success of the system depends also on the quality of the implementation in the organization. Therefore the system should be nicely fitted in the organizational structure by delegating the various tasks and clearly defining responsibilities to the various members in the organization.

Appendix 1: Properties and application areas of products

This appendix describes for each of the three product-categories what the properties are, the areas of application and gives some of the most important commercial names which fall into the specific category [6].

RSH: These steel-grades are characterised by particular resistance to chemically corrosive substances. In general they have a chromium content of at least 12% by mass and a maximum carbon content of 1.2% by mass. These steels can fulfil the highest demands with respect to their resistance to corrosive media, their high strength and elongation values (*Festigkeits- und dehnungwerte*) and their high thermal stability (*Temperaturbelastbarkeit*). Owing to their corrosion-chemical and mechanical properties, the stainless, acid and heat-resistant steel grades are particularly used in the chemical industry, mechanical engineering, textile finishing and the food-industry. Further fields of application include power-engineering, the onshore and offshore industries, automotive engineering and medical engineering. They sell for example the stainless steels under the commercial name REMANIT® and the heat-resistant steels under the name THERMAX®.

Engineering steels: Engineering steels are used for a multitude of automotive components: in engines, drive trains, wheel suspension systems and steering assemblies. These steels are for example also used in aircrafts and power plants. Another important example of use is ball and roller bearings. Because of exposure to high compressive and abrasive stresses, ball and roller bearing steels have to possess maximum hardness and very good cleanness. In addition to a large number of quenched and tempered steels in different heat-treatment conditions, case hardening and nitriding steels are produced for components requiring a high wear resistance, good fatigue strength and favourable core toughness. An important grade that fall into this category is for example PANTANAX®.

Tool steels: The four most important grades in this group are THYRODUR®, THYROTHERM®, THYROPLAST® and THYRAPID®.

THYRODUR® is the trade-name for cold-work tool steels. It has a high surface hardness (*oberflächenhärte*), good toughness (*zähigkeit*) and compressive strength (*druckfestigkeit*) and high wear resistance (*verschleisswiderstand*). Applications include for example cutting tools (*schneidwerkzeuge*), punching tools (*stanzwerkzeuge*), dies (*matrizen*), stamping tools (*prägewerkzeuge*), drawing tools (*ziehwerkzeuge*).

THYROTHERM® is the trade-name for hot-work tool steels. This grade has such properties that it can resist the high temperatures that apply in such an environment. Typical areas of application include compression casting, extrusion pressing, die forging and tube production.

THYROPLAST® are steels used for dies in which plastic is being moulded. They are characterised by good thermal conductivity, high wear resistance and corrosion resistance, dimensional stability, hardness, compressive strength and toughness. Moulds made out of these steel also offer good repair weldability and require only little maintenance and upkeep.

THYRAPID® are steels used for high-speed tools. Material for high-speed tools require the following properties: a high warm wear resistance, warm hardness and toughness. This in order to be able to prevent the cutting-sides from breaking out. These high-speed steels are being used for machining tools like drills, cutters, broaches (*Räumnadeln*) and deformation tools.

All the above mentioned grades can be supplied in specific forms. Here an overview is given of all possible forms:

- Semis (*Halbzeug*)
- Bar steel (*Stabstahl*)
- Round billets for tubemaking (*Röhrenvormaterial*)
- Flat steel (*Flachstahl*)
- Wide flats (*Breitflachstahl*)
- Sheet bars (*Platinen*)
- Forgings (*Schmiedestücke*)
- Cold rolls (*Kaltwalzen*)
- Bright steel (*Blankstahl*)
- As-cast ingots (*Blockguss*)
- Continuous cast blooms (*Strangguss*)

Not every form is available for a certain *Werkstofgruppe*. Also restrictions in the sizes that can be delivered for a specific form apply. Most terms speak for themselves. However a few of these terms (the cases *stabstahl*, *halbzeug* and *röhrenvormaterial*) are a bit vague and will therefore be explained somewhat more.

Stabstahl has a quite high density and can be round, square or rectangular. *Stabstahl* is mostly bought by the machining and automobile industry which have high demands with respect to the material.

Halbzeug means that the customer who buys this, will use it as semi-finished product, so the material will be subject to another deforming-step. Because it is being deformed a second time less high requirements are demanded for its density (and consequently it has a somewhat smaller density than *stabstahl*). *Halbzeug* has a square or round form.

Röhrenvormaterial is the material out of which tube manufacturers produce their tubes (and is of course always round). Because the inner-part of the material is being removed in the process of making tubes the density of the inner-part does not have to be as high as for *stabstahl*.

Forgings mean that a specific form is forged the way the customer it wants.

Sales is organized according to the above mentioned product-categories. These are the different departments (*verkaufs-abteilung*) in which Sales is organized.

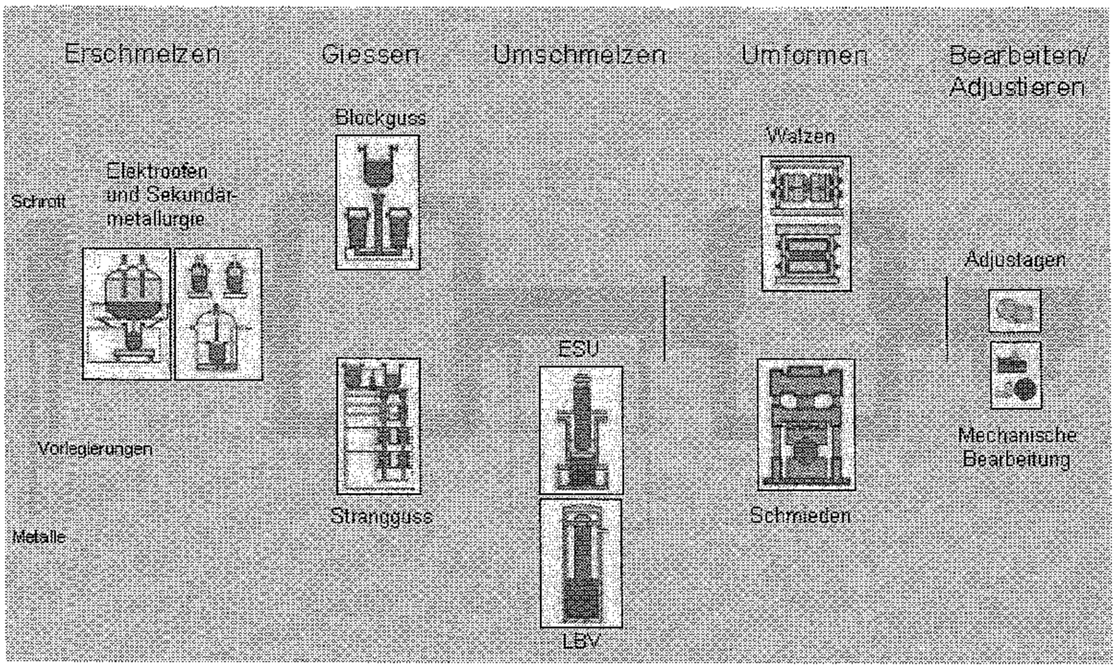
VR1: this is the Sales-department for the German market of *RSH-stahl*
VR2: this is the Sales-department for the non-German market of *RSH-stahl*
VW1: this is the Sales-department for the German market of *Werkzeug-stahl*
VW2: this is the Sales-department for the non-German market of *Werkzeug-stahl*
VW3: this is the Sales-department for high speed tool steels
VW4: this is the Sales-department for *Baustahl*/Cold rolls/Forgings
VB1: this is the Sales-department for the German market of *Bau-stahl*
VB2: this is the Sales-department for the non-German market of *Bau-stahl*

There are also a few other departments which take care of the order-taking for the more special products like FERRO-TITANIT.

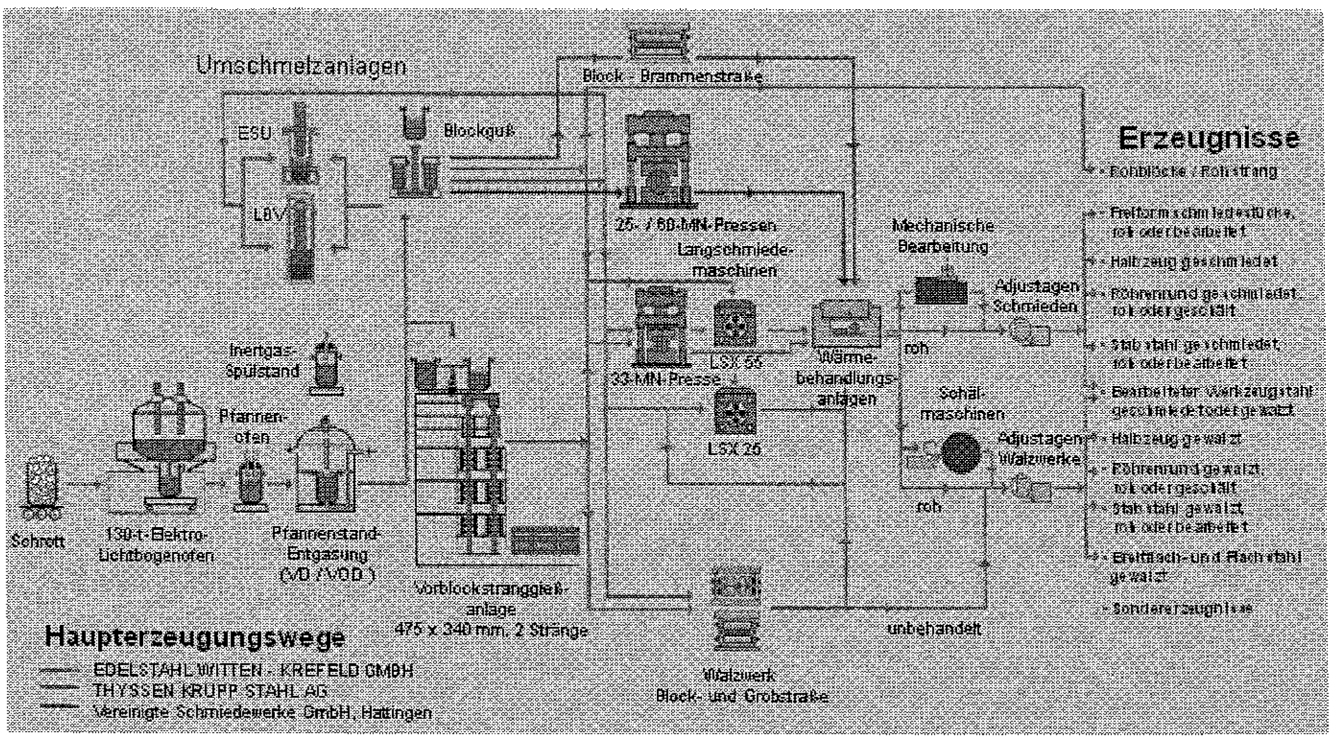
Appendix 2: Description of technical production processes (1)

This appendix describes in more detail (and somewhat more technical) the various production-processes at the different sites. This information is based on material from the intra-net site of EWK [4].

Produktionsfluss (prinzipskizze):



Produktionsablauf erzeugnisse:



Die Haupterzeugungswege der Edelstahl Witten-Krefeld GmbH basieren auf der Stahlerzeugung aus einem Elektrostahlwerk in Witten mit einem Schmelzgewicht von 130 Tonnen, sowie einem Umschmelzstahlwerk in Krefeld.

Stahlwerk Witten

Das Elektrostahlwerk besteht aus

- einem 130-t- Elektro- Lichtbogenofen
- einer Abschlackmaschine
- einem Pfannenofen
- zwei Pfannenstandentgasungsanlagen mit der Möglichkeit des Sauerstoffaufblasens (Vacuum-Oxygen-Decarburization, "VOD") und
- einer Inertgas-Spülstation die eine operative Einheit bilden.

Besonderheiten des Lichtbogenofens sind der von der Edelstahl Witten-Krefeld GmbH entwickelte und erstmalig in der Welt praktisch genutzte zentrische Bodenabstich.

Im Lichtbogenofen werden Schrott, Legierungen und Schlackenbildner eingeschmolzen und auf die notwendige Abstichtemperatur erhitzt. Dabei wird durch die zentrische Herd-Bodenspülung eine für die Homogenisierung günstige Badbewegung erzielt. Der Stahl wird über den Bodenabstich in die unter dem Ofen stehende Pfanne entleert und mittels der Abschlackmaschine von der mitgelaufenen Ofenschlacke getrennt. In der Pfanne werden dabei - je nach metallurgischen Anforderungen - Legierungsstoffe wie z.B. Kohlenstoff, Silizium, Mangan, Chrom, Nickel sowie Schlackenbildner zugesetzt.

