HELSINKI UNIVERSITY OF TECHNOLOGY

Department of Electrical and Communications Engineering

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PRODUCTION PLANNING METHODS IN PAPER AND STEEL INDUSTRIES

Thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Engineering.

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Supervisor: Professor Kari Koskinen

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TEKNILLINEN KORKEAKOULU **Diplomityön tiivistelmä**

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Tämän diplomityön tarkoituksena on ollut tutkia, kuinka paperiteollisuuden tuotannon suunnittelun menetelmät eroavat ja yhtenevät terästeollisuuden tuotannon suunnittelun kanssa. Tavoitteena on ollut tutustua tuotannon suunnitteluun ja sen ongelmiin ensin yleisellä tasolla, minkä jälkeen on keskitytty kuvaamaan tarkemmin tarkastelussa olevien teollisuudenalojen erityispiirteitä. Lopuksi on tehty prosessien vertailuja ja johtopäätöksiä niistä löydetyistä yhtäläisyyksistä.

Työssä on kuvattu sekä paperin että teräksen tuotantoprosessit ja materiaalivirrat. Karkealla tasolla tarkasteltuna prosessit ovat hyvinkin samantyyliset, koska kummassakin prosessissa juoksevassa muodossa olevista raaka-aineista valmistetaan ensin isompi yksikkö, joka paloitellaan pienemmiksi palasiksi asiakkaiden tilausten mukaan. Syvemmät prosessien tarkastelut tuovat kuitenkin esiin niiden ainutlaatuiset erityispiirteet, jotka vaikeuttavat tuotannon suunnittelua ja yhtäläisyyksien löytämistä.

Eräs työn alkuperäisistä tavoitteista oli tehdä abstraktiot molemmista prosesseista, minkä avulla niiden samankaltaisuudet tulisivat parhaiten esille. Työn edistyessä kävi kuitenkin ilmi, että syvempien abstraktioiden tekeminen ei ollut järkevää ja parempiin tuloksiin päästäisiin vertailemalla prosesseja rinnakkain ilman harhaanjohtavia yleistyksiä.

Paperikone on hyvin merkittävässä roolissa koko tuotannon ajoituksen ja suunnittelun kannalta. Paperiteollisuudessa suurin hävikki aiheutuu yleensä lajinvaihdoista ja trimmihukasta. Lajinvaihdoista aiheutuvan hukan minimoimiseksi eri paperilaatujen tuotanto-ohjelma suunnitellaan sykliseksi, jolloin paperin ominaisuudet muuttuvat vain vähän kerrallaan ja lajinvaihtohukka on pieni. Toinen tärkeä suunnittelun kohde on siis trimmitys. Sen tarkoituksena on suunnitella emorullan leikkauskohdat siten, että pystytään hyödyntämään käytettävissä oleva rullaleveys ja -pituus mahdollisimman tarkasti huomioiden samalla asiakkaiden vaatimukset.

Terästeollisuudesta ei ole löydettävissä paperiteollisuutta vastaavaa syklisyyttä. Siellä tärkein suunnittelukohde on sulaton ajoitus ja käytössä olevan konvertterikoon mahdollisimman tarkka hyödyntäminen. Paperiteollisuudesta tuttua lajinvaihto-ongelmaa ei itse teräksen teossa ole. Sen sijaan muut tuotannon yksikköprosessit vaativat tarkkaa suunnittelua juuri lajinvaihtojen osalta. Tuotteiden erilaiset paksuudet, leveydet ja lämpötilat ovat ongelmana terästuotannon jatkuvatoimisissa linjoissa, sillä peräkkäisten tuotteiden ominaisuudet eivät saisi poiketa toisistaan liian paljon. Koska teräksestä tehdään paperin tapaan määrämittaisia levyjä ja nauhoja, paperiteollisuuden kaltaiset trimmitys- ja leikkuuongelmat tulevat esille sielläkin. Teräksen teossa leikkuuongelma ei kuitenkaan ole yhtä merkittävä kuin paperin teossa, sillä lopputuotteiden mitat voidaan huomioida jo aihiokokoa suunniteltaessa.

Paperiteollisuuden tuotannon suunnittelu on paljon pidemmälle vietyä ja kokonaisvaltaisempaa kuin terästeollisuudessa. Tähän vaikuttaa prosessien erilainen luonne ja paperin lyhyempi valmistusaika. Teräksen teossa on myös paljon enemmän erillisiä tuotantovaiheita kuin paperin valmistuksessa.

Avainsanat: terästeollisuus, paperiteollisuus, tuotannon suunnittelu, tuotannon ohjaus, tuotannon ajoitus

HELSINKI UNIVERSITY OF TECHNOLOGY **Abstract of the Master's Thesis**

Author: Janne Valkonen

Name of the Thesis: Production planning methods in paper and steel industries

Date: 5.10.2001 **Number of pages:** 80

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Professorship: AS – 116 Information Technology in Production

Supervisor: Prof. Kari Koskinen

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The goal of this master's thesis has been to explore what the paper industry and the steel industry production planning have in common. The aim has been to become familiar first with the methods and principles of production planning and scheduling in general. After that the focus has been set on describing the characteristics of the industries concerned. At the end, there are some comparisons between the processes, which make a basis for conclusions.

This thesis introduces the production phases and material flows of the paper and steel making processes. On a superficial level, the processes look very similar. This is because in both of them the running flow of raw materials transforms into large solid units that must be broken down into smaller pieces according to customer specifications. However, deeper inspections show their differences and unique special characteristics, which make production planning more difficult.

One of the initial goals of the thesis was to make abstractions of the processes, which could help to compare them and to find the similarities between them more easily. As the work advanced, it became obvious that there was no sense making deep abstractions. Better results could be achieved by comparing the processes without misleading and confusing abstractions.

The paper machine has a very remarkable role when considering production planning and scheduling. The biggest sources of waste are usually the grade changes and trimming losses. In order to minimize the grade change loss, the production schedule is cyclical. It means that the properties of paper are changed gradually and it is decided in advance what types of paper are produced. Another important factor to be planned is trimming. Its aim is to plan the cutting patterns and schedules in a way that utilizes the tambour width and length as efficiently as possible. Still the customer specifications and possible restrictions have to be taken into account.

The steel production process is not cyclical as the paper process is. The most important things to be planned are the smelting plant and the efficient utilization of the converter. The steel industry does not have the same kind of grade change problem as the paper industry has. Instead, the separate unit processes of steel making require strict planning. The unit processes have many rules and restrictions concerning the dimensions, temperatures, and types of the adjacent products to be treated. Because the end products in a steel plant are coils, strips, and sheets of customer specified dimensions, the trimming problem also exists in the steel industry. However, the trimming problem is not as significant as in the paper industry because the dimensions of the end products can be taken into account already when choosing the suitable slab sizes.

Production planning in the paper industry is much more sophisticated than in the steel industry. The reason for this is the different appearance and characteristics of the processes. Also the differences in lead times and the number of production phases are remarkable factors.

Keywords: steel industry, paper industry, production planning, production control, production scheduling

PREFACE

Before I started to study in Helsinki University of Technology, I thought I already knew quite a lot of things. During my studies, I realized that there were many things I had to learn before I would be ready to graduate. Now, just before graduating, my eyes are totally opened: Throughout the ages, man has been researching and investigating the problems of technology and science. Many of them have been solved but there are still a lot of things to be researched. Whilst the development advances, solved problems are regenerating new ones and the cycle goes on. This is the law of continuous development.

I want to thank the supervisor of this thesis, Professor Kari Koskinen, for his interest and constructive comments concerning my work. I also want to thank the supervisor of this thesis, Simo Säynevirta M.Sc. (ABB Industry Oy), for his valuable ideas that helped me to progress with the thesis.

Kari Keskinen, Petteri Kiiskinen, Jaakko Koistinen, and Pasi Rajala from Rautaruukki Steel helped me a lot when studying the characteristics of the steel industry. Thank you very much for that.

Finally, I want to thank my whole family for all the support they have given me during this project and my studies. Special thanks also to Janna. Suuret kiitokset! Ilman teitä tämä olisi ollut paljon vaikeampaa.

Espoo 5.10.2001

Janne Valkonen

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1.1 Initial Situation

When talking about the paper industry, the world is getting smaller all the time because the global competition is getting harder and harder. Customers have more possibilities to choose and in order to be at the top of the competition, one must be very flexible and capable to adapt different situations quickly and efficiently. This means that paper mills have had to change over from the standard papers to more customer-specified grades. Also the reel and sheet sizes are nowadays customer specified.

At the same time customers require more, the business management's profitability requirements are also getting higher. Waste and total cost have to be minimized and profit maximized. Production has to be efficient and pro-environmental. One key to solve these problems and meet the requirements is to optimize the use of the machine capacity and minimize the capital investment in the finished stock while ensuring on-time delivery to customers.

When we start considering these problems in a larger scale, we discover that the same problems and trends appear also in some other branches of industry, e.g. in the steel industry. Roughly speaking, the steel manufacturing process is like the paper manufacturing process: In the beginning of both processes, there are raw materials that are processed through complicated machinery as a running flow. However, at the end of the process you have distinct units - reels, sheets, disks, plates, or coils - that have to be processed and handled separately. When converting this running flow of material into the distinctly considered units there is done some cutting, slitting, and trimming, which always cause some waste. Thus, the possible causes of waste and loss are the same in both processes.

1.2 Aims of This Master's Thesis

The first goal of this master's thesis is to get acquainted with the basic principles of the paper and steel manufacturing processes. The purpose is not to study both processes in detail but to give a general overview about them. Only the particularly important details or the ones that have an effect on production planning are described. In general, it is hard to learn how some procedures are planned if you do not know, at least at some level, how they actually work.

The second goal is to familiarize with generally acknowledged production planning and control methods and objectives. It is important to know what are the main targets that production planning focuses on and what kind of parameters there are to be optimized. When those basic principles are known, the focus is set on a more detailed level.

When the general operations management principles suiting to almost all branches of industry are introduced, the focus is on the production planning and scheduling in the paper and steel industries.

One of the most important things is to try to find a suitable abstraction level and depict the processes within it. It means that with a generalized pattern, it may be easier to see if there is something common between the processes. From that abstraction one should see the synergies and differences between the processes, if possible.

At the end of the project there should be a clear concept of the synergies and differences between the steel and paper processes. With that information it should be quite easy to make clear decisions if it is possible to adapt existing paper industry software to the steel industry.

1.3 Structure of Thesis

The theoretical part of this thesis first introduces roughly the paper and steel manufacturing processes. Some of the phases and actions are described more carefully than others but the central idea is to give a general knowledge to the reader about those two processes at hand. After introducing the processes, there is a rough abstraction of them so that the reader understands how close these two industries really are to each other. Still, it is good to remember that we are looking at them on a quite superficial level and there is a lot more to come.

After roughly made abstractions, there are descriptions about paper and steel after-treatment processes. The term “after-treatment” includes here all the steps that are performed to paper tambours and steel slabs before they are customer-specified products ready for delivery. These after-treatment processes are described quite detailed because they are very important from the whole thesis’ point of view.

When the production chains of both industries are clear to the reader, the focus is set on production planning that is explained in a very detailed level. Objectives, benefits, restrictions, and reasons for actions in production planning are defined for both industries.

After the production planning chapter the similarities and differences between the processes and their planning principles are compared. Then there is a short description about scheduling systems in general and some characteristics about paper industry production planning software.

Finally, there are some conclusions and the last few pages contain the list of references.

1.4 Methodology

The methods and techniques of doing this thesis have been mostly literature studies and interviews of experts. The basics of production planning and scheduling have been studied from literature. Similarly the characteristics of the paper and steel making processes have been studied from literature as well as from practical cases. The production planning part is the largest section of this thesis. Most of the information has been gathered from several interviews and discussions with skilled peopled. The conclusions are based on the growing expertise of the author of this thesis.

2 Paper and Steel Manufacturing

This chapter describes how paper and steel are produced from their raw materials. There are short explanations about the processes and their main phases but deeper inspections are left to the reader because the scope of this thesis does concern production planning and scheduling, not production processes.

The process descriptions given here are meant to be as introductions to the paper and steel production planning. In order to understand how production is planned and why some things are as they are, it is important to know something about the processes themselves. The view this chapter gives is quite simplified but still deep enough to clarify how the paper and steel production processes function.

Knowing the basic principles of production gives a good and solid ground to understanding how paper machine reels and steel slabs are converted into smaller units and how the production is made as smooth and uninterrupted as possible.

2.1 Paper Process Description

The main material for papermaking is pulp that is produced in a separate process to paper making. Pulp making itself is already a quite complicated process because there are many different pulp grades and qualities that affect the paper grades and qualities. As explained earlier, pulp production is not described here but there is a lot of literature concerning it.

The paper manufacturing process can be divided into five main steps that are illustrated in Figure 2.1.

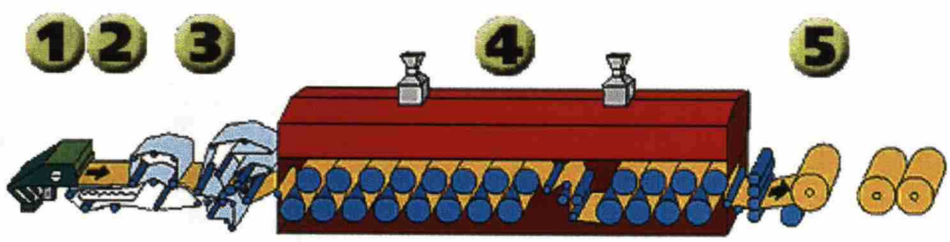

Figure 2.1 Steps of paper manufacturing process [Metsäteollisuus 2001].

1. Head box. The pulp compound is led into the head box where it is watered down until the mixture contains ca. 99% water. The function of the head box is to distribute the pulp smoothly onto the wire.

2. Wire. A wire is a dense net made of fabric or plastic. The paper line is formed over the wire when extra water flows through it.

3. Press. In the press the expulsion of water continues and the pulp mixture becomes smooth paper line. After this step, the paper contains ca. 55% water.

4. Dryer. Evaporation of water continues until the humidity is about 5%. Drying can also affect properties of the paper like smoothness.

5. After-treatment. The after-treatment process can improve the printing and surface properties of the paper. After that the paper is cut and packed.

Those are the main parts of the process. They include a lot of automatic control engineering and have many possibilities to contribute to the properties of paper grades.

An important thing to notice is that a continuous flow of pulp and some chemicals becomes a distinct unit, machine reel, during the process. Later those reels are cut and slit into smaller units according to customer requirements.

2.2 Steel Process Description

Crude iron for steel is like pulp for paper. Iron is produced separately in its own process and it is the main raw material in steel production. Crude iron is made from iron concentrate, limestone and coke by dumping them into the top of a blast furnace where they become liquid iron.

The production flow of a steel production process is illustrated in Figure 2.2 below.

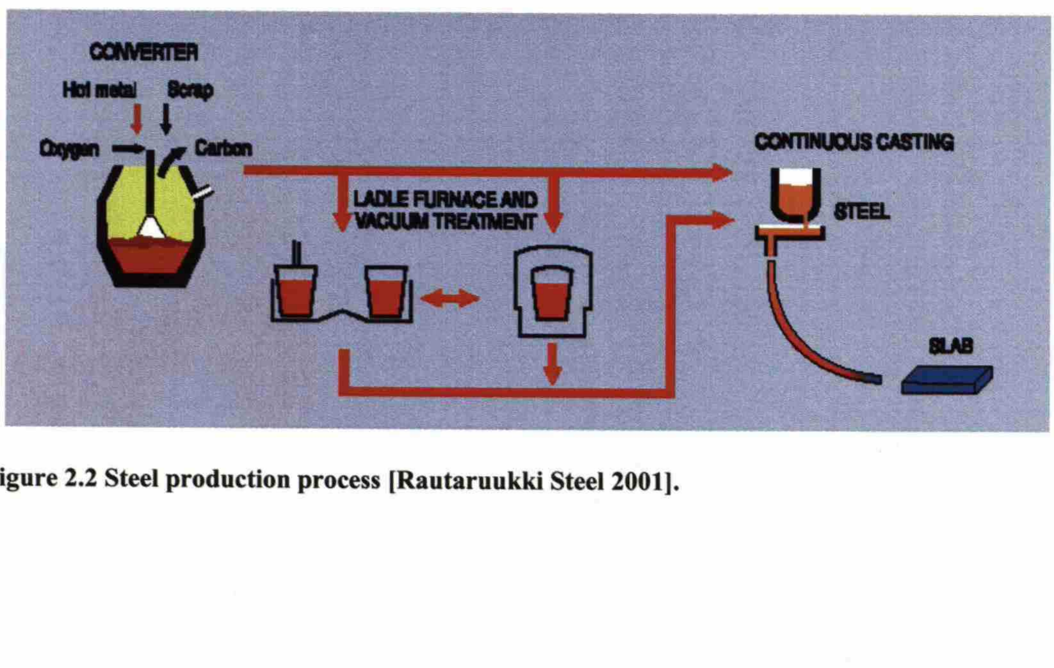

Figure 2.2 Steel production process [Rautaruukki Steel 2001].

The iron tapped from the blast furnace is taken in ladles to the steel plant via the desulphurization plant. The carbon content of liquid iron is many times that of steel. Hot metal is processed to steel in converters where the excess carbon contained in hot metal is removed by oxygen blowing. After converter process the alloying materials required are added to steel and the required ladle treatments and composition adjustments are carried out. The surface of the strand solidifies in the mould. Steel is poured into the mould in a continuous stream and the solidifying strand is drawn from the mould at a predetermined speed [Rautaruukki Steel 2001].

As the figure above shows, steel can be recycled by dumping scrap metal into the converter along with iron concentrate. Molten steel can also be produced from scrap in an electric arc furnace. However, whatever the production method, the molten steel is cast into slabs, blooms, and billets of desired dimensions.

The process has a direct relation to the paper production process. A continuous flow of materials becomes a distinct unit during the process. Later those units like slabs, blooms, and billets are after-treated, cut, and slit into smaller units according to customer requirements.

3 Abstraction of Paper and Steel Manufacturing Processes

3.1 Introduction

In the processing industry in general, the raw materials are processed through complicated machinery as a running flow. Production is continuous, batch sizes are quite big, and plant shutdowns are costly and time-consuming.

In many cases the type of the industry changes from processing industry to manufacturing industry while the process goes towards the end. That is what happens especially in the paper industry and steel industry as well. In other words, in the beginning you have a running flow of materials and at the end you have distinct units like reels, sheets, disks, plates, and coils that have to be processed and handled separately [Koskinen 2000].

This chapter gives some general information about the paper and steel manufacturing processes and especially about their material flows. It makes an abstraction of them on a superficial level and goes then to a bit deeper and more detailed level. The abstraction is performed in two stages.

3.2 Abstraction of Material Flows of Processes

The manufacturing processes of paper and steel are divided to five sequential material flows, which are illustrated in Figure 3.1. As can be seen, the figure is a general abstraction of both processes. Every part is essential for the process and all of them should be in balance with each other. If one of the parts does not work well, others will suffer from it and the whole mill's performance is not optimized. Reasons for this are explained in later sections.

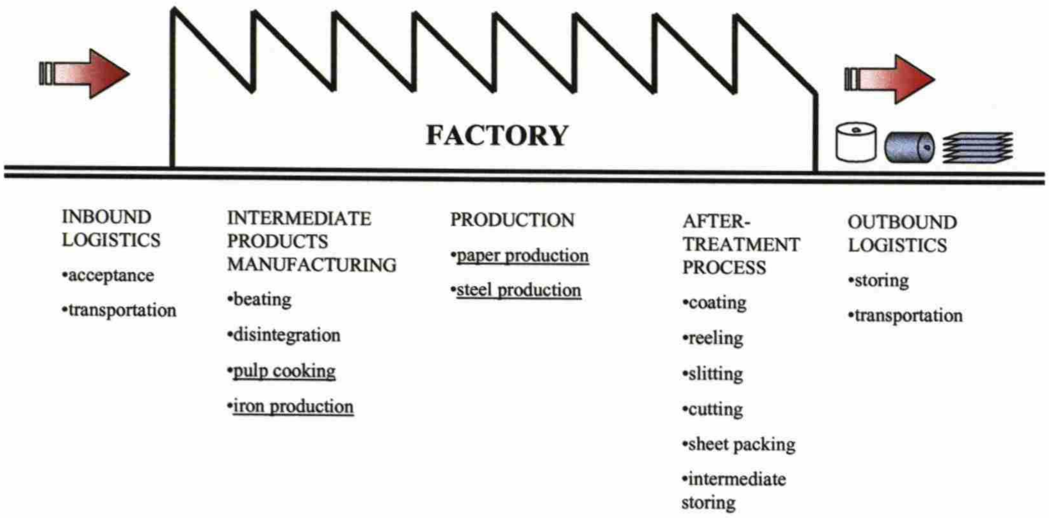

Figure 3.1 Material flows of production process [Pöyhönen 1997, modified].

