Chapter 5. Planning concept for the Food Processing Industries

5.1. Introduction

The framework that is described in Chapter 4 is fairly abstract. It has two purposes. First, it can be used to describe specific scheduling situations. Second, it can be used to make abstractions of specific cases. These abstractions make it possible to find similarities and differences between cases. Similarities in a situation can be exploited to reuse (parts of) solutions that are created. We will make use of these mechanisms for the food processing industries as follows. First, we will use the models to describe the characteristics in food processing industries in general. Second, the models will be used to generically design a way to make the planning in these types of companies. Third, the generic models can be used as templates to specify case specific solutions (of which an example will be given in Chapter 6).

With these three steps, we disregard the original SEC philosophy to base abstract models on complete models of specific cases. We now base the abstract models on an analysis at different companies and theories about organization and production. Implicitly, this assumes that a scheduling situation can be (partly) designed on the basis of generic domain knowledge. This is easy to imagine for computer support. If planners in different cases face the same problems and solve their problems in a similar manner, we can assume that computer support for the one could at least be used as an example for the other. By building computer programs in a way that they can easily be adapted, we have a strong case of reuse, for the program can be adjusted to the differences in the planner’s task and domain. The explanation of the paradox of task support in Chapter 3, where we argued that task support itself changes the task, indicates that computer support can be used in a prescriptive way. For this, we first need to know how the task should be performed, and second how a planning system can support this supposedly good planning practice. As Benbasat & Todd (1996) argue, a user will be inclined to allow changes to his task that are caused by the introduction of computer support, if the use of the system provides enough benefits, for example the interestingness of the task components that remain, the time that is saved, or the increase in quality of the outcome. Still, it assumes that we can prescribe how planners should work.

In this chapter, we use the paradox of task support to deal with the alleged arrogance that we can prescribe a way of working for planners. This is based on the following argument. On the one hand task support is supposed to adapt to the user’s task, but on the other hand it possibly forgoes the potential of the computer. In other words, if a planning system would only account for the current way of working, it does not reckon with learning effects that will undoubtedly occur. We will argue that the planning practice in food processing industries is not adequately adapted to the environment in which it functions, and that adequate computer support can help the planners to adapt. Thereby, computer support becomes an enabler for a specific way
to carry out the task. In other words, the planning system and task performance are mutually dependent, and we make use of this by specifying both a way to make the planning and a way to support that.

This discussion could also have been held if we would have made task support for a planner in a specific case. In this chapter, we do not deal with a specific case but with a whole domain. This presumes that we can formulate (to a certain extent anyway) how planners should do their job on the basis of characteristics that are shared by a class of companies. The SEC-models will be used to exploit reusability of the description and design models, so the results can be used in multiple cases. We do not presume that the models will possess enough detail to be used directly in a specific case, but the (object oriented) modeling language allows extendibility explicitly. Chapter 6 will show the application of the models in a specific situation.

The research question in Chapter 1 asks how day-to-day planning in food processing industries can contribute to more flexibility. In Chapter 2, several reasons describe why flexibility is hampered by current planning practice. There, the conclusion is drawn that events that require a fast reaction (i.e., a short lead time) can not be processed adequately for a number of reasons, e.g., sequence dependent setup times, decay of material, and the limitation in information processing capacity. In this chapter, we argue that hierarchical planning can cause inflexibility, that one of the reasons of hierarchical planning has to do with information processing, and that computer support can increase the available information processing capacity. From these arguments, we can formulate requirements for computer support to contribute to flexibility. In Section 5.2, the SEC-models will be used to describe current practices in food processing industries. Section 5.3 will recapture the research question and analyze the factors that determine flexibility. This will be elaborated in Section 5.4, that looks at the flexibility of planning process, and in Section 5.5, where a task strategy is proposed that can increase the flexibility. Section 5.6 discusses computer support requirements that are needed to enact the proposed task strategy.