Die Pfannenböden sind ebenfalls mit Spülsteinen ausgerüstet, durch die inerte Gase (Argon und Stickstoff) eingeleitet werden, die den flüssigen Pfanneninhalt umwälzen. Hierdurch wird die gleichmäßige Legierungs- und Wärmeverteilung gewährleistet sowie die Transitorik zwischen Stahl und Schlacke verbessert.

Während des gesamten Ablaufs wird die chemische Zusammensetzung der Stahlschmelze über mehrfache Probennahmen kontrolliert.

Sekundärmetallurgie

Die Entwicklung der pfannenmetallurgischen Verfahren (Sekundär-Metallurgie) hat dazu geführt, dass wesentliche metallurgische Arbeiten zunehmend vom Elektroofen in die Pfanne verlagert wurden. Hierzu zählen Legierungs- und Temperatureinstellung, Homogenisation, Desoxidation, Entgasung, Spülbehandlung (Reinheitsgrad- Spülen) mittels Argon sowie sondermetallurgische Verfahren wie z.B. die Calziumbehandlung. Zur Erzeugung von RSH-Stählen erfolgt eine Sauerstoffbehandlung unter Vakuum (Vacuum Oxygen Decarburization = VOD).

Diese sekundärmetallurgischen Arbeitsschritte, die Verwendung basischer Pfannen zwecks Einstellung eines optimalen Reinheitsgrades sowie eine gezielte Schrottauswahl zur abgestimmten Einstellung auch von Begleitelementen sind wichtige Vorraussetzungen zur Erzielung eines hohen Qualitätsniveaus. Der Pfannenofen bildet eine Zwischenstation, in welcher der Schmelze bei gleichzeitiger Wärmezufuhr notwendige Legierungen zur Feineinstellung der geforderten Analyse zugesetzt werden, in welcher aber auch die Abscheidung von nichtmetallischen Einschlüssen in neu aufgebrachte Abdeckschlacken erfolgt.

Wie beim Lichtbogenofen wird die Wärme über Lichtbögen der Elektroden dem Schmelzbad von oben zugeführt. Damit ist die Pfannenbehandlung ohne den sonst üblichen Temperaturverlust möglich.

Auch bei der Pfannenofenbehandlung sorgt eine Badbewegung durch Einleiten eines inerten Gases durch den Pfannenboden für den notwendigen Konzentrationsausgleich.

Anschließend wird die Schmelze in einer Pfannenstand-Vakuumanlage weiterbehandelt. Neben der Einstellung niedrigster Wasserstoffgehalte wird hier die Feinstkorrektur der chemischen Zusammensetzung vorgenommen, die Desoxidation durchgeführt und die bei dieser Reaktion entstehenden nichtmetallischen Ausscheidungen in eine auf dem Stahlbad liegende Raffinationsschlacke überführt. Die diese Vorgänge unterstützende Bodenspülung sorgt dabei auch für die Einstellung einer homogenen Gießtemperatur.

Durch Einbau von Sauerstofflanzen werden diese Anlagen auch für den VOD-Prozeß (Vacuum-Oxygen- Decarburization) zur Erzeugung von hochlegierten Stählen mit niedrigsten Kohlenstoffgehalten genutzt.

Das sekundärmetallurgische Zentrum wird vervollständigt durch eine mobile Stickstoff - Einblasstation für das Stickstofflegieren, vier Drahteinspulvorrichtungen für das Legieren von z.B. Ca, Te, Al und S sowie einer Inertgas-Spülstation zur Homogenisierung von Temperatur und chemischer Zusammensetzung.

Gießen

Je nach Stahlsorte und Abmessung des Endproduktes wird der im Elektrostahlwerk Witten erschmolzene Stahl als Blockguss oder Vorblockstrangguss vergossen.

Für die Herstellung der unterschiedlichen Erzeugnisse stehen im Blockguss über 50 verschiedene Kokillenformate von 600 kg bis 170 t zur Verfügung.

Senkrecht Stranggießanlage (VCC)

Vorblockstrangguss wird über eine zweistrangige Vertikal-Stranggießanlage im Format 475 mm x 340 mm hergestellt. Die Anlage ist mit elektromagnetischen Rühreinrichtungen in der Kokille und im Strang (variable Position) ausgestattet und für die Erzeugung höherlegierter Stähle mit höchsten Anforderungen konzipiert.

Diese Anlage kann die gesamte Palette der Edelstähle von unlegierten und legierten Edelbaustählen, Werkzeugstählen bis hin zu den rost-, säure- und hitzebeständigen Stählen für höchste Anforderungen vergießen.

Das Konzept der Vertikalanlage wurde gewählt, um bei besonders rissanfälligen Stählen Biegeverformungen der Strangschale während der Erstarrung und Abkühlung auszuschließen. Gegenüber Kreisbogenanlagen sind in Senkrechtanlagen besonders günstige Abscheidebedingungen für nichtmetallische Einschlüsse gegeben.

Es wird mit komplettem Gießstrahlschutz über Schattenrohr und Tauchrohre vergossen. Beim Verteiler handelt es sich um einen T-Verteiler mit 19 t Arbeitsinhalt und 900 mm Badhöhe.

Die Anlage ist mit Kokillenrührern ausgerüstet, die die Abscheidung von Verunreinigungen begünstigen und den Abbau von Überhitzungen beschleunigen, sowie eine globulitische Randerstarrung bewirken.

Je ein weiterer Drehfeldrührer pro Strang erlaubt im Bereich der Sekundärerstarrung eine Beeinflussung der Kernbeschaffenheit des vergossenen Stahls. Diese Rührer sind im Bereich zwischen 11 und 15 Meter unterhalb des Gießspiegels verfahrbar, um je nach Stahlzusammensetzung und Gießgeschwindigkeit die jeweils günstigste Rührwirkung zu erreichen.

Umschmelzstahlwerk Krefeld

Sonderschmelzverfahren

Für besonders hohe Anforderungen bezüglich Seigerungen und Reinheitsgrad verfügt EWK am Standort Krefeld über ein Umschmelzstahlwerk mit zwei Elektro-Schlacke-Umschmelzöfen (ESU) und einem Lichtbogen-Vakuum- Ofen (LBV).

Elektroschlacke-Umschmelzverfahren

Beim Elektroschlacke-Umschmelzen, das mit Wechselstrom arbeitet, taucht eine gegossene oder geschmiedete, selbstverzehrende Elektrode in eine als elektrischer Widerstand dienende schmelzflüssige Schlacke.

Vom Elektrodenende tropft das umzuschmelzende Material durch die Schlacke hindurch und baut in einer wassergekühlten Kokille den neuen Block auf. Die Wärmeabfuhr führt zu einer gerichteten Erstarrung in Richtung der Blocklängsachse.

Die Umschmelzschlacke erfüllt bei diesem Verfahren mehrere Funktionen. Sie entwickelt zum einen die notwendige Prozesswärme, ist gleichzeitig Verursacher chemischer Reaktionen wie der Entschwefelung und dient als Oxidationsschutz für den Schmelzsumpf des neu aufzubauenden Blocks. Hinzu kommt die hohe Aufnahmefähigkeit der Schlacke für nichtmetallische Einschlüsse, sodass das umgeschmolzene Material frei von Makroeinschlüssen ist. Die Verbesserung des mikroskopischen Reinheitsgrades ist auf eine Entschwefelung und dadurch bedingt einen hohen sulfidischen Reinheitsgrad sowie auf eine Verringerung der Größe und Menge der oxidischen Einschlüsse zurückzuführen.

Lichtbogen-Vakuum-Umschmelzverfahren

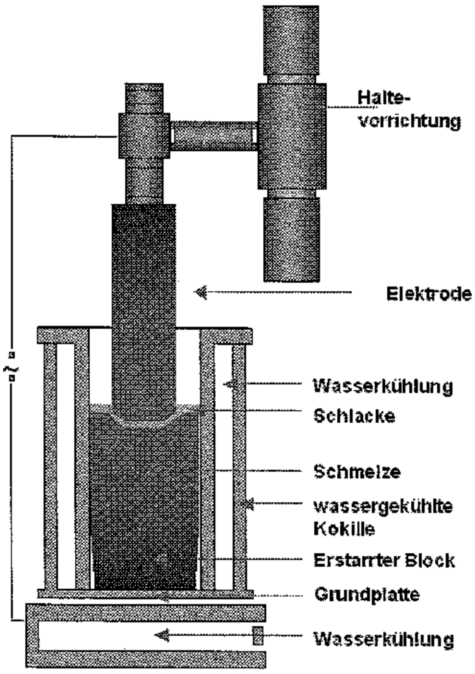
Das Lichtbogen- Vakuumverfahren arbeitet mit gegossenen oder geschmiedeten, selbstverzehrenden Elektroden unter Vakuum.

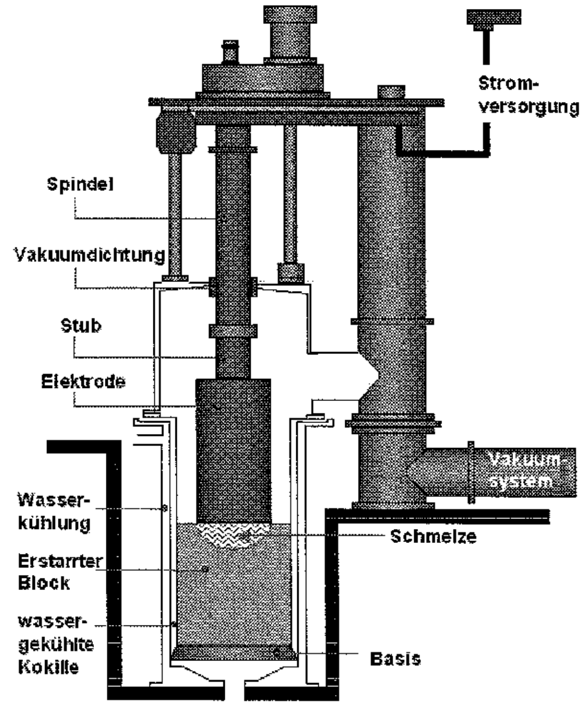
In einem Kupfertiegel, der als Gegenpol zur Umschmelzelektrode dient und über Stromkontakte mit einer Gleichstrom- Spannungsquelle verbunden ist, wird ein Schmelzsumpf mittels Lichtbogen unter Vakuum erzeugt.

In einem kontinuierlichen Prozess bildet sich aus dem verflüssigten Elektrodenmaterial tropfenweise ein neuer Block. Die Raffination des Stahles erfolgt beim LBV-Verfahren durch Reaktion des im Stahl gelösten Sauerstoffs mit dem Kohlenstoff in der Schmelze, bedingt durch das Vakuum und durch Flotation der Einschlüsse in die Blockrandzone, die nach dem Umschmelzen durch Schleifen entfernt wird. Hierdurch wird ein bestmöglicher mikroskopischer oxidischer Reinheitsgrad sowie Freiheit von makroskopischen Einschlüssen erzielt.

Da bei diesem Umschmelzprozess keine Entschwefelung stattfindet, müssen vor dem Umschmelzen niedrigste Schwefelgehalte eingestellt werden, um höchste Anforderungen auch an den sulfidischen Reinheitsgrad zu erfüllen. Darüber hinaus gewährleistet dieses Verfahren niedrigste im Stahl gelöste Gasgehalte und Seigerungsarmut.

Für das Umschmelzstahlwerk werden gegossene oder geschmiedete Elektroden eingesetzt. Der Direkteinsatz von Stranggussriegeln als Elektroden für das ESU- und LBV-Verfahren ist ebenfalls möglich. Im Lichtbogen-Vakuum-Ofen mit einer Nenngröße von 6,4 t werden Umschmelzblöcke in Tiegeln von 305-660 mm Durchmesser hergestellt. Zwei Elektro-Schlacke-Umschmelzöfen mit einer Nenngröße von 1,8 t bis maximal 27,5 t erzeugen Umschmelzblöcke in Tiegeln von 406-1030 mm Durchmesser.





wu989992.ppt ESU LBV

Schmiedebetriebe Krefeld und Witten

Die Werke Krefeld und Witten verfügen beide über einen modernen Schmiedebetrieb.

Die Krefelder Schmiede ist mit einer 33-MN-Presse mit zwei schienengebundenen Manipulatoren und einer Horizontal-Langschmiedemaschine des Typs GFM-LSX 55 ausgestattet.

Die Verformung an der ölhydraulischen 33 MN-Freiformschmiedepresse und an den 2 Langschmiedemaschinen erfolgt nach vorgegebenen, an das Verformungsaggregat überspielten Stichplänen zur Herstellung qualitativ gleichmäßiger Produkte mit engen Toleranzen. Nicht nur an der Schmiedepresse, sondern auch an den beiden Schmiedemaschinen ist durch Wahl entsprechender Werkzeuge die Herstellung von rotationssymmetrischen Werkstücken mit konischen und gestuften Absätzen möglich.