The first part of the flow is inbound logistics. It takes care of transportation, inspection, and acceptance of raw materials. It is quite similar in all branches of industry. The second part is called intermediate products manufacturing, which includes pulp production in the paper industry and iron production in the steel industry. Pulp and iron can be considered as raw materials of paper and steel that are the end products of the processes concerned.

In the third part, pulp is processed into paper in a paper machine, which includes many complicated parts and sub-processes. The paper machine produces machine reels, which can weigh tens of tons and be wider than ten meters. Similarly, iron is processed into steel through various elaborate processes. The result after continuous casting is called slabs, blooms, or billets that are quite large and heavy pieces of steel with different shapes and dimensions.

The fourth part of the process is called after-treatment process. It means that large articles, like reels and slabs are converted into smaller products according to customer specifications. Chapter 4 goes into more detailed levels with after-treating and converting.

The last phase is outbound logistics. Like inbound logistics, it is not important in the scope of this thesis. It is enough to know that it includes final inspection, storing, and transportation of products.

As illustrated before, the material flows of these two industries are quite similar. Structures of the production chains have many common aspects that are investigated in later sections. In this thesis, the main focus is on the production part and especially in the after-treatment part. Those are the most critical contributors for successful and effective production planning and scheduling.

3.3 Abstraction of Processes on Superficial level

Now, when we know what are the basic material flows of production in the paper and steel industries, we can go into a bit more detailed level and develop a closer connection between them. However, the main focus is still on the general issues, not on details.

In Figure 3.1 the middle row contains common terms for the process phases that can be found from both industries. At the top and bottom lines are the corresponding phases of the paper and steel manufacturing processes respectively.

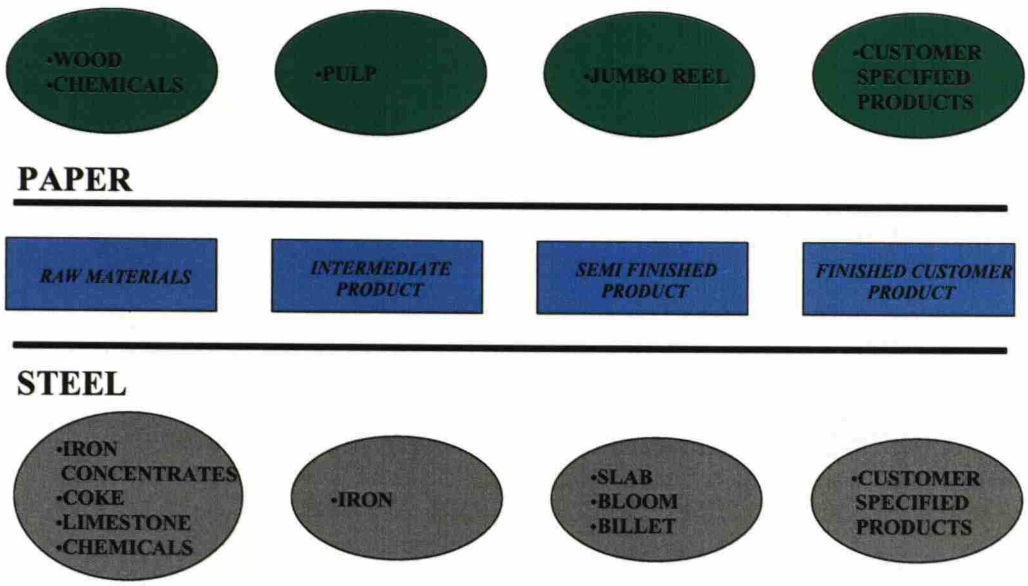

Figure 3.2 Abstraction of paper and steel manufacturing processes.

The raw materials required for pulp production are wood and various chemicals. Iron is made from iron concentrates, coke, limestone, and chemicals. In that level, we can say that the raw materials are of quite similar type. Also pulp and iron correspond quite well each other because they are considered as intermediate products before we get to the semi-finished products. Pulp and iron are produced in their distinct processes, which are not always directly connected to the rest of the process.

In a paper mill, the pulp compound is led through a paper machine where it becomes paper that is rolled around a large tambour. Similarly, in a steel works the iron is lead through desulphurization, converter, and casting processes before it becomes slabs, blooms, or billets. It is remarkable that in both industries the running flow of raw materials transforms into large solid units that must be again broken down into smaller pieces.

A machine reel of paper must be slit into smaller rolls or sheets. Also some other actions like coating or calendering can be performed before the paper is ready for delivery. In a steel works, the slabs are cut and rolled until the desired plates, strips, or bars are in customer-specified dimensions. Typically steel is also led through annealing or galvanizing line before it is ready for storing and delivery. Sometimes it is painted or laminated also.

In a more general frame of reference, we can say that pulp corresponds to iron and machine reels correspond to steel slabs. That is a quite fundamental piece of information when looking at the processes at this level.

4 Paper and Steel After-Treatment Processes

4.1 Converting Jumbo Reels into Customer Specified Products

As described earlier, the paper machine dry end produces reels, which have to be converted into smaller rolls before packing and delivery. If necessary, the reel can be coated and calendered before winding. Coating means that the surface of the paper is covered with one or more coating layers. Calendering means polishing, sealing, stretching, or smoothing the surface of the paper in a super calender.

Before or after coating and calendering, rolls can be re-reeled, if necessary. A re-reeler is used to repair possible holes or other defects in the paper. Also if the paper is reeled unevenly around the barrel, it can be fixed by a re-reeler. Re-reeler can also be used to remove low quality sections from a reel. When required after-treatment processes are finished, reels are eventually wound and cut into rolls at the winder. Figure 4.1 shows some possible production routes starting from a paper machine dry end and ending to a winder.

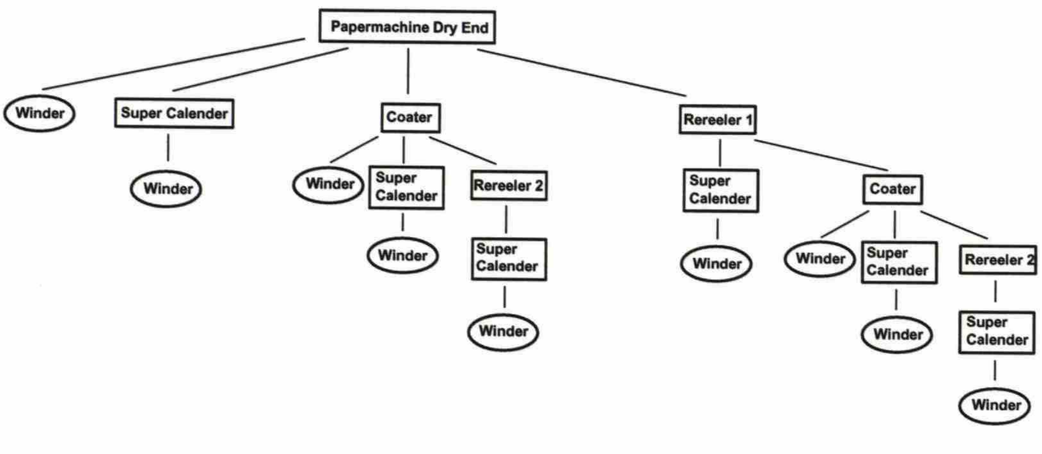

Figure 4.1 Paper after-treatment process from paper machine dry end to winder [ABB 2001].

Sometimes there are technical restrictions in the winder setup and rolls have to be rewound in a rewinder. After that rolls are sent to the wrapper where they are packed and moved to the warehouse waiting for delivery. In some mills the rolls are cut into sheets at the sheet cutter. The sheets can be packed as such on pallets or they may go through the sorter, ream cutter, and the ream wrapper as indicated in Figure 4.2.

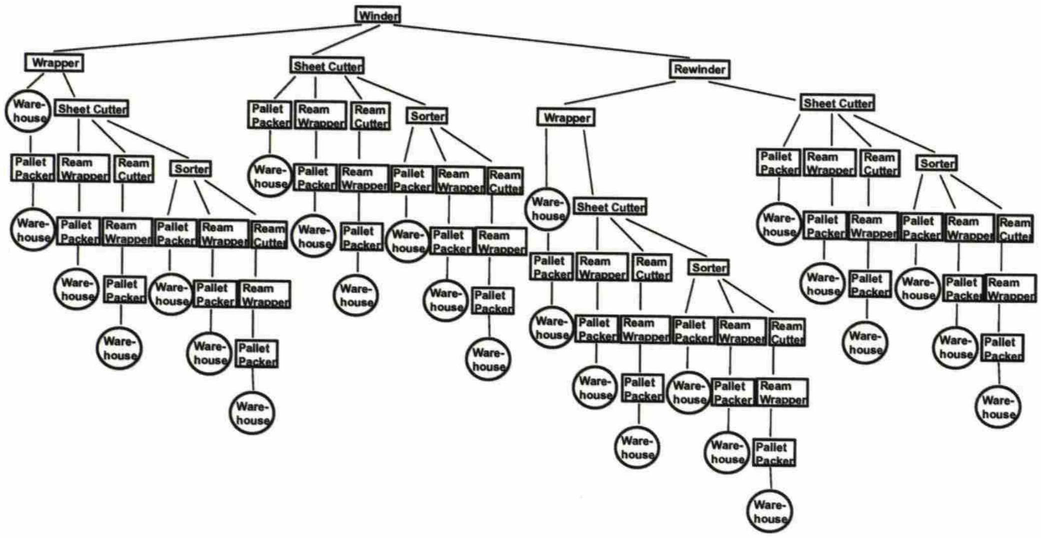

Figure 4.2 Process routes of paper after-treatment process from winder to warehouse [ABB 2001].

In order to get a bit more illustrative image of the after-treatment process in the paper industry, see Figure 4.3 that describes product flows starting from the paper machine dry end and ending to the warehouse, delivery, or repulping.

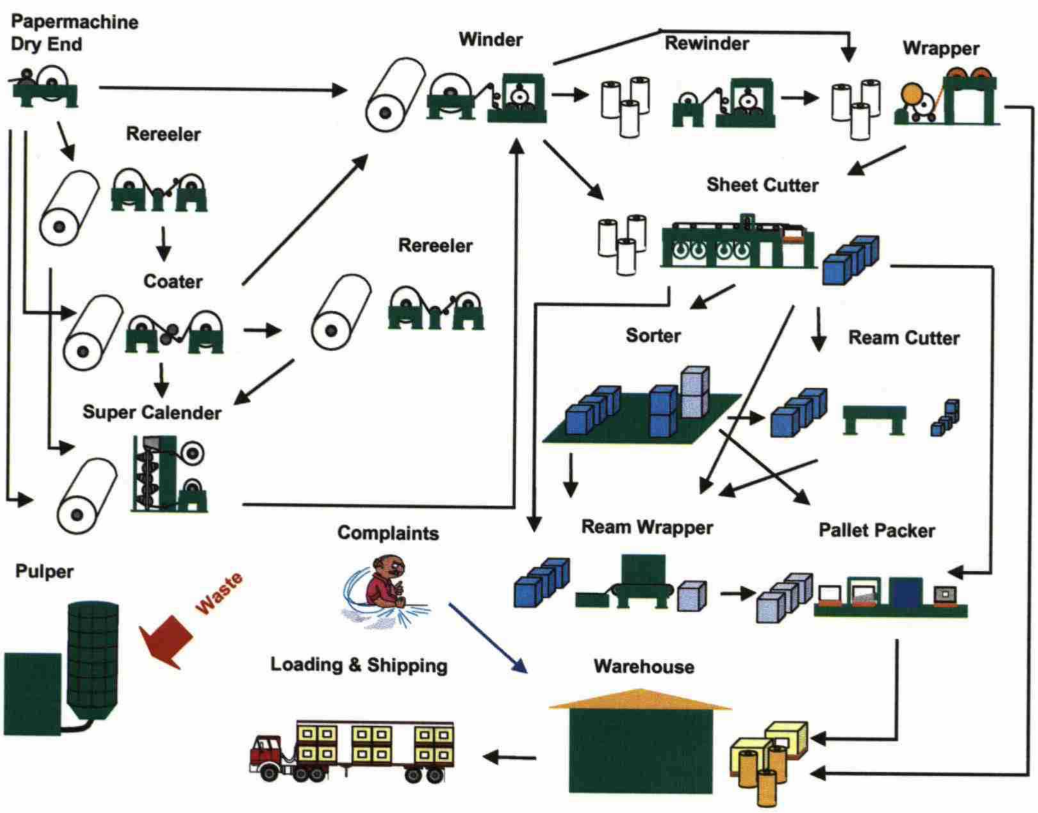

Figure 4.3 The product flows in a paper mill [Kostiainen 2001].

4.2 Converting Steel into Customer Specified Products

In general, steel products can be divided into three categories that are hot-rolled flat products, cold-rolled products, and hot-rolled long products. As described earlier in Section 2.2, the semi-finished products that come from continuous casting can be either slabs that have a rectangular cross-section, or blooms, or billets, which have a square cross-section. These semi-finished products are transformed, or "rolled" into finished products. Some of these undergo a heat treatment known as "hot rolling". Some of the hot-rolled sheets are subsequently rolled again at ambient temperatures. The procedure is known as "cold rolling". Figure 4.4 clarifies the idea how semi-finished products are related to finished products. The following sections describe a bit more specifically how plate products and strip products are finally produced from slabs. Converting blooms and billets is left outside the scope of this thesis.

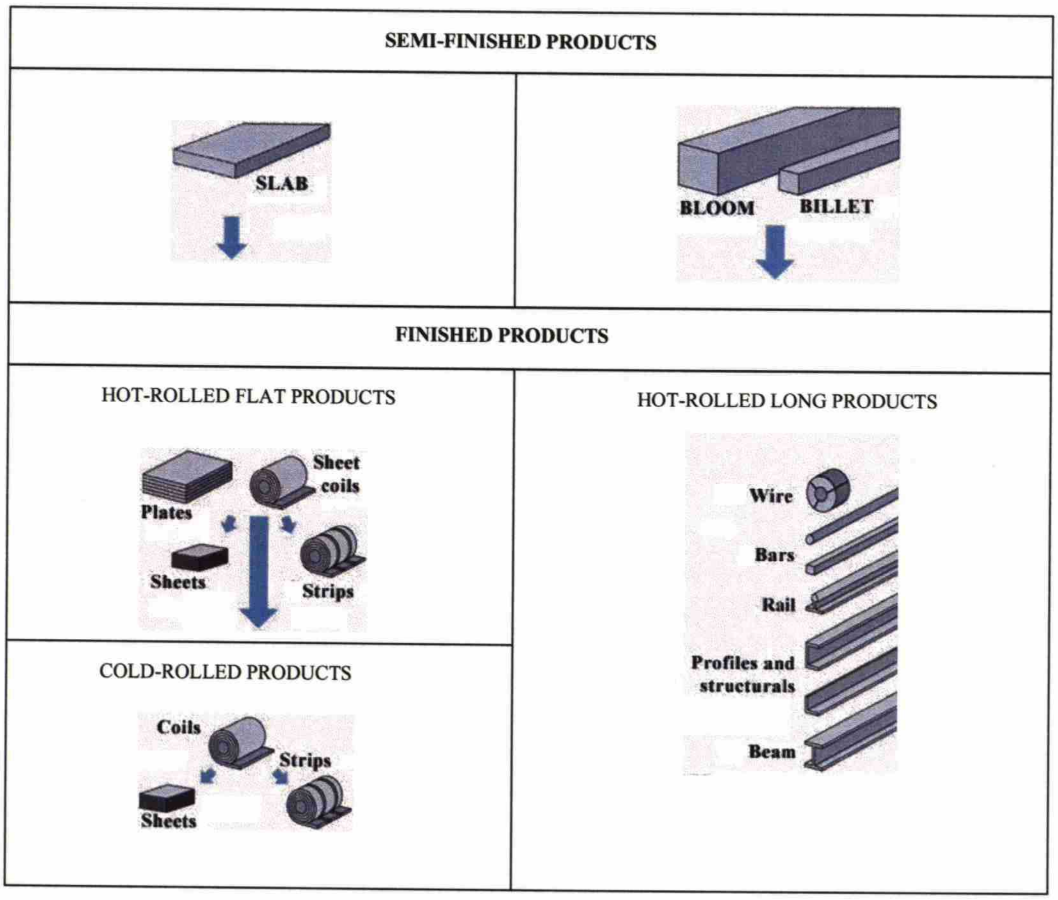

Figure 4.4 Steel products [World Steel 2001, modified].

4.2.1 Steel terminology 1

Like all industries, also steel industry has its own terminology [IBM 1999]. Here are some general steel industry terms that may be beneficial when studying the following sections. More terminology is introduced later when the production planning is considered in detail.

Charge, heat; a batch of molten steel with a single grade; a charge contains usually 100 to 300 tons depending on the converter size

Continuous casting; a process in which molten steel is poured into a tundish whose width can be adjusted, the molten steel takes on a solid form after which the slab is cut to the required dimensions

Grade; a particular chemical composition for steel; grade is related to physical properties such as hardness; grade is affected by the primary and secondary refining process; grade may be changed by the introduction of alloys

Mother slab; a slab that will be cut into smaller pieces to satisfy orders

Slab; the primary product of continuous casting; slabs are usually rectangular (though sometimes trapezoidal, i.e. a **tapered** slab), usually on the order of 200-250 mm thick, 5000 to 12000 mm long, and 300 to 1500 mm wide; slabs are made into a variety of other products including hot and cold rolled sheets and coils, pipes, and plates

Stock slab; a slab that is not associated with an order either because it was cast to satisfy a casting constraint or it did not meet the quality requirement for the order for which it was intended;

Tundish; a funnel that provides a constant flow of molten steel to a continuous caster

4.2.2 Plate Products

Hot-rolled plates, plate components, rolled and welded profiles are used in shipbuilding as well as both offshore construction and engineering, and steel construction.

Plate products are manufactured in a plate mill. Depending on the grade of the steel produced by the caster, the slabs are first reheated in re-heating furnaces. After descaling, rolling begins with a sizing pass during which any possible slab thickness variation is eliminated.

Next, the slab is rolled broadside to the specified plate width. Then the slab is turned and rolled longitudinally down to the target thickness. Scale is removed during rolling by means of high-pressure water sprays. During rolling, the roll-gap adjustment is based on the computer rolling model and online mill measurements.

The properties of the steel are affected by the finishing temperature, cooling rate and heat treatments. Steel grades requiring normalization are heat-treated after rolling in normalizing furnaces. Rolled plates are cut to the specified dimensions by mechanical or flame cutting, depending on the plate thickness.

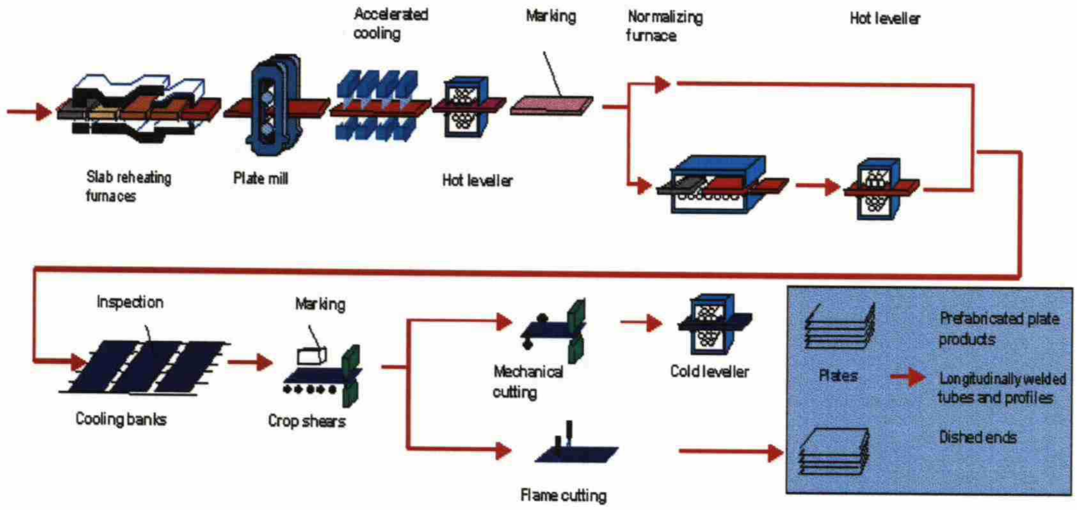

Figure 4.5 Plate production flow chart [Rautaruukki Steel 2001].