5.2. Models of planning in Food Processing Industries
This section will describe current practices of planning in the food processing industries with the SEC-models that were specified in Chapter 4. This means that models will be created for respectively the organization of the planning, the tasks, and the domain. These models are not case specific but general to the small and medium sized food processing industries. The models are based on the description in Chapter 2, which is an amalgam of case research results and production control literature. Therefore, we will first shortly recapture the findings that are reported in Chapter 2.

5.2.1. Food processing industry characteristics and their influence on planning
In Chapter 2, we have outlined characteristics that are common for small and medium sized food processing industries. Because these characteristics are the main
determinants for how the planning is done, we will shortly recapture the most important characteristics and their influence on the planning.

*Characteristics related to the market*

- There are both stock orders and customer orders. Stock orders can be used to balance a production plan somewhat, i.e., they can be used to supplement a collection of customer orders that will be made in one batch to a preferred batch size.
- The majority of the customer orders has a recurring pattern each week or fortnight. Such orders have a fixed delivery day of the week. This means that the planning does not have to be empty at the start of the plan creation process but that it can contain a frame in which a lot of customer orders are already filled in.
- There is a tendency to reduce order size, increase the number of orders, and reduce the required lead time, which makes that planners face an increasing number of orders that must be dealt with in a shorter lead time.

*Characteristics related to equipment*

- There are two kinds of equipment: processing machines and packaging machines. These differ in characteristics that influence the performance, e.g., setup-time, processing speed, cleaning time, minimum batch size, and preferred sequence of product types. Processing steps can not be scheduled independently due to limited shelf life of products or storage space restrictions. This precludes decomposition of the problem into several smaller and easier to solve sub-problems. It also means that processing and packaging need to be scheduled as one step, although the requirements of these phases are not the same. Because the preferred batch size in the processing phase is typically larger, and setup-times in the packaging phase are typically short for products that only differ in their label, orders that require the same ingredients but different packaging can be combined to one production order. Such a production order requires the production of one half product (by the processing step) and differentiation to multiple end products in the packaging phase, without a buffer between processing and packaging. The entity that is planned (i.e., assigned to machines and time) is therefore a collection of stock orders and customer orders instead of individual customer or stock orders. The fact that stock orders and customer orders are grouped first before they are scheduled reduces the number of entities that must be assigned to production lines considerably.

*Characteristics related to product characteristics*

- Variable quality of raw material lead to uncertainty whether orders are executed according to plan. Therefore, starting and ending times of orders are usually not incorporated in the plan.
Characteristics related to production processes

- The process is flow oriented, so the order of production steps is always the same.
- Long sequence dependent set-up times can result in fixed sequences of production, for example from light to dark color or from weak to dominating taste. This means that the sequence of production is for a large part trivial to determine.
- Variable yield of processes leads to uncertainty whether orders are executed according to plan. Therefore, starting and ending times of orders are usually not incorporated in the plan.

If we look at planning in food processing industries from a production scheduling perspective, the kind of planning under consideration is a flow shop planning problem, with somewhat trivial sequencing. Although the number of individual stock and customer orders might be large, the number of orders that ultimately end up in the planning is typically small because they are combined to production orders that can be made in one processing batch. Such a batch must be finished once it is started so the machines that are needed are grouped to one production line or capacity group from a scheduling perspective (Van Donk & Van Dam, 1996). In addition, for most customer and stock orders the production day is known. Therefore, the planning problem is not very intricate from a mathematical perspective. From a task perspective, however, there can indeed be complexity, in the sense that human decision makers can find it difficult to deal with lots of information, and uncertainty in information. The characteristics in food processing industries lead to planning problems that are divided in the following subtasks: collecting information (e.g., stock levels, needed stock orders, customer orders), creating production orders (i.e., combining individual customer and stock orders to production orders that can be made in one batch), and assigning the production orders to days and production lines. Note that this division occurs in other kinds of industries as well. The remainder of this section will provide models for these subtasks with the SEC with respectively the organization of the planning, the task structure and task strategy, and the domain model.