Bemerkenswert ist, dass die 33 MN-Presse in Krefeld auch als Vorschmiedeaggregat für die Langschmiedemaschine LSX 55 dient. Ca. 50% des Durchsatzes der Presse werden "im Verbund" an der Schmiedemaschine auf Endkontur geschmiedet, davon die Hälfte ohne weiteres Nachwärmen.

An der 33 MN-Presse können Erzeugnisse bis 850 mm rund bzw. Flachabmessungen bis 1600 mm Breite bei einem Stückgewicht von max. 27 t gefertigt werden. Die Langschmiedemaschine fertigt Erzeugnisse bis 470 mm rund bzw. Flachabmessungen bis 350 mm Breite bei einem maximalen Stückgewicht von 7 t.

Im Wittener Betrieb wird eine kleinere Horizontal-Langschmiedemaschine des Typs GFM-LSX 25 betrieben, deren Abmessungsprogramm an das der Krefelder Schmiedemaschine anschließt. Das maximale Einsatzgewicht beträgt 1.500 kg.

Die Stahlversorgung der Schmiede Krefeld wird überwiegend durch im Warmtransport angelieferte Rohblöcke und Stranggussriegel aus dem Elektrostahlwerk Witten sichergestellt. Ein geringerer Anteil der Versorgung stammt aus dem Umschmelzstahlwerk in Krefeld.

Die Schmiede Witten wird ebenfalls mit Rohblöcken aus dem Elektrostahlwerk Witten sowie mit Halbzeug aus der Schmiede Krefeld und der Block-/ Grobstraße in Witten versorgt.

Walzwerk Block - und Grobstraße Witten

Die Block-/Grobstraße in Witten besteht aus einem 1000-er Blockgerüst und einer 2-gerüstigen, offenen 800-er Fertigstraße. Dieser vorgeschaltet ist ein prozessgeregelter Drehherdofen zur Erwärmung der Rohblöcke (Standardformat 4,9t) und der Stranggussvorblöcke (Format 475 x 340 mm) auf die jeweilige stahlspezifische Walztemperatur.

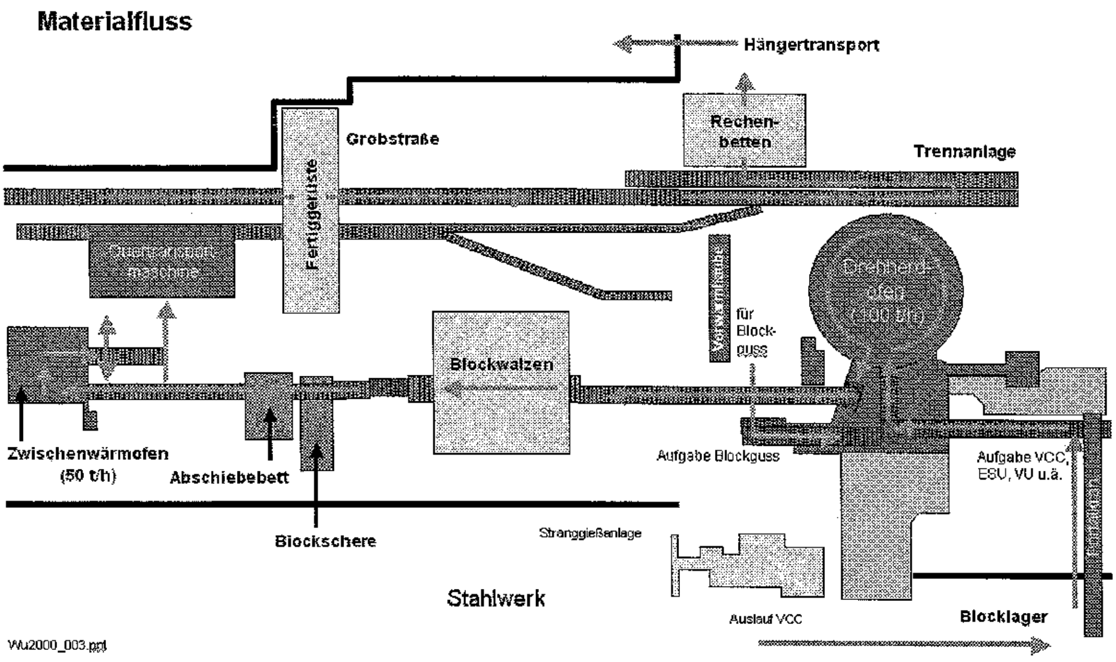
Nach dem Transport durch eine Presswasserentzunderungsanlage (240 bar) erfolgt im teilautomatisierten Blockgerüst die Walzung auf dicke Vorblöcke bzw. auf den Anstichquerschnitt, der für die jeweilige Endabmessung in der nachgeschalteten Grobstraße erforderlich ist.

In der Grobstraße wird das erste Gerüst als Vor- und Fertiggerüst, das zweite Gerüst als reines Fertiggerüst genutzt. Analog dem Blockgerüst sind beide Gerüste der Fertigstraße in ihren wesentlichen Funktionen (Anstellung der Oberwalze, Drehrichtung der Walzen, Walzgeschwindigkeit) automatisiert, damit die Walzung von Halbzeug, Stabstahl, Breit- Flach- Abmessungen reproduzierbar gestaltet werden kann.

Danach wird die Walzader rechnerunterstützt an Heißsäge- oder Heißtrennanlagen aufgeteilt und mittels automatischer Stempelmaschinen gekennzeichnet.

Die Abkühlung erfolgt auf Wendekühlbetten, die Einzellängen bis 26 m (z.B. Dornstangen) aufnehmen können.

Im Anschluss daran wird je nach qualitativen Anforderungen das Material zunächst dem Wärmebehandlungsbetrieb oder direkt den Adjustagen zugeführt.



Wärmebehandlungsbetriebe Krefeld und Witten

Für die Wärmebehandlung stehen in Krefeld und Witten Betriebe mit modernen Einrichtungen zur Verfügung. Hierzu zählen Rollenherdöfen einschließlich einem 55 m langen Rollenherdschutzgasofen (in Zusammenarbeit mit der Wälzlager Rohr GmbH), Herdwagenöfen, Tieföfen, Horizontal- und Senkrechthärteanlagen sowie verschiedene Arten von Abschreckmedien (Öl, Polymer, Wasser, Pressluft). Mit diesen Anlagen können die erforderlichen Wärmebehandlungen wie das Glühen, Härten und Vergüten der unterschiedlichen Erzeugnisse durchgeführt werden.

Der Wärmebehandlungsbetrieb in Krefeld besteht aus einer Glüherei und einer Härterei / Vergüterei. Mit den vorhandenen Anlagen können alle erforderlichen Wärmebehandlungen wie Glühen (G, BG, BF, GKZ) Härten und Vergüten durchgeführt werden. Für spezielle Anforderungen können die Glühungen unter Schutzgas erfolgen, das Härten bestimmter Bauteile wie Kaltwalzen und Richtrollen kann induktiv durchgeführt werden.

Die Glüherei verfügt über acht Rollenherdglühöfen, einen Rollenherdschutzgasofen, 14 Herdwagen-Glühöfen, einen Haubenofen, zwei Glühhauben und einen Tunnelofen. Als Abschreckmedien dienen Wasser und Polymerlösungen. In den Herdwagenöfen können Schmiedestücke bis 32 t Stückgewicht vergütet bzw. geglüht werden. Alle Öfen besitzen automatische Temperaturregelungen. Die Herdwagenöfen werden zusätzlich über einen Prozessrechner gesteuert, der die Glühprogramme einschließlich der Durchlaufzeiten überwacht. Die Wärmebehandlungsvorschriften sind in einem Fertigungsleitrechner hinterlegt und werden für jeden Auftrag abhängig von Werkstoff, Abmessung, gewünschter Wärmebehandlung, Kundenvorschrift usw. speziell erstellt.

Die Härterei / Vergüterei verfügt über drei Induktionshärteanlagen zum Oberflächenhärten von Kalt- und Richtwalzen bis 750 mm Durchmesser und Längen bis 5740 mm sowie elektrisch- und gasbeheizte Tiefföfen zum Anlassen bzw. klassischen Härten und Vergüten. Zum Abschrecken stehen Wasser, Öl, Kochsalzlösung und ein Ölwarmbad zur Verfügung. In der Vergüterei befinden sich zwei Rollenherd-Abschrecköfen sowie zwei Rollenherdanlassöfen, die kontinuierlich im Verbund betrieben werden können. Das Abschrecken kann mit Pressluft, Wasserbrause bzw. im Flutbehälter mit Wasser erfolgen. In diesen Öfen können Stäbe bis 270 mm Durchmesser und 28 m Länge vergütet werden.

Die Wärmebehandlungsbetriebe in Witten bestehen aus einem zentralen Betrieb sowie einem der Block-Grobstraße angegliederten Betrieb. In zentralen Betrieb sind vier Durchlauföfen und 10 Herdwagenöfen vorhanden. Drei Durchlauföfen werden im Verbund betrieben und überwiegend für die Wärmebehandlungsarten BG-Glühen, Lösungsglühen, Vergüten und Abschrecken genutzt. Als Abschreckmedien dienen Wasser und Polymerlösungen. Die für den Härtevorgang einzustellenden Prozessparameter werden, abhängig von Werkstoff/Abmessung, aus einer Datenbank abgerufen und an die Ofensteuerung weitergegeben. Ein weiterer Durchlaufofen wird überwiegend für das GKZ-Glühen von Wälzlager- und Werkzeugstählen genutzt. Es besteht die Möglichkeit, Schmiedestücke bis zu ca. 20 t über Herdwagenöfen in Wasser oder Polymer zu vergüten.

In dem der Block-Grobstraße angegliederten Betrieben stehen zwei Durchlauföfen sowie drei Haubenöfen zur Verfügung. Die Durchlauföfen werden schwerpunktmäßig für die Abkühlung spannungsrissempfindlicher Güten aus der Walzhitze sowie G-, BG-, BF- und GKZ-Glühungen eingesetzt. Sämtliche Öfen sind erdgasbeheizt und besitzen automatische Regeleinrichtungen.

Mechanische Bearbeitung

Die Werke in Witten und Krefeld verfügen über zwei moderne Bearbeitungsbetriebe für spanabhebende Bearbeitungsverfahren.

Der Bearbeitungsbetrieb Witten fertigt auf modernen, leistungsstarken Aggregaten die breit gefächerte Produktpalette der bearbeiteten Werkzeugstähle. Hier stehen Fräs- und Schleifmaschinen zur Bearbeitung von Stäben, Platten, Blöcken und Formteilen mit Stückgewichten bis zu 50 t zur Verfügung. Tieferangearbeitete Bauelemente werden nach Zeichnungen bzw. nach Oberflächendaten, die auf CAD/CAM-Systemen aufbereitet werden, erzeugt. Hierfür stehen leistungsfähige CNC-gesteuerte Bohr- und Fräsaggregate zur Verfügung.

Im Bearbeitungsbetrieb Krefeld werden rotationssymmetrische Teile auf konventionellen und modernsten CNC-testierten Dreh- und Schleifmaschinen hergestellt. Schwerpunkte der Fertigung bilden Pilgerdorne, Walzen, Wellen, Zylinder und Stranggussführungsrollen.

Das Spektrum der Teile reicht von kleinen Walzen im Kugelschreiberformat für das Umformen von Edelmetallen über Sendzimirwalzen für die Herstellung von Blechen aus schwer umformbaren Werkstoffen bis hin zu Walzen für die Herstellung von Breitband. Daneben sind Pilgerdorne für die Herstellung nahtloser Rohre, Rohlinge für die Kurbelwellenfertigung sowie bearbeitete Werkstücke für die Kunststoff-, Druck- und Erdölindustrie Schwerpunkte der Fertigung. Es können Teile bis zu einer Länge von 10 m und einem Gewicht von 20 t bearbeitet werden.

Die zu bearbeitenden Teile haben einen Durchmesser von bis zu 1000 m, in einigen Fällen sogar bis 2000 mm. Eine Anlage zum Aufpanzern von Werkzeugen der Schmiedebetriebe rundet die Fertigungsmöglichkeiten ab.

Zurichtung und Prüfung

Eine hohe Produktqualität lässt sich nur durch moderne Produktions- und Prüfanlagen und durch eine umfassend geschulte und motivierte Belegschaft garantieren. Von der stofflichen Kontrolle der Rohstoffe über chemische Kontrollen in der Metallurgie sowie Innen-, Oberflächen-, Dimensions- und Identitätskontrollen in den Walzwerks- und Schmiedeadjustagen bis hin zu mechanisch-technologischen Prüfungen an Proben werden alle Prozesse im Fertigungsablauf überwacht, statistisch ("SPC") oder 100%ig kontrolliert und geregelt. Die Anforderungen der Kunden werden über Fertigungs- und Prüffolgevorschriften ebenso wie Prozess und Prüfdaten in EDV-Systemen erfasst, verarbeitet und ausgewertet. Diese Auswertungen dienen der direkten Regelung der Prozesse und der Bewertung des Qualitätsniveaus und sind damit Basis einer kontinuierlichen Qualitätsverbesserung.