4.2.3 Hot-Rolled Strip Products

Hot-rolled, cold-rolled and coated steel sheets are used in the construction industry, in home and professional electronics, certain transportation components, and infrastructure construction.

Slabs for strip rolling are heated to rolling temperature in walking beam or pusher-type re-heating furnaces. After descaling, the slabs are rolled in the roughing mill into transfer bars. The width of the transfer bar is adjusted in the vertical edger. The temperature of the steels requiring thermo mechanical rolling is also adjusted during rolling in the roughing mill.

The transfer bars are then rolled down to a strip in the computer controlled finishing mill. The transverse thickness profile of the strip is maintained by controlling the shape and axial displacement of the work rolls. The control system of the strip rolling is based on mathematical models. It provides data on the various rolling stages and controls the rolling process.

From the last rolling stand the strip continues to the cooling zone. After cooling, the strip is coiled the maximum weight of a coil being 20 - 30 tons. If required, the strip can be skin pass rolled at ambient temperature to improve its mechanical properties. The production flow of strip products is illustrated in Figure 4.6.

Finally, the strip is cut or in the cutting line or in the slitting line. Hot-rolled strip products can also be delivered as pickled. Pickling process is explained with cold-rolled products.

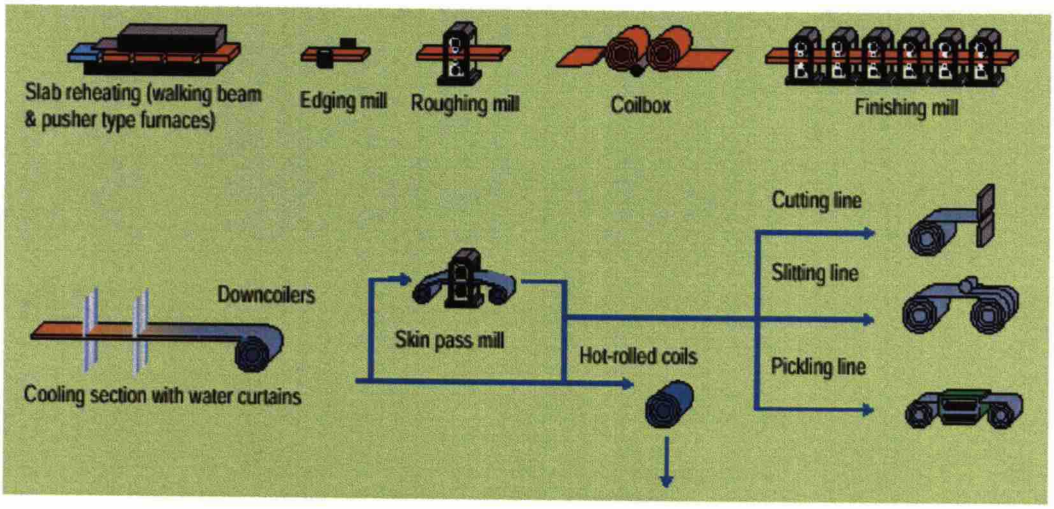

Figure 4.6 Hot-rolled strip production flow-chart [Rautaruukki Steel 2001].

4.2.4 Cold-Rolled Strip Products

Some of the hot-rolled coils are taken to the pickling line where the iron oxide deposited on the surface of hot-rolled steel strip can be removed by pickling. The pickling procedure is carried out with hydrochloric acid in a closed, continuously operating system. At the entry end of the pickling line, strip ends are cut off and spliced in a flash welding machine so as to form a continuous strip to pass through the line in one piece.

After welding, the strip proceeds to the strip accumulator, where warm water acts as lubricator between strip layers and warms the cold steel surface. Actual pickling takes place in pickling tanks where the strip is exposed to hot hydrochloric acid. In this process, acid is sprayed directly onto the strip surface. The regenerated hydrochloric acid is recirculated. Acid residue and iron chloride are rinsed from pickled strip with hot water and the surface is dried with hot air.

After pickling, the steel strip is cold rolled to a lot thinner strip. The rolling force, strip tension, rolling speed, roll flattening, and the friction conditions in the roll gap are computer controlled during rolling. See Figure 4.7, which shows the possible routes and treatments of the cold-rolled strip products.

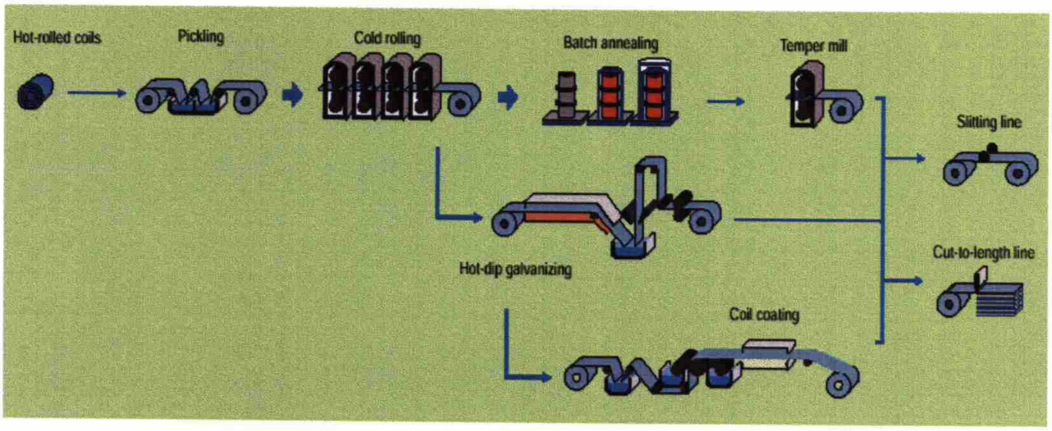

Figure 4.7 Cold-rolled strip production flow-chart [Rautaruukki Steel 2001].

In batch annealing, cold rolled coils are heat-treated in batches of stacked coils. The batch is built up on an annealing base by means of a crane and covered with the inner cover. Protective gas is kept circulating inside the cover during annealing in order to drive hot air to the coils being treated.

Protective gas also prevents the oxidation of strip during the annealing and removes any residues of rolling emulsion and oxide from the steel surface. The plates used to separate the coils in a batch also function as channels that lead protective gas in between the laps of strip. The annealing temperature depends on the steel grade and the required properties.

The annealing time is set according to the coil dimensions and weight. After annealing, the batch is cooled by replacing the heating bell with a cooling bell equipped with fans that cool the batch down to the required discharge temperature. Cooling can be accelerated by pouring water over the cooling bell. The annealed cold-rolled coils continue to the temper mill for temper rolling to achieve the required formability, flatness and surface finish.

The down-ended coil is taken by a coil car onto the mandrel of the temper mill. Before threading, the shear at the entry side of the temper mill squares the entry end of the strip. The strip is threaded into the temper mill and further to a recoiler. A belt wrapper at the recoiler ensures that the strip is properly around the mandrel when rolling begins. After temper rolling, the coils are transferred to the slitting line, cut-to-length line, or to the packaging department.

Instead of annealing, cold-rolled steel sheets can be galvanized on a hot-dip zinc coating line. Surface cleaning, heat treatment, zinc coating, skin pass rolling and stretch leveling are carried out before the strip is cleaned in a furnace. After that, the strip continues to the actual heat-treating furnace, where it is heated to the required temperature that depends on the steel grade and its mechanical properties. Next, protective gas is blown onto the strip surface in the cooling jet that is connected to the zinc pot with a snout through which the strip passes into the molten zinc bath. After cooling, the zinc-coated steel strip is passed through a stretch leveler for complete flatness. Finally, the strip is chromated or oiled for surface protection [Rautaruukki Steel 2001].

Hot-dip galvanized or cold-rolled sheet steel strip can be also handled on the coil coating line. First on the line are uncoilers, joining equipment, a chemical preparation unit and a strip-looping unit for continuous coating. For good adherence, the strip is first washed and treated with chemicals. Each treatment phase is followed by roller drying. In the first painting machine, both sides of the strip are primed. The paint is applied by means of paint rollers. After painting, the strip passes through a catenary oven where the paint dries. After water quenching, the second painting machine applies the top coat and back coat, which are dried in the next catenary oven. If the coating is provided as a plastic film, the second painting machine is used to apply the adhesive layer onto the strip surface. The adhesive is activated in the oven and the plastic film is then immediately applied to the strip surface with a roller. Some types of coating can be embossed with a special embossing roller. Coatings can be furnished with self-adhesive film for protection against mechanical damage and staining during handling.

5 Production Planning and Scheduling

5.1 Definitions of Terms Planning and Scheduling

5.1.1 Introduction

What is "Planning"? What is "Scheduling"? How do they differ? Where do they overlap? What is the point? In this thesis terms planning and scheduling are used quite often. That is why the differences between those two terms are explained here.

Niland defines planning as the development of a method for accomplishing a production requirement, and scheduling as the assignment of specific times for projected operations either of the plant as a whole or of individual work centers [Niland 1970].

Planning and scheduling both involve the allocation of tasks to resources across a time horizon. The English Dictionary defines a plan as a scheme or a way of proceeding and a schedule as a plan of procedure, a list or a timetable.

However, this is not usually sufficient to differentiate between the two. The commonly accepted differences are that plans generally address medium and long-term requirements (months to years) in time buckets of weeks or months and are not as detailed or as rigid as schedules. Using an analogy with rail travel, the list of destinations served daily from Station X would be a plan; the timetable of trains from Station X to Destination Y is the schedule, containing departure and arrival times with all intermediate stops and train-changes listed to the nearest minute [Prescientsystems 2001].

5.1.2 Planning

Usually planning is considered the process of breaking demands down into executable production jobs to generate materials and resource requirements for purchasing and scheduling. It is often a central activity for one or more production sites involving several people, planning over a 3-12 month horizon - typically driven by forecast and/or firm orders in daily, weekly or monthly buckets. In a nutshell, production plan determines how much and when to make each product [Sipper 1997].

Planning is concerned mainly with [Prescientsystems 2001]:

- What, when and where to make
- Working with product families and groups

- Key capacities, rates, and constraints
- Inventory, plant, and labor planning
- Campaign planning
- Balancing resource usage
- Meeting/setting stock and replenishment targets
- Budget planning

Figure 5.1 below illustrates the relation between planning and scheduling [Prescientsystems 2001].

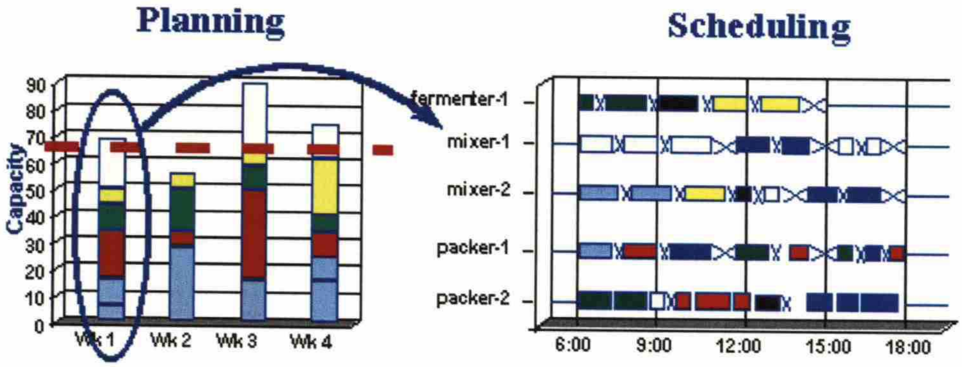

Figure 5.1 Planning and scheduling [Prescientsystems 2001].

5.1.3 Scheduling

The task of scheduling is the temporal assignment of activities to resources where a number of goals and constraints have to be regarded. Scheduling covers the creation of a schedule of the activities over a longer period (predictive scheduling) and the adaptation of an existing schedule due to actual events in the scheduling environment (reactive scheduling) [Smith 1992].

Usually scheduling is a site-related activity controlled by a single person, focusing on sequencing and scheduling of production orders. Scheduling is typically demand driven, tightly constrained, complex and detailed, and working to firm due dates. In terms of time, scheduling is usually continuous, and depending on the industry, spans a few days to a few weeks.

Scheduling is concerned mainly with [Prescientsystems 2001]:

- Meeting due dates
- Detailed products and recipes

- Routing (how best to make it)
- Sequencing and minimizing changeovers
- Synchronizing activities across resources
- Handling priorities, constraints, and conflicts
- Monitoring shop floor execution
- Managing change

5.1.4 Summary

Different people in different contexts use terms planning and scheduling quite often interchangeably. There is almost always some overlapping between the planning and scheduling activities. One of the difficulties today is that the boundary between them is constantly shifting. When people say they are doing planning, they are often doing some scheduling as well. When they say they are scheduling, they are invariably doing also some longer term planning.

This chapter describes first some general characteristics and requirements for a scheduling system. Secondly, there is a description of the schedule structure for paper industry. The most important parts of the scheduling procedure are listed and commented shortly. The parts described are essential for scheduling and they should be attached to a production planning system.

The production is always running according to a production plan. Sometimes exmill dates are determined by the production plan and sometimes the production plan is determined by exmill dates. It depends on the customers and the general situation in the market.

5.2 Scheduling Systems

A scheduling system shall support the human scheduler in his daily work in creating and revising schedules of the production. Several criteria influence the requirements for such a system, e.g. the area of production and the preferences of the producing company as well as the need for presentation of specific information and sophisticated scheduling algorithms. In spite of a large number of developed scheduling methods, only a few practical applications have entered into everyday use in industrial reality. It is important to notice that not only the applied scheduling methods but also several other features play a significant role for the acceptance of scheduling systems, including user interface, possibilities for manual interaction, and information presentation [Kempf 1991]. Hence, a knowledge-based scheduling system should meet the following requirements [Sauer 1997]:

- **Information presentation**

The information necessary for the scheduling task must be presented in an appropriate manner, showing specific information at a glance on capacities or alternative process plans. Moreover, it should be possible to monitor all scheduling actions in order to see the immediate consequences of specific decisions and to maintain consistency.

- **Interaction**

Interaction shall allow for full manual control of the scheduling process. All decisions may be made by the user (e.g. selecting orders, operations, or machinery) or by the machines. However, the support of interactive scheduling merely by information presentation and consistency control seems not to be sufficient due to the combinatorial complexity of the problem domain. Pure automatic scheduling, on the other hand, is not realistic either since it neglects the important role of the human expert who has the ultimate responsibility for all decisions. Thus, industrial scheduling systems should support the interactive as well as the automatic part of predictive and reactive scheduling [Hsu 1993].

- **Incorporation of scheduling expertise**

One of the main features of a knowledge-based scheduling system is the identification and application of problem-specific knowledge for the solution of the addressed problem. By using this knowledge the system can employ heuristics for the problem solving process that are similar to the ones used by the human expert, who, in turn, can verify the plausibility of the solution. However, it is not sufficient to merely mimic the decision-making of a human expert since his decisions are often myopic, aimed at solving small sub-problems immediately instead of global optimization.

- **Integration in the organizational environment**

An existing complex information technological infrastructure can be found in every modern industrial enterprise. Scheduling systems cannot be designed as stand-alone components since they have to communicate, interact, access the same data, and share information with their organizational environment. Therefore, knowledge-based systems have to be an integrated part of an existing information system, thus providing well-defined interfaces to standard application systems such as database systems and computer networks.

- **Participation of the user**

The incorporation of the user in all phases of the system design process is extremely important for the final acceptance of the scheduling system.

- **Communication between scheduling levels**

This is a crucial task in order to maintain consistency, coordinate the activities between the different scheduling systems on the two scheduling levels, and to inform the participating systems of events that might affect them.

5.3 Scheduling Options

Because there are a large number of different types of end products, there must be some options and rules for scheduling. Rules can determine e.g. that all scheduled orders in a run should have the same grade or product, same properties, or same roll dimensions. There can also be some rules and options for delivery times, scheduling order, and type of scheduling. As will be stated in the following sections, there are many conflicting goals in production planning and scheduling.

5.4 Production Planning in Paper Industry

5.4.1 Introduction

Production planning in paper industry can be broken down to four levels as shown in Figure 5.2. The most important levels are sales budgeting, rough planning, and fine planning. Notice also the time periods marked in the figure. Sections 5.4.3, 5.4.4, and 5.4.5 describe the main tasks of each level more in detail.

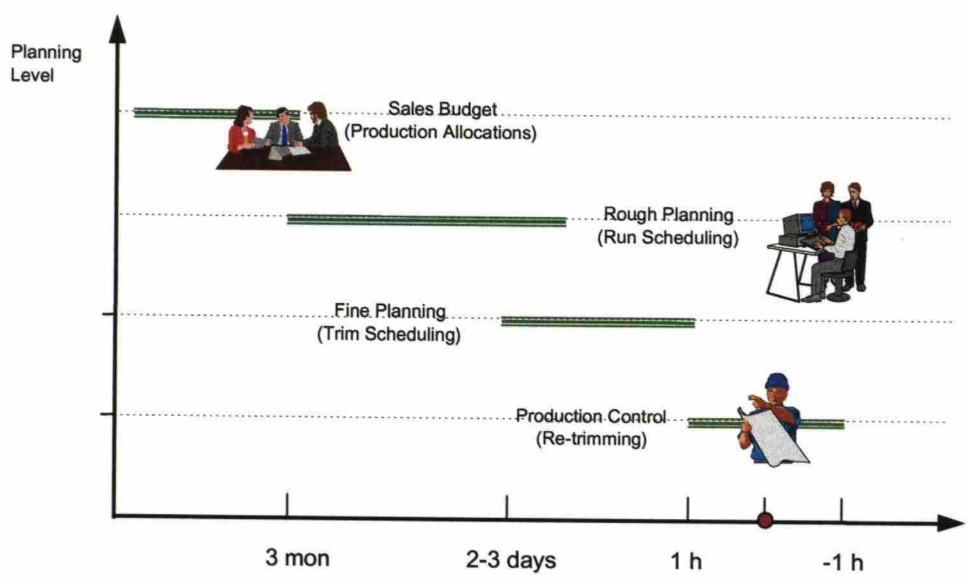

Figure 5.2 Levels and time scales of production planning in a paper mill [ABB 2001].

Most production planning principles described here are common in all kinds of industries, and especially in process industries. Of course, all the industries have their own special characteristics but roughly speaking, the basic ideas and principles are same.

Later, there is a chapter concerning production planning in steel industry, which shows how those basic principles are utilized there.

5.4.2 Paper Industry Production Planning Environment

Most of the equity invested in the paper producing process is committed to the paper machine. Investments for to be profitable, the functions in the paper machine must be efficient and economical. That is why a paper machine controls the whole production chain [Sauvonsaari 1990], [Venäläinen 1998].

Because most paper machines operate 24 hours per day, seven days a week, capacity is perishable. It means that non-production time will never be recovered and flexibility in terms of the total capacity is very limited. The main issue in production planning is the availability of capacity, not materials or labor. The industry is very susceptible to economic cycles, i.e. a cyclic industry. Product mix flexibility is low due to cyclic production plans and long grade change times - that, in addition to time loss, also produce waste [Lehtonen 2001].

5.4.3 Sales Planning and Budgeting

Sales plan is a rough production plan that gives basic lines for controlling the production. It can also define the main strategy for a bit longer period in the future. Sales planning outlines also the amounts of products to be produced, product specific prices and customer specific prices, and how often each product (paper grade) will be produced during the planning period.

Sales planning and budgeting utilizes historical data when estimating how the situation will advance and develop in the future. Alternative plans are compared between each other and tried to find the one, which maximizes the total profitability of the plant. Figure 5.3 clarifies the results of sales planning.

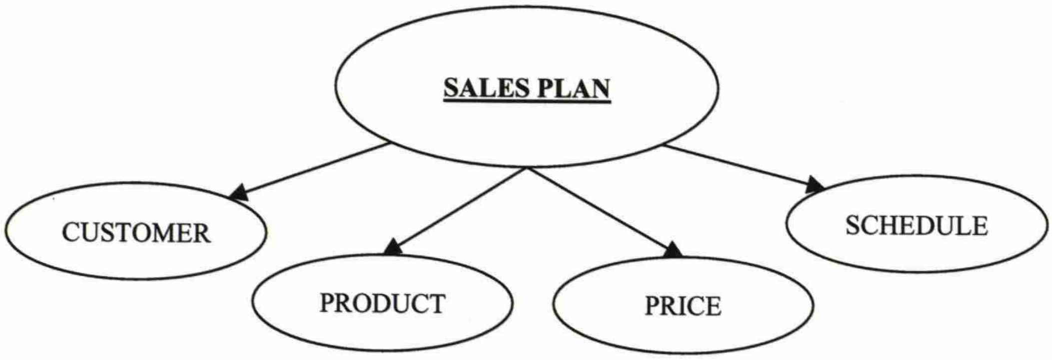

Figure 5.3 Results of sales plan.

