Chapter 1. PLANNING PROBLEMS WITHIN THE CARDBOARD INDUSTRY

1.1. Introduction

The source of all “planning problems” is uncertainty. The management of a cardboard company must react to uncertain events that threaten the realization of the approved performance criteria. What are appropriate ways to control the impact of uncertainty? Phenomena affecting the planning problem can be analyzed in order to control the impact of uncertainty. These phenomena cover a broad area and a large part is beyond our scope of interest because they do not significantly affect the planning problem. We restrict ourselves to phenomena that affect the planning problem and that are related to the planning and scheduling domain within a cardboard plant.

What do we mean by the concept of the planning problem? The planning problem is the problem that might appear when someone, for example a production planner, must make a plan. In order to formulate the plan, groups of entities, whereby the entities originate from different groups, must be assigned to each other. The assignments are subject to constraints, and the available alternatives are compared based on their level of objective realization. Generally, the objective of a company is to arrange customer order due dates to deliver a certain amount of product to the customer such that the profits or other performance measures are maximized.

We introduced the definition of the planning problem and linked it to uncertainty. Aspects that affect the planning problem are phenomena related to:

- General industrial trends
- Characteristics of the process industry
- Characteristics of the cardboard industry
- Location of the cardboard industry in the supply chain and the bullwhip effect.
The following sections examine the phenomena related to the above-mentioned aspects.

1.1.1. *General industrial trends*

General economic trends are globalization and mass customization. These trends also drive existing industrial trends that will increase in the future.

General industrial trends indicate that customers demand reduced time windows for due dates, increased product variety, smaller order quantities, and higher quality and reliability standards. The general industrial trends demand more flexibility from the production process of a cardboard factory, thus complicating the planning problem (apart from the cardboard industry and the specific characteristics of the process industry). For a more detailed introduction of industrial engineering we refer to Salvendy (1992).

1.1.2. *Characteristics of the process industry*

Besides the cardboard industry, there are many process industries in the Netherlands, such as the manufacture of bulk chemicals, glass production, paper production, and steel molding. Normally, the process industry is characterized as an industry that produces batches of products (see Fransoo, 1993; and van Wezel & van Donk, 1996) compiled an inventory of characteristics of food process industries. Here, we only present the characteristics that generally apply to the process industries:

1. *Plant characteristics*
   a. Expensive and single purpose capacity lead to limited product variety and high volumes. Additionally, this leads to a flow shop oriented factory design.
   b. There are long set-up times between different product types.

2. *Product characteristics*
   a. In contrast to discrete manufacturing that uses fixed entities, volume or weights are used.

3. *Production process characteristics*
   a. Processes have a variable yield and processing time.
   b. At least one of the processes deals with homogeneous products.
   c. The processing stages are not labor intensive.
   d. Production rate is mainly determined by capacity.

The combination of plant, product and process characteristics indicate that process industries have complex planning problems. Cardboard industry denotes a particular branch of industry that belongs to the process industry. Given the particular characteristics of the cardboard industry, the planning problems in this area may even be more complex. The next section discusses the specific characteristics affecting planning problems within the cardboard industry.
laminated on the layer that is manufactured on the cardboard machine. The lining paper is manufactured on the paper machine, which is considered the second stage of the manufacturing system. Depending on the size of the cardboard sheets, an additional third stage is necessary; the sheets are cut into smaller dimensions after the second stage on the cardboard machine. Two types of machines can perform this stage.

In general, three stages will have been performed before the product is finished. Several dependencies exist among the three stages that may complicate the planning problem. Note that both the second and third stages are optional, depending on the characteristics of the product ordered.

As a general property of process industries, production occurs by batch. This also holds for the cardboard industry. However, we noticed that production machines are rigid and inflexible, making it difficult to completely revise previously formulated production planning. Production by batch combined with rigid and inflexible production machines makes the planning problem complex.

With respect to product characteristics, we consider two important elements, namely the options that determine the properties of the product ordered and the variety in weight, if the product is manufactured.

The customer has the following options related to the type of cardboard sheet.

1. A particular color can be specified. Generally, a mill has more than one cardboard and/or paper machine using the same water housekeeping. If a particular color runs on a particular machine, it may influence production on other machines within the same mill, giving additional constraints to the planning problem.

2. A cardboard sheet is manufactured in a particular caliper. Orders manufactured within certain time windows generally consist of several calipers. The planning problem also considers the sequence of calipers.

3. Liquid percentage varies between products. Some products require a lower liquid percentage than others. If more default liquid percentages are offered, it also introduces a sequence problem.

4. Dimensions of orders differ significantly. Each customer demands specific dimensions of cardboard sheets, suitable for a particular application. We consider dimensions as a parameter that increases product variety.