Zurichtung Walzerzeugnisse

Für die Prüfung und Adjustage der gewalzten Erzeugnisse stehen moderne Prüf- und Adjustageanlageeinrichtungen im Werk Witten zur Verfügung. Nach Walzung und Wärmebehandlung durchläuft das Walzgut der Block-/Grobstraße eine der modernsten "Fließadjustagen" Europas. Hier wird in einer rechnergestützten Prüflinie das Material den Kundenanforderungen gemäß adjustiert. Neben der Laser-Dimensionsprüfung und einer Ultraschall-Innenkontrolle werden die Oberflächen mit Hilfe einer Therm-O-Matic-Anlagen inspiziert. Die erkannten Fehler werden lagegetreu markiert und in einer nachgeschalteten Revision online beseitigt. Anschließend wird das Material entsprechend der jeweiligen Kundenanforderung gebündelt, gewogen, identitätsgeprüft, gekennzeichnet und zum Versand bereitgestellt.

Auf Wunsch kann das Halbzeug in einem Schleifzentrum auf zwei Hochdruck-Schleifmaschinen allseitig geschliffen werden. Für den Stabstahlbereich 50 - 110 mm rd. steht eine Circofluxanlage mit nachgeschalteter Ultraschall- und Laser-Dimensionsprüfung zur Verfügung.

Zurichtung Schmiedeerzeugnisse

Für die Adjustage der Schmiedeerzeugnisse stehen in Krefeld, Witten und Hattingen insgesamt vier moderne Adjustagebetriebe zur Verfügung. Die beiden Betriebe in Krefeld sind mit Richt- und Strahlanlagen, Schleif- und Trenneinrichtungen, sowie Oberflächen- und Ultraschallprüfstrecken ausgerüstet, mit denen Rund-, Vierkant- und Flachabmessungen adjustiert werden können. Auch die Bearbeitung von Umschmelzelektroden und umgeschmolzenen Blöcken wird hier vorgenommen.

Schälbetriebe Witten und Krefeld

Für die Oberflächenbearbeitung von Stabstahl sind die Schälbetriebe in Witten und Krefeld mit modernen Schäl- und Poliermaschinen ausgestattet. Gewalzter oder geschmiedeter Stabstahl sowie Röhrenvormaterial können in Abhängigkeit von der Fertigabmessung und der Länge nach dem Richten in den Schälbetrieben Witten (40 - 160 mm rd., max. 12,5 m Länge) oder Krefeld (90 - 400 mm rd., max. 30 m Länge) geschält, druckpoliert und - auf Wunsch - angefast werden. Die Schälbetriebe verfügen außerdem über entsprechende Einrichtungen für das anschließende Prüfen auf Oberflächen- und Innenfehler sowie Chargenidentität (Spektrotest).

Appendix 3: Description of technical production processes (2)

In this appendix the various operations at EWK will be described in more detail

Melting:
The main production route utilized by EWK are based on a 130-tonnes electric arc furnace steel plant in Witten. Precisely defined properties are achieved by means of exact alloying and process specifications. The metallurgical precision work is performed in a downstream ladle furnace (*pfannenofen*) of the same size.

Casting:
Depending on the steel grade and the dimensions of the end-product, the steel melted in this way is cast in ingots or continuous cast blooms. For ingot casting there are over 50 different ingot mould sizes available, ranging from 600 kg to 170 t. The continuous cast bloom is produced in a two-strand vertical continuous caster in a section measuring 475x340 mm.

Remelting:
To meet particularly high requirements with regard to segregations and cleanness, a remelting plant is available in Krefeld which includes two electroslag remelting furnaces and one vacuum arc remelting furnace. For the *Umschmelzstahlwerk* casted or forged electrodes are used. The direct use of continuous casts for the ESU and LBV process is also possible. In the LBV furnace remelt-casts with a net weight of maximal 6,4 t are produced in a diameter of 305-660 mm. In two ESU furnaces remelt-casts with a net weight of 1,8 t to a maximum of 27,5 t can be made in a diameter of 406-1030 mm.

Deforming:
The hot shaping of the ingot-or continuously cast material takes place on the blooming/billet/large-size bar rolling mill in Witten (*block-grobe strasse*) or in the forging shops in Krefeld (P33 and SX55) and Witten (SX25). Larger wide flat dimensions are rolled from slab ingots on a hire-basis (*Lohn-arbeit*) on blooming-slabbing mills (*block-brammen strasse*). The blooming/billet/large-size bar rolling mill produces semis, bar steel, universal plate, flats and sheet bars in a blooming stand and two finish rolling stands. The forging shops are equipped with a 33 MN Press, a horizontal long forging machine of the GFM LSX55 type, and one of the GFM LSX25 type. Forging can also be done on a hire basis on a P25 and P60.

Heat treatment:
Annealing, hardening and quenching and tempering lines are available for heat treatments at the two sites Witten and Krefeld.

Straightening:
When material has been heat-treated and afterwards has to undergo some mechanical operations, it has first to be straightened.

Machining:
Rolled or forged bar steel as well as round tubemaking billets up to 300 mm in diameter can, after undergoing straightening, be peeled, polished and chamfered (*abkanten*) in Krefeld and Witten. In Krefeld, rotationally symmetrical parts with single piece weights as heavy as 20 tonnes are manufactured on conventional as well CNC turning and grinding machines. The products include mainly rolls, shafts, cylinders. At the Witten works, tool, die and moulds products are manufactured. The mix of products ranges from rough-milled blooms, and precision flats and squares, through to ready to install shaped parts with single piece weights as heavy as 50 tonnes.

Finishing:
There are various finishing lines at the different shops, to test the internal and the external quality and to check the dimensions and identity.

Appendix 4: Resource overview of various shops

This appendix describes for each shop the specific resources it consists of [5]:

Wärmebehandlungsbetriebe Witten (Wä1 en Wä2):

- Roh- und zwischenlager
- Durchlauföfen
- Herdwagenöfen
- Haubenofen
- Abschreckeinrichtungen
- Fertiglager

Zurichtungsbetriebe Witten (Zurichting 1 (Z1) and Zurichtung 2 (Z2)):

Z1

- Rollenrichtmaschine
- Richtpressen
- Prüflinie mit:
    - Entzunderungsanlage
    - Querschnitts-/Längenprüfung
    - Ultraschallprüfung
    - Oberflächenrissprüfung
    - Revisionsständen mit handschleifplätzen
    - Kaltsäge- und Kalttrenneinrichtungen
    - Waagen
    - Paketiereinrichtungen
- Revisiontischen
- Handschleifplätzen
- Hochfrequenzschleifmaschinen
- Knüppelschleifmaschinen
- Haubenofen
- Kaltsägen und Kalttrennanlagen
- Paketiereinrichtung

Z2

- Rollenrichtmaschine
- Richtpresse
- Schrägrollenrichtmaschine
- Zweiwalzenrichtmaschine

Schälbetrieb Witten:

- Schälmaschine
- Richt-/Poliermaschine
- Prüflinie mit:
    - Durchmessermessung
    - Ultraschallprüfung
    - Oberflächenrissprüfung
    - Waagen
    - Paketiereinrichtungen
- Schleifmaschine
- Revisionsständen mit handschleifplätzen
- Kalttrenn-/Kaltsägeeinrichtung
- Anfasanlage
- Paketiereinrichtungen

Bearbeitungsbetrieb Witten (BBW):

- 3 horizontale CNC-Bohr-und Fräsmaschinen
- CNC-Portalfräs-und Bohrmaschine
- CNC-Bohrwerk
- 2 CNC-Drehmaschinen
- Tiefbohrmaschine
- Portal-Langfräsmaschine
- Doppelständer-Fräsmaschine
- 2 Portalfräsmaschinen
- Trennfrasmaschine
- Umfangschleifmaschine
- Laufwagenschleifmaschine
- Trennschleifmaschine

Schmiedebetrieb Witten (SB-Wi):

- Vormateriallager
- 2 Hubbalkenöfen
- 4 Herdwagenöfen
- Horizontal-Langschmiedemaschine LSX25 (long forging machine) für abmessungen
  50-180 mm vkt.
  50-220 mm rd.
  Flachstäbe von 50-270 mm Breite, 20-190 mm Dicke
- Schmiedehammer mit Automanipulator
- Heisstrennschleifmaschinen/Bandsägen

Block-/GrobstraBe (BG) (blooming mill) in Witten:

- Vormateriallager
- Vorwärmöfen
- Drehherdofen
- Vorwalzgerüst (blockgerüst)
- Blockschere
- 2-gerüstige offene Duo-halbzeug-/Stabstahlstrasse
- Warmtrennanlagen
- Kühlbetten

Stahlwerk (ST) in Witten:

- Platzbetrieb
- Elektro-lichtbogenofen (ELO) (Electric arc furnace)
- Pfannenofen
- Vakuumanlagen
- Spülstand
- Giessbetrieb für blockguss and strangguss
- Blockbearbeitung

Schmiedebetrieb Krefeld (SB-Kr):

- Vormateriallager
- 7 Herdwagenöfen
- 2 Drehherdöfen
- 4 Stecköfen
- 3 Glühöfen
- Hydraulische Freiformschmiedepresse P33 (forging press)
- Horizontal-Langschmiedemaschine LSX55 (long forging machine)
- Manipulatoren
- Heisstrennmaschine

Bearbeitungsbetrieb Krefeld (BBK):

- CNC-Drehmaschinen
- Karusseldrehmaschinen
- Konventionelle und CNC-Rundschleifmaschinen
- Flachschleifmaschinen
- Fräsmaschinen
- Horizontalbohrwerk
- Tieflochbohrmaschinen
- Schweissmaschinen

Schmiedeadjustagen Krefeld (Schmiedeadjustage 1 (SAD1) and Schmiedeadjustage 2 (SAD2)):

SAD1

- Schleifenmaschinen/Trennanlagen
- Strahlanlage und Kontrollböcken
- Elektrodenvorbereitung
- Oberflächen-, US-Prüftechnik
- Versandbereich
- Schrottplatz

SAD2

- Schälmaschine
- Trennanlagen/Poliereinrichtungen
- Oberflächen-, US-Prüftechnik
- Kontrollböcken
- Versandbereich

Wärmebehandlungsbetriebe WBK1 and WBK2 in Krefeld:

- 9 Rollenherd-Glühöfen
- 1 Rollenherd-Schutzgasofen
- 1 Haubenofen
- 14 Herdwagenöfen
- 2 Glühhauben
- 1 Tunnelofen
- 3 Induktionshärteanlagen
- 4 Tieföfen gasbeheizt
- 8 Tieföfen elektrisch beheizt
- 2 Rollenherd-Abschrecköfen
- 1 Rollenherd-Anlassofen
- 1 Rollenherd-Vorwärmofen
- 3 Polymer-Abschreckbecken
- 3 Wasser- Abschreckbecken
- 1 öl- Abschreckbecken
- 1 öl- Warmbad
- 4 Härteprüfanlagen
- 1 Richtpresse für Kaltwalzen

Appendix 5: Information about lagertype

A lagertype-number is a number consisting of 7 positions. For each lagertype-number there is also a *material-kurz-text* available. The following example will illustrate this:

Lagertype ≡ *material-kurz-text*
2072129 ≡ 15300.440462.06.V.130.01.6000-8000

The *material-kurz-text* can be described as follows:

15300	*Kunden-nummer*	
440462	*Werkstoffnummer*	This is the number of the particular grade of the steel
06	*Wert in produkt hierarchie*	Each product has a certain value in the product-hierarchy
V	*format*	This can be V(ierkant), R(und) or F(lach)
130	*abmessung*	
01	*wärmebehandlung*	This describes the type of heat-treatment the material undergoes
6000-8000	*länge (interval)*	This describes the length in which the customer wants its e.g. bar

The lager-type of each end-product always begins with a 2. The lagertype of a *vormaterial* (or *einsatz-material*) always begins with a 4. For each lagertype number a detailed description of the technical specifications exists. This is called the *merkmal-bewertung*. This specifies for example for a rolled product which roll-group it uses, what the upper and lower bounds for the different chemical elements are, the length in which the *strangguss* has to be cut or which *kokille* it uses when it is ingot casted etc.