Usually the top and middle management are responsible for the sales planning [Pöyhönen 1997], [Holmström 2001].

Based on the sales plan it is usually made an annual (or semiannual) cycle plan, which makes a basis for production rough planning. Cycle plan determines the rough production order of the paper grades produced. This production order is often made cyclic so that some specified delivery times can be guaranteed for all the grades produced. Otherwise there might be a need to do some costly and unplanned grade changes.

5.4.4 Rough Planning

Rough planning is made from the basis of sales plan and cycle plan. It is remarkably important when considering competitiveness and total profitability of a paper mill. The main tasks of rough planning can be seen in Figure 5.4. Explanations are listed below the figure.

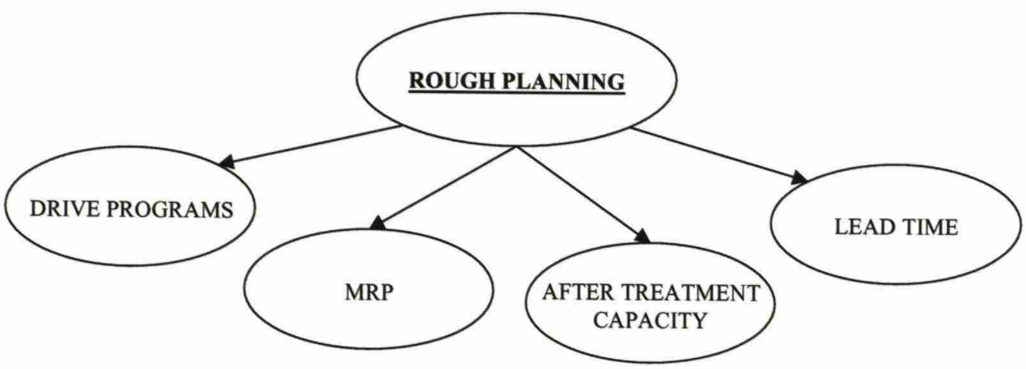

Figure 5.4 Results of rough planning.

- Building a drive program for paper machines

The orders of a paper mill have to be shared between different machines in a way that minimizes total costs. Scheduling and ordering the batches is also important because grade changes and paper cutting cause loss and cost. Also delivery delays and storing of the finished products cause extra cost and problems.

- Material requirements planning

Material requirements planning in a paper mill is not as easy task as one might think because production schedules and drive-programs are usually changing quite often. The aim of the materials requirements planning is that the right amount of the right material is in a right place at the right time. The purpose is to satisfy the needs of the production having neither material shortages nor large inventories. The most important materials used in the paper production are pulp and various chemicals.

- Calculating of after-treatment capacity

The purpose of calculating the after-treatment capacity of a paper mill is to reveal the bottlenecks and loading peaks of scheduled actions. Based on the calculations it is possible to compare different alternatives and adapt the capacity according to the production requirements [Eloranta 1982].

- Quantification of lead times of orders

Quantification of lead times is mainly performed in association with accepting the orders. The sales personnel can determine the first possible ex-mill date from the rough schedule. Sometimes there are exceptional situations and new ex-mill dates will have to be determined. In that kind of situations the prioritizing of orders is in key position.

Through efficient rough scheduling can be affected to the production capacity, grade change costs and raw materials costs, lead times, delivery certainty, and energy costs. In total, well-planned and organized rough scheduling is one of the keys to improved customer satisfaction [Pöyhönen 1997].

5.4.5 Fine Planning

Carefully done rough planning gives a good base for successful fine planning, which is illustrated in Figure 5.5.

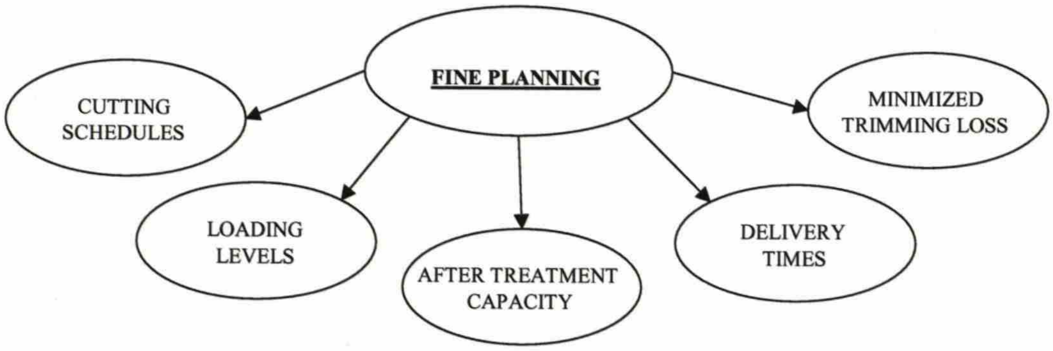

Figure 5.5 Results of fine planning.

Its main results are listed below:

- Planning the winder and sheet cutting schedules
- Calculating efficiencies and loading levels of cutters
- Planning and controlling after-treatment capacity
- Controlling delivery times and volumes
- Minimizing trimming loss

5.4.6 Relation between Rough and Fine Planning

Even if both rough and fine planning are done in separate processes, they are very closely connected to each other. In fact, they even have some partly overlapping goals. If rough planning neglects e.g. the effects of trimming, the final planning result may not be very good. If there are only a limited number of orders to be trimmed, the result may be a huge amount of waste. Instead of producing a lot of waste, it is usually better to wait for other orders so that solving the trimming problem will be easier. When there are a lot of orders to be trimmed, it is easier to find a suitable trimming solution that minimizes the loss. That is why successful rough planning usually includes characteristics of fine planning.

5.5 Scheduling Example

The schedule structure is divided into several hierarchical stages. They are described in Figure 5.6. Some further explanations are given below the figure.

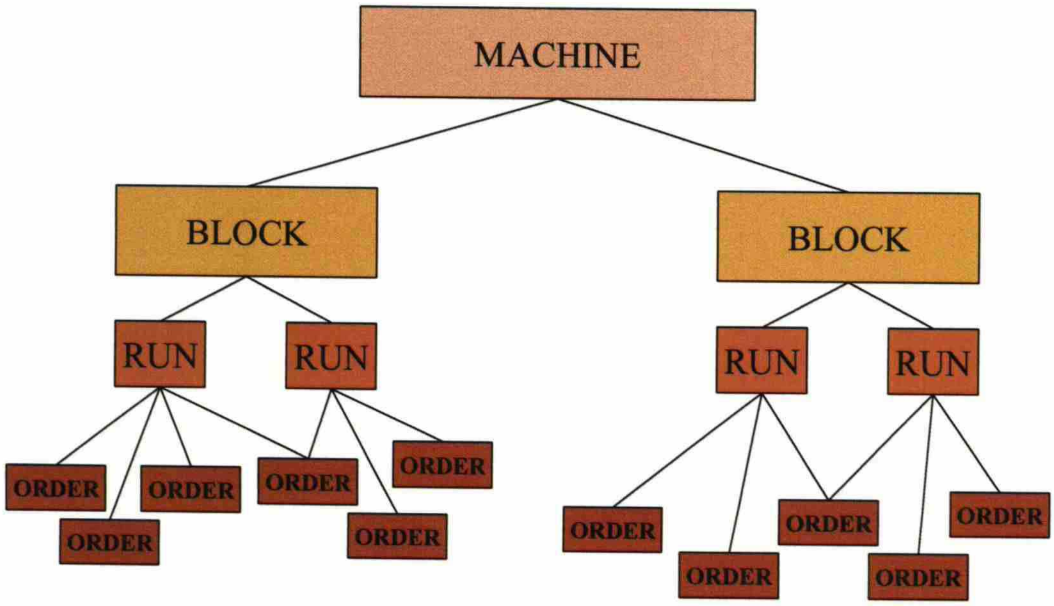

Figure 5.6 Hierarchical schedule structure.

Industrial scheduling is embedded in the logistics chain responsible for the creation of a feasible schedule for performing the production processes in order to achieve the economical goals of the company. Scheduling integrates different tasks of production planning and control systems to plan and carry out the manufacturing of products on the available resources respecting time, capacity, and cost restrictions.

5.5.1 Grade Structure

Usually in the paper industry production planning systems, grade data is handled on two levels: grade and product. There can be several products (sub-grades) for one grade. Grade data is used mainly on the production block level, while the more detailed product data is used on the production run level. Grades typically involve several different products with the same basic properties, but with different grammages, freeness, purity etc. The run schedule is based on grade and product data (grade and grammage).

5.5.2 Paper Machines

A paper machine is the basis of the schedule. Different paper machines are usually used to produce different types of paper. Some machines are specialized producing various types of boards and others make soft tissues, fine papers, or newsprint papers.

The production time of a paper machine is divided to production blocks, which can be considered as grade groups. A grade group means that paper grades having the same color and the same pulp type are grouped together. Other parameters like the grammage can be different as long as the color of the paper and the type of pulp remain same.

5.5.3 Production Blocks

Production blocks can be used to specify a production template according to mill's sales budget or production capabilities for a given period. It also serves as a production budget that can be used to provide information about the rough production plan for sales purposes, such as allocations and delivery time inquiries. The blocks can be related to certain grades or they can specify a time period in production, e.g. one week.

The block size can be specified either by giving the reserved tonnage or according to the orders that have been scheduled to the block. Within a block, there can be several runs with different grammages. It is also possible to ignore the production block level and use only run level.

Essential data concerning production blocks includes: block number, line name, block status (e.g. planned, locked, or completed), grade of the block, production speed (t/h), planned tonnage, reserved tonnage, duration of the block, start and end dates of the block.

5.5.4 Runs

Blocks are divided into runs, which contain orders that have the same grade and the same grammage. When talking about roll orders that do not have to be sheeted, a suitable amount of capacity is reserved from the production schedule right away. If a customer wants e.g. sheets that have to be trimmed, it is usually better to wait for other orders so that solving the trimming problem will be easier. When there are a lot of orders to be trimmed, it is easier to find the suitable trimming solution that minimizes the loss. Of course, minimizing the loss means minimizing cost.

Runs can be read from an external system or created by the user. A run contains normally orders that are planned to be trimmed together. It is also possible to split the run to trim-groups just before trim scheduling according to e.g. the diameter or to add new orders to improve the trim result.

The following information about the production runs is essential: run number, production line, block, machine, run status, grade, product, production time, start and end dates, and all trim parameters.

5.5.5 Orders

Each order should include the following general data: order number, width, length, roll/sheet, grade, product, grammage, and ex-mill date. Other important pieces of data could be e.g. specific information about delivery dates and places, elaborate figures about sheet and reel sizes, chosen options for packing, and other special options.

5.5.6 Practical Level

Different runs inside a block are arranged so that the grade changes are minimized. It means usually that the changes in the grammage of the paper are tried to handle as smoothly as possible. So, big leaps are avoided and gradual small changes preferred as described in Figure 5.7 below.

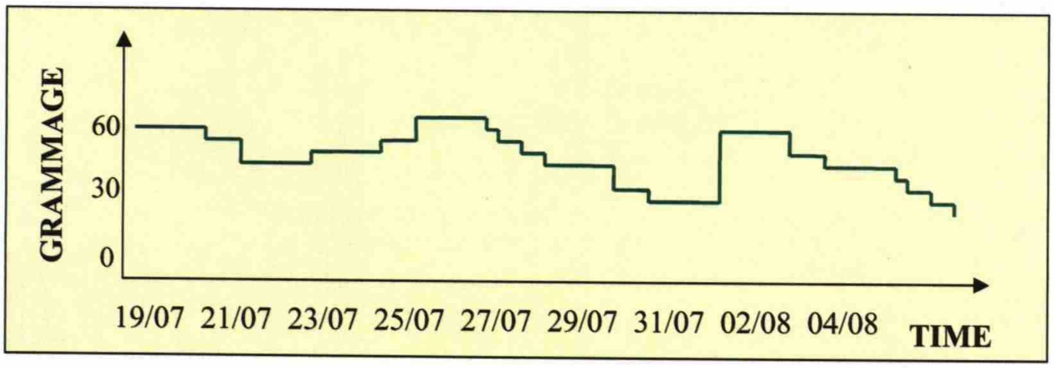

Figure 5.7 Grade changes in a paper machine [ABB 2001, modified].

There are also a couple of bigger leaps in the grammage in the figure above. Those may be because some other parameters have been changed or the production block has been changed. When a production block is changed, it means that the color of the paper, the type of the pulp, or some other parameters have to be changed. In that kind of situation, the grammage of the paper can be changed also without extra cost because changing other parameters causes waste no matter if the grammage is changed or not.

Naturally, production blocks are arranged so that the properties of the paper are changed as little as possible at a time. For example, the color of the paper must be changed gradually from lighter colors to darker ones and vice versa.

In order to minimize total costs, paper mills are often following a predetermined production program that defines what kind of grade groups are produced and when they are produced. This is called a production cycle. The cycle period may change a lot in different mills but usually it varies between one week and one month. If there are not enough orders of certain paper grade, the cycle may be changed and the transfer to the next grade group is performed earlier than was planned in advance.

When a customer makes an order, it is easy to check from the production plan if there is enough free capacity for that kind of order. If not, the cycle plan shows when is the next possibility to have that specific paper grade. That kind of cycle system works quite well because customers usually know the cycles and that way they can prepare and adjust their orders according to it.

Still, not all paper mills are using cycle plans. There are also paper machines producing only certain types of paper all the time. This may well be when talking about newsprint paper. Its demand is quite stable and constant, because the demand of newspapers is nearly constant also.

In the Figure 5.8 is described how blocks and runs can be presented. Each row of the figure equals one run inside a block. Blocks are presented on the leftmost column in the figure. The red rectangles are planned orders and their ex-mill dates can be seen from the schedule.

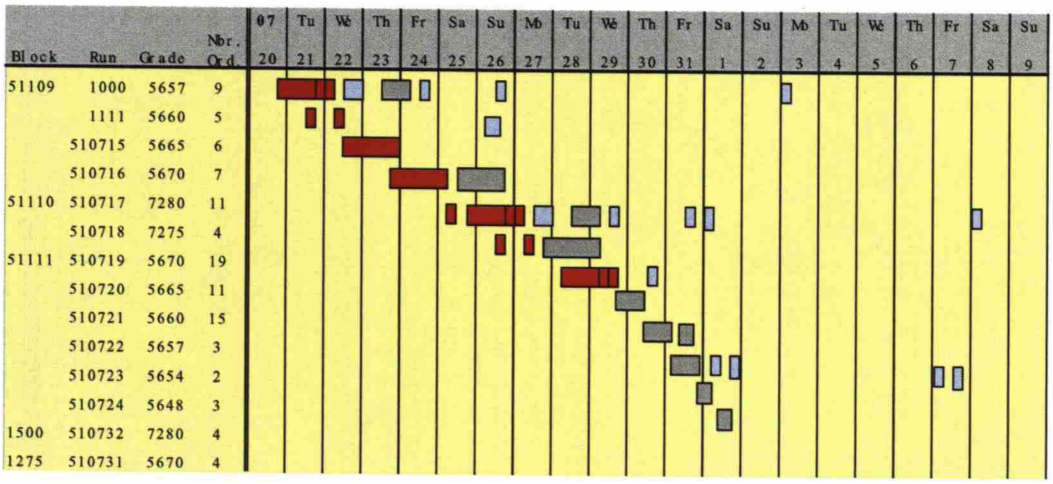

Figure 5.8 Run list in a paper machine [ABB 2001, modified].

As already mentioned above, this is called rough scheduling. Fine scheduling, which is done after rough scheduling, means making cutting schedules and planning trimming. The trim loss problem is introduced next.

5.6 Trim Loss Problem

5.6.1 Definition of Trimming Process

The trim-loss problem can be identified in many different industries (e.g. in the paper and metal industry) but in this section the main focus is on the paper industry. In the trim loss problem, an optimal strategy is sought for cutting a wide raw-paper reel into narrower, customer specified reels in such a way that the appearance of waste - the trim loss - is minimized.

In the paper industry, coating often precedes cutting. Therefore, it is not always possible to recycle the material loss of the process. Also, other operational issues need to be considered in order to be able to solve the practical problem successfully. Besides, being a numerically challenging non-linear programming problem, the choice of objective is of great importance and a non-trivial task in order to alter sustainable and environmentally benign solutions.

In the mathematical model, the key element is the cutting pattern. A cutting pattern describes how the knives are positioned and can be expressed by the number of each product type that is cut out from the raw-paper [Harjunkoski 1998].

The Figure 5.9 shows how a big mother roll is cut and slit into smaller rolls and sheets. Every time a roll is slit, a certain amount of waste is produced from the ends of the roll.

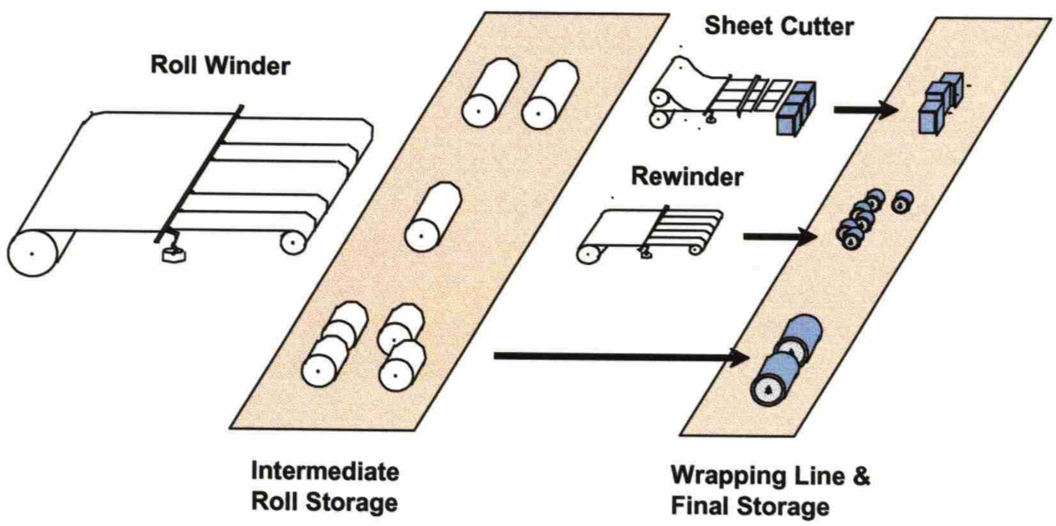

Figure 5.9 Trimming process [Säynevirta 1994].

By carefully arranging the needed customer rolls, sheeter rolls, and rewinder rolls it is possible to minimize the trimming waste. The procedure of arranging the rolls in a mother roll is illustrated in Figure 5.10.

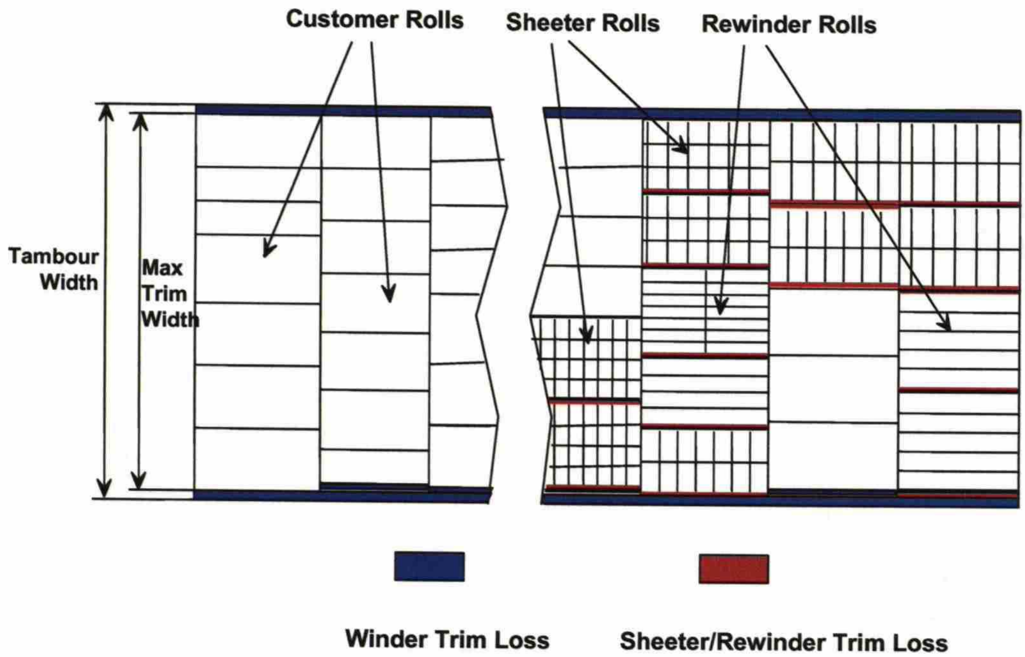

Figure 5.10 Arranging the different types of rolls [ABB 2001, modified].