5. The customer has several options with respect to laminating the lining paper on the cardboard sheet. A maximum of two different lining papers can be laminated on a cardboard sheet above and/or below the inner layer that is manufactured on the cardboard machine. The option to select the lining paper generally results in higher product varieties, which may complicate the planning problem. The company reduces this complicating effect by reducing the product variety by means of offering a restricted standardized product range.
1.1.3. Characteristics of the cardboard industry

The characteristics of the process industry also apply to the cardboard industry in general. In addition to these characteristics, a number of special characteristics are also specifically applicable to the cardboard industry. Within the cardboard industry, two types of mills exist: solid board and corrugated board mills. Excluding detailed aspects, the planning problems from a planning point of view are more or less similar. We omit the special characteristics of corrugated board mills and emphasize the characteristics of solid board mills. We use the same subdivision presented above to define the characteristics of solid board mills:

1. **Plant characteristics**
   a. There is a maximum of three manufacturing stages: 1) production of lining paper, 2) production on the cardboard machine, and 3) converting activities, like cutting the cardboard sheets into smaller dimensions.
   b. Inflexible and rigid production machines.

2. **Product characteristics**
   a. Application of color, caliper, liquid percentage, dimensions, and laminating options of the lining paper on the cardboard sheet.
   b. Variable weight of a cardboard sheet per squared meter.

3. **Production process characteristics**
   a. Manufacturing on order versus manufacturing on stock; most production is on order.
   b. Trim loss. Orders run side-by-side. However, the machine width is generally not fully utilized; the amount of cardboard not utilized is called *trim loss*.
   c. Stacking cardboard sheets on pallets.
   d. Pallet height in relation to the demanded quantities.

*Plant characteristics* are related to the manufacturing system. Within a solid board mill, three stages can be considered: 1) production on the cardboard machine, 2) production of lining paper on the paper machine and 3) converting activities. Figure 1 shows the stages; it presents both the output and the type of processing in a particular stage.

![Figure 1: Three-stage manufacturing system](image)

In the first stage the products (cardboard sheets) are manufactured on the cardboard machine. Depending on the caliper, which shows the thickness of the cardboard sheet, lining paper is used as additional input on the cardboard machine. Lining paper is
Variety in weight is more a result of the input that is used for production. Cardboard sheets are manufactured from old newspapers and advertisement magazines. Based on cost considerations, a particular grade of input is selected. However, the distribution of newspapers and advertisement magazine input changes over time, ultimately affecting the quality and the weight of the final product.

Production process characteristics that complicate the planning problem can be categorized into four elements. The first is the concept that most solid board mills manufacture on order, where each order has specific properties (as previously described). Only a small part of the whole output is manufactured on stock (in standardized dimensions and quantities). Thus, manufacturing on order implies a higher product variety that complicates the planning problem. The second aspect is trim loss. Orders generally run side-by-side. The combination of these orders results in a particular part of the cardboard machine that is not utilized. The part of the cardboard machine width that is not utilized is called trim loss. In order to manufacture economically, the trim loss should be minimized. The third aspect is the stacking of the cardboard sheets on pallets. Here, additional restrictions that may affect the planning problem arise. The fourth aspect is related to pallet height. Generally, a particular order runs side-by-side with another customer order. If the demanded quantity of one order is satisfied, generally the other order needs additional cardboard sheets. It ultimately leads to overproduction or underproduction of one of the orders that run side-by-side, or additional handling during production.

All these cardboard industry characteristics, with respect to the plant, the product, and the production process characteristics may complicate the planning problem. This makes it a challenging domain to perform research on how production planners cope with these types of problems.

1.1.4. The bullwhip effect in the cardboard industry

Cardboard plants deliver several types of products to customers, both in a national and an international market. This section emphasizes the location of the cardboard industry within the supply chain. The supply chain represents the flow from raw materials to final products and all intermediate stages. In this case, the supply chain starts at the cardboard manufacturer and ends at the consumer. Figure 2 is a graphic depiction of the supply chain.

Figure 2: Supply chain of the cardboard industry

The cardboard manufacturer represents the first stage of the supply chain, where cardboard is manufactured for use as an intermediary product in the next stage. The second stage consists of a factory that processes the cardboard, resulting in a final
product, like puzzles, books or files. In the third stage, the wholesaler orders the final product and delivers it to the shop (fourth stage). Finally, the fifth stage represents the customer purchasing the final product in the shop. Within the supply chain the so-called bullwhip effect causes demand variability, which shows greater fluctuations in the upstream direction. There are five major causes of the bullwhip effect: demand forecasting, lead times, batch ordering, supply shortages, and price variation, see Chen et al. (1999), Lee et al. (1997a), and Lee et al. (1997b).

The ultimate result of the bullwhip effect is high demand variability in the beginning of the supply chain; the cardboard factory is located at the beginning receiving all disturbances. Thus, the cardboard factory is faced with high demand variability, potentially complicating the realization of an adequate plan.

1.1.5. Recapitulation

The above-mentioned phenomena concerning the general industrial trend of reduced windows for due dates, increased production variety, smaller order quantity, higher quality and reliability standards, combined with characteristics of the cardboard and process industry respectively, the location of the cardboard industry in the supply chain, and the bullwhip effect, indicate that the planning problem is becoming more complex. These factors affect the complexity of the planning problem and the degree of freedom to solve the identified planning problem. It demands new strategies and solutions to the problem. For us, represents a challenge to investigate new ways to deal with the complex planning problem.

