Tasks, hierarchies, and flexibility
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Chapter 7. Conclusions and generalizations

7.1. Introduction
Cooperation and concentration of retailers in food processing industries have changed the food supply chain considerably. The shift in power balance enables retail organizations to demand a better logistical performance and a wider collection of products. Manufacturers of consumer food products are increasingly faced with the trade-off between flexibility and efficiency. We have analyzed how production planning can contribute to flexibility of the production system and developed a planning concept that enables more flexibility.

In Section 7.2, the answers to the research question will be summarized and a reflection on the choices that are made will be given. Section 7.3 discusses how the research results can be generalized, and Section 7.4 provides directions for further research.

7.2. Research conclusions
Our observations in the food processing industries have shown that there is a mismatch between the flexibility that is asked for by the market and the flexibility that the production system can offer. Although there are many physical barriers to being very flexible, the planning also influences flexibility. Therefore, we have stated the following research question:

How can day-to-day planning in the Food Processing Industries contribute to flexibility?

We will discuss the answers to the question in three parts: the effects of more orders, smaller batch sizes, and shorter lead times on production in food processing industries (Section 7.2.1); the relation between day-to-day planning in food processing industries and flexible product replenishment (Section 7.2.2); and computer support for flexible and hierarchical planning (Section 7.2.3).

7.2.1. The effects of more orders, smaller batch sizes, and shorter lead times on production in food processing industries.
Chapter 2 provides an extensive overview of the relations between product, machine, process, and market characteristics and the planning. The analysis of these food processing industry characteristics shows that the tendency of customers to order more (smaller) batches with a shorter lead-time, conflicts with the planning in a number of ways. Figure 7.1 summarizes the contradictions between customers, the production system, and the planning. Some of these conflicts have their origin in machine and process characteristics that impose constraints that can only be relaxed by changing the hardware or recipes.
The origin of other conflicts can be found in organizational aspects, for example, the procedures of order acceptance. The latter kind of contradiction is the subject of this research.

![Diagram](image)

**Figure 7.1.** Contradiction between customers requirements, production system, and planning.

7.2.2. The relation between day-to-day planning in Food Processing Industries and flexible product replenishment.

This subject is covered in three chapters. The overview in Chapter 3 describes planning from an organizational and task oriented perspective. The literature review from Chapter 3 is used in Chapter 4 to devise a framework with which planning situations can be modeled. In Chapter 4, the planning is described as a hierarchically ordered process. In Chapter 5, we describe how hierarchical planning can obstruct flexibility. More specifically, tasks that are organizationally divided between several people can result in a high throughput time of decisions, and the fact that the planners divide their own planning problem in a number of subtasks that are executed sequentially can result in reluctance to change partially finished plans or plans at higher levels of abstraction. This is depicted in a concise way in Figure 7.2.

![Diagram](image)

**Figure 7.2.** Causes of inflexibility

On the basis of this argumentation, we propose to increase the flexibility with the following line of reasoning:

- Hierarchical planning is one of the sources of inflexibility.
- Limitations of the information processing capacity of planners is one of the reasons that planning takes place hierarchically. An increase in information processing capacity can reduce the need for hierarchical planning.
- The information processing capacity can be increased by applying computer support.
This suggests that a change in task strategies can be achieved with the appropriate computer support. Thus, computer support enables flexibility, but the flexibility itself must be accomplished by changing the task division and task strategy. To summarize, changes in the task strategy will provide flexibility in the following way:

- Increasing the information processing capacity increases the number of events that can be handled.
- If the number of events that can be handled increases, then more events can be handled within the required lead-time.
- An increase in information processing capacity will remove the need for organizational task division, and thereby create the possibility to remove hierarchical levels of which the task division is the cause.
- The increase in information processing capacity means that there might be time to reconsider decisions at a high hierarchical level, despite that hierarchically lower decisions might be invalidated. Thereby, the tendency to aggregate different dimensions simultaneously is suppressed, so aggregation does not necessarily mean a low planning frequency or a long planning horizon anymore.

As said, appropriate computer support can enable these changes by increasing the information processing capacity. This is covered in the last part of the research.