The mother roll illustrated in the figure above is wind open so that all the smaller rolls planned to be made from it can be seen. There are rolls with different lengths and different widths, and they all should be placed on a mother roll so that the whole area is utilized as well as possible. The trim loss caused by a winder is marked with blue color and the sheeter and rewinder losses are marked with red.

Some customers may have requirements that they do not except their roll to be taken from the side of the tambour width. They may define a minimum width that is allowed be to between the edge of the jumbo reel and the customer roll before they accept it. The reason for this is that the profile of the paper may not be totally uniform along the whole tambour width. The sides of the tambour may not be as good quality as the center. These special requirements have to be taken into account when planning the utilization of the mother roll.

5.6.2 Objectives of Trimming

The general goal of the trimming process is to minimize the production costs. Though, the other side of that goal is maximizing the productivity because efficiently functioning production decreases the unit costs caused by the production machinery [Karhu 1992].

Trimming is normally not considered as a separate function in production planning. Also effects of other parts of production planning are tried to take into account when minimizing the total costs.

The objectives contributing to minimizing the total costs are listed in Figure 5.11. Below it there are short generalizing explanations of them.

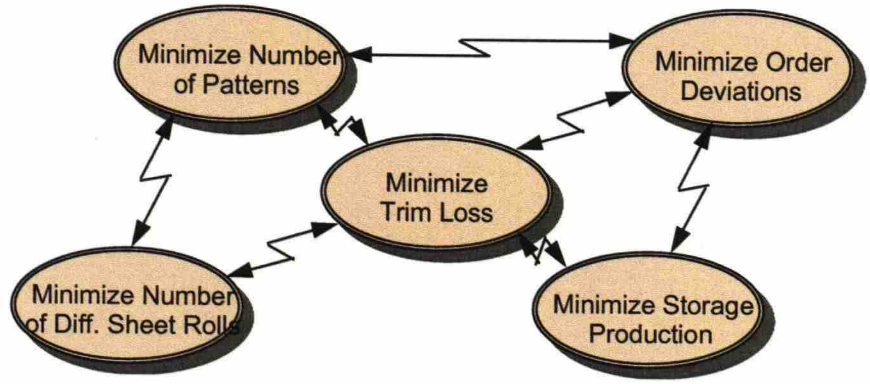

Figure 5.11 Objectives of Trimming [ABB 2001].

- Minimize Trim Loss

Trimming loss has a direct effect on costs. Even though the trimming loss can be returned into the production process, a lot of energy and production capacity has been used while producing it. Especially when the market situation is good, the trimming loss has to be considered as lost demand and the coverage of sold paper must be added to the costs.

- Efficiency of the cutting process
  - Efficiency of slitting
    - Number of winder setups
    - Minimizing movements of knives

Changing the positions of knives delays the cutting process and that is why it is appropriate to try to minimize the number of winder setups and knife movements. The reel buffer (intermediate storage) between the paper machine and winder is usually quite small and sometimes the number of winder setups can be a critical factor steering the trimming process.

  - Efficiency of sheet cutting and rewinder
    - Reel width
    - Reel diameter
    - Distribution of production between different winders

When the width and diameter of reels are as large as possible, the number of changes decreases. That means the process is more efficient and fluent.

- Inventory control

Inventory control is very closely related to the trimming process. By producing certain types and sizes of paper to stock, the trimming loss may be decreased remarkably. Short delivery times due to inventories may be a considerable competitive advantage. On the other hand, keeping inventories causes costs and finally we face the same problem as stated later in Figure 5.12 (page 41), which describes the conflicts of goals in a production system. The advantage of producing reels to stock must be greater than the costs caused by keeping the stock [Karhu 1992].

5.6.3 Restrictions of Trimming

The machine width is one of the restricting factors in trimming. Depending on the number of winders, trimming can be done for one or more machine widths. Other restrictions are technical properties of winders and cutters. The number of knives, maximum and minimum diameters of reels, maximum and minimum width of the edging strip are also restricting trimming setup.

Also customer orders may have some restrictions that allow only orders of specific type to be produced at the same setup. This kind of properties may be the diameter of the reel, size of the sleeve and the direction of the wire side in the reel. In some cases the order may have quality requirements that prevent cutting it from the edge of the machine reel because the quality of paper may be better in the middle.

The restrictions of production quantities are usually absolute limitations. Occasionally, it is possible to deviate from the production quantities up or down. Then the additional paper is stored or the whole order is delivered from somewhere else or as incomplete. Also the production to stock has usually limits that must not be exceeded.

5.6.4 Trimming Algorithms

Because there are many factors and goals with different importance contributing the desired trimming result, there must also be different algorithms for different purposes.

Occasionally there may be a need to produce paper as quickly and efficiently as possible and the trimming loss is not so important. Then the algorithm should be capable of minimizing the number of winder setups and movements of knives. That way the production flow would be as uninterrupted as possible. This kind of situation could be e.g. when the raw materials of the paper grade are not very expensive and it is more important to keep the production at high level without time consuming setups.

Usually it is essential to minimize the trimming loss because the raw materials of the paper are so expensive. In that case, there are usually more time-consuming set-ups and knife movements but the total cost is smaller just because of savings of the raw material.

As said, there are different possibilities to optimize the production costs. The selection of the algorithm to be used depends on the priorities and desires at that very moment. Algorithms can be based on e.g. integer optimization or heuristics or they can be linear.

5.6.5 Trimming Parameters

Basic trimming parameters are used to define the different machine-dependent restrictions and mill-dependent optimization targets. There can be individual parameters for winder, rewinder, and sheeter defining the properties of the cutting machinery.

Parameters include limits for the sizes and weights of the rolls and sheets to be packed, trim loss price, and penalties for optimizations. The last one means that it is possible to emphasize desired properties like small trim loss or few pattern changes. Also selecting between underproduction and overproduction is important because sometimes it is better to store some extra products and sometimes not.

5.7 Production Control in Paper Industry

5.7.1 Goals of Production Control

Production controlling is about consolidating the main functions of a corporation in order to achieve the goals of production. It consists of various activities coming about through different levels of the organization.

There are four primary goals in production control [Uusi-Rauva 1994]:

1. Delivery capability

Delivery capability must be in the high enough level in order to satisfy the requirements of the customers. Use of the capacity and material functions must be planned so that the efficiency is as high as possible. Though, it is important to note that the capacity available plus the stocks must always be greater than or equal to the sales. Otherwise it is impossible to adhere to the promised deliveries.

2. Minimizing floating assets

Inventories bind a remarkable share of the corporation's equity. The production and material planning must be controlled in a way that minimizes the floating assets without causing serious problems with material availability.

3. High load rates

The bigger the output of the factory, the better is also the productivity of facilities and machinery. In order to ensure effective utilization of the employees and the machines, production must be planned so that the lack of work does not cause any loss of capacity.

4. Steerability

Properties of the production system must be developed in a way that the goals of production are more easily available.

As can be seen from Figure 5.12, there is a conflict between some of the goals defined above.

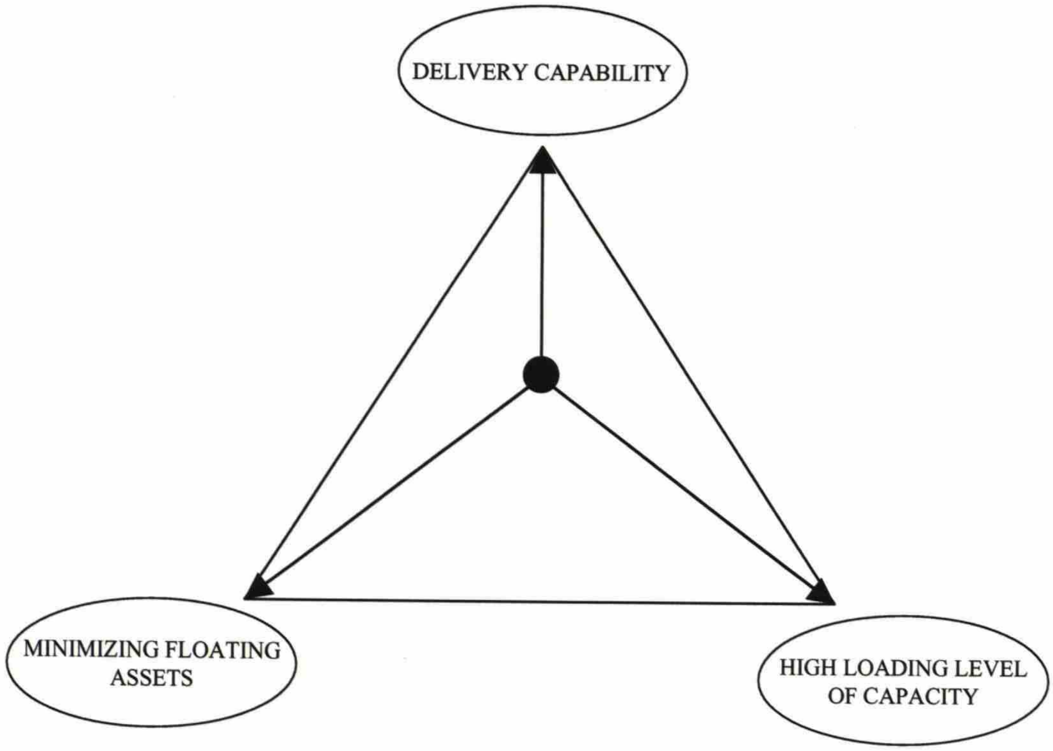

Figure 5.12 Conflicts of goals in a production system [Uusi-Rauva 1994].

A good delivery capability requires inventories of products and raw materials. It also assumes capability of producing small lot sizes at short notice and taking customers' desires into account [Kauppinen 1985].

Producing aims at the high utility levels by producing large batches of constant products. Large batches require large inventories and constant demand of products [Bowersox 1996].

Changes in grade and type of the paper disturb the efficient usage of the machinery and cause waste and cost. Grade change costs can be categorized into two groups: The first group includes costs due to production of poor quality products e.g. energy and material. The second includes costs due to wasted production capacity.

Minimizing floating assets requires small inventories and reducing the work-in-process expects small lot sizes [Lehtonen 1999].

Production control should consolidate these conflicts and steer the corporation into the direction that is the best from the whole mill's point of view. It also helps defining the principles of decision-making process.

The reason why the production control is so important is that it has very strong effect on financially remarkable decisions. E.g. the value of inventories can be 50% or even more of their added value [Insko 1986], [Vollmann 1996].

5.7.2 Problems in Production Control

Production control is not a separate function. It is closely related to all the functions of an enterprise, especially to the parts having a close connection to the material flow. Because there is never entirely stable production situation, the production control should adjust the requirements of the market and the possibilities of production to each other. Possible disturbing factors can be e.g. changes in customer orders, malfunctions in the productive machinery, defective raw materials or human errors.

Some defective factors can be prepared for and appropriate actions can be taken in advance. E.g. good rough scheduling can ease effects of changes in customer orders. Changes can be made to properties of an order (width or the ordered amount of paper) or the whole order can be cancelled.

Other defective factors are not easily foreseeable and they often have severe consequences. Malfunctions in the productive machinery are most difficult situations and they can change the whole rough scheduling. Malfunctions and their effects can be cut down by preventive maintenance [Valkonen 2000].

If the number of customer orders is very small, there are often many grade changes, which cause a lot of waste and cost. Problems with quality can be anticipated or unexpected. If there is a need to reproduce the order, it is often difficult to find quickly the suitable capacity for it. By developing quality control and other preventive actions, quality problems can be cut down remarkably [Nurmilaakso 1995], [Krajewski 1997].

5.8 Introduction to Production Planning in Steel Industry

Steel companies produce batches of various different types of products for different customers. The customers will specify dimensions, properties such as tensile strength and yield point, and chemical composition for their individual orders. Ability to fill these orders profitably depends on the steel company being able to quickly decide the right processes and processing conditions for each batch and being sure that a batch will meet the customer's specifications. Since more than 100 input and 100 output variables may have to be considered, this is a complex task for even a person experienced at the job.

When talking about grade changes, paper machines are driven in cycles, where the properties of paper are changed a little at a time in order to minimize grade-changing costs. This kind of phenomenon does not exist in the steel industry. The cycle of the steel production is one casting sequence, which may consist of one to about ten smeltings, which all have the same grade. One smelting contains several slabs depending on the converter and slab sizes. If the converter size is e.g. 100-150 tons, it means that there is enough material for 4-8 slabs.

5.8.1 Steel Industry Production Planning Environment

As in the paper industry, the production machinery in the steel industry is very expensive and complicated. Steel works operate all the time, day and night - just like paper mills do. This means that the capacity also in a steel works is perishable and the main issue is to utilize the available capacity as efficiently and exactly as possible.

The industry is susceptible to economic cycles but usually steel works (in Finland) could sell more steel than they can produce. However, steel making is not so easy. There are lots of things to be considered in optimizing the production capacity utilization. Also material requirements planning (MRP) and overall production scheduling are more complicated tasks than in the paper industry. The reason for this is that steel making has more production phases than papermaking and these phases have all their specific rules and restrictions (see section 5.9.9), which set high demands on production planning.

To compete in today's global steel market, steel producers must be able to deliver products to their customers when they need it, on time, every time. This difficult task is complicated by the growing desire for customers to reduce inhouse inventories and provide just-in-time service as a part of an extended supply chain [Jahnukainen 1996].

5.8.2 Goals of Steel Industry Production Planning

The beginning of the process, until the smelting plant, is concentrated on producing crude iron of uniform quality, which practically has a stable composition. Before the smelting plant there is no need to take the special requests of individual customers into account because they can be noticed later. Controlling the beginning of the process is mainly steering large unit processes, which should be efficient, economic and produce material of uniform quality. By high quality raw materials, efficient usage of energy, and thorough actions can be achieved a competitive base for business.

The task of production planning in a steel works means steering the steel production and the rolling mills so that the whole production chain works efficiently and customers get their products according to their orders.

- Steering of production means planning, making instructions, and tracking production. Things to be steered are quality, amount, and manufacturing order.

- Production functions efficiently when planned production amounts are reached, production costs and rejection rates are low, and intermediate storages are small.

- Customers assume that the internal and external quality of products is high and products are delivered as complete delivery lots and on time [Karjalainen 1993].

5.8.3 Problems in Steel Industry Production Planning

The problems in the steel industry operations management are quite difficult to break down into well-structured partial problems that could be solved separately and independently of each other. The three central functions in the steel industry operations management are:

1. Production timing

2. Quality control

3. Controlling the properties of products

As Figure 5.13 shows, those three functions are partly overlapping and generally quite difficult to define [Hintsa 1994].

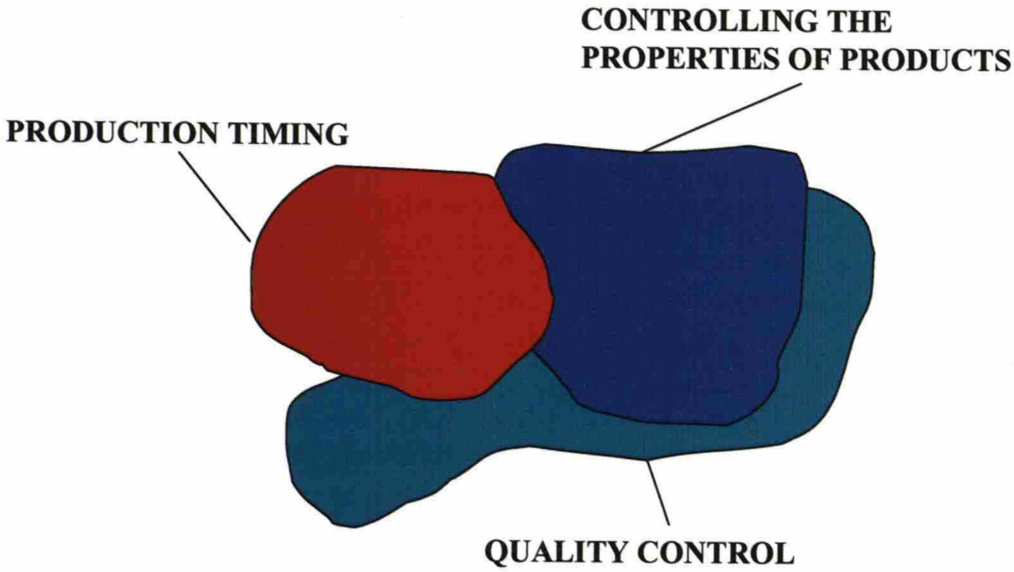

Figure 5.13 Problems in the steel industry operations management [Hintsa 1994].

Production timing aims at allocating resources so that products can be produced efficiently. The timing problem arises when common resources – labor, materials, and equipment – must be used to produce different products during the same time period. The objective of timing is to find a way to sequence the use of allocated resources that satisfies the restriction clauses and minimizes the production costs [Rodammer 1988].

When planning the actions of a smelting plant, the most important question is what grades to smelt and when to smelt them? In order to be able to answer that question, the following list of questions have to be answered first.

- How to combine the most urgent customer orders so that other planning requirements are still satisfied?
- What dimensions should slabs have?
- How to combine slabs to make mother slabs?
- How to avoid producing too many storage slabs?
- How to use available stock slabs efficiently?

All these issues are important and often a compromise must be done in order to get the best possible result.

5.8.4 Timing Attributes

Production schedule starts and ends at a certain moment, so the timing system must be able to display all the relevant start and end states. The production situation is at the zero level very rarely – only when starting the line or when the order book dies out. In practice, timing is mostly continuous re-timing.

Taking batch sizes and set-up costs into account is central for the timing system. Because large batch sizes decrease the need for machine set-ups and changes, they stress performance and workload. Small batch sizes decrease work in progress and increase timing possibilities. That is why small batch sizes stress products, technology, and resources.

Selecting process routes is often a dynamic task including several options. When selecting the next process stage or the next machine, there can be both totally different and totally identical options. The state of the plant (e.g. availability of resources) or the state of the task (e.g. need for preparation) can cause dynamic changes to timing. Random occasions and failures are daily incidents in production: machinery breakdowns, labor absences, lack of raw materials, and deviations in processing times can be included just to mention some. Of course, these random occasions can be taken into account in some level but e.g. machine breakdowns are not easy to forecast.

The production environment contains several inconsistent restriction conditions and performance goals. Examples of requirements are machine specific capacities and examples of goals are minimizing lead times and delays and maximizing utilization rates. In practice, the aim is often to create and maintain stable process schedules, which can be achieved by deliberately decreasing the utilization rates of machines from their theoretical maximum values [Paloranta 1993].

5.8.5 Timing of Steel Production

Production timing in the steel industry is extremely important task and its importance increases because of the following reasons:

- Quality requirements of products are increasing all the time
- Connections between different functions are causing strict time restrictions
- Production is getting more and more customer intensive
- Lead times must be continuously cut down

The most important part to be scheduled in a steel works is the smelting plant where many time and order based restrictions are emphasized. E.g. molten steel cannot wait long time in a ladle for the casting machine to be free because the molten steel cools down and gets solid.

5.8.6 Steel Terminology 2

The second part of steel terminology includes terms especially concerning production planning. Some of the most common and the most important terms are explained here so that the reader would be able to understand the text better [Hintsa 1994], [Summo Steel 2001].

Mechanical properties; customer and standards assumed properties of a material that reveal the elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain

Blend components; chemical elements due which steel gets its mechanical properties

Customer specification (customer grade); customer and standards defined minimum and maximum limits for mechanical properties and blend components

Metallurgical grade; internal grade classification made by steel companies, it helps to combine different customer grades into one smelting, metallurgical grade is defined as target values of certain mechanical properties and blend components

Quality space; N-dimensional space defined by mechanical properties and blend components where vectors have defined initial, target, and ending values

Uniform quality; if the target values of the steel delivered to a certain customer are equal inside one delivery lot and between many delivery lots, those deliveries are said to be of uniform quality

Incoherent quality; if the target values of the steel delivered to a certain customer differ inside one delivery lot and between many delivery lots, those deliveries are said to be of incoherent quality

Over quality; if the steel ordered by a certain customer contains some blend components more than the target value requires (still less than the acceptable maximum value), steel is said to be over quality, the meaning of the over quality for the customer can be positive (better quality than ordered), neutral (most often), or negative (more incoherent quality)

5.8.7 Quality Space

The Figure 5.14 illustrates an example of quality space of the required properties of steel in a customer order. The example contains six solid line rectangles that are customer grades (1-6), and three metallurgical grades (A, B, and C) that are described with dashed lines. The axes of the picture represent metallurgical properties of steel.