Several approaches have been proposed to cope with these factors. Galbraith (1973), and Galbraith (1977) discussed these types of problems from an organizational perspective. One method of coping with the complexity is to introduce planning support systems. However, the various planning support systems that have been developed for the cardboard industry were often too general. These systems have resulted in restricted support of planning problems and offer too fewer options to manipulate production plan proposals or existing production plans. Part of the mismatch can be explained by means of the origins of Enterprise Resource Planning systems (ERP) in Material Resource Planning (MRP). MRP was developed in the 1960s to support planning within the area of discrete manufacturing (see e.g. Bertrand et al., 1990; Brevé, 1990; Boskma, 1988; Slack et al., 1995; Bemelmans & Durlinger, 1995; and Dennis & Meredith, 2000). For an introduction of the concept of ERP we refer to Robinson & Dils (1999) and Motwani et al. (2002). Given the typology of a cardboard industry identified as process industry, a large part of the discrepancy comes from the applied conceptual framework that does not fit the appropriate concept of a solid board plant.

Based on the notion that current systems do not provide the required functionality, combined with the identified and strengthening industrial trends, the complexity of the planning problem (motivated by characteristics of the process industry in general, the cardboard industry in particular), and the location of the cardboard industry within the whole supply chain, we have identified a need for effective and efficient planning
support, which has stimulated the initiation of this research. We have now determined why it is challenging to deal with the planning problem. However, we do not know how human production planners handle planning problems and what types of planning strategies are applied during planning task execution. This topic is discussed in the following section.

1.2. Dealing with planning problems

1.2.1. Introduction

The basic planning problem at a cardboard company is to arrange customer orders in such a way the output of the production machines is maximized and the orders are delivered on time. In general, this overall planning problem is far too complex to be solved in a single step. It is broken down into smaller planning problems, thus reducing the complexity and making it more manageable (see Simon, 1981), but the problem is that the decomposition is not complete; Simon calls it nearly ‘decomposable’. A commonly accepted ‘decomposition’ of the planning problem in the cardboard industry is the following. Generally, a cardboard mill has more than one manufacturing machine. Thus, it is sensible to assign orders to a default manufacturing machine. Thus, it is sensible to assign orders to a default manufacturing machine depending on particular parameters.

The planning operates on two levels: a rough and a fine planning level. On the rough planning level, the machine load is controlled and pre-processing actions, such as which orders can be combined with a minimal trim loss, have been performed. At the fine planning level, the assignment of orders to a production schedule is finalized. If all desired orders are in the production schedule, it is ready to be released. The decomposed planning problem is solved and controlled by the human production planner. Problem solving is part of his task. A task is defined as an action that can or should be performed to achieve a particular goal (Vicente 1999). One or more additional planning problems may arise during the task execution. In order to solve these planning problems, the production planner may apply a particular planning strategy (Valente & Breuker 1998). A strategy is the application of meta-level management, control, and planning functions that affect the ordering and dependencies of processes in the process descriptions and problem-solving templates (Gardner et al. 1998). Thus, planning strategies are important elements in the planning task execution. A planning strategy guides the search to a solution of a particular problem.

1.2.2. Some examples of planning strategies

In this section we analyze examples of some relevant planning problems and show the applied planning strategies and their impact on the situation within a solid board mill. The planning strategies depend on the state of the mill at a particular moment. Planning strategies are based on a number of factors, including available capacity, stock levels of finished and semi-finished products, and the order book level.
The first example shows the effects of a low lining paper stock level.

**Example 1: Low stock level of lining paper**

The factory has both cardboard machines and paper machines. The production planner is planning a collection of customer orders with the same properties. Suppose the factory must manufacture laminated cardboard. This means that the cardboard uses lining paper as input. The lining paper is produced on the paper machine. In order to produce a certain amount of cardboard sheets on the cardboard machine, we need a particular amount of lining paper. The factory produces different calipers; each caliper of a laminated cardboard sheet corresponds to a particular weight of lining paper. Within a week several calipers must be produced on a cardboard machine. If the lining paper stock is low, it might be impossible to produce the calipers on the cardboard machine in the most efficient way, i.e. from small to large and vice versa. The production planner needs to make smaller plans on both machines, which cause more set-ups and a capacity loss. After that week, the stock level of lining paper might be decreased again. Without any action the vicious circle continues to worsen the utilization of the capacity.

Example 1 shows that the production on the cardboard and paper machine may have a high level of interdependencies. Disturbances on the paper machine may influence the planning of the cardboard machine and vice versa. The introduction of a certain amount of stock within the process reduces the interdependencies; it basically decouples both machines (for a general introduction of the concept, see Bemelmans & Durlinger (1995), Bertrand et al. (1990), Brevé (1990), and Hoekstra & Romme (1987). See Lehtonen (1998) for a discussion of this concept in the paper industry. The degree of interdependency highly determines the applied planning strategies.

In case of totally decoupled machines, there is sufficient inventory in between and the planner may determine the most efficient flow for both types of machines. Disturbances do not have any affect on the other machines. The applied planning strategy searches individually for optimal patterns on each machine. If the machines are totally coupled, there is no inventory in between; disturbances on the one machine immediately affect the other machine. It is difficult to eliminate the disturbances, and the total capacity on both types of machines decreases. Thus, decoupling increases the capacity of both machines against an inventory cost. There is an exchange between capacity and the inventory level. Overall, the location of the decoupling point determines the available planning strategies of the production planner. If the economic situation changes dramatically, it may result in a shift from a totally decoupled to a coupled cardboard and paper machine control. These trends are hard to predict and make the planning problem complex.