7.2.3. Computer support for flexible and hierarchical planning
Planning support issues are discussed in three chapters. Chapter 3 discusses generic planning support issues and contemporary functional requirements. Chapter 4 adds as a requirement that planning systems should include support for hierarchical processing (i.e., support for decision making at multiple hierarchical levels). In Chapter 5, it is argued that sequential hierarchical planning hampers flexibility, and that hierarchical planning must be avoided or that decision making at different hierarchical levels ought to take place in parallel. For the latter case, the fact that decisions on all hierarchical levels can be taken at any time means that planning support must show the effects of decisions on other decisions real time. On the basis of this analysis, we proposed the following planning support functionality:

1. Link to external systems for information collection
2. Show and manipulate the plan (i.e., the objects, attributes, constraints, goals, and assignments)
3. Work with multiple alternatives to try solution paths (the blackboard)
4. Check the plan for errors and evaluate the quality
5. Mixed initiative plan generation support at the subtask level
6. Support for hierarchical planning (show relations between sub-plans real-time)
To show the viability of these functional requirements, the functionality has been implemented in a prototype planning support system.

Next to functional requirements from the domain and task perspectives, we also stated requirements from a development perspective, especially with respect to reuse. Not all cases are the same, and small changes in the domain or task should be reflected in small additional development efforts. For that reason, we proposed to distinguish three layers in the components of the system: a class and object administration module and blackboard functionality that can be used for all planning situations, (2) a domain model and user interface that is structurally the same for all cases in our application domain, and (3) attributes, calculations, and constraints that are case specific. The system architecture was implemented and illustrated for a case.

7.2.4. Reflections on research choices

The basic line of reasoning behind this research is the following. The increased external dynamics in small and medium sized food processing industries can to some extent be answered by an increase in the flexibility of the planning, which can be enabled by the use of appropriate planning support. Dynamics, flexibility, planning, and planning support are concepts that can be approached in many ways. We will reflect on the choices that are made during this research.

There is no adequate theoretical framework that can be used to design the way in which the planning can best be organized or the way in which the planning task should be performed by human planners. This complicates the process of thinking about an adequate form of planning organization, task performance, and support. We have tried to base our choices on existing research in planning literature, decision support literature, and production planning and control literature. Thereby, our point of focus has been the human planner, and we have considered the planning organization and planning support as descendants from the fact that the task must be performed by someone. Still, the way in which the organization, task, and support enable and constrain each other means that an integrated approach is necessary.

Because we look at planners and their decision processes, a good understanding of the planner is crucial. For this purpose, we have looked at the differences and similarities between planning for yourself and planning for others. These two have their own research schools and the theoretical frameworks are not easily integrated. Still, there are two ways in which models of cognitive planning can be applied in organizational planning. First, the planner must plan his own task, for which the models are directly applicable. Second, the models can be used as a paradigm. In the latter application, it becomes apparent that organizational planning in a dynamic environment can learn from the way in which humans integrate planning, execution, and adaptation of their own activities.

An integrated approach of organization, task, and support stumbles upon the paradox of task support. If a task is supported with a computer program, the task changes. If the task changes, the support might not be appropriate anymore. Of course, this is a never ending story. An understanding of the possible roles of the computer in the planning task can help. In addition, task support at the subtask level
instead of a black box approach makes it easier to change the support if subtasks change.

The hierarchical approach that is taken in this study differs in certain respects from traditional hierarchical approaches. Hierarchies of planning are usually based on hierarchical relations between the objects that are planned. In contrast, we have looked at the hierarchies that emerge in the process of plan creation. This enables a view on planning that is consistent for all planning decisions. We have extensively discussed three characteristics of decisions from a hierarchical point of view. First, a planning decision is either a restriction for other decisions, or an assignment of objects. Second, objects are either decomposed or aggregated in a hierarchy. Third, a decision relates to sub-problems that are to be solved by other decision makers, by the same decision maker in another subtask, or by the same decision maker during the same subtask. These three characteristics can be used to analyze and possibly (re)design the planning organization, the planning task, and planning support. In essence, we state that the characteristics of the decision process are more important for the analyses of flexibility and hierarchical planning than the objects that are planned.

Knowledge about the relations between the planning environment, planning organization, task components, and task support enables reuse of analyses and designs. The models we propose contain mechanisms for reuse by providing small building blocks and allowing inheritance. We have chosen to use a composition based reuse approach so the models can be applied in a domain of companies that are similar but not equal. This choice is based on the fact that the companies that fall in the research domain have little differences, and therefore do not require many different components. Of course, this means that the components can not be used outside the food processing industries. More about this is discussed in Section 7.3 about generalization.