The minimum and maximum limits of customer grades are determined by the customer and general steel industry standards. Metallurgical grades are defined primarily as target values instead of defining strict minimum and maximum values. In order to be more illustrative, all the grades in the example have both the maximum and minimum values. In real situations, either one or both of them may be missing. Those maximum and minimum limits can be determined by adding and subtracting the general tolerance limits to and from the target value, respectively. The tolerance limits are based on metallurgical theory and accuracy of the smelting plant.

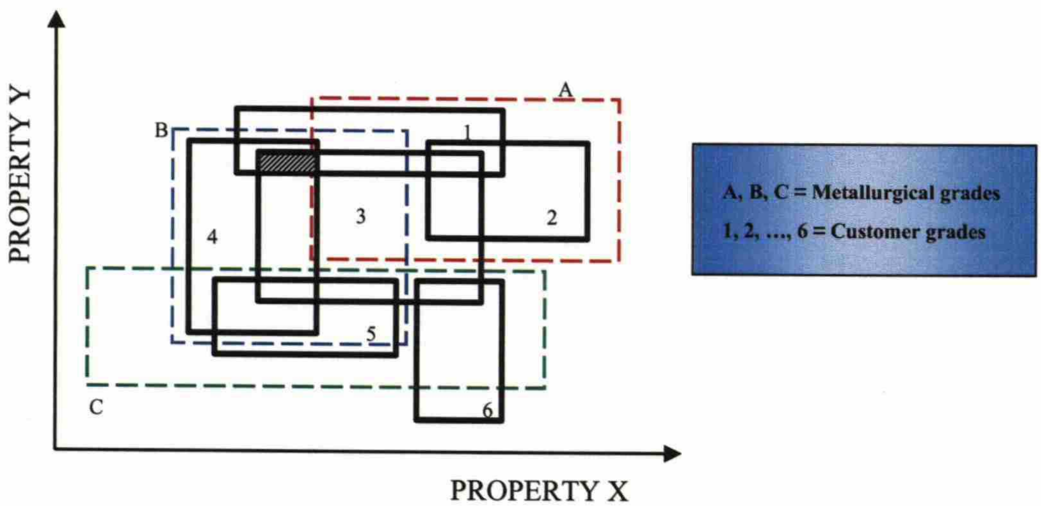

Figure 5.14 An example of steel quality space [Hintsa 1994, modified].

The figure above shows that the customer grades 1, 2, and 3 can be made of the metallurgical grade A. The metallurgical grade B can be used to make customer grades 1, 3, 4, and 5 and the metallurgical grade C can be used to make customer grades 3, 4, 5, and 6.

If the target value of the metallurgical grade B is set to the area that is common to customer grades 1, 3, and 4, they all can be made of the metallurgical grade B. The condition is, of course, that the properties of the metallurgical grade hit the target area, which in this example is the shaded area in the figure above. As said before, the accuracy of the smelting plant is a quite remarkable factor.

Another example: even if customer grades 3, 4, 5, and 6 can be made of grade C, they cannot be made simultaneously because the customer grade 6 has no common area with grades 3, 4, and 5. Instead, customer grades 3 and 6 can be made simultaneously of metallurgical grade C.

5.9 Steel Industry Production Planning and Control

5.9.1 Order and Material Chains in Steel Industry

In a steelworks, there are lots of semi-finished products around the plant waiting for processing. Some of them are just waiting for processing while others are cooling down before they can be treated further. All the products have their individual production numbers so that they can be recognized and processed further according to the production plan. Figure 5.15 below shows roughly the planning and manufacturing processes. It shows also how the material used for a specific coil can be traced back to the very beginning of the process. All the phases in the figure are explained literally in later sections. At this stage it is important to only have a general overview of the process at hand.

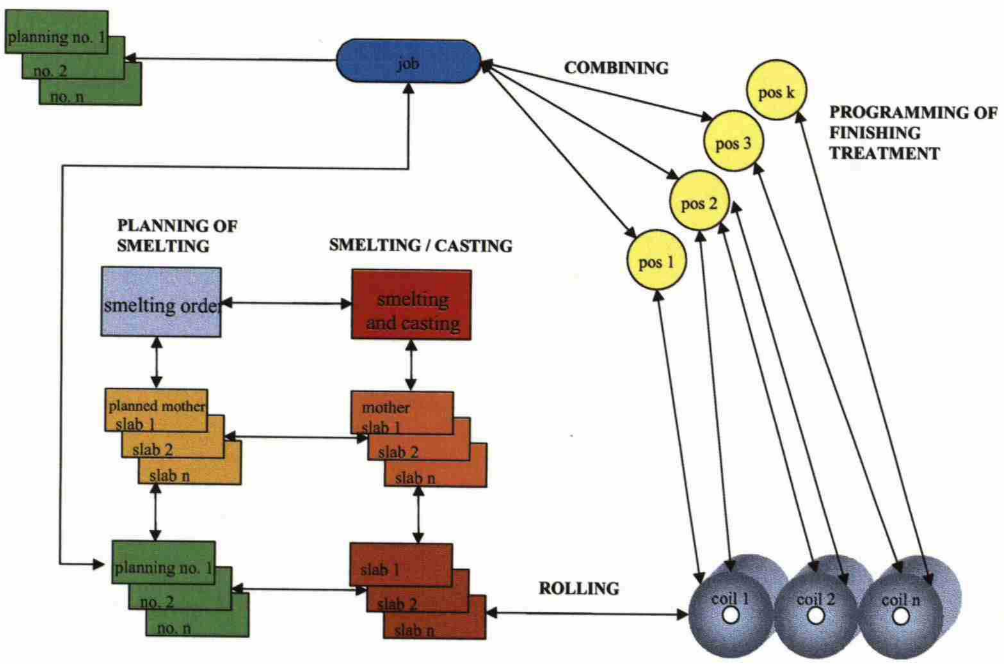

Figure 5.15 Order and material chains in the steel industry.

The chain in the figure above starts from the yellow circles named pos1, pos2 etc. Those mean positions that are made by combining similar orders. Then several positions are combined to make a job, which is given a planning number. Then the combined positions are used to form plans of mother slabs. Then the smelting is planned and the smelting order can be given further in the chain. The casting process produces mother slabs, which may contain several slabs. Before rolling, mother slabs are cut into slabs that will have their own identity numbers. In this example, slabs are rolled to coils but as well there could be plates instead of coils.

It is important to notice the arrows and their directions in the figure. If one wants to know what was the job number of a certain coil, it can be traced back by following the arrows in the figure and the production numbers specified for each phase. From coil number we can conclude what was the number of the slab it was made of. And from the slab number we see the planning number of the smelting where the slab was cast. And finally from the planning number we see the job number. It is also possible to move to the other direction in the diagram. That is beneficial especially when tracing back the material of which some defective products were made of.

5.9.2 Phases of Production to Be Planned

This chapter describes shortly, how steel industry production planning can be divided into sections that have to be planned more or less individually. However, they are still very closely connected to the whole process and there are lots of things that have to be taken into account from the whole process' point of view.

Within the scope of this thesis, the first things to be planned in the steel products manufacturing are material demand and smelting. The next larger parts to be planned are the scheduling of slab re-heating furnaces and hot rolling machines.

After that there are many production phases between hot rolling and cutting. Those phases can include several different routes according to the type of desired end product and the mill's appearance. More detailed process descriptions were introduced in Chapter 4.2. However, whatever the route is, the production should be planned so that it runs fluently until the beginning of the cutting lines. Finally, cutting and slitting should be planned almost like in the paper industry. The trimming problem in the steel industry is not as big and remarkable as in the paper industry, but the same basic principles count for steel as they do for paper. The trim loss problem was described in Chapter 5.6.

Here we have a framework according to which we can start exploring this planning problem more carefully.

5.9.3 Outline of Steel Industry Production Planning System

As said in earlier chapters, the problems in the steel industry operations management are quite difficult to break down into well-structured partial problems that could be solved separately and independently of each other. However, problems have to be solved somehow and it is easier to handle them if they are broken down to smaller pieces. In Figure 5.16 there is an outline of the steel industry production planning system. On the left side of the figure, there are six main phases (from A to F), which contain the sub phases described on the right side of the figure. This chapter describes all the phases in a quite detailed level.

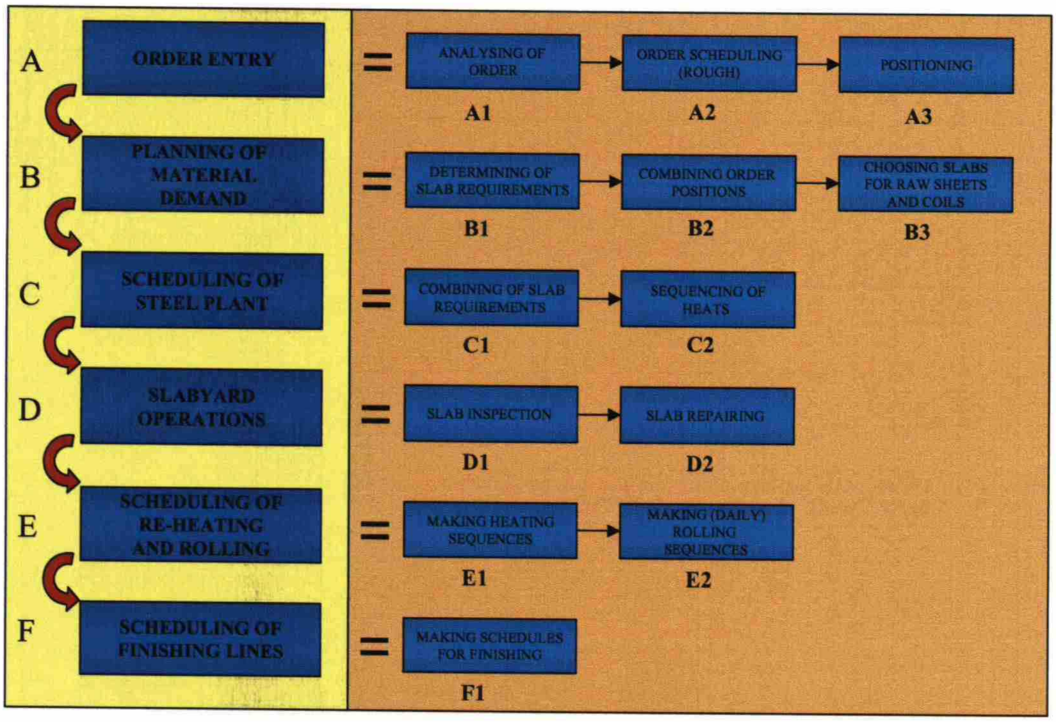

Figure 5.16 Outline of the steel production planning system.

A. Order entry

In the steel industry, the production lags sales remarkably. The system goes like this: a customer buys in advance a certain tonnage of capacity from a certain production week. When the time goes and the specified production week gets closer, the customer informs the producer about what kind of products he wants to have. So, each order contains the following information [Kaartinen 2001]:

- Order number
- Customer name
- Due date
- Grade
- Chemistry information
- Surface quality
- Appearance (plates or rolls)
- Thickness (and tolerances for it)
- Width and length

- Size of the mandrel

In the order entry, the orders are first analyzed and sorted according to their dimensions, grade, and total amount. Then the order information is inserted into the order processing system where the order is scheduled. This rough scheduling means that approximate production dates are decided for smelting, rolling, coating, and cutting of the ordered products. Also customized production instructions are attached to the order information, if necessary.

The parts of the customer order having the same grade, width, thickness and production route are called positions. Therefore one order can contain several different positions. Usually the production routes for different positions are set after positioning.

B. Planning of material demand

At first it is determined what kind of slabs are required to make the products in the order position. Grades of the slabs are set according to the customer requirements.

Next, order positions are combined, which in the case of plate products means that a combination model of a raw sheet is build up and the alternative slab types are arranged according to their usability. In combining, the ordered customer sheets are made up to batches, which contain sheets of the same slab grade and target thickness. The customer sheets of the batch are used to form one of the approved combination models of a raw sheet. Those combination models contain the customer sheets' locating possibilities on the raw sheet. Some of the order positions have to be combined manually [Hintsa 1994].

A raw sheet can be often made of several different slab sizes. The amount of different alternatives depends on the slabs' thicknesses and widths, which are determined by the chill sizes used in the casting machines. All the possible alternatives are arranged to the order of superiority by calculating the planned output (i.e. planned slab weight and weight loss). The plate combination problem is described more detailed in Chapter 5.9.7.

In the case of strip products, the procedure is almost the same as with plates. Just like building up raw sheets that are later cut into smaller sheets, ordered coils are tried to combine into bigger coils that can be cut into smaller ones after rolling and pickling. The strip combination problem is described more detailed in Chapter 5.9.8.

Before scheduling smeltings, it should be checked if there are suitable inventory slabs that could be used instead of casting new ones. This is called slab inventory problem, which is described more specifically in Section 5.9.5.

C. Scheduling of steel plant

When scheduling the steel plant, the required slabs are first combined into complete smeltings. The smelting plant casts and cuts them into mother slabs according to the plan. The term "batch" means here a group of slabs that can be smelt in the same smelting series because of their grade and chill size. The output is always the best when the primary chill size is used. The output of the slabs made with secondary chill size or secondary grade is always worse because of the quality costs or the weight losses.

The slabs are chosen from the order batch according to their urgency. The first priority is to handle unfinished orders and parts of individual orders that are behind the agreed schedule. If there are no suitable storage slabs available for the remainders that do not make a complete smelting, a new smelting must be ordered and some storage slabs may have to be produced. Smeltings are always planned to be complete by inserting suitable slabs to the part of the smelting that is left over from the actual need. After urgent orders all the complete smeltings of each chill size and each grade are planned. Then it is time to plan complete smeltings with secondary chill size and at last complete smeltings having secondary grades.

Planning of smeltings is a very difficult task because costs are increasing when using secondary chill sizes and grades. However, it is nearly impossible to make smeltings complete by using only primary chill sizes and grades. The available casting strip is tried to utilize as well as possible. In addition, the number of storage slabs is being tried to minimize by combining different customer grades into the same smelting as much as possible. Several smeltings of the same grade are tried to combine to a series that can be cast without any breaks and grade changes.

The slabs of a smelting are combined to mother slabs after choosing the slabs included to the smelting. Then the planning problem is to divide the slabs included to the casting strip to mother slabs without breaking the length limits. The cast and slab design problem is described more detailed in Chapter 5.9.6

D. Slabyard operations

After the slabs are cast, they are taken to the slabyard where they are inspected. The cast mother slabs are compared to the planned mother slabs and if there is any deviation between them, the plan must be changed. Possible causes for this can be e.g. deviations in weight, casting faults, and grade deviations. In that kind of situations the faulty mother slabs are taken to reconditioning or the contents of the mother slabs are canceled.

E. Scheduling of re-heating and rolling

After casting, slabs are usually cooled down a bit before they are taken to hot rolling. However, the steel temperature must be about 1200°C when the hot rolling begins and that is why the slabs must be re-heated. The problem of scheduling the re-heating furnaces comes up when there are slabs requiring different heating times. This can be because some grades need to be heated longer than others, some slabs may be larger than others, and some slabs may be much hotter than others when inserting them into the furnace. In addition, there can be totally cold storage slabs and purchased slabs, which naturally have to be heated quite long before they are ready for rolling.

The problem is that re-heating furnaces should feed hot rolling machines all the time without letting slabs cool down too much or be too long periods inside the furnace. In addition, the temperatures of the re-heating furnaces must be adjusted according to the slabs inserted. If the temperature is adjusted up and down very often, it takes a lot of time and money. So, that is why the re-heating furnaces should be scheduled according to the needs of the slabs.

A rolling sequence is the amount of strip or sheet that is rolled with the same rolls during the planned rolling period. A rolling period is the time between the roll changes. The rolling periods are rescheduled daily and they are based on the information about mother slabs, slabs, smelting orders, and planned orders. By planning the rolling sequences efficiently can be influenced to intermediate storages, lead-times, and delivery accuracy.

When planning the rolling sequences, the restrictions of the rolling mill must be taken into account. E.g. the thicknesses of slabs and their deviations can be restrictive factors. The differences between the solidity of sequential slabs may be a restriction and also the rolling cylinders run out along time and they must be changed from time to time. Some steel grades cannot be rolled by worn rolls.

The most important criterion in planning the rolling sequences is timing. When building up a sequence, the aim is to minimize the roll cylinder changes and maximize the utilization of the re-heating furnaces. That way the likelihood of successful rolling is maximized.

F. Scheduling of finishing lines

The term finishing line includes here pickling lines, hot-dip zinc coating lines, annealing stations, painting and laminating machines, and cutting lines. The scheduling of finishing lines includes defining of what positions are treated and when they are treated.

Available cooled coils and timeliness of the positions to be cut serve as a basis for scheduling the cutting and slitting lines. Some of the most important things to be taken into account are the available capacity, waiting inventories, and the cooling time of the coils. The aim is, as usually, to minimize the set-up changes and maximize the batch sizes.

5.9.4 Several Machines, Several Product Lines

Scheduling of the steel plant is not only choosing the best possible sequences and routes for material in order to use machinery as efficiently as possible. There are often several machines performing the same tasks: there can be several re-heating furnaces, rolling lines, pickling lines, zinc lines and cutting and slitting lines.

Multiple machines of similar type enables the production to flow more smoothly and uninterruptedly because machines can run continuously with different set-ups. For example, separate rolling lines can be set for different thicknesses of coils. Rolling line 1 may be adjusted to roll thin coils and rolling line 2 may be used for thicker coils. That way the total set-up times are decreased.

The same idea counts for re-heating furnaces. With multiple furnaces, the heating times of the slabs are more easily optimized and overheating problems are avoided.

Also zinc-coating lines can be programmed to make different types of zinc layers. Other lines may produce thicker zinc coatings than others. Also differences between zinc types can be handled more easily when having several zinc lines with separate zinc pots.

On the other hand, multiple machines of similar type make the planning procedure more complicated because in that situation there are much more to be planned. Situations when e.g. one rolling line is running all the time while the other one is idle must be avoided. The idea is to divide the coils to be rolled between different machines so that total set-up times are minimized and all the machines are utilized as efficiently as possible. If necessary, required set-ups must be done even if the machine is usually used for different types of products. There is no sense to pile up intermediate storages just to avoid extra set-ups.

5.9.5 Inventory Problem

Steel manufacturers produce slabs, coils and sheets usually on a make-to-order basis. However, surplus items can be produced for three reasons:

- Surplus materials are requested during scheduling to satisfy restrictions on machines and operations
- Materials are found to be out of specification during production
- Orders are cancelled

Some amount of inventory is desirable to accommodate rush or regularly placed orders. However, in many circumstances, inventory not only has a negative impact on cash flow, but also requires storage space. Hence, from the viewpoint of mill operation, it is important to use as much of the inventory as quickly and judiciously as possible.

When a steel manufacturer receives orders from customers, it is best to first consider the possibility of using existing inventory items for these orders instead of producing them from the beginning. It means that inventory application is performed as a preprocessing step to production planning. Orders that can be applied against existing inventory, either partially or completely, can be shipped to customers with appropriate additional processing.

The inventory problem can be stated as a matching problem, where a set of orders from the order book is applied against an existing inventory. The goal of inventory utilization is to maximize the amount of inventory items applied against the order book while minimizing the waste that might occur due to partial use of inventory items [IBM 1999].

5.9.6 Cast and Slab Design Problem

The cast design problem starts from a set of designed slabs, i.e. slabs that have specific dimensions and to which orders have been assigned. The task is to sequence slabs into charges, and charges into casts such that the following constraints are satisfied:

- Charge weight is within some minimum and maximum weight
- Cast weight is within some minimum and maximum weight
- Differences between widths of adjacent slabs are within limits
- The position of a slab within a charge and within a cast does not violate quality requirements of the orders assigned to the slab

Also the following objectives should be optimized:

- The production of stock slabs is minimized
- The average charge weight is close to some specified value
- Grade substitution is minimized
- Orders in the same cast have similar due dates
- Hot metal availability
- Converters capacity for the grades to make
- Secondary metallurgy capacity for the grades to make
- Ladle capacities

The Figure 5.17 below illustrates how castings are planned and how mother slabs consist of regular slabs.