Appendix 6: Batching and scheduling restrictions of heats

Restrictions when grouping orders into heats:

Grade compatibility:
Heats are generally composed of a single grade. Allocating orders of different grades to a heat is allowed only for a small number of compatible grades, in order to fill up a heat.
Chemistry constraints:
In addition to grades being compatible, the chemistries of various orders need to be compatible as well to allow the orders to be allocated to the same heat. Even when orders have the same grade, the chemistry values on certain orders might have tighter tolerances, making them incompatible.
Ingots or continuous cast:
All the orders in any given heat must have similar casting requirements i.e. they must all be ingot casted or all be continuous casted.
Constraints for mixing orders:
This is a soft-constraint which means that ideally all the orders in one heat are produced for one shop. However this is not strictly necessary. So all the orders in any given heat must have the requirement of either being:

- forged or/and
- rolled in Witten or/and
- rolled elsewhere

Size limitations for ingot cast heats:
Each heat can be made up of orders which will be cast in moulds of different sizes. It is preferable to reduce the number of different mould sizes of the various orders in a heat.
Maximum numbers of moulds per type:
There is a limited set of moulds available to be used during the ingot casting. The planner should not allocate more orders which require a given mould size than there are moulds available

Sequencing restrictions:

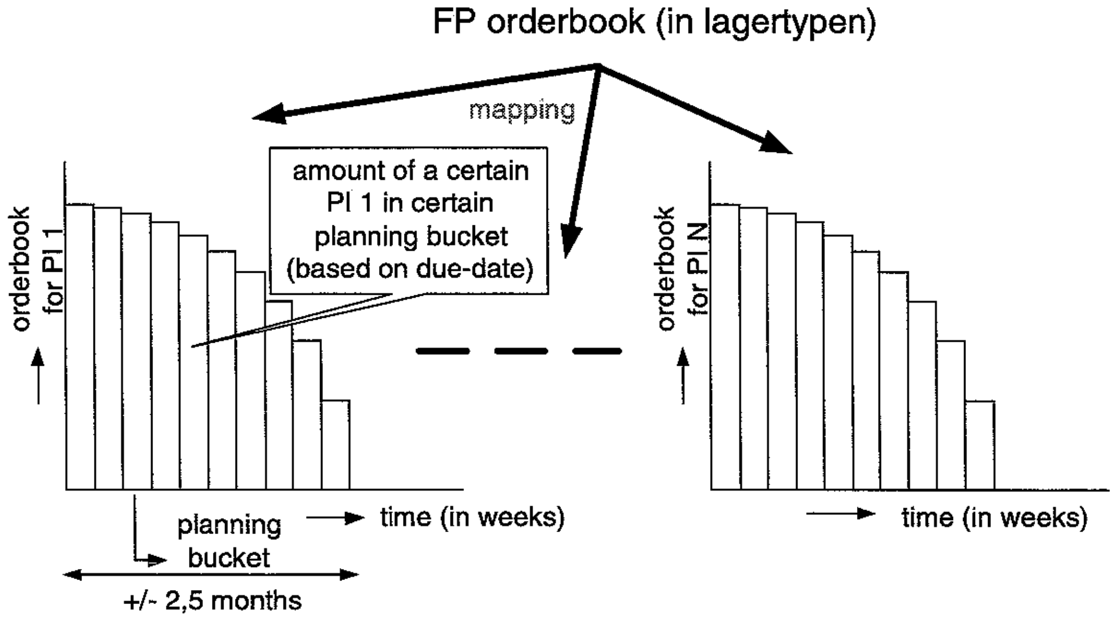
Besides the grouping of orders into heats, the sequencing of the melts is also an important issue. Some sequencing restrictions that apply are the following:

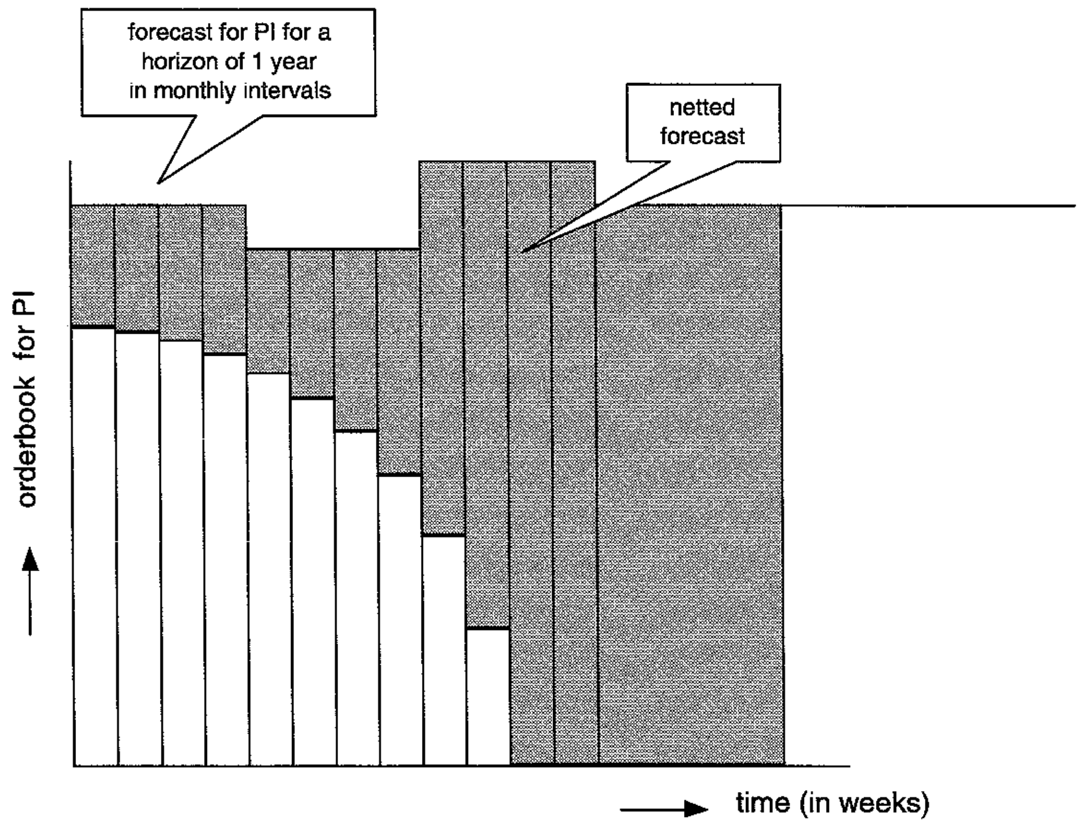
The change-over of one grade to the other is not always possible. For example the transition in Table 1 is not possible, since the change in the chromium -content is too high. The furnace is then still "polluted". Therefore between these two heats another heat must be inserted which takes care of a more gradual transition in chromium-content.

Heat		Min	Max
1	Cr	16	17
	.....		
2	Cr	1	2
	....		

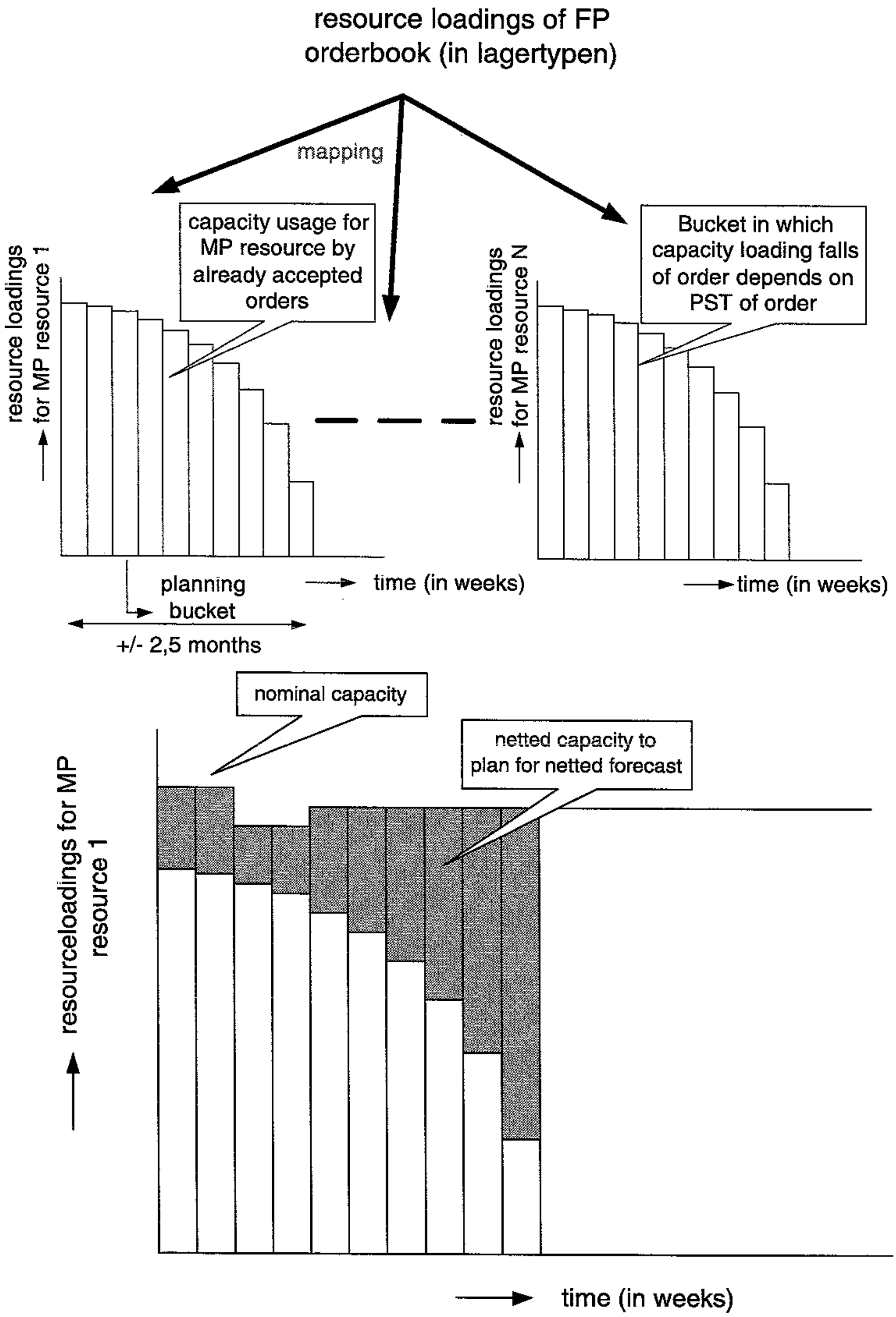
There is also a sequencing-restriction in the form of the amount of melts that can be casted in *blockguss* or strangguss per day. This restriction has a minimum of approximately 10 *strangguss* and 3 *blockguss* per day and a maximum of 6 *strangguss* and 7 *blockguss* per day. It can be seen that casting into *blockguss* requires the most capacity (*blockguss* is the limiting factor).

Appendix 7: Plots illustrating netting forecast logic





Appendix 8: Plots illustrating netting capacity logic



Appendix 9: Technical issues regarding mapping

Technical issues mapping lagertype → planning-item when netting forecasts:

What is important is a clear mapping from lagertype to planning-item. In the FP order-book information concerning lagertype, *verkaufs-abteilung* and customer is available. For performing the mapping the following tables should be available (in the form of a flat-file):

- A table lagertype → planning-product
- A table VA_customer → VA_team

The first table ensures the mapping of the lagertype to its planning-product. The second table ensures the mapping of the customer to the seller (market-dimension) it belongs.

Technical issues mapping lagertype → planning-item at order-entry :

When entering an order, all the relevant information should be available to match the specific order to the appropriate planning-item. One has seen that this is only possible when information about the lagertype, VA and the customer is available. In SAP only information containing the VA and lagertype is available. So within the i2 solution some flat-files should be available which enable the system to match a request for a product to its corresponding planning-item's ATP. Again (just like when netting the forecast) the following tables should be available (in the form of a flat-file):

- A table lagertype → planning-product
- A table VA_customer → VA_team

The first table ensures the mapping of the lagertype to its planning-product. The second table ensures the mapping of the customer to the seller (market-dimension) it belongs. So a lagertype should be entered, together with the VA and customer.

Care has to be taken in the maintenance of the right tables. These are the tables when mapping the FP-order-book to planning-items and those tables that are necessary when matching an order request to a planning-item at order-entry.

Lagertype → Planning-product mapping:

The routing-data of each lagertype is used to see in which planning-product it falls (this is called lagertype → planning-product mapping). Currently this is done by extracting lagertypes from the data repository of FP. However this data-set only contains the lagertypes in the current order-book. So this does not necessarily contain all the different possible lagertypes. Therefore in the future lagertypes will be imported from SAP which guarantees that a mapping for each lagertype to a planning-product is possible.