The next example shows the situation in which the company has a surplus of capacity on the cardboard machines.
Example 2: Surplus of capacity on the cardboard machines

The economic perspectives in the cardboard market deteriorate. Clients demand less cardboard sheets, causing a surplus of capacity on the production machines (both on cardboard and paper machines). The branch of industry is such that if cardboard machines in a solid board mill operate, they operate 24 hours a day, because of high set-up and start-up costs. The production planner is faced with gaps in his planning. Customer orders that have due dates within two or more weeks will be produced earlier in order to remove the gaps. If the situation continues to deteriorate, one or more cardboard machines will eventually be taken out of production for a long time (e.g. a couple of days) in order to eliminate the gaps in the production planning of the other machines.

What follows from Example 2 is typical for solid board mills: it is not profitable to stop the production on a cardboard or paper machine for a small time period, e.g. two hours, because significant start-up and set-up costs are involved. The applied planning strategy here shifts orders from the next planning week to the current planning week. In this way, gaps in the current week planning have been removed, resulting in more available capacity in the consecutive weeks.

The opposite of a surplus is the lack of capacity. Example 3 describes such a situation.

Example 3: Lack of capacity on the cardboard machines

In the case of lack of capacity, the planner behaves differently compared to a surplus situation. The customer orders have already been sorted according to due dates. Some orders do not have a hard due date: they are at buyers’ option. These orders offer flexibility, which the production planner needs in order to insert orders with higher priority or to make the production plan feasible. If buyers’ option orders are called and capacity is experiencing a bottleneck, the production planner may experience a problem. The planner estimates the risk of a late delivery for each order, especially for those at buyers’ option.

In the case of lack of capacity, the applied planning strategy is different from the previous example. The lack of capacity makes a shift of a selection of customer orders to a later production date necessary. Respecting the due dates is in this sense a dominant criterion. One particular type of order, the order at buyers’ option, is a candidate for shifting to a subsequent planning week. In this way, these orders function as a means to create flexibility in the planning process. A buyers’ option order offers the originating customer the opportunity to call the order from a particular date. It does not mean that the order must be physically in the warehouse of the manufacturer. Experience shows that many orders at buyers’ options remain in the warehouse for several days or even weeks. As a result, the applied planning strategy analyzes the orders at buyers’ options and shifts some of these orders to a later production date. If lack of capacity persists, the same action can be taken for other orders with a specific due date (in consultation with the customer).
Another type of situation is the handling of rush orders. The next example shows how a rush order is handled.

Example 4: The treatment of a rush order

A rush order arrives at the planning department. If the production plan shows that the caliper of the rush order cannot be produced within the short term, the production planner must decide if the requested due date of the rush order can be honored. Three considerations are important. First, the question is addressed whether capacity is available to manufacture the rush order such that the due date does not interfere with other customer orders. Second, if the planner does not have any other customer orders in the demanded caliper, and if the volume of the rush order is relatively small, the production of this specific order may not be profitable for the company. It may result in an additional set-up with corresponding costs and negligible profits. Third, if the customer is very important for the company, the planner may decide to honor the requested due date for the rush order, although the rush order is not profitable. In this situation, strategic issues such as satisfying the demand of an important customer are more important.

The rush order entry has several implications for existing production plans. In Example 4, we already discussed some considerations whether to accept a rush order, namely availability of capacity, profitability of the rush order, and importance of the specific customer. If capacity is not the bottleneck, the production planner can accept the order without hesitation. Only if the available capacity within a particular time window is too low, the planner assesses the disturbances against expected profits. In addition to planning factors, the importance of the customer order is also a consideration. If the customer is an important buyer, it may be profitable to produce the rush order, even if the order generates a loss. The production planner makes a final decision based on the order data.

These four examples exemplify the range of planning problems that often exist at a solid board mill. The planner considers three factors in the decision process: 1) available capacity, 2) disturbances in existing production plans (effects on the due dates), and 3) the importance of the customer placing the customer order. From a planning perspective, only the available capacity and the effect on the due dates are important considerations. The importance of the customer is determined using logistical and commercial arguments, which are to a large extent located outside the planning domain. However, these aspects can also be considered as constraints or objectives, hence falling within the planning domain.

The situation described in Example 1 is caused by the configuration of the logistical process and the characteristics of the production machines. It discusses an inventory problem, which is a deduced problem: the goal is not the inventory level itself, but the effects of a particular inventory level on the available capacity of the production machines and due dates of the individual orders.
Example 2 and Example 3 show situations that are caused by the economic conditions in the served markets. These economic conditions simply occur and cannot be acted upon. These two examples show opposite situations: 1) a surplus of capacity and 2) a lack of capacity. If there is a surplus of capacity, orders are produced earlier in order to remove the gaps. If there is a lack of capacity, orders are produced later. In this way, the strategies are opposite in nature: Which orders are to be selected for the shift operations?

Example 2 focuses on efficiency: short run orders that can be combined easily will be produced earlier. In Example 3, the focus is on the type of order and the demand behavior of the customer. Based on the judgments of the production planner it is decided to produce a restricted set of orders, particularly orders on call, later.