The Scheduling Expertise Concept (SEC) has been used in this research as an analysis and design framework. We will reflect on the use of the SEC in five ways. First, the SEC provides a set of modeling languages that can be used to describe situations and designs. The models can be used to communicate, and models can be compared to enact reuse. The models are based on an underlying ontology in which planning is seen as assigning objects. In this respect, the SEC has proven to uphold its claims. The models that were created could be used to describe the planning situation in a detailed manner. Second, the SEC should contain a set of rules that can map situation to design. Such rules can be used to judge the planning of a company, and to design a way to organize, perform, and support the planning. This part of the SEC is not elaborated. At some points, we have tried to contribute to this. In particular, we have focused on planning under dynamic circumstances, and for this, organizational guidelines and functional requirements for computer support were formulated. Third, the SEC is a task oriented approach. This means that planning is regarded as a task that must be performed by someone. Other approaches see planning as a problem that must be solved, and formulate ways to do that, either by organizational design, mathematical concepts, or planning support systems. In these
approaches, the planner is seen as someone who must work with constructs that are created to solve the planning problem. Although in the task oriented approach the task itself can also be subject to changes if necessary, the planning problems and planning support are derived from the task, and not the other way around. This is a limitation of the task oriented approach, because powerful algorithms or existing computer support can possibly not be used if the current task is the starting point of analyses. Furthermore, the SEC does not (yet) contain models for algorithms, which can hamper applications that need algorithmic support rather than task support. Fourth, the SEC should enable reuse. The possibilities for this are embedded in the modeling languages, and to a certain extent the models that are developed in this study can be reused. We have chosen to apply a composition based reuse approach, which implies that the models are not created top down but bottom up. Still, the models and the prototype can be used as exemplars for situations that are alike. More about that will be said in the next section about generalization of the research results. Fifth, the SEC is work in progress. We have extended the original models by emphasizing that planning is hierarchical, which enables that all planning subtasks can be expressed with the same task primitives. This could advance the ontology of tasks in the SEC, which is something that has not been fully worked out yet.

The conclusions that are drawn until now focus on the research questions that underlie this research. In the following section, we will investigate if the research results can be used outside the context they are originally meant for.

7.3. Generalization of the research results
This research focuses on planning at small and medium sized factories that produce consumer food products. Undoubtedly, however, some analyses and answers of this research can be applied to other domains as well. This section will discuss possibilities of generalization of the research results. Thereby, we assume that we have reasoned from left to right in the model that is depicted in Figure 7.3 (that is also shown in Figure 3.10). On the basis of this model, we will look if we can reason the other way around, i.e., we will look at the research findings and hypothesize where they can be applied.

The research question is focused on companies with a specific configuration of market, product, and production characteristics. We have only considered small and medium sized companies that produce food for the consumer market. Typical characteristics of the market are requirements for short lead time, and a low profit margin for the producer. Production processes are flow oriented with major sequence dependent setup-times. We have stated that the planning in such companies needs to be flexible, and we proposed continuous planning at all hierarchical levels to achieve this. We will analyze the specificity of the answers for the research domain, i.e., whether the answers are also applicable if factors that are presumed to determine the planning problem are not present. The generalization will be described around three themes. First, we will look at the market characteristics, second, at the production system characteristics, and third, at the planning support requirements that we have deduced and the prototype that is created.
7.3.1. The market characteristics: dynamics and flexibility  
The first thing that comes to mind when denoting the market characteristics is the kind of product. The planning characteristics, however, are not directly related to the fact that the product is some kind of food. Still, the characteristics of the product together with the power balance in the supply chain determine a number of requirements for the planning from the market perspective. (Although the distinction is not very sharp, the characteristics of the product that have an influence on planning from a production perspective will be discussed in the next section). The analysis of flexibility together with the hierarchical decision model of planning shows how the planning can be adapted to meet the requirements of the customers. These notions are not limited to food processing industries. The ideas apply to all situations where hierarchical planning hampers plan adaptation.

Is all this necessary if the market does not require short reaction times? If the producers could determine the order size and frequency themselves and decline rush orders, a lot of uncertainty could be passed on to the retailers. If deviations of forecasts do not occur or are not allowed to influence already made plans, there is no need to change sub-plans. Then, external dynamics do not result in internal dynamics and the flexibly that is proposed is not needed. The traditional sequential plan hierarchy would suffice and an increase in information processing capacity (and adapted computer support) is not needed.
7.3.2. The production system characteristics: medium volume flow production

The research questions have been centered around the trade-off between market requirements and production efficiency. Thereby, the research questions have focused on the balance between efficient production and short lead times. In order to determine the applicability of the research for other production domains, we need to know in what way the production characteristics influence this balance.