Lagertype → Planning-item mapping:

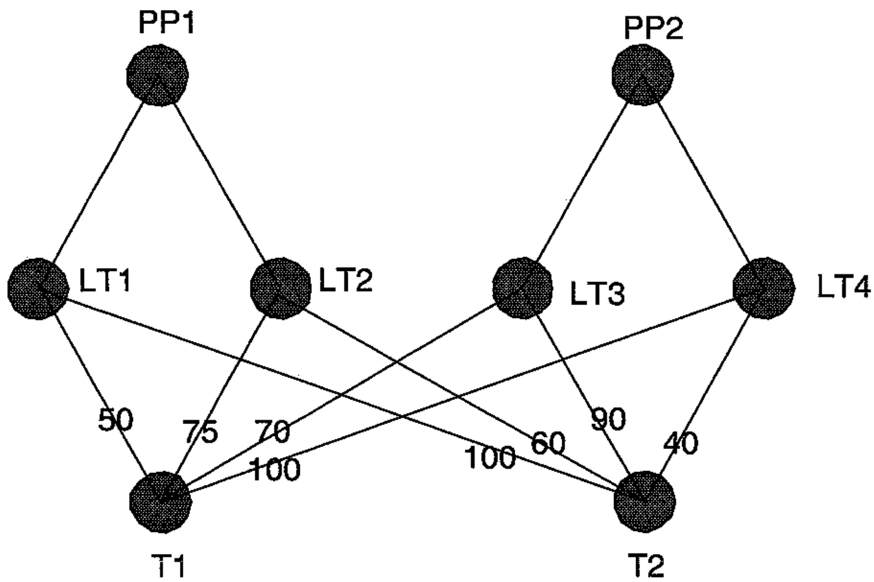
The mapping from a lagertype to a planning-item is necessary for order-entry and for the integration between MP/FP (when mapping the order-book).

Mapping of a lagertype to a planning-item is done in two parts. The first part is mapping the lagertype to its planning-product. After that information about the *verkaufsabteilung* and the specific customer has to be extracted. When combining these three pieces of information (planning-product, VA and customer) it is possible to map the lagertype to a planning-item.

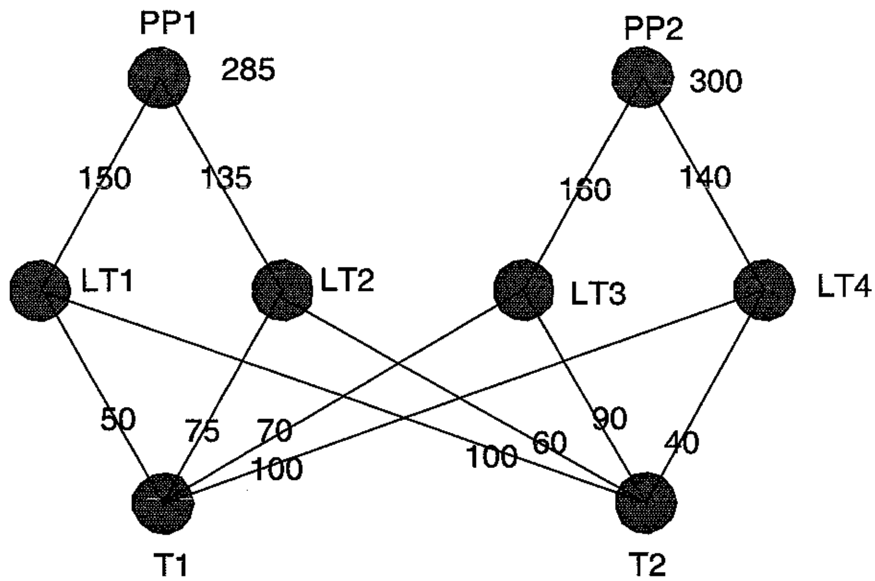
Given the forecasts for a lagertype and a VA_Team combination, it is possible to translate these figures to figures on planning-product level or planning-item level. Next will be shown how:

The following graph illustrates the inter-relations between:

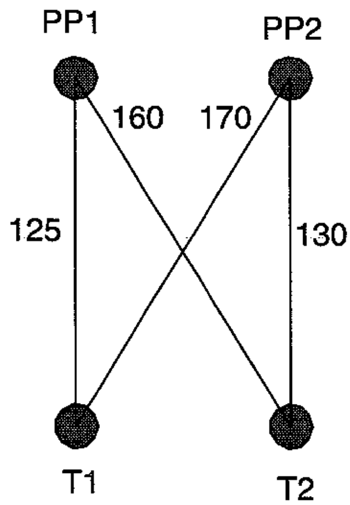
1. planning-product (PP)
2. lagertype (LT)
3. team (T)



As can be seen a lagertype could have several customers (as indicated by the two arrows that leave the lagertype to two distinct teams). Each lagertype can be matched to one and only one planning-product. The forecasts per PP can now be deducted by simply adding the appropriate figures.



The forecasts per PI can be deducted by adding those forecast-figures that fall in a specific planning-product and team. In this picture a line between a PP and a T represents a planning-item.


PP1
PP2
160
170
125
130
T1
T2

Appendix 10: Detailed workflow of CFP

1. First the *verkaufs-abteilung* (VA) is selected. Then the button "ABC Kunden" is clicked. The result is an ABC-classification: this is a sorting of all the various customers in this department to the amount of tonnes that has been sold in the last half year to this particular customer. These historical sales-data are imported from SAP. One can see also the percentage:

(amount of tonnes customer A bought/total amount sold in this *verkaufs-abteilung*) * 100%

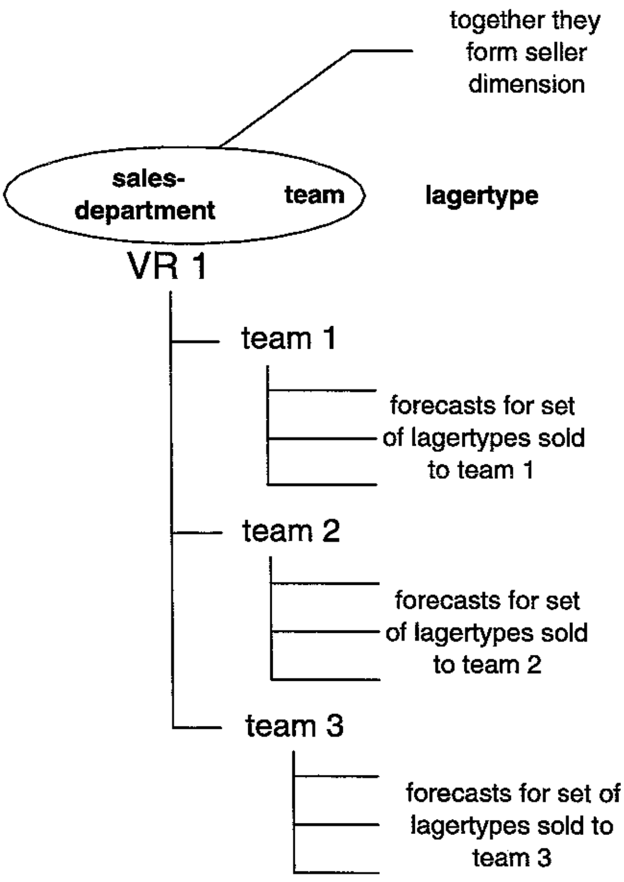
For each customer one can select if this customer falls in the *einzelne, sonstige* or unplannable category (in which category it falls depends on the above mentioned percentage). A proposition is already made by the database based on the above mentioned percentage. This automatic categorisation is done as follows:
A Customers (*einzelne kunde*) are those customers with a ratio of at least 2%
B Customers (*sonstige*) are those customers with a ratio between 0,1% and 2%
C Customers (unplannable) are those customers with a ratio less than 0,1%.

Forecasts for the A and B customers will get priority 1 and forecasts for C customers will get priority 2.

This ABC classification is well-known in literature and is also called the 80/20 rule or the Pareto curve.

2. For the user of the system it is possible to override this proposition and to make some changes in the categorization of the different customers.

3. When this has been done the database creates then automatically the various teams (a team can exist of one or more customers). A listing of all the lagertypes sold to the customers in a team is also given. One could see this as follows:



It is possible that the same lagertype is sold to different customers.

The dimension market-sector (seller) of a PI is thus formed by the VA_team. So the following options are possible for the dimension market-sector:

1. VA_some specific customer
2. VA_sonstige

4. For each customer one can add or delete lagertypes if this is necessary. One can also add or delete customers in a team. Additionally one can create other teams.

These first four steps are performed initially when all this goes on-line. It is expected that revisions in this only now and then take place (so the definitions of the market-sector dimension are quite static).

5. The booked orders for a particular lagertype underneath a VA_team of the past half year is given in monthly buckets. These booked orders are used as an initial forecast for the next year. Procedure: for a particular lagertype the booked orders for each month are summed and divided by 6. This average value for the sales per month is used as an input for the initial forecast per month for the next 12 months. On each level in the tree Sales can view what the forecasts are (so on lagertype level or VA_team level).

6. It is possible for Sales to revise these initial forecasts. One can change the forecasts on lagertype level as well as the summed amount of the different lagertypes underneath a VA_team combination. If this is done the forecasts on lagertype level are changed proportionally. Also the option to spread the forecast evenly over all 12 buckets is possible.

7. When this procedure is done, the database compresses all these forecasts to forecasts for planning-items with some priority (this result of this can be seen in the forecasts.dat file). How this compression is done will be illustrated with an example:

Suppose these are the forecasts given by Sales according to the above described logic for some month.

VA	Team	Lagertype	Forecast
VR 1	Team 1	LT1	1000 t
		LT2	2000 t
		LT3	3000 t
		LT4	4000 t
		LT5	5000 t
		LT6	7000 t

Suppose the following mapping of the lagertype to a planning-product applies.

Lagertype	Planning-product
LT1	Halbzeug
LT2	Stabstahl
LT3	Halbzeug
LT4	Stabstahl
LT5	Rohstrang
LT6	Rohstrang

This results then in the following forecasts for planning-items:

Planning-item	Forecast
VR1_Team1_Rohstrang	12000 t
VR1_Team1_Halbzeug	4000 t
VR1_Team1_Stabstahl	6000 t

The Demand Manager also creates the other .dat-files[8] as well.

[8] As is described in the i2 MP documentation.

8. The Master Planner calculates the Available to Promise allocations per planning-item.

9. At PW will be looked at the results of Master Planner. If some planning-items have too little allocated capacity (result of their forecast shorting), PW will look if it is possible to increase the available capacities for some resources in order to take away this shortage. PW can thus perform several what-if scenarios to see what the result of this modifying is on the ATPs. One has to realize that the result of consensus forecasting should drive the resource-calendars on FP-level. The decision to shut down or open up capacity is thus the result of this Master Planner. Therefore the end-result of this process should be somewhere recorded which forms the input later on the FP-level.

10. These ATPs are then written back to the Access database and disaggregated to lagertype-level. So one can see what the ATPs are for a particular lagertype underneath a VA_team per month for the entire horizon. Sales can also look at a more aggregated view of the ATPs: namely they can view how much ATP a certain VA_team got per month for the entire horizon. So on each level (on lagertype level or on VA_team level) in the tree Sales can review what the allocations are per month compared to the forecasts. Next the disaggregation logic will be described (given the same data as in the last example)

Suppose these are the calculated ATPs per planning-item at t=n which the Master Planner calculated:

Planning-item	Forecast	ATP
VR1_Team1_Rohstrang	12000 t	9000 t
VR1_Team1_Halbzeug	4000 t	3800 t
VR1_Team1_Stabstahl	6000 t	5400 t

The ATPs per lagertype are then calculated as follows (see last column):