Example 4 is mainly unrelated to the economic situation, although in a booming market more rush orders may enter the solid board mill. The rush order entry restricts the application of planning strategies. The restrictions stem from the way the logistical control is organized. If there are capacity problems, the production planner makes decisions based on three factors: availability of capacity, profitability of the rush order, and importance of the specific customer. In this way, the decision process considers other factors as demonstrated in the previous three examples.

This section presented a number of planning problems within the scheduling and planning domain of a solid board mill. We discussed the structure of these problems and showed that it can be difficult to solve them. In the next section we discuss several scientific disciplines and their approaches that may help to support the planning problem.

1.3. Views on the planning problem phenomena

In the first two sections of this chapter we introduced the planning problem within a practical context. We focused on solid board mills. Having introduced some aspects of the planning problem, this section continues with a detailed discussion about how relevant scientific disciplines view the planning problem. We use these scientific disciplines in order to select some appropriate approaches that may help to solve the planning problem at a solid board mill.

First, we present the definitions that apply for the three distinct scientific fields: cognitive science (CS), operations research (OR) and artificial intelligence (AI). Second, we relate the planning problem to problem-solving and analyze several definitions of planning. Then, we continue from a planning support perspective: what disciplines provide significant support with respect to developing a new planning support system? Finally, we project the discussed approaches in CS, OR and AI. We show the analogies, distinctions and sketch the applied methodology within the research. An earlier view on the contribution of different scientific disciplines to the planning problem is presented in Wanders et al. (1999).
In this study we particularly focus on methods with origins in CS, OR and AI. We start by providing the definitions of the applied scientific fields. **CS** is defined as the study of intelligence and intelligent systems with particular reference to intelligent behavior as computation (Posner 1989). For a good introduction of CS we refer to Dawson (1998) and Andringa et al. (1997). **OR** in the most general sense can be defined as the application of scientific methods, techniques, and tools to problems involving the operations of systems so as to provide those in control of the operations with optimum solutions to the problem (Churchman et al. 1957). For a good introduction of OR we refer to Bertsimas & Tsitsiklis (1997) and Sierksma (1996). **AI** incorporates the belief that the concept of intelligence can be extended beyond human and animal performance to include artificial systems, i.e. computers (Posner 1989).

In section 1.1 we introduced the planning problem as the problem that might occur when someone, for example a production planner, must make a plan. The planning problem is often related to problem-solving. Problem solving is defined as a competence characterization that describes a way to realize a task (Benjamins 1993). A problem-solving method provides a means of identifying candidate actions at each step. It provides one or more mechanisms for selecting among candidates (McDermott 1988). **Planning** is a way to solve the planning problem and is part of a general problem-solving technique (Newell & Simon 1972). In the later work of Newell and Simon, the explicit distinction between planning and problem-solving disappears. Planning is then just a very interesting example of the general problem-solving approach. Das et al. (1996) disagree with this view, saying that a difference exists in “problems to prove” and “problems to find”. Note that the arguments in this section were composed from unpublished work of Jorna and van Wezel. According to Newell and Simon, the question is how a task environment gets its representation in a state space description, i.e. how do human production planners construct an initial representation, in addition to operators and a problem space?

The link between planning, problem-solving and the planning problem is derived from above (see e.g van Wezel & Jorna, 1999). However, we did not discuss the definition of planning. What are generally accepted planning definitions? We would like to distinguish between planning as a process and planning as a task. **Planning as a process** is defined by van Dam (1995) as the process of allocating production quantities to the next planning periods and making the relevant decisions concerning the availability of resources, such as operators, machines, and materials. Note that the subject of research within the definition of van Dam is production: it focuses on domain properties. **Planning as a task** presents another view of planning. Hoc (1988) defines planning as the cognitive activity that does not only imply generating action plans or anticipation of changes in the environment, in addition to abstract representation capable of guiding activity during execution. This definition is in line with the definition presented by Hayes-Roth & Hayes-Roth (1979): planning is the predetermination of a course of action aimed at achieving some goal. Based on the definition of Hoc, it can be concluded that abstraction and anticipation are important notions. Abstraction is related to hierarchies within the planning stages (Sacerdoti 1974), whereas anticipation is related to the projection of the consequences in the future.
The planning as a task / PSM (problem-solving method) literature also considers several views on how planning is performed. Some dominant views in this domain have been labeled script-based planning (Schank et al. 1975), opportunistic or hierarchical planning (Hayes-Roth & Hayes-Roth 1979), and case-based planning (Hammond 1990). The product of planning is called a plan, which could involve anything from a rough sketch of a course of action to a detailed specification of each operation. It is the plan that controls human information processing and supplies patterns for essential connections between knowledge, evaluation and action (Miller, Galanter & Pribram in Das et al., 1996).

The applied paradigm of planning is important, because it determines to a large extent the research design. From the definitions presented above, we select planning as a task performed by a human information processing system because in our opinion planning entails more than just allocating quantities to a particular time period. Planning implies several types of activities in order to generate or revise the plan. Given this view, planning as a task shows a better match. The human production planners within a solid board mill formulate production plans. During the planning process, they are faced with the planning problem. We have already sketched some characteristics of the planning problem in the above sections. We also described the emerging industrial trends of increasing product variety, reduced windows for due dates and lower order quantities; each making the planning problem more complex. How do human production planners respond to the industrial trend that may make the planning process even more complicated? In order to answer this question, the planning process should first be analyzed. The question also arises as to whether human production planners require more planning support within the planning process?