5.2.2. Organizational arrangements

An example model of the organization of planning is depicted in Figure 5.1. This model is not meant to be fixed because other ways to divide the tasks are also found. We will shortly explain the picture. The production manager makes a rough aggregate plan that determines the amounts of the products that will be made and the capacity that is needed. The planner uses the product planning to determine what stock orders should be made and what customer orders can be accepted. This is used to make a production planning in which stock orders and customer orders are combined to production orders and assigned to production lines. Typically, this planning is for the next week. The foremen determine the exact starting and ending times of the production orders, which depends on actual progress of the production...
planning on the production floor. The model of the organization of the planning will be further elucidated by making separate models of the decisions that are made at each decision layer and the entities that are manipulated with that decision. This will be discussed as respectively the task models and the domain models.

5.2.3. Subtasks
From the case analyses that were carried out we extracted the tasks that constitute production planning in food processing industries. These tasks will be described from two perspectives. First, the subtasks describe what operations on objects happen in the planning process. Second, the task strategy shows when and under what conditions the subtasks are carried out.

![Organization of the planning in food processing industries](image)

**Figure 5.1.** Organization of the planning in food processing industries

A major problem of generic task models for planning is that the way in which a task is performed is to a large extent determined by the individual that makes the plan. There is no natural level of detail above which all is generic and below which all is case specific. Since the purpose of this chapter is to provide a generic model of planning for food processing industries, we are forced to make a choice that will always prove wrong. Thus, no matter the level of detail of the generic models, some aspects will have to be added and some aspects will have to be removed for application in a specific case.

The description of subtasks proceeds as follows. First, the planning tasks will be recaptured from Chapter 2 and linked to the objects that are manipulated. Such manipulations are creating an object, deleting an object, setting attribute values, determining constraints, and linking objects. Second, we will show the relations between the tasks in the task strategy.
Determine stock levels.
If a company has production to stock, the minimum and maximum stock levels must be determined over time. This is not a one time activity because the required stock levels can depend on seasonal patterns, weather expectations, special product actions in retail, etc. The stock level can be used to balance capacity and demand to some extent because the stock levels are determined by the production organization itself whereas the customer orders are of course triggered externally. This decision puts a constraint to the stock orders that can be scheduled. The constraint can only be checked if the orders are scheduled (i.e., when the moment of production is determined) because then the resulting stock levels can be calculated for the planning period. The apparent objects types that are manipulated are products or product families and time.

Determine the amount per product family.
A product family is a collection of products that are similar with respect to characteristics that determine whether they can be made in the same batch, e.g., color, taste, or packaging size. The decision is based on aggregated demand of expected and accepted customer orders and stock orders, and stock levels. Again, apparent objects types are products or product families and time.

Determine the boundaries for customer order acceptance.
The predictability of customer orders is often rather high because most customers have a fixed ordering pattern weekly (sometimes, even an order that is not yet placed is planned because the order is expected to be placed). Objects types for this task are products or product families and time.

Configure production lines.
Production lines can be created by placing a number of machines in a certain configuration. Of course, these machines can then not be used in another configuration. What production lines are needed depends on the product families that are going to be made. The configuration of production lines constitutes the following activities: creating production line objects and assigning machine objects to production line objects and time periods. This task can occur in three settings:

- Production lines are highly variable and are configured each time. This is not likely in food processing industries because product variations are limited.
- There is a fixed set of possible production lines but they can not function all at the same time due to capacity or space restrictions. A production line then consists of a configuration of processing and packaging equipment that is specific to a certain product family and is built only if needed.
- There is a fixed set of production lines that does not change.
In the second setting, there is a fixed set of production lines from which the needed production lines are chosen. In the last setting, there is also a fixed set of production lines but no choice has to be made since all are always available and hence it is no planning subtask.