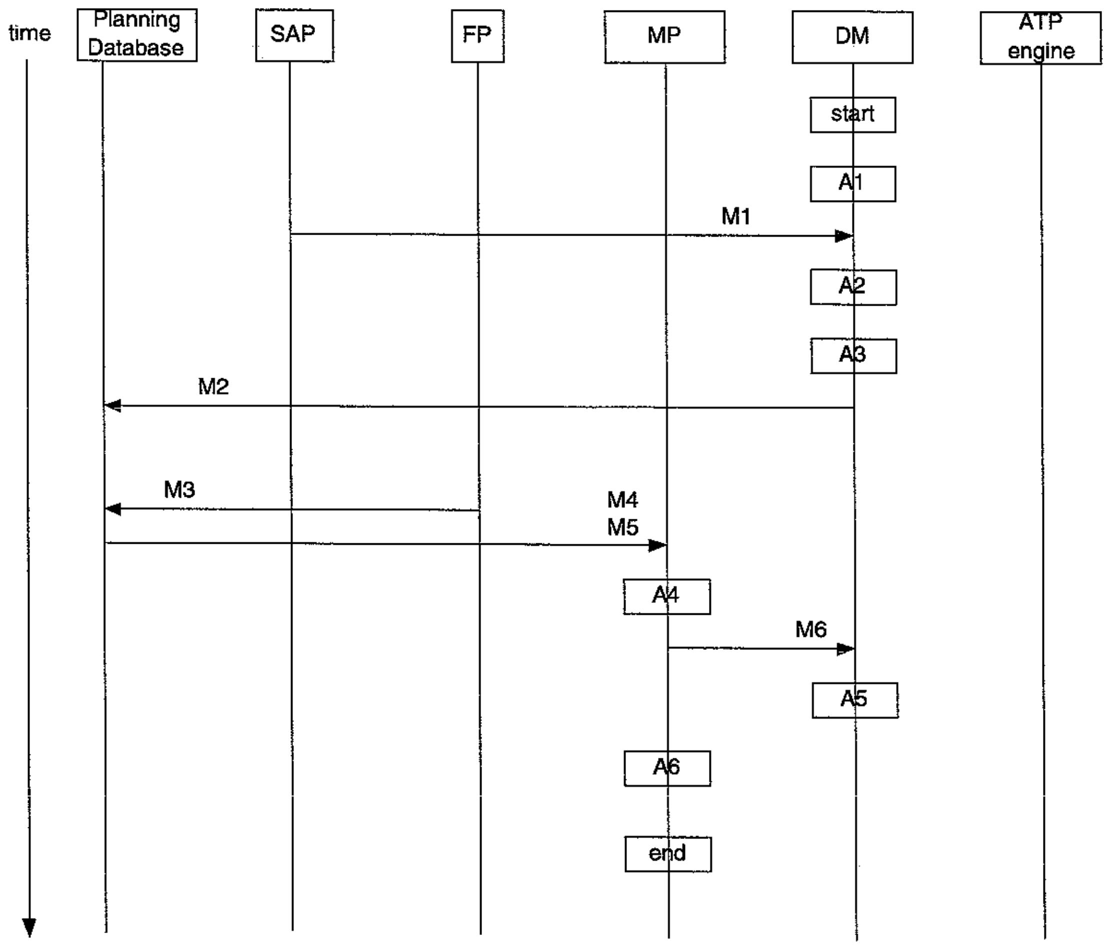
VA	Team	Lagertype	Forecast	ATP
VR 1	Team 1	LT1	1000 t	(1000/4000)*3800=950 t
		LT2	2000 t	(2000/6000)*5400=1800 t
		LT3	3000 t	(3000/4000)*3800=2850 t
		LT4	4000 t	(4000/6000)*5400=3600 t
		LT5	5000 t	(5000/12000)*9000=3750 t
		LT6	7000 t	(7000/12000)*9000 t =5250 t

11. Sales reviews these figures and if they are unsatisfactory they should revise the forecasts. This process of revising should be done in a structured meeting between PW and Sales.

Appendix 11: Activity and message diagrams and descriptions

Activity and message descriptions of process 1:

The following data and message diagram shows the most important activities and dataflows of the first process:

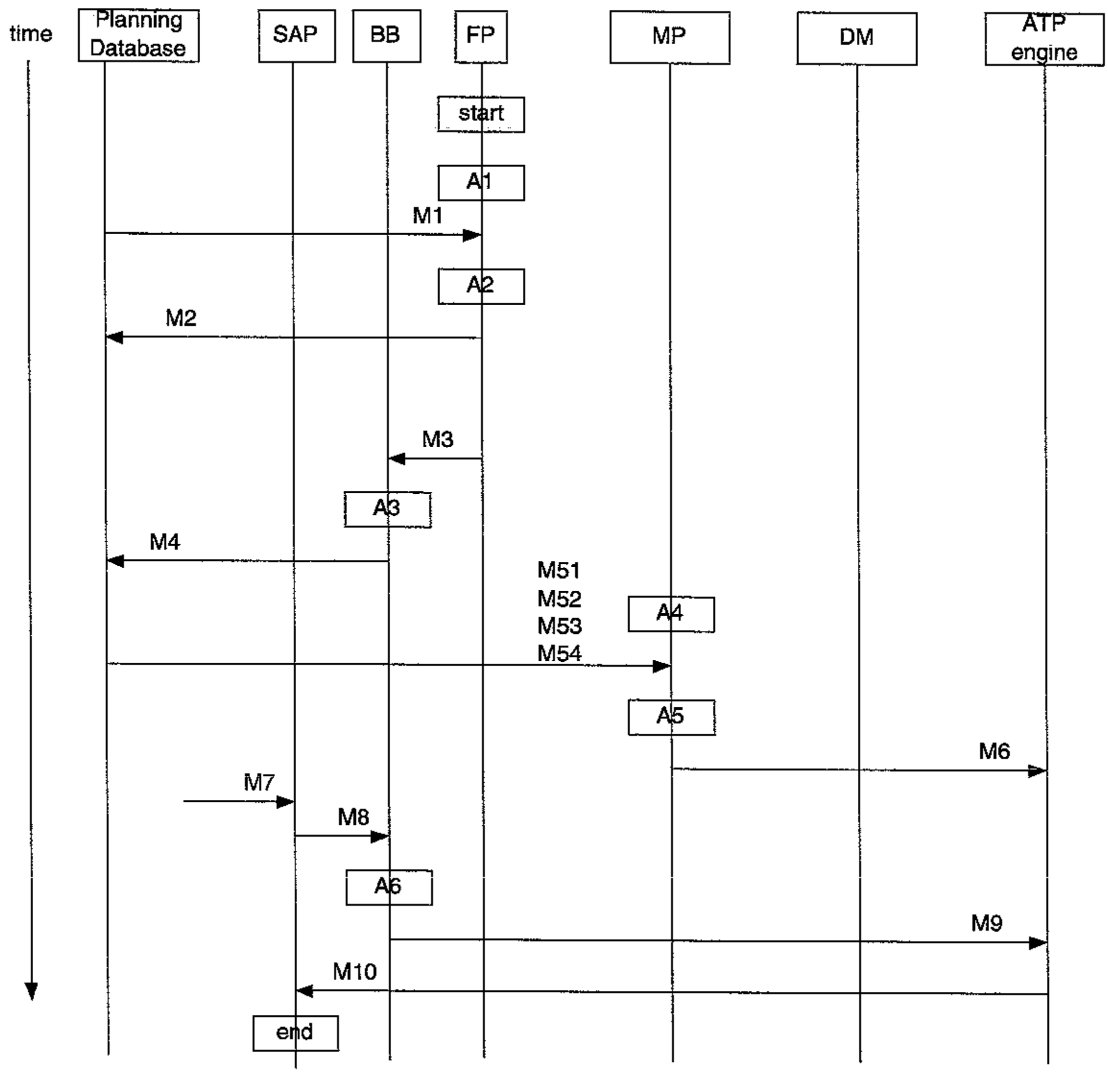


A1: Start-up of Demand Manager: the application user starts Demand Manager.
M1: Historical sales information is loaded into the Demand Manager from SAP and the table planning-product/lagertype is updated with information from SAP.
A2: Forecasting by Sales in DM
A3: Necessary .dat-files[9] are written by the DM (automatically done)
M2: These .dat-files are exported to planning database.
M3: The resource-calendars are exported to planning database.
M4: The .dat-files for the Rhythm Metals Master Planner are loaded.
M5: The resource-calendars are imported from planning-database to Metals Master Planner.
A4: Generation of allocations – the user of PW interacts with the Rhythm Metals Master Planner by modifying the resource calendars. This result has to be recorded somewhere because of the "driving capacities function" of this process. The view is here on PP level.
M6: Save allocations: this message saves out the allocations to the Demand Manager
A5: Demand Manager disaggregates these ATPs per planning-item to ATPs on lagertype level (automatically done by Access)
A6: Review by Sales and PW. Eventual revision of forecasts takes place in MP.

[9] As is described in the i2 MP documentation.

Activity and message descriptions of process 2 and 3:

The second data and message diagram shows the most important activities and dataflows of the second process:



A1: Startup of Rhythm Factory Planner: the application user starts the Rhythm Factory Planner.
M1: The actual orders that are accepted and for which promise dates have been given to the customers form the order-book and these are loaded to the Rhythm Factory Planner.
A2: The user creates a production plan using the Rhythm Factory Planner (including modifying the resource calendar)
M2: The resulting resource loadings of the Rhythm Factory Planner's Plan are saved out to form a base to initialize the Rhythm Metals Master Planner.
M3: The Rhythm Factory Planner's order-book is loaded into a black-box.
A3: Mapping of lagertypes in order-book to planning-items.
M4: The mapped order-book is put into the planning database
A4: Startup of Rhythm Metals Master Planner: the application user starts the Rhythm Master Planner.
M51: The .dat-files[10] for the Rhythm Metals Master Planner are loaded.
M52: The order-book in PIs, which is already planned in the Rhythm Factory Planner, is also fed into the Rhythm Master Planner. This piece of information is used to net the forecast.

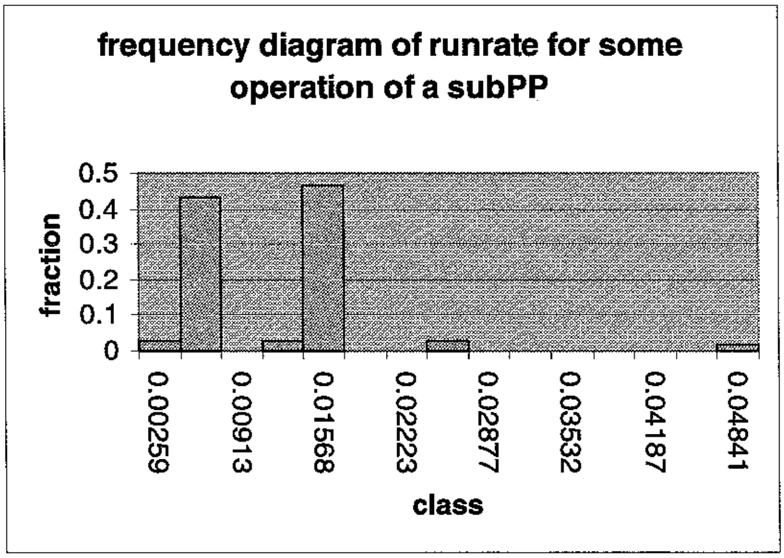
[10] As is described in the i2 MP documentation.

M53: The resource loadings as planned in Rhythm Factory Planner are passed to the Rhythm Metals Master Planner so that Rhythm Metals Master Planner can net the capacity to plan for the netted forecast.
M54: The resource-calendars are imported from the planning database.
A5: Generation of allocations
M6: Save allocations: this message saves out the allocations to the ATP-engine.
M7: An customer arrives and is entered into SAP.
A6: Mapping of this request to corresponding planning-item.
M8: This request for a planning-item goes to the ATP-engine
M9: This order is accepted and quoted based on ATP-engine's figures
M10: The decision taken by ATP-engine is written back to SAP

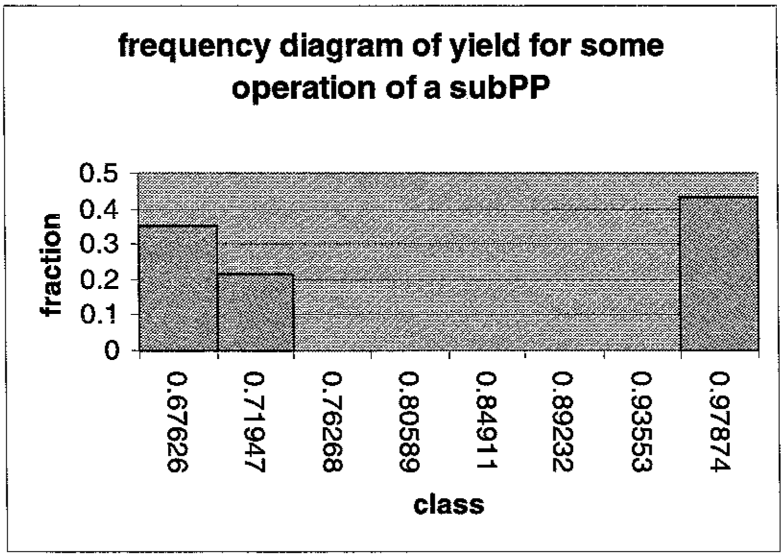
Appendix 12: Results of various analyses

This appendix will present some plots which support the arguments and reasonings made in chapter 6.

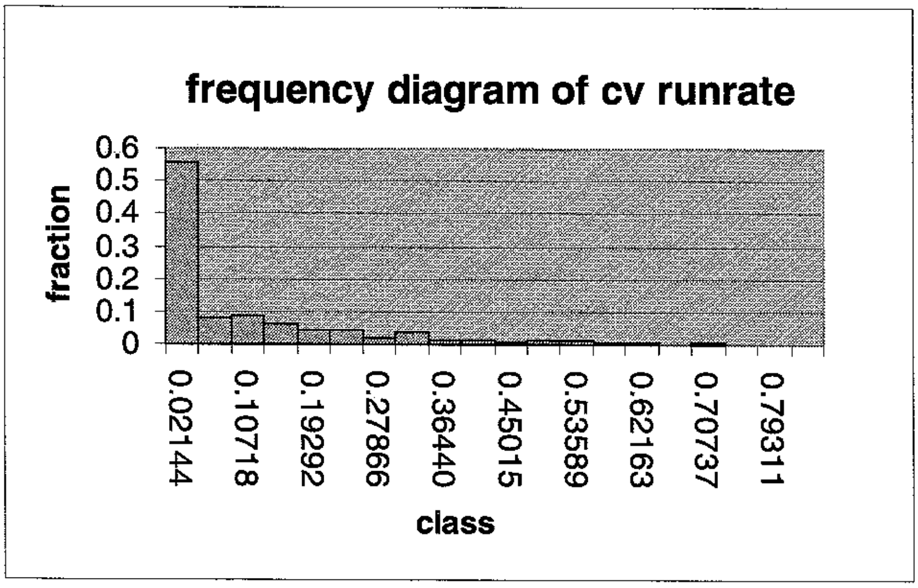
In this plot the variation of the run-rate can be seen. The vertical axis shows the fraction in which LTs fall into this run-rate-class This plot is made for one of the operations of a subPP which had a coefficient of variation of 0.56.