If more planning support is demanded, it can be offered in several ways, e.g. altering the planning task, introducing planning support systems, or introducing new supportive tools. One important assumption during the research is that the content of the current planning task is manifested in time. It is strongly related to the axiom in CS that the content of a planning task evolves over time and makes sense. Therefore, altering the task beforehand is not a topic in the research design. In this research project, we investigate whether planning support improves from the introduction of a planning support system. A planning support system is defined as a computer system that provides support in executing the planning task. The way the support is implemented in the system can be as follows: calculating intermediate results, proposing alternative solutions, safeguarding the integrity of the data, presenting information in various ways, communication, etc. A planning support system is a particular kind of decision support system (DSS).

Literature distinguishes two types of DSS: knowledge-driven and data-driven. A data-driven DSS emphasizes access to and manipulation of a time-series of internal company data and sometimes external data. Simple file systems accessed by query and retrieval tools provide the most elementary level of functionality. A knowledge-driven DSS can suggest or recommend actions to managers. These DSS are person-
computer systems with specialized problem-solving expertise. The "expertise" consists of knowledge about a particular domain, understanding of problems within that domain, and "skill" at solving some of these problems. For a more detailed discussion, we refer to the classical books of Sprague and Carlson (1982), Sprague and Watson (1993), Keen and Scott Morton (1978), and Thierauf (1991)\(^1\).

A DSS may give faster and more flexible responses to the planning problem. Motivations for the introduction of a DSS are:

- Reduced dependency on the knowledge and experience of production planners
- Calculations support
- Reduced labor hours
- Increased information support level throughout the organization

The introduction of planning support by means of a DSS may improve the performance of the company as a whole. Theoretically, frameworks can be adopted to develop a DSS:

- DSSs that replace the human and its tasks (‘user follows system’)
- DSSs that adjust to human actions and interact with human tasks (‘system follows user’)

The first type of framework implies that the system performs all (planning) tasks, motivated by the view that a planning task consists of a finite number of well-defined and easy to automate subtasks. Planning decisions are adequately deduced by the system; all tasks are within a closed definition. This framework is particularly applied in classic OR and/or AI (Bisdorff 1999). The second type of framework is more common in CS. It starts with the needs of the human user and investigates its task (Hoc, 1988; Waern, 1989; Rasmussen, 1986; and Sebilleto, 1995. The Groningen SOM research school often applies the second type of framework (Budihardjo, 2001; van Heusden & Jorna, 2001; Jorna, 2001; Jorna, 2000; Mietus, 1994; and van Wezel, 2001). The assumptions underlying the first type of framework might be true in a simple and static environment. In reality the human decision maker, in our research the production planner, and/or support system often act in a complex, dynamic and uncertain environment. As a result, the assumptions of the first type of framework do not hold. As we already have demonstrated that the planning and scheduling domain at a solid board mill represents a complex, dynamic and uncertain environment, the second type of framework is therefore more suitable to develop a DSS for a solid board mill.

We must consider the relation of the DSS to the specific role of the human production planner, the structure of the planning problem and the restrictions arising from the logistical processes. These elements are the subject of research. Thus, in this research

\(^1\) In case of a cardboard company, the logistical information system can be considered as a data-driven DSS, whereas the planning support system is more considered as a knowledge-driven DSS.

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we would like to analyze the effect of supporting the human production planner of a solid board mill by means of a DSS. If this is our target, we have to develop a DSS. Literature in the field reveals several theories are known that provide guidelines for developing a DSS. What theories provide appropriate guidelines to improve the planning support by means of a DSS?

A survey of appropriate theories and methods from scientific literature may provide guidelines to improve the planning support. Klein & Methlie (1995) presented a detailed description of theories that support the development of decision support systems. Figure 3 shows the science disciplines that are relevant according to Klein and Methlie with respect to Knowledge-Based Decision Support Systems (KB-DSS). We omit the exact differences between KB-DSS and DSS (see e.g. Stefik, 1995). In our opinion, the emphasis within a KB-DSS focuses more on the incorporation of user knowledge within the DSS.

Figure 3: The science disciplines that deal with (KB-)DSS (Klein & Methlie 1995)
Within Figure 3, Klein and Methlie distinguish among descriptive and prescriptive theories. Descriptive analysis provides insights on the values, beliefs, and choice processes actually used by decision makers. Prescriptive analysis helps to clarify values and beliefs and suggests ways of improving decision processes using criteria from rational models of choice, such as expected utility, as guidelines. From the science disciplines considered in Figure 3, we mainly apply the gray shaded ones. Thus, methods from human problem solving, operations research and (KB-)DSS. From the disciplines mentioned in Figure 3, we therefore start with human problem solving, questioning: what type of strategies does the production planner apply during the planning process? Then, given this view, can we apply some simple algorithms that have the same outcomes in the planning process? Both these insights have been merged within the development of the decision support system.