**Customer order acceptance.**
Orders are accepted on the basis of the boundaries that were determined. Orders in food processing industries have a high degree of repeatability. Only large or otherwise exceptional orders require special attention. In terms of the object model, if a customer order is accepted, a customer order object is created.

**Determine stock orders.**
As said, stock orders offer some flexibility since there is no external party involved. In addition to normal stock order generation on the basis of expected sales, these orders can be used to level capacity and to fill production runs to a desired level (e.g., fill kettles to the maximum to fully utilize capacity). Stock orders are created on the basis of the minimum and maximum stock order levels, the available stock, the already created stock orders and customer orders, and the room there is for production orders per product family. The output is instances of the class ‘stock order’.

**Determine production orders.**
Different orders might deal with the same product. These can be combined in production orders. Also, large customer orders can be split into several smaller production orders, e.g., each half a day’s worth of production. Thus, objects of the type ‘production order’ are created and customer orders and stock orders are assigned to them.

**Determine production runs and assign production orders to production runs.**
On the basis of the available orders, it is decided what production runs are needed and production orders are assigned to production runs. A production run consists of a collection of production orders within the same product family. Combination of orders is at product family level, where products of the same family are combined in a batch with the same color, flavor, etc. Small changes in the packaging phase (e.g., changing the wrapper) can be done in the same run. Objects of the type ‘production run’ are created and stock orders and customer orders are assigned to these objects.

**Assign runs to production lines.**
Often, there are multiple production lines on which runs or batches can be made. The choice is important if these production lines differ in, e.g., the speed or the products that can be made on it. If there is no choice, i.e., product families are always made on the same production line, then this task is a trivial one.
Sequencing and scheduling of runs.
The sequence of planned production orders depends on setup- and cleaning times, and due dates of orders that are aggregated in production orders. These can be opposing so they must be weighed to get a satisfactory sequence. An unfavorable sequence leads to more setup- and cleaning times. This can induce that there is not enough time to produce all specified orders.

Finally, the exact starting and ending time can be determined. This is to some extent trivial since it is determined by the size of the production order and the place in the sequence. From there, starting and ending times can be calculated. There are three options. The first option is that the schedule can be given to the production floor without determining the time buckets explicitly. Still, these are implicitly assumed by calculating the expected run time of orders. Otherwise, due dates can not be checked. The second option is that the planner assigns production runs to days. In the first and second option, large deviations during execution of the plan (e.g., that influence the plan of the following day) are reported to the planner so he can assess the consequences. Third, the planner can put starting and ending times of runs explicitly on the plan. The fact that this does not occur often is caused by the unpredictability of processing times and the fact that it does not matter much when during the day a product is finished if it is shipped at the end of the day or later.

The description of subtasks is of a static nature. The way in which subtasks are related to each other and the order in which they are performed is described by the task strategy.

5.2.4. Task strategy
Figure 5.2 provides a high level overview of the relations between subtasks. These relations are based on the inputs and outputs of the subtasks. There are three areas of decisions. First, there are decisions that relate to capacity determination. These decisions weigh the types of products that are made, how these products are divided between customer orders and stock production, and the capacity that is used. These decisions all influence each other. The planning horizon stretches over multiple months. These decisions are taken periodically without too much detail. These are typically decisions at the detail planning level (Van Dam, 1995). Second, stock order generation and customer order acceptance must be attuned. These decisions are often taken continually, especially with respect to customer order acceptance. Orders are sometimes promised for specific days but sometimes a bit less detailed, e.g., the week in which delivery will take place. The boundaries that are set often give some flexibility for exchange between customer and stock orders. For example, if there are less than expected customer orders for a product family, then capacity could be filled with extra stock products of the same family. Third, the customer and stock orders are grouped into production orders, which usually are specified as one or more batches or production runs. The production orders are assigned to production lines, where they are sequenced and scheduled. This is done weekly with as much detail as is needed (see the discussion of the subtask Sequencing and scheduling of runs).
A typical scheme for the planning strategy is the following. Capacity considerations are made periodically with a time horizon of one to three months. The same goes for stock order generation and customer order acceptance. A production schedule is made each week. When the creation of this schedule starts, the production lines, customer orders, and most of the stock orders are assumed fixed. To fill capacity, additional stock orders can be generated, and stock orders can be postponed if there is not enough capacity for all customer orders. Note that postponement is not possible for most customer orders since these are promised to customers. Customer orders that require a delivery date for which a plan is already made, are typically met with reluctance because it can result in a waterfall of changes.
5.2.5. **Object model**