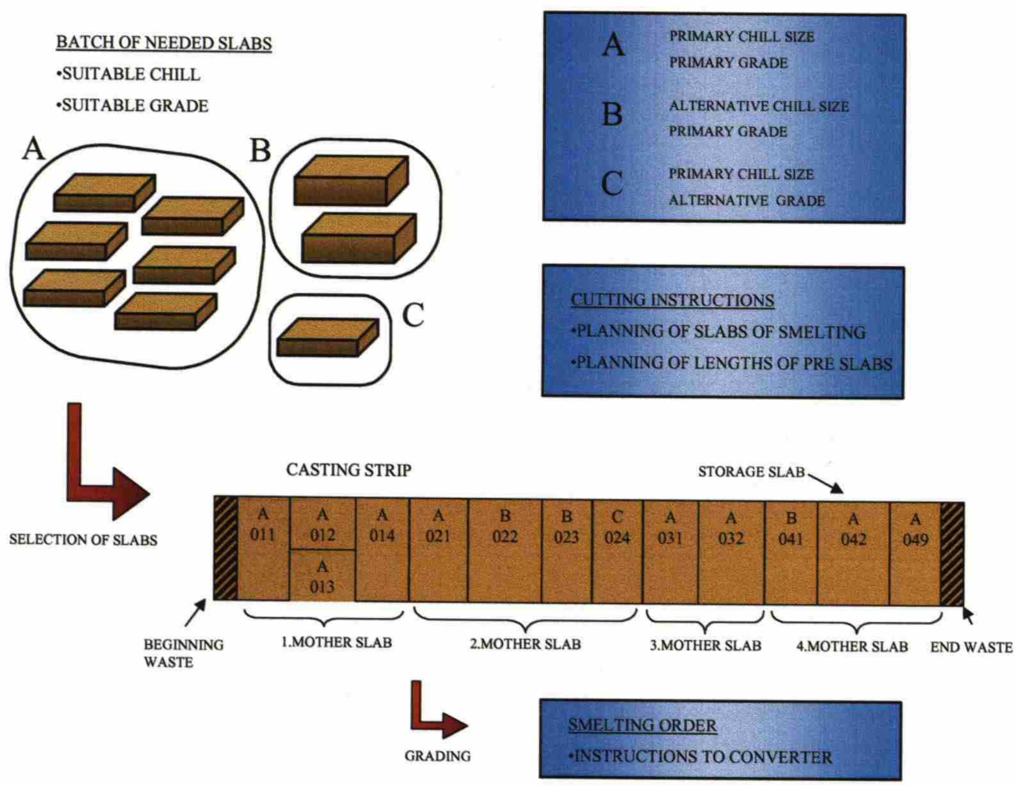

Figure 5.17 Principles of casting planning.

The figure shows a casting strip that is divided into mother slabs. It means that during casting the strip is cut between the adjacent mother slabs. The individual slabs are separated later. In the beginning of the casting series, there is always some amount of steel that is not of uniform top quality. The same situation is at the end.

As explained in earlier chapters, planned order positions can be made of three kinds of slabs. In the right top corner of the figure are the possible slabs that have the following properties:

A: Primary chill size, primary grade

B: Alternative chill size, primary grade

C: Primary chill size, alternative grade

The best option is always A, but sometimes it is necessary to use also other two alternatives in order to get casting series utilized as well as possible. Choice B means that the chill size is not optimal for required slab and that will lead to a greater amount of waste in some production phase. Choice C has the same problem with increased amount of waste and also the steel grade is not the best choice for the position concerned. Sometimes it may be difficult to give the steel the desired properties when using alternative grades.

5.9.7 Combining of Plate Products

The main objective of plate design is to create mother slabs, which are packed with plates from the order book so as to minimize the waste in each mother slab, while maximizing the size of mother slabs designed to fulfill the order book.

As Figure 5.18 shows, in the beginning of the plate combining process there is a group of ordered sheets or plates that may have different grades and sizes. The ordered sheets that have the same quality and the same thickness are taken to a batch. After that, a raw sheet is made of the batch of sheets.

There are several things to take into account when planning raw sheets. Ordered sheets should be organized on a raw sheet so that the total side and end wastes are minimized. The width of the side waste is usually constant, which makes planning a bit easier. So is with the end waste too. Usually there are a couple of different slab sizes in a steelworks, and that is why the sizes of raw sheets are fixed. The most important thing in sheet combining is minimizing the number of different slab sizes; i.e. minimizing the number of used chills.

Another important thing to be optimized is the number of raw sheets. That is obvious, because that way the waste is minimized, of course. The third thing to take into account is the direction of rolling. Some sheets must be cut so that the specified length is parallel with the rolling direction.

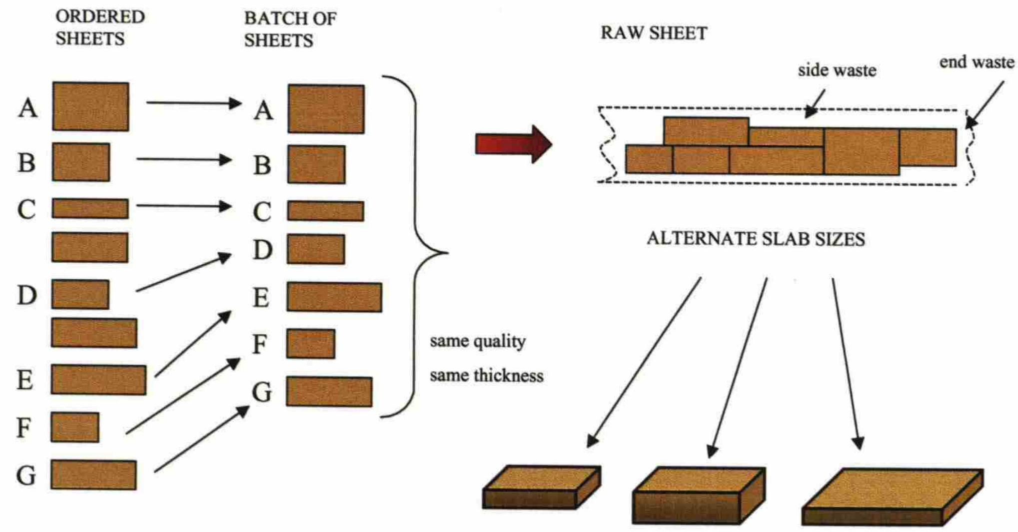

Figure 5.18 Combining of plate products.

Sheet design is a two-dimensional packing problem that can be described as follows. We have as input N demand rectangles (sheets from the order book) of length l_i and width w_i, $i = 1, \dots, N$. We have available a set of stock rectangles (mother slabs) $\{R_1, R_2, \dots, R_m\}$ of given length and width. The goal is to find layouts for cutting all demand out of stock rectangles so that we use a minimum number of stock rectangles. A mother slab can have only a limited number of demand sheets placed along each of its axes. It is assumed that the thickness of all the sheets in a mother slab is the same.

The plate design problem is conceptually very similar to the slab design problem where slabs are designed to minimize partial surplus while maximizing the size of slabs designed to fulfill the order book. Since the packing of orders into slabs involves only weight, this problem is a one-dimensional packing problem [IBM 1999].

When there are optional slab sizes, the optimization problem is divided between the slab size selection and organizing the ordered sheets on the raw sheet.

5.9.8 Combining of Strip Products

Just like with plate products, strip product orders are combined too. In the left side of Figure 5.19 there are different steel web orders. Orders that have the same quality and the same thickness are taken to the same batch.

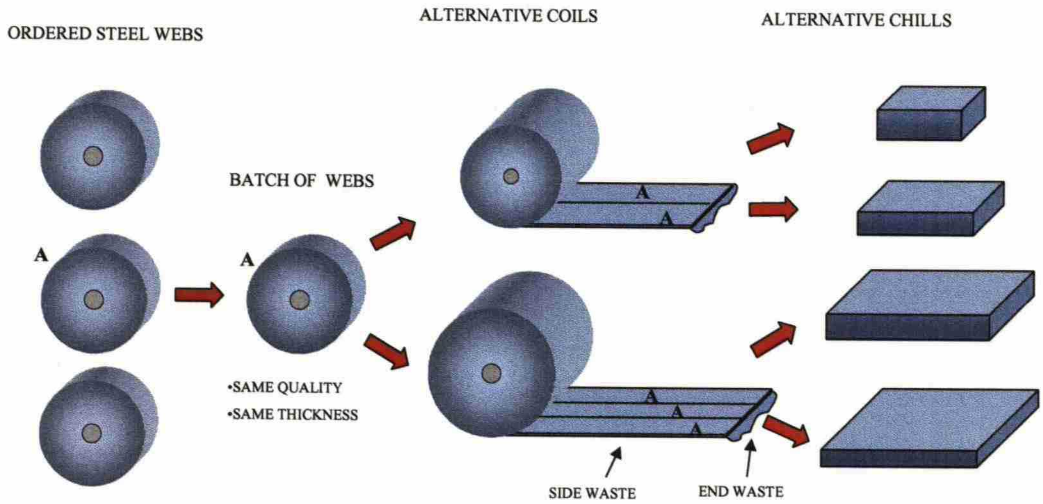

Figure 5.19 Combining of strip products.

After that, the type and size of the coil from which the desired webs are slit must be chosen. And after that, there is another chose to be made when deciding what kind of chill to choose. Once again, there are some alternative chills that all have different dimensions. The chill should be chosen so that all the orders of a batch would be satisfied with minimum waste and minimum number of coils.

5.9.9 Sources of Problems and Discontinuities in Production Planning

As described before, the unit processes of the steel industry are quite complicated and also quite difficult to break down into well-structured partial problems that could be solved separately and independently of each other. It means that all the parts of the process have their own requirements and specific rules that have to be noticed when planning the production. Those special requirements are described here.

Re-heating furnaces

Some steel grades need to be heated longer than others, some slabs may be larger than others, and some slabs can be much hotter than others when inserting them into the re-heating furnace. That is why different slabs need to be heated different times and also in different temperatures.

When starting the rolling, the slab temperature has to be as high as around 1200°C. Because we are talking about such high temperatures, it means that it takes a lot of energy and also some time for a slab to get warm enough. Of course, the colder the slab when inserting it into the furnace, the longer it takes to heat it up to the acceptable temperature.

Usually re-heating furnaces are pusher type furnaces, which means that they follow the FIFO (First In, First Out) rule. So, the slab inserted first into the furnace must be rolled first, because its temperature goes down quite quickly after taken out from the re-heating furnace.

Because the furnaces are usually of pusher type and they follow the FIFO rule, it is necessary to sequence the slabs into the furnaces according to their temperatures. If there would be a totally cold slab between two much warmer slabs inside the furnace, following problems could arise: if the furnace would be adjusted according to the warm slabs, the colder slab would not be warm enough when it would be its turn to get rolled. If the furnace would be adjusted as the coldest slab requires, the two warmer slabs would be overheated and they might smelt inside the furnace. That kind of situation is to be avoided as well as possible.

Just this kind of sequencing situation is not very typical but it illustrates the problem at hand quite well. Initial slab temperatures must change step by step or the temperature of the furnace must be adjusted when there is no slabs inside that could cause serious problems.

The ideal situation would be that the slabs could be taken to the re-heating furnaces straight after casting. Then they would be still quite warm and the re-heating time would be shorter. Also energy savings would be remarkable.

However, re-heating furnaces should be able to feed hot rolling machines constantly with slabs suitable to be rolled sequentially. The suitable rolling sequences are handled later.

Rolling

In hot rolling, the problem is how to sequence the desired slabs so that the rolling machine is capable of producing the best possible quality. The widths of slabs should not change very much at a time when rolling. Also the thickness of the desired strip or plate should not change much at a time. This is because the rolling force, strip tension, rolling speed, roll flattening, and the friction conditions in the roll gap are computer controlled during rolling and too big variation confuses the procedure severely.

The sequencing order of rolled slab thicknesses is presented in Figure 5.20. When the rolls are still quite new, the quality is not the best possible and that is why it is better to start rolling with a bit thicker strips and then move gradually towards the thinnest ones. As the figure below shows, the first thickness is 8mm, the thinnest one is 2mm and after that, when the rolls are already quite worn, the sequence goes back towards thicker strips. Of course, thick strips can be rolled also in the middle of the roll period but usually the thinnest ones get the best quality when rolled as the figure suggests.

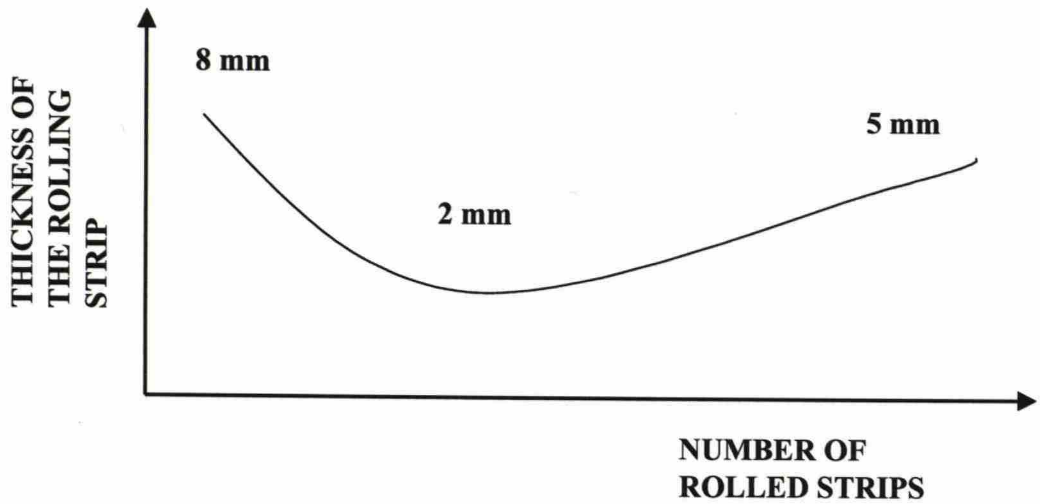

Figure 5.20 Example of sequencing order of rolled slab thicknesses.

Another thing to notice is the widths of the strips to be rolled. With new rolls, the rolling should be started from the widest strips and then move towards to the narrower ones. The reason for this is that the edges of the strips may leave some marks on the rolls. If the widest ones are rolled first, then there is no problem of bad quality due those marks.

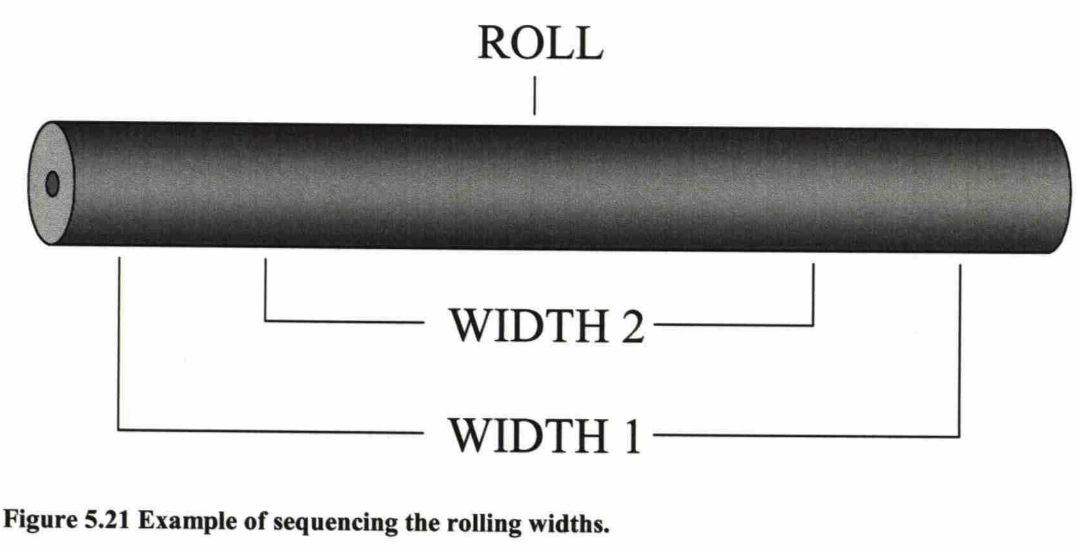

Figure 5.21 Example of sequencing the rolling widths.

As the Figure 5.21 above suggests, the width 1 is rolled first and after that the width 2. Naturally, there can be a lot of other widths too but in order to be simple, this example contains only those two. This problem is generally known as the coffin shape problem. That name comes from the shape of the rolling pattern. Sometimes it is better to start with narrow products, move then to wider ones quite quickly and after that return gradually back to the narrower products. As the Figure 5.22 illustrates, the changes of rolling with draw a coffin shape pattern.

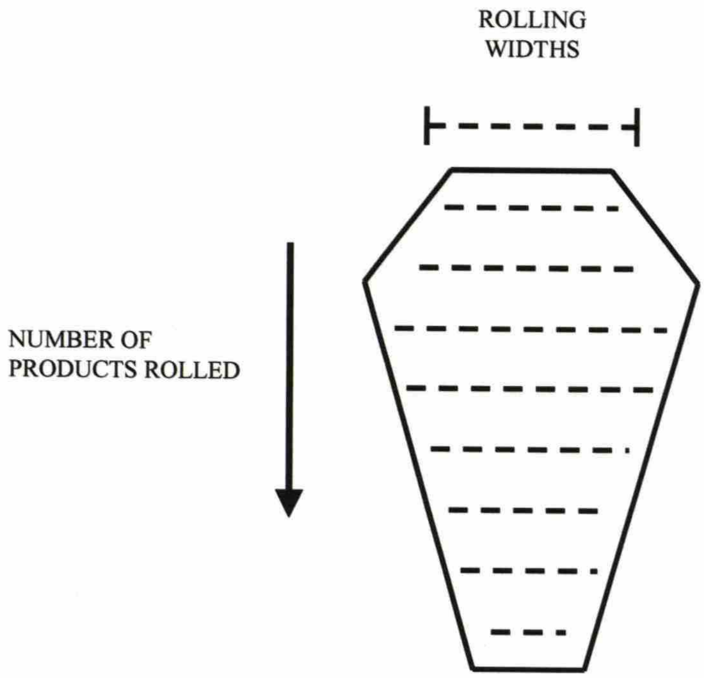

Figure 5.22 Coffin shape problem.

Pickling

The pickling procedure is carried out in a closed, continuously operating system. At the entry end of the pickling line, strip ends are cut off and spliced in a flash welding machine so as to form a continuous strip to pass through the line in one piece.

When splicing strips of different thicknesses, there is once again a problem. Too big leaps in thicknesses may be impossible to handle and they may cause serious problems later. So, strips with different thicknesses should be scheduled so that changes are performed gradually. If there is no possibility to put a strip of suitable thickness between two mutually incompatible thicknesses, a waste strip can be used. Waste strip means a short strip that is spliced between two normal strips in order to balance the difference between them. Usually those waste strips are re-used as many times as possible.

Differences in strip widths cause the same problems as with thicknesses. Waste strips are the solution here as well.

Zinc coating line

Cold-rolled steel can be galvanized on a hot-dip zinc coating line. This line has exactly the same problems as the pickling line has. Widths and thicknesses have to be arranged same way as with pickling. In addition, there are some other things to be taken into account as well.

After zinc coating the strip is cleaned in a furnace. After that, the strip continues to the actual heat-treating furnace, where it is heated to the required temperature, which depends on the steel grade and its mechanical properties. If two consecutive strips require a heat-treatment in different temperatures, a waste strip is needed also here. When the waste strip goes through the treatment, the temperature can be adjusted to the suitable level.

Sometimes there are grades that require thicker layer of zinc than others. In that kind of situations, a waste strip is needed once again.

Batch annealing station

The annealing temperature is generally around 700 °C but it depends mainly on the steel grade and the required properties. The annealing time is set according to the coil dimensions and weight.

Because the capacity of the annealing station is limited and all the coil types cannot be annealed simultaneously under the same cover, the procedure has to be planned in advance. In order to save energy and utilize the annealing capacity as well as possible, it would be good to get full batches.

Coil coating lines

After zinc coating, coils can be painted or laminated. In addition to all sources of problems mentioned before, there are still some additional ones when talking about coating lines. Naturally, different types of coatings may require different kind of treatments but the biggest problem is paint changes. Every time a color is changed, the whole machine has to be washed. When painting special colors, the availability of paint may be a problem. Sometimes the paint has to be tested with a sample unit before the whole customer coil can be colored.