The other science disciplines that have not been shaded gray also provide methods that are applicable and valuable in the development stage of a DSS. However, our focus in the research is not on these methods and theories.

The three main scientific fields that involve the three disciplines as shaded in Figure 3 are CS, OR, and AI. Figure 3 does not refer to CS as a separate discipline. However, its origins can be found in the boxes cognitive psychology, human problem-solving, human choice, behavioral decision-making, and decision methodology. We have introduced the three main scientific fields (OR, CS, and AI) that provide us with methods for implementation within the research design. Of these methods, we particularly focus on OR and CS. We would like to discuss the main contributions of these fields in general, and focus particular attention regarding a solid board mill. The main contribution of OR is related to algorithms that solve general problem formulations.

With respect to the cardboard industry, we may consider three different types of problem formulations. First, queuing theory (French 1982) can be applied to solve problems concerning the three-stage manufacturing system (see Figure 1). Second, orders run side-by-side on the cardboard machine; trim losses are minimized in relation to additional constraints. This type of problem is commonly known as the cutting stock problem. For algorithms that solve the cutting stock problem, refer to Goulilimis (1990) and Dyckhoff & Finke (1992). Third, there are several inventory points. Thus, inventory problems (both in determining inventory levels and the layout of the warehouse) can be formulated and solved. A example of the layout of a paper reel warehouse is discussed in Lai et al. (2002). However, there is a huge gap between general problem formulations in OR and problems found in practice. McKay et al. (1988) claimed, “the problem definition is so far removed from reality that perhaps a different name for the research should be considered … Research in a number of areas could ultimately benefit the real-world scheduler in robust scheduling, real-time dispatching tools for schedulers, forecasting tools, and real-time expert systems capturing soft constraints. As we search for solutions in these areas, we must consider the problem definition and how the solution will fit the real problem.” Hsu et al. (1993) make a similar claim stating that, “scheduling behavior differs significantly from
scheduling theory. Two primary sources of scheduling difficulty in manufacturing environments are: 1) nature of the constraints and 2) unpredictability of the environment”. Therefore, it is important not to model for modeling’s sake, but to consider the practical relevance of a particular model and use this as a guide. Given this view it is strictly necessary to perform the research within a solid board mill and to understand the planning process in detail before the models are formulated.

The main contribution of CS is related to understanding the human cognitive processes. The research in this field ranges from detailed functional views of the brain to more aggregated levels that analyze planning strategies applied to real life decision-making scenarios. Much of CS rests on empirical studies that describe the performance of human subjects in cognitive tasks (see e.g. Prietula et al., 2000; Clancey, 1997; Anderson, 1993 and Newell, 1990). From the whole spectrum of approaches within CS, we particularly apply methods related to knowledge acquisition and knowledge engineering. These methods provide insight as to how planning tasks are executed. For a more detailed description of this type of methods, refer to chapter 3.

Practical relevance is a significant factor during the research process. The planning problem must be solved. OR provides a significant contribution by applying particular algorithms, not to find optimal solutions but to also provide additional tools to assist the human production planner with planning tasks and an improved response can be achieved regarding dynamic changes in the environment. CS contributes significantly by applying approaches to understand the human cognitive processes that guide the planning tasks executed by the human production planners better.

The boundaries between AI, CS, and OR have not been clearly delineated in the literature. Some argue that CS is the main discipline and other disciplines such as AI and OR are sub-disciplines of CS (Posner, 1989 and Gardner, 1987). Others maintain that AI and CS are opposites, and the OR is a sub-discipline of AI. We hold the view that CS and OR are complementary, hence dismissing the boundary discussions because this does not further the main objectives of this study. Overall, the scientific disciplines under discussion may contribute with respect to the planning and scheduling domain. Of these disciplines, we restrict our attention to the gray-shaded areas as shown in Figure 3. We apply various approaches from CS and OR with a focus on conforming to the current planning task execution while increasing the planning support level. Excluding CS and OR approaches, we also apply some generally accepted concepts from organizational science and logistics in order to present the organizational setting within a solid board production plant. The overall target is to investigate options to increase the planning support level by means of introducing a DSS.

1.4. Research design and research questions

The planning problem within the cardboard industry is complex. Recent industrial trends indicating a more flexible customer demand have already been initiated and increase in the future. They may even increase the complexity of the planning prob-
lem. Human production planners at a solid board mill have to cope with the complexity of the planning problem. They are the key persons within the planning and scheduling process. One of the first elements that should be analyzed is whether the production planner identified a need for more planning support to cope with the more complex problem. Suppose that the need for planning support is identified, what type of planning support is available? In general, the planning support currently available on the market is rather limited. This stimulates further research for developing planning support. Having noticed limited planning support in the market, what type of planning support should be offered? Verschuren & Doorewaard (1995) offer a good framework to design a research project. We believe detailed planning tasks demand a planning support that is flexible, shows alternatives, can be manipulated easily, and recalculates the whole production plan in case of revisions. Most importantly, it should be able to perform planning tasks in several ways, depending on the particular planning strategies that have been applied. This type of planning support is obviously often omitted by current planning support systems, which frequently follow the first type of framework (‘user follows system’) as discussed in section 1.3. In general, a straightforward solution of the planning problem cannot be found. Planning problems exist both during the formulation stage of a production schedule and during the replanning stage of a completed production schedule that becomes unfeasible. Note that the planning problem itself is not the object of study, but the emphasis is on how human production planners are solving these types of problems in practice and how this process can be supported by means of a DSS. The developed DSS follows the second type of framework (‘system follows user’) as discussed in section 1.3.