Production planning in food processing industries results in schedules that denote the attunement between production lines, production runs, and time buckets. Or, in other words, what run will be produced when on what production line. There are three hierarchical levels that exist due to the stepwise creation of the plan but that are not expressed in the ultimate schedule. The first is the grouping of customer orders and stock orders into production orders and the production orders in production runs. The second is that machines are configured to production lines. The third is that production runs are first assigned to production lines (an assigned production run), after which the assigned runs are sequenced and thereby scheduled, i.e., their production sequence is determined and the production time can be calculated. Figure 5.3 shows the domain model of all entities.

![Diagram of planning in food processing industries](image)

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Each decision layer in the model of organizational arrangements constitutes a separate planning problem for which a task model and domain model can be made. Note the equivalence of both models. In this case there is a one to one correspondence of aggregation layers in the domain model with decision layers in the model of organizational arrangements. The added value of the object model is first that it corresponds to the objects that are attuned rather than decisions that are made. Second, the object model allows to show generalization of objects. This can enhance our understanding of a particular model.

The use of the aggregation layers has several advantages. First, it becomes explicit what stages are used in the task performance. Second, each planning problem (i.e., aggregation layer) is modeled in the same way. Third, due to the previous point, constraints can be specified in a uniform way.
We will describe the most important attributes and constraints of the objects in the domain model. Attributes will mostly occur at the singular objects, whereas most constraints will apply to combinations of objects.

*Customer order / stock order / Production order / Production run*

An order specifies a certain amount of product that must be made before the due date. A product is a compound structure of information. Usually, it mentions the product itself (e.g., a chocolate stick) and the packaging form (e.g., 20 sticks in a box, 6 boxes are wrapped together in a unit, each unit gets a label, and 32 of such units are put on a pallet). The size of the order can be expressed in individual items, boxes, pallets, weight, etc., and these measures can be translated into each other with the use of the recipe and/or bill of materials. An order can either be a stock order or a customer order. Customer orders in this model are specified per product. Customers can order a number of items simultaneously. This can be important if the ordered products must be shipped in one truck or container.

Production orders are groups of customer orders and stock orders for the same product. Suppose the following orders must be produced:

- Customer order 1 (with two order lines): 100 boxes of product A and 50 boxes of product C
- Customer order 2: 100 boxes of product B
- 200 boxes of product C for own stock

Thus, there are two object instances of a customer order and one object instance of a stock order. These orders can be combined to production orders in the following way:

- Production order 1: 50 boxes of product A
- Production order 2: 50 boxes of product A
- Production order 3: 100 boxes of product B
- Production order 4: 250 boxes of product C

In this example, the order for product A is split, for example because 50 boxes of product A constitutes a day’s worth of production. The two orders for product C are grouped. A number of production orders can be grouped to a production run, but the production run can also exist of one production order.

The only generic constraints on this level are the minimum and maximum size of production orders and production runs. Note that due date violation and the availability of ingredients and packaging will specified with the object ‘scheduled production order’.
Machine / Production line
Food processing industries usually produce in flow shops. The specific production lines, however, are configurable. This means that machines can be put in the order that is needed to make a specific product. This can mean a simple switch of a button to route the flow of mixed ingredients through other pipes, or physically move machines so they are connected to each other. In both cases, the use of a machine in one production line means that another production line that also uses this machine can not exist then. This constraint, however, can only be checked at the level of scheduled production order because it contains temporal restrictions.