6 Similarities and Differences between Paper and Steel Production Planning

Now the characteristics of both the paper and steel making processes and their production planning have been introduced. In the beginning of the thesis, there was a rough abstraction of the processes and at that time it seemed to be obvious that the processes have lots of common attributes. After scrutinizing the processes and their planning principles and methods, their similarities are not so obvious any more.

This chapter describes the most important similarities and differences of the processes.

6.1 Differences

As said before, on the superficial level the processes look alike. But when you look deeper and study the characteristics of the unit processes, you see that there are lots of differences between them. The paper producing has less separate production phases and the production time is much shorter than in the steel industry. It means that in a steel plant there is also much more work in progress.

Lead times in a steel plant, depending on the desired treatment, may be up to 5 weeks. During that time, there may be a lot of changes in the schedules. Also because the unit processes of steel production have all their own special rules, requirements, and restrictions, the production planning and scheduling for a specified order is not done at a time. The product route is usually determined at once, but scheduling of the unit processes is often done locally at the machines concerned.

6.1.1 Grade Cycles

Chapter concerning paper industry production planning described how different paper grades are produced cyclically and how the cycle periods are planned in advance. Of course, the cycle periods are not very strictly binding but usually it is known in advance what kind of grade groups are produced and when they are produced.

In the steel industry, there are no such cycles as in the paper industry. It could be said that the cycle of a steel plant is one smelting. Still, the cycles are not predetermined. Customer orders determine what grades are produced. Of course there is always intention to make smelting series as long as possible but the grade changes are handled much more easily than in the paper industry.

6.1.2 Grade Changes in Paper Industry

Grade changes along with trimming losses are the biggest sources of waste in the paper industry. As described earlier, the changes between different grades or grade groups are tried to make smoothly so that the properties of paper are changing as little as possible at a time.

Several adjustments need to be done for example in the pulp composition every time the grade is changed in the paper machine. The required set-up time of adjustment is dependent on both the grade before the change, and the target grade. The bigger the adjustments are, the more time it takes before paper of uniform quality can be produced with the new grade. This set-up time can vary from some minutes up to several hours. In the worst case the paper machine must be stopped and cleaned before the grade change can be performed and the paper fulfills the requirements of the new grade.

This production set-up time has significant financial influences. Production planners try to minimize this by grouping paper grades according to their grammage.

Grade change costs can be categorized into two:

- Costs due to production of poor quality products. E.g. energy and material.

- Costs due to wasted production capacity.

The cost of poor quality product remains same despite of the state of the economic trend. This is not the case with the wasted production capacity. In the state of high demand the lost capacity is valuable because the missed production could have been sold with a profit. In addition to this, the wasted production may cause delays in the subsequent production. In the state of low demand the situation is different. Then the cost of lost production capacity is negligible.

If a paper machine produces e.g. three different grade groups, the costs of grade changes between each of them (to both directions) are determined in advance. Also the required change times are normally known beforehand. See Figure 6.1 below.

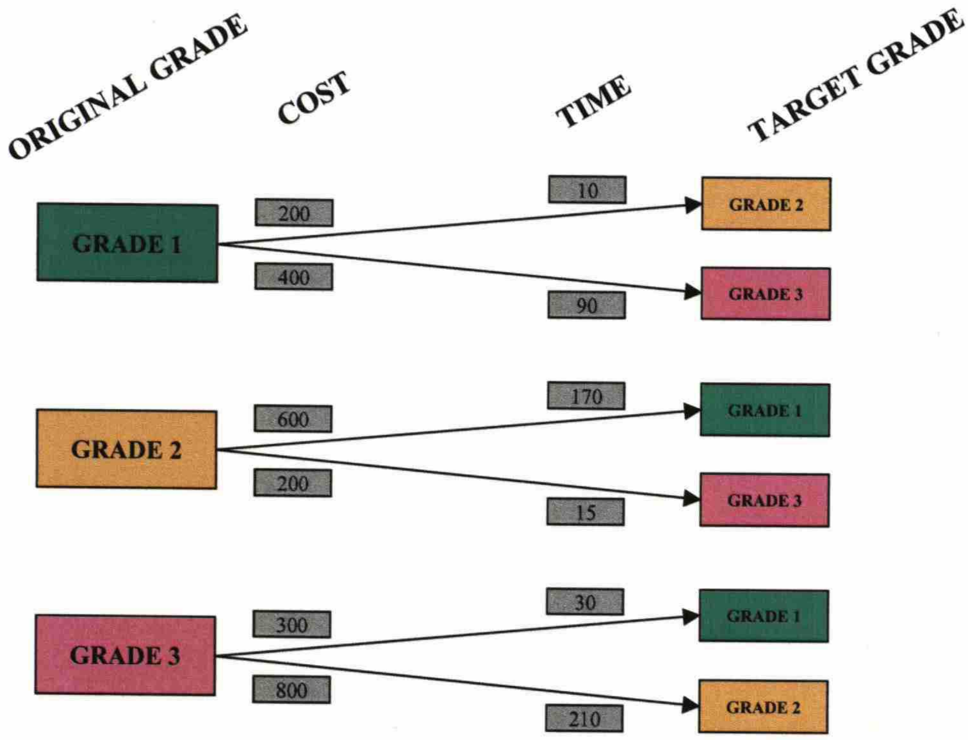

Figure 6.1 Grade changes in a paper machine. The numbers in the figure are fictional.

On the left hand side of the picture there are grades from which we want to change to the grades that are on the right hand side. Each change takes some time and some cost. The cost numbers and change times in the example are fictional.

6.1.3 Grade Changes in Steel Industry

In the steel industry, there has to be done grade changes in almost all machines because the types of products differ quite a lot from each other. However, in this context when we are comparing these two types of industries, we have to look at the grade changes at the smelting plant, not at single machines.

In the steel industry, the changes between different steel grades are not as remarkable and long lasting as grade changes in the paper industry. When it is time to change grade, the converter is charged with materials suitable for the target grade. That is not a problem at all, because converters have to be recharged every time the batch is poured down for further treatment. Thus, recharging must be done regardless of grade changes.

The next question is how grade changes affect on casting. In a continuous caster, the steel strip runs continuously. When the steel grade is changed, the ladle is changed just like it is changed normally without a grade change. Only the properties of the molten steel inside the ladle are different. So, the only loss that comes from the grade change is one slab having two different grades mixed in their junction. Depending on the types of the grades concerned, it may be possible to sell the mixed zone as over grade. However, a slab having two different grades in it may be quite difficult to roll. Different grades have different mechanical properties that usually have to be rolled with different machine set-ups. This makes things difficult and that is why slabs of transitional grades are usually smelted again in later charges.

As a conclusion, we can say that grade changes are more easily handled in the steel industry. They can be made without planning them long periods before the actual change. Grade changes in the steel industry compared to them in the paper industry are very much different. The nature of the problem is different and so are the solutions.

6.1.4 Structure of Orders

When a customer orders some paper from a paper mill, he determines very strictly and accurately what kind of properties he wants. He informs the paper producer about the pulp type, paper grammage, brightness and many other things. In the steel industry, the customer usually defines only the limit values between which the desired metallurgical properties must be. This gives steel maker more possibilities to combine different orders and sequence production more efficiently. So, the structure and accuracy of orders differ from each other in the industries concerned.

In a paper mill, mostly the production cycle and the production situation determine when the customer may have his order delivered. In the steel industry the customer has more power. Of course, the general production situation determines how much and how fast desired products can be produced but still the customer can affect more than in the paper industry.

Actually the grade changes in the steel industry are determined by the customer orders. Of course, smeltings are tried to be planned plan so that casting sequences are as long as possible but when the order situation says that the grade change should be done, it is done.

Paper products have usually an exmill date that is the date when the order must be delivered. In the steel industry, there is usually no such thing as exmill date; there people are talking about exmill week. One reason for this is that steel products have a lot longer production time than paper products do.

6.1.5 Rolling

Rolling is a production phase that changes the properties and appearance of steel more than any other phase. It changes both the physical and the metallurgical properties of steel. All steel products are rolled somehow. Every slab is first hot rolled and some of the hot rolled coils are then cold rolled. So, rolling is very important part of steel production. Rolling, especially cold rolling requires a lot of set-ups for different types of products.

The same kind of production phase in the paper industry is calendaring, which means that paper is compressed with several rolls by means of temperature and pressure. The calendering process may require some scheduling because there may be different types of treatments and the set-up times should be minimized as always.

Even if rolling and calendering have a couple of similar things, it does not mean that the processes would be closely related. Rolling changes the metallurgical and physical properties of steel very much. The dimensions of steel change very much when a short and thick slab is rolled into a thin and long coil. Also calendering changes the properties of paper but the changes are very small compared to the changes in steel rolling.

6.1.6 Non-Stop-Working Production Phases

The steel industry has several non-stop working production phases like pickling, zinc coating, painting, and laminating. It means that the separate coils are attached to each other in the beginning of the line and the strip runs unbrokenly through the whole line. At the end of the line the strip is cut again into coils of desired tonnage.

These continuously working lines have a lot of machine specific requirements and restrictions. The physical dimensions of the strip must not change a lot in a too short length. Also the type of the treatment should be changed smoothly. E.g. the thickness of the zinc layer cannot be changed instantly very much. Paint changes in painting machines mean that the whole machine must be cleaned before new color can be used. This and all the other reasons mentioned above make the problem of sequencing jobs quite complicated.

In the paper industry, there is no such thing as this. All the after-treatment phases are executed for separate rolls. There is no need for joining reels like in the steel industry. When the rolls have to be changed, it is easy to change the machine set-up at the same time. There are no restrictions between successive roll dimensions. Of course, it is always good to minimize set-up times, but the nature of the problem is different between these two industries.

6.2 Similarities

6.2.1 Positioning of Orders

In the paper industry, orders are positioned according to their desired properties like pulp types, grades, colors, and grammages. Paper machine has several blocks that consist of runs. Runs comprise of orders of similar type.

In the steel industry, positioning of smelting orders is done in a similar manner. Grades and target thicknesses are the most important factors in optimization. Those two determine also the grade changes.

Basically, the positioning and sequencing of orders is quite similar in both industries. Even if they have different scheduling priorities, the basic principle is the same. Immediately when a single order is positioned, the production route is known in both industries. Exact timing and scheduling are usually done later, especially in cases of the steel industry.

As the paper industry is looking for smooth grade and grammage changes, the steel industry wants long casting series. When talking about these two areas of industry, these planning problems can be considered to be almost same.

6.2.2 Trimming

In the paper industry, the trim loss is the biggest source of waste along with grade changes. Trimming sequences are planned already when customer orders are inserted in to the system. With effective trim scheduling, a paper mill can have remarkable cost savings even during quite short time periods. One could say that planning the trimming is one of the most important production planning phases in the paper industry.

Steel plants are also producing coils that have to be cut and slit. There is a same kind of problem but it is not so serious. The reason for this is that the width of the slabs can be adjusted according to the desired width of coils. So, the trimming result can be improved by means of efficient planning in the smelting and casting plant. Usually, the edge strip that is slit away is of standard width and it is taken into account already when planning smeltings and slab sizes.

However, when making plate products, there is a lot of potential for production optimization. The problem is how the ordered customer sheets should be organized on a raw sheet so that the total side and end wastes are minimized. This is like the paper-trimming problem but in a smaller scale.

In general, we could say that the both industries have the same kind of trimming and ordering problems but in a different scale. Within the paper industry, the problems have more severe and costly consequences.

The companies that are reprocessing the steel have exactly the same trimming problem as in the paper industry. Usually the reprocessing companies do not know beforehand how they will slit the ordered coils. It means that they usually order coils of standard width and then they have to optimize the usage of material according to the customer orders. E.g. a reprocessing company making steel pipes has to optimize the usage of the width of the coil when slitting it into webs. Thus, the trimming problem is exactly the same as in the paper industry.

6.3 About Abstractions and Process Models

In the beginning of this thesis (in Chapter 3), we made an abstraction of the processes. We saw there that the basic principle of the both industries was first to make bigger units of basic products and then cut it down into smaller pieces, which could all have individual properties and dimensions. Abstractions on a superficial level are beneficial because they help to see the basic similarities between the processes. They also give simplified knowledge about how similarly things can be seen when looking at them on a superficial level. However, we are not going to go into deeper level of abstractions any more. Instead of trying to put both industries under the same umbrella, it is better to make straight comparisons between them. That is because the way the production is planned differs so much between the industries concerned.

When making abstractions, there is always danger to get too abstracted and then the focus may be set on wrong targets. In this situation, similarities and differences are more easily seen without deeper abstractions.

In addition to making abstractions, the initial idea was to use some standardized process-modeling notation to model the processes. After a general survey about different modeling notations, there were two alternatives to choose from: UML (Unified Modeling Language) and IDEF (Integrated Computer Aided Manufacturing (ICAM) Definition Language. After familiarizing with them, the final decision was not to use either of them in this thesis. Deeper investigations showed that process models made with UML or IDEF would have only made the problem more complicated. Neither of them turned out to be very good for modeling these production planning processes in way that would have been as illustrative and clear as desired.

UML is as its best for modeling software and organizational processes but using it for comparing two different processes is difficult and complicated. The notations of the IDEF-family have the same kind of problems. A thoroughly made process model would have had too many different levels that would make comparisons too complicated. Another reason why the processes were not modeled with some standardized notation was that the similarities and differences were quite easy to see without standardized models. Instead, the models might have been quite confusing and steer the conclusions to wrong direction.

6.4 Comparison between Production Flows

Below is a comparison between the production flows of the processes. The top row of Figure 6.2 below illustrates the most common production phases of paper. Not all of them are always performed to all kinds of products, but they are taken into the picture just for comparison. See descriptions of other rows in further chapters.

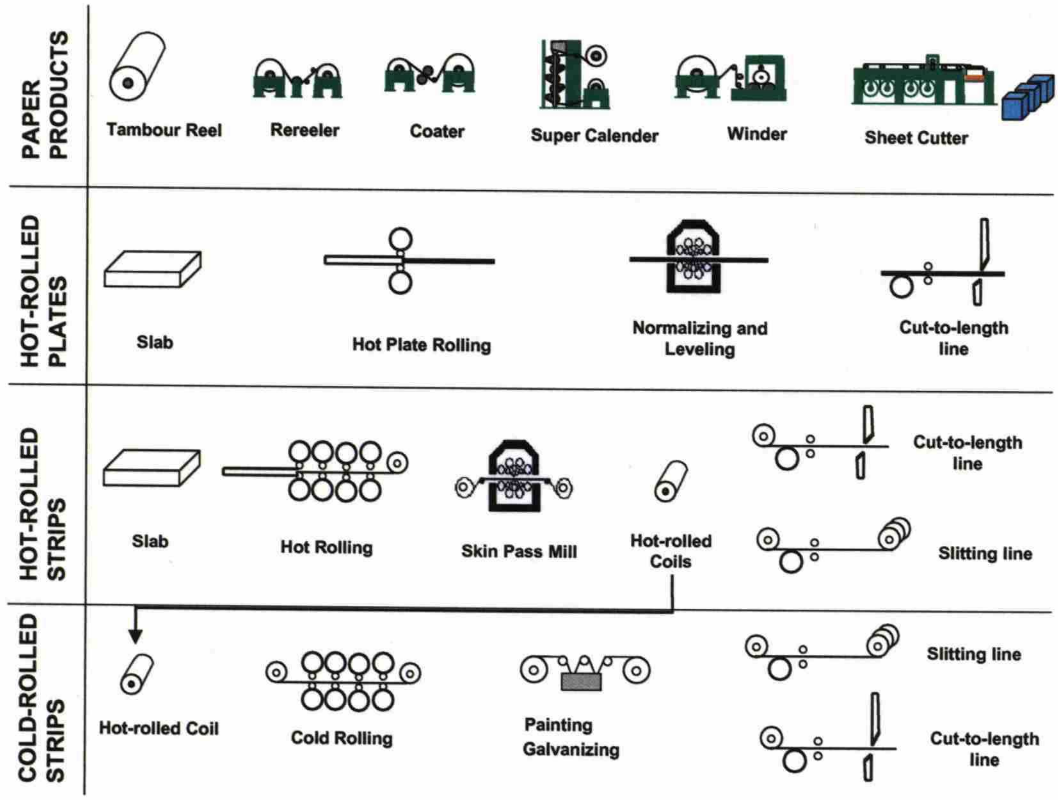

Figure 6.2 Comparison between the processes.

6.4.1 Hot-Rolled Plates

The second row in the figure illustrates how hot-rolled plates are made. The figure contains only the most important production phases that somehow change the appearance of steel. Production phases that are left away from this figure are also very important but they do not change the properties of steel that much. They are e.g. marking, coiling, and cooling.

The most obvious similarities between paper and hot-rolled plates production are in the very beginning and at the very end of the processes. As explained earlier in Chapter 3, jumbo reels and steel slabs can be considered to be products of similar type. They are treated and shaped in many machines that cannot be compared so straightforwardly. At the end, you finally cut products into customer specified dimensions. The cutting procedure is very similar in both processes.

6.4.2 Strip Products

The third row contains the production flow of hot-rolled strip products. There the similarities are more obvious because we are talking about strip products. As with plates, the initial situation is that we have a slab that is rolled into a strip. After that the similarities become more visible. The skin pass mill in the steel production line is like coater of super calender in a paper mill. All of them change the properties of the surface of treated material. Because we are now talking about steel strips that are very similar to paper reels, the cutting and slitting procedures are very similar. Both cutting processes have same kind of objectives, restrictions and problems. Naturally, the solutions are alike too.

Some of the hot-rolled strips are also cold-rolled. There the comparison to paper products is the easiest one, because in the beginning the both processes have roll-kind of products. The most obvious similarities are in the different kind of coating lines. Steel strips can be coated with zinc, paint, or plastic layer. Similarly paper products are coated with e.g. clay or polished in a super calender. The cutting and slitting are similar than with hot-rolled products.

7 Conclusions

In the beginning of this process – to make this master's thesis – there was some knowledge about steel industry and a lot of knowledge about paper industry. The paper industry production planning was already explored quite deeply and the most challenging problems were solved at least at some level. The knowledge concerning the steel industry was quite restricted. It was known that the basic idea of the steel process was like producing paper. Also the appearance of the end products was known to be similar to paper products. However, the production planning was mostly unknown except that there was same kind of trimming problems in the steel industry as in the paper industry. Also the characteristics and steering principles of the separate unit processes were unknown.

Now, at the end of this thesis, there is more information about steel industry. Just to mention a couple of things, now there is knowledge about how the production flows, what production phases there are, and what has to be taken into account when planning production sequences. There is also a lot more information.

The paper and steel processes look quite similar on a superficial level but after more specific explorations, the differences pop up one after another. Adapting the same production planning and scheduling principles to both industries is not easy. Still, it is not impossible. Things just have to be explored more deeply and thoroughly than the scope of this thesis enabled.

In a paper mill, the paper machine plays a very big role in production planning. Usually the after treatment machinery is capable of executing jobs that are assigned to it and that is why the paper machine controls the whole production chain.

In a steel works, the smelting plant does not have as big role as the paper machine has in a paper mill. In the steel industry, there are also many other very important and sensitive production phases that require careful planning.

Usually paper is produced in cycles, where the properties of paper are changing gradually. That is one of the most important things that make the steel production planning so much different. Grade changes are much more easily performed in the steel industry.

The production planning in the paper industry is much more comprehensive than in the steel industry. Although the steel industry has many complicated unit processes to be planned, the planning is not done at once. The production route is decided almost always in the very beginning of the process but the scheduling of the unit processes is done more or less individually. There are usually intermediate storages in front of the production lines that help to balance production. Another reason for intermediate storages is that often steel has to cool down before further treatment. That justifies intermediate storages at least at some level.

When thinking about the question if it is possible to use the similar kind software for the steel industry production planning than for the paper industry production planning, the answer is: "Yes, it is. You just have to change a lot of things in order to do that." The software itself could be quite similar. When the paper industry software shows grade changes and production schedules for different paper types, the steel industry software could plan the functions of the smelting plant: it could show the slab dimensions and casting series in a similar manner. Of course, the optimization algorithms and the visual appearance should be different but the paper industry software would be a good basis for the steel industry software.

Also the trimming and sheet cutting software could be used for steel. As said many times, the problems are the same at that area. Probably that is the clearest and easiest way to adapt the paper industry software to the steel industry. The unit processes of the steel production between smelting and cutting are so much different from the paper processes that there is not very big changes to adapt the existing paper industry planning software for the needs of those individual processes of steel.

As a summary, there are some possibilities to utilize the paper industry production planning methods for the purposes of the steel industry. However, it requires lots of work and lots of further research.

8 References

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