The research is performed at one company, called “Cabofa”. The case enables us to analyze the planning problem in a more detailed way. It also provides insight into real-world circumstances. We anticipate that our research findings can be generalized and applied to the solid board industry, possibly to the cardboard industry as a whole, as well as to planning in general. Employing terminology developed by Yin (1984), this type of research is labeled explorative single case study. This type of research is particularly suitable for the first stage of developing a new theory. In our domain, the theory building level is rather low, especially if combining approaches from separate disciplines (OR, CS) is the target. Therefore, we decided to initiate a single case and analyze the planning problem very thoroughly at this selected company. The first step was an analysis of current planning processes, based on a CS paradigm stating the content of a planning task is constructed in an evolutionary manner. Years of experience demonstrate that the content of the planning task becomes ‘stable’. Therefore, the research design should not influence the planning task beforehand.

The research objective is to investigate appropriate methods for improving planning support within a solid board mill. It was decided to restrict the development of planning support on the fine planning process with respecting to the current method of planning task execution. This choice is based on the following arguments:

- Supporting the entirety of the planning and scheduling domain by means of a DSS is far too much for a project like this.
• During the research period at Cabofa, the logistical control of the order flow was redesigned by means of introducing a new logistical information system. The proposed changes may affect the content of the planning tasks. From the planning tasks under consideration, the fine planning tasks were relatively autonomous and it was expected that the content of the fine planning tasks would remain the constant.

• In order to test the framework, merging methods from CS and OR, it is not strictly necessary to develop a DSS for the whole domain. The research executes an explorative case study which provides additional insights into developing a new theory of combining CS and OR. If the DSS applies for a specific part of the domain, we may generalize the conclusions and apply them to the whole domain.

The first argument is more pragmatic and claims that it is not possible to investigate the whole domain and develop a complete DSS for all planning tasks within a solid board mill. In our opinion, the fine planning task is relatively autonomous and separate from the selected organization model or logistical concept, which is expected to have only a slight impact on the design of the planning support. The objective of an explorative single case study is to test the suitability of the approach. If it succeeds in one particular stage of the whole domain, the conclusions may provide evidence for further research in order to expand the theory.

In the area of planning support, we want to develop a DSS that structurally integrates the planning strategies in order to test our approach. This ultimately leads to the formulation of the following research questions.

1. Do human planners require planning support? If so, what options are available to design the planning support?

2. Does effective planning support depend on the specific role of the human planners? If so, what are the consequences of this relationship for the planning support?

3. What does a decision support system look like in terms of planning support, if it takes into account the structure of the planning problem, the specific role of the human planner, and the restrictions resulting from the logistical processes?

The key notions within the research questions are the following: 1) identification of the need for planning support and how to implement the planning support, 2) the specific role of the production planner (planning tasks and planning strategies) within the whole planning process with/without planning support, and 3) the functionality and the effects of introducing a DSS to support the planning tasks.
1.5. Outline of the thesis

In this introductory chapter, we have presented the object of study including the research questions. In this section we outline how the research questions will be addressed in the remaining chapters. An overview is presented in Figure 4.

![Figure 4: Structure of the thesis](image-url)

**Figure 4: Structure of the thesis**
Chapter 2 presents an analysis of the logistical processes within Cabofa. First, the primary process is explored, i.e. all processing steps in the production of cardboard sheets are discussed. Second, production planning and control are analyzed. Third, based on both analyses, we differentiate the various bottlenecks within the production process and propose measures to eliminate them. The improvements may ultimately lead to a complete redesign of the logistical concept. However, for the fine planning prototype we only consider the current logistical concept because the redesigned logistical concept may have unanticipated effects on the planning tasks. Chapters 3, 4 and 5 deal with the planning task and domain. Chapter 3 discusses methods utilized in the research to uncover the task and domain. Chapter 4 presents a detailed analysis of both the mill and conversion planning tasks within Cabofa. Beginning with an ethnographic analysis based on verbal reports of the production planners, chapter 5 presents an in-depth exploration of the domain. Note that the analysis is restricted to the mill planning tasks. We also apply object-oriented methods to derive the relevant objects within the domain and their properties. Chapter 6 considers the development and functionality of the fine planning support prototype. The prototype, tagged using the acronym Paperclip (Prototyping Advanced PapER & Cardboard Logistics In Planning), supports the fine planning task. First, we formulate the functional and technical design to explicitly specify the design requirements. Second, we discuss the use of the prototype and analyze the match between the current fine planning task and the planning support offered. Finally, Chapter 7 summarizes the results of the study and discusses general topics for further research.

If we return to the research questions, it is hard to assign the research questions to the specific chapters in this dissertation. Chapter 1 motivates the demand for better planning support, which is the subject of the first research question. The second research question is answered in Chapter 1 (section 1.2.2) and Chapter 4. Finally, the third research question is answered in Chapter 6, where we discuss the developed DSS.