The problem for planners in the food processing industries is that they need much information beforehand in order to be able to produce efficiently. Causes for this are sequence dependent setup-times, minimum batch-size requirements, high capacity usage ratio, and procurement lead times. This contradicts the requirement of short delivery lead times. Parallel decision-making at multiple hierarchical levels is proposed to deal with this. The effects of new information (e.g., new orders) can be processed immediately, and boundaries that are set early in the planning process on the basis of forecasts are not so restricting anymore because they can be altered. Clearly, this planning paradigm is useful for all production circumstances in which decisions must be made on the basis of uncertain forecasted information. The specific domain and task models, however, are less generically applicable.

Some of the subtasks that we found in the food processing industries are generic production planning tasks. Determination (or estimation) of required capacity and product families at an aggregate level, stock level determination, stock order generation, and customer order acceptance occur in most situations. Also, orders must be assigned to machines and time periods. The division of planning tasks over organizational members, and the exact way in which orders, machines, and time are attuned can differ. In food processing industries, orders are first grouped to product families, after which the product families are sequenced. This is done to minimize setup and cleaning times. Of course, when there are no sequence dependent setup-times, this is not necessary. However, in other situations, other grouping criteria might be used to decrease complexity if there are a lot of orders.

The flow oriented production processes and the fact that buffers do not occur often in the process reduce the complexity of the planning problem considerably. If the routing of products can differ, the complexity of the planning problem increases because another dimension of assignments is introduced. In a flow process, it is immediately clear what machines are allocated at what time if an order is planned. In a job shop environment, customer orders are split in operations that are planned as separate production orders. In such situations, the planning hierarchy contains an assignment of production orders to machines (or groups of machines), after which a sequence and schedule is made per machine(group). The setup-times of the individual operations and due dates of orders (of which the operations are assigned to multiple machines) must be balanced. This kind of partitioning is not covered by the domain and task models in this research.

7.3.3. Complexity reduction and hierarchical planning

Both from a production perspective and a market perspective, uncertainty appears to be the major trigger for continuous planning. However, the planning paradigm can
also be useful for planners that do not need to work with uncertain information. In Chapter 4, we have argued that two main reasons to plan hierarchically are uncertainty of information and the complexity of the (unpartitioned) problem. Thus, in situations where all information is known before the planning process starts (i.e., no uncertainty), there might still be a planning problem that is solved hierarchically due to its complexity. Hierarchical planning means that constraints are set that can turn out to be unfavorable, and the possibility to reassess such decisions could be valuable. Therefore, parallel planning at multiple hierarchical levels will also be useful in situations that require hierarchical planning for complexity reasons.

7.3.4. **Functional and reuse requirements for planning support**

The functional requirements that we have proposed are applicable in all planning situations where a planner makes the plan by trying solution paths. The prototype implements the functional requirements, but is of course adjusted to the task models. The main characteristic from a production scheduling perspective is that the prototype can not be used to show and analyze the relations between the operations of an order. In other words, because we presume the order of operations in food processing industries to be fixed, the prototype support system does not contain functionality to deal with orders that are split in multiple production orders which are assigned to independent machines. This means that it can only be applied to flow production situations. There are of course more limitations to application in other production domains, for example:

- The number of orders per planned period must be small because there is no representation of grouping of production orders other than in runs.
- The system does not deal with alternative recipes.
- There is no representation to show the effects of alternative choices if a product can be made at multiple production lines.
- The system contains functionality for reactive sequencing and scheduling. In situations where this is not needed, the system would be overkill. For example, in high volume process industries such as sugar refineries and potato starch factories, runs are typically very long, product variety is limited, production is often to stock and customers are other manufacturers, which means that the pressure from the market with respect to lead times and product variety is not as high as in food processing industries.

From a research perspective, the functional requirements (and the underlying assumptions) are more important than the prototype. It would not suffice, however, to regard the development of the system as a mere ‘technical question’. Still, we can hypothesize about the viability of the system from the fact that existing systems for planning support are far more complex. Perhaps it is their complexity (and accordingly high price) that is a hindrance to application in the practice of food processing industries.
Next to requirements from the perspective of the use of the system, we have also formulated requirements regarding reusability of the planning support. The class and object administration module, as well as the blackboard (which is described in Section 3.4.1), can also be applied to other domains than the food processing industries due to their direct link to the SEC-domain models. The other components of the system, however, are not directly applicable, but the prototype is configured in such a way that modules for other domains can easily be implemented.