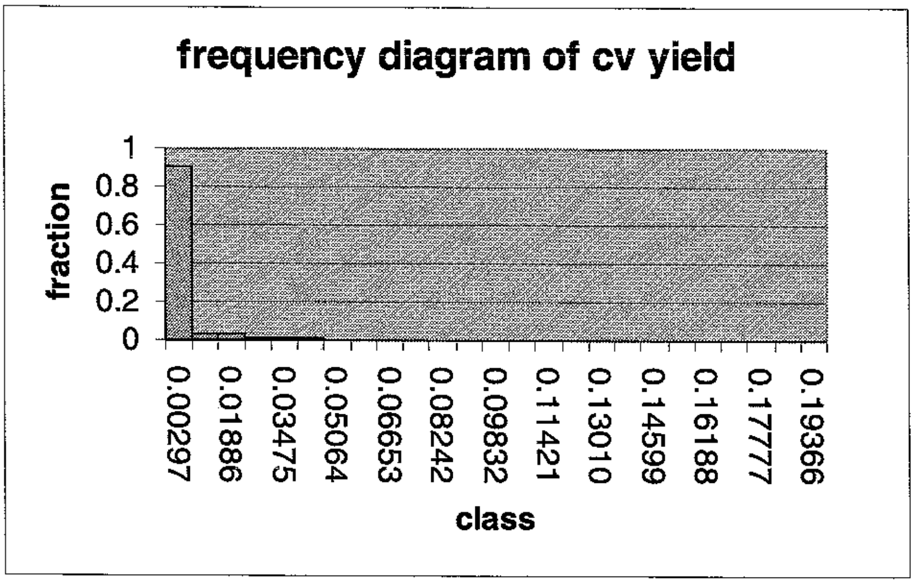
In this plot the variation of the yield can be seen. The vertical axis shows the frequency in which LTs fall into this yield-class. This plot is made for one of the operations of a subPP which had the highest coefficient of variation, namely 0.20.



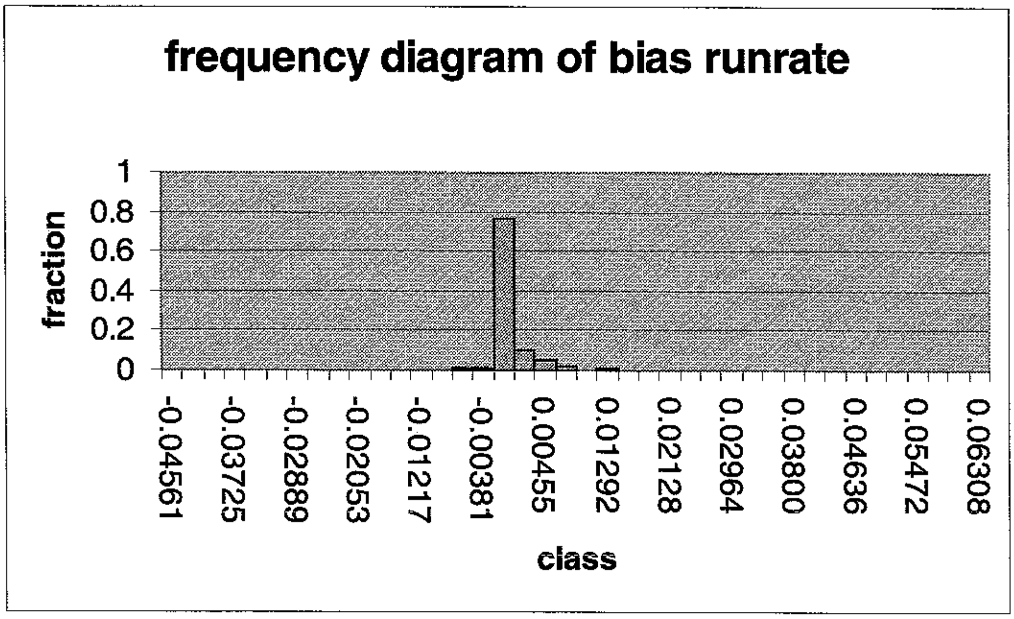
This plot shows the frequency diagram of the coefficient of variation for the run-rate. The population are the run-rates of all the modelled operations/resources in each PP (approximately 750). The values of the classes range from 0 to 0.85.



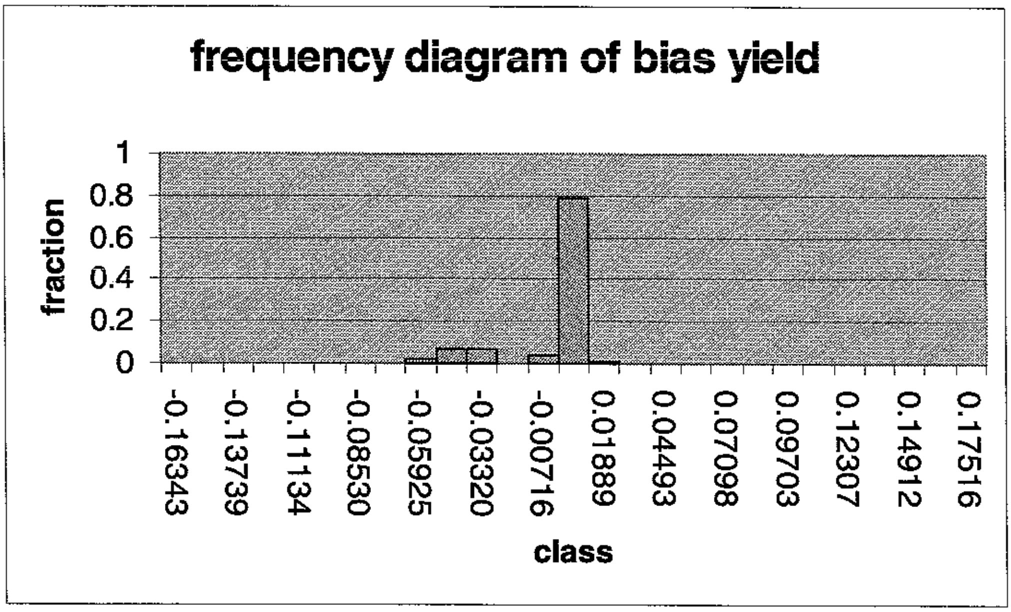
This plot shows the frequency diagram of the coefficient of variation for the yield. The population are the yields of all the modelled operations/resources in each PP (approximately 750). The values of the classes range from 0 to 0.2.



The next plot shows the bias for the run-rate for all the modelled operations/resources in each PP. This shows us that overall a positive bias exists, since more than 95% of operations has a bias greater than or equal to zero. The average bias is equal 0.000695 and the standard deviation is equal to 0.0049.



A plot like the one above can also be made for the yield. One sees here that most biases are negative (which means that in "old" situation too much capacity is consumed when planning the forecasts). However since yields can vary between 0 and 1 the effect of the bias in yield which has an average bias of -0.0065 (and standard deviation of 0.024) is negligible. This is logical when one looks at the frequency diagram of the coefficient of variation for the yield.



Appendix 13: Time-phased project

A/W	15	…	23	24	25	26	27	28	29	.	32	33	34	35	…	38	39	40	….	43
1.	■	■	■	■																
2.			X																	
3.					■	■	■													
4.							■	■												
5.								X												
6.								■	■											
7.									■	■	■									
8.											X									
9.												■	■	■						
10.														X						
11.														O						
12.														■	■	■				
13.																O				
14.																■	■			
15.																	X			
16.																		■	■	■
17.																				X

The list of activities is given below:

1. Description of production processes, products, organization and planning-processes at EWK
2. 1st Milestone: Presentation of findings activity 1 (7th of June)
3. Interview people about ideas on integration (EWK, I2, TUE, etc)
4. Study MP modelling and architecture various modules
5. 2nd Milestone: Formulation of findings and further steps (12th of July)
6. Analysis of the aggregation and disaggregation of items
7. Design MP/FP/ATP/DM workflow & dataflow
8. 3rd Milestone: presentation of findings activity 7 (7th of August)
9. Making of project and scope documentation about testing quality MP model
10. 4th Milestone: presentation of finding activity 9 (30th of August)
11. Forecast-test
12. Analysis 3 parameters
13. Forecast-test
14. Technical implementation
15. 5th Milestone: presentation of test-results and analyses (27th of September)
16. Finish up final report and preparing end-presentation
17. End presentation (31th of October)

List of abbreviations:

FP: Factory Planner
MP: Master Planner
CFP: Consensus Forecasting Process
DM: Demand Manager
LT: Lagertype
PP: Planning Product
PI: Planning Item
VA: Verkaufs-Abteilung
HLT: HauptLagerType
NLT: NebenLagerType
PW: Produktionswirtschaft
ATP: Available-To-Promise
PA: Plan-Auftrag
FA: Fertigungs-Auftrag
GUI: Graphical User Interface
VBA: Visual Basic for Applications
FIFO: First In First Out
TAB: Technische Auftrags Bearbeitung
FCP: Finite Capacity Planning
ICP: Infinite Capacity Planning
PST: Planned Start Time
PROSE: Database with information about unassigned material
FLS: Fertigungs Leit System
CAO: Constraint Anchored Optimization
(E)DV: (Elektronische) Data Verarbeitung
SAP: Enterprise resource planning system used at EWK
ESU: Elektro-Schlacke-Umschmelzofen
LBV: Lichtbogen-Vakuum- Ofen
MRW: A rolling resource from subcontractor Mannesman Röhrenwerke in Mülheim
B2: Block-brammen strasse in Brückhausen
BG: Block-/GrobstraBe in Witten
ELO: Elektro- Lichtbogenofen
ST: Stahl Werk
UST: Umschmelz Stahl Werk
PPS: Produktions Planungs System
BBW: Bearbeitungsbetrieb Witten
BBK: Bearbeitungsbetrieb Krefeld
SB-Kr: Schmiedebetrieb Krefeld
SB-Wi: Schmiedebetrieb Witten
Z1/Z2/Z3: Zurichtungsbetriebe 1,2 and 3 in Witten
WBK1 and WBK2: Wärmebehandlungsbetriebe 1 and 2 in Krefeld
SAD1 and SAD 2: Schmiedeadjustage 1 and 2 in Krefeld
Wä1 and Wä2: Wärmebehandlungsbetriebe 1 and 2 in Witten
RSH: Rost-, Säure- und Hitzebestandige Stähle
BS: Edelbaustähle (Engineering steels)
WS: Werkzeugstähle (Tool steels)
TST: Thyssen Krupp Stahl AG

Literature and references used:

[1] Meal H.C. (1984); *Putting production decisions where they belong*; Harvard Business Review, Vol.62, pp.102-111.
[2] Bertrand J.W.M., Wortmann J.C. & Wijngaard J. (1990); *Production Control: a structural and design oriented approach*; Elsevier, Amsterdam, The Netherlands.
[3] Schneeweiss Ch. (1999); *Hierarchies in distributed decision making*; Berlin, Springer.
[4] Intra-net site EWK
[5] Qualitäts-handbuch EWK
[6] Various prospectuses
[7] Kempen P.M. & Keizer J.A. (1996); *Werkboek Advieskunde: De stagepraktijk als uitdaging*; Wolters-Noordhoff, Groningen, The Netherlands.
[8] Montgomery D.C. & Runger G.C. (1994); *Applied statistics and probability for engineers*; John Wiley & Sons.
[9] van Dijk J. et al. (1995); *Onderzoeken en veranderen: Methoden van praktijk-onderzoek*; Stenfert Kroese, Leiden, The Netherlands.
[10] Raaymakers W.H.M (1999); *Order acceptance and capacity loading in batch process industries*; Ph.D. Thesis, Eindhoven University of Technology, The Netherlands.
[11] Bertrand J.W.M., Wortmann J.C. & Wijngaard J (1990); *Produktiebeheersing en material management*; Stenfert Kroese, Leiden, The Netherlands.
[12] *Rhythm Metals Master Planner Implementor Manual* (version 3.08C: April 1999)
[13] Various i2 documentation concerning EWK project