7.4. Directions for further research
The most apparent follow-up to the research that is conducted is to extend and test the prototype empirically. The current functionality can be tested in the food processing industries, and the reusability can be tested by applying it to other cases and other domains. This would not only provide information about the appropriateness of the prototype itself, but also about the underlying task and domain models. Unfortunately, what is appropriate and what not is not well defined, and we would immediately stumble upon the second challenge: the paradox of task support. The introduction of computer support changes the task, and hence the support is not appropriate anymore. Knowledge about the learning strategies of planners (or users of other computer programs) could possibly be used to predict the stages the user will experience. Two issues complicate this research subject. First, it is questionable whether there would be some sort of end-point where the computer and human user are both used to their best abilities. Ricardo's Law of Comparative Advantage, that states that each actor should do the task that they are relatively best at, is hard to apply when the actors are allowed to learn. Second, it is only to hope that there would somehow appear structure in the learning strategies. In other words, what elements could translate into a path of stages that would be suitable for multiple humans? Would it be the cognitive architecture of humans? Or the structure of the underlying planning domain? Or a combination of both? Could the path of stages be influenced by the designs that are made or is there some sort of universal best way to support someone in a given task domain at a given level of experience? The answers to these questions would not only help planning support in food processing industries, but computer support of other complex tasks as well.

The relations between external dynamics, internal flexibility, and hierarchies in production planning need to be approached in an integrated way. The notion that a plan hierarchy not only exists at the organizational level, but also at the individual level, needs further elaboration. To fully exploit this idea, the possibilities to manipulate with the hierarchical structure of the plan creation process need to be investigated. The removal of hierarchical levels, the transformation of hierarchies at the organizational level to hierarchies at the task level and from there to hierarchies at the problem solving level, and the place of computer support in all this, is important with respect to the flexibility of the planning. Especially, the relation between automatic sub-plan generation and the view on planning as a number of hierarchically related independent sub-plans that are always structurally the same (either setting constraints or making assignments), provides a way to determine for
what sub-plans algorithms can be used. Or, in other words, it provides the means to describe (and possibly design) the levels of human decision making, mixed initiative, and solitary search. Further research along these lines can contribute to the question how and where algorithms can be applied in planning support.

In a way, planning is an inconvenient way to attune activities. A lot of planning activities that take place are performed because of uncertain or incomplete information. Processes that extend over organizations could be better attuned if information would be shared more transparently. In the food processing industries, the effort of retail chains to reduce the order lead times can be (and sometimes is) accompanied by providing Point of Sale data of the stores. This study only provides a way to deal with short lead times without looking at the relationships in the supply chain. Supply Chain Management and Efficient Consumer Response aims to go further than this. In that view, a production plan of the manufacturer is only a part of the larger ‘plan’ that attunes agricultural yields to the consumer’s wishes. And not surprisingly, the manufacturer’s plan is again structurally the same as all other sub-plans, which means that it only solves a part of the puzzle on the basis of constraints and feedback. In a way, we could add another hierarchical level to the problem solving, task, and organizational planning levels. Planning at the manufacturer is a part of inter-organizational planning, and explicit attention to the relations between all plans in the supply chain should certainly be a subject of research in Efficient Consumer Response, or in supply chain management in general.

This research started from the perspective of the Scheduling Expertise Concept (SEC). In a concise definition, the SEC is a set of models to describe planning situations. In its broadest sense, however, the aim of the SEC is to accumulate knowledge about planning. The presumption is that this knowledge can be used to describe, analyze, and design the task performance of planners, the organization of the planning, and planning support. Somehow, the characteristics of the entities that are planned, the environment in which they reside, the characteristics of the planners, and the possibilities that computers have to offer, relate to the best way to organize, carry out, and support the planning process. We still don’t know the cause and effect relations between these planning elements. Do the domain entities determine the best way to plan? Or is ‘good’ planning determined by the individual? Probably both, but how do they integrate? Should we aim to replace human planners by computers? If not, how could we determine the best way to divide tasks between the computer and the planner? Where and how can the task oriented planning support approach meet or even be integrated with the quantitative/algorithm oriented approaches? These questions can only be answered with an approach that contains aspects of the context, the domain, the task performance, and computer support of planning as well as the relations between those areas.