Important characteristics of production lines are the production speed, change-over times, and the products that can be made on the line. The speed of a production line depends on the bottleneck machine and can vary per product. Change-over times are specific for the combination of the machine, the old product, and the new product, although they can be generic to product families instead of individual products.

Assigned production run
Production orders are assigned to production lines by assigning their run to a production line. Often, there is not much choice since production lines are dedicated to a specific product family. Still, there might be a choice between several production lines.

Two generic issues can be taken into account when assigning. First, the production speed of the lines can differ. Second, product lines can differ in the range of products that can be made on them, so if a product can be produced on both, the allocation should reckon with the rest of the products that must also be assigned.

Starting time / Ending time / Time bucket
The size of the time bucket is calculated from the run size and the production speed.

Scheduled production order
A production run that is both assigned to a production line and to a time block is a scheduled production run. An important constraint for this object is that the order may not finish later than its due date. Other constraints state that machines can not be used simultaneously, that raw material and ingredients must be available when needed, and that the maximum capacity of the production lines may not be exceeded.

Schedule
The schedule is the collection of scheduled production runs. If the whole schedule is known, it can be checked whether the stock levels of stock products are not too low or too high, if the product families are balanced, how much due dates are violated, how much idle time the machines have, etc.

The way in which the planning in food processing industries is performed and what kind of entities are used in the process of plan creation are now described with the
SEC-models. The following sections will discuss the changes that are proposed to make the planning more flexible.

5.3. Reflection on the analysis of conflict
Planning decisions are not reconsidered lightly if a change would have many consequences. In terms of task strategy, it is only done if it is really necessary because, for example, a machine breaks down or raw material is out of stock. It is this absence of strategies to deal with change that has our primary focus. In Chapter 2, we concluded that there are a number of reasons to decline short lead times of planning events. For example, sequence dependent setup and cleaning times, lead-time of perishable raw material, and process variability, call for planning with a long lead time. Another reason is that planners simply do not have the time or tools to assess the effects every time an opportunity arises. We argue that if the planner would be able to assess changes at any moment, then events such as machine breakdowns could be processed better. In addition, this would provide the opportunity to accommodate the wishes of customers for lead times that are shorter than the planning horizon.

One of the reasons that planners can not deal with all events all the time, is the fact that the process of planning is organized as a hierarchical decision system. Although hierarchical planning can be needed due to lack of information or can help to manage to navigate through the vast amount of alternative plans, it has disadvantages. First, not all possible plans are examined, so it might very well be that a better solution exists somewhere outside the restrictions that the hierarchy imposes. Second, subsystems in hierarchies are presumed to operate more or less independently; a plan at a given hierarchical level is supposed to be stable because it defines boundaries for levels lower in the hierarchy. If changes in the environment invalidate a plan at a high hierarchical level, invalid assignments can cascade to lower hierarchical levels. For example, if raw material that was ordered does not arrive on time, planned orders that presume that the raw material will be available, will be invalid. Reassessing decisions in the hierarchical chain requires extra information processing, which is exactly why the hierarchy has come into being in the first place. This contradiction suggests that there is a relation between flexibility and hierarchical planning.

As an answer to the flexibility requirements from the market we propose the concept of continuous planning. What we mean by this concept is that planning decisions at all hierarchical levels must at any moment be prone to reconsideration. It does not mean that the decisions are not taken hierarchically anymore or that changes should be made lightly. What it does mean is that there must be a full insight in the following aspects when an event (e.g., requests of customers) is considered for processing: (1) the advantages of answering the event, (2) the capacity that it costs to process the event, (3) the throughput time needed to make the decisions, and (4) the effects that the resulting changes in the plan might have on the organization. The advantages must outweigh the costs (in terms of planning capacity) and the negative consequences. These ideas will be explored in the following sections.
5.4. Analysis of flexibility

5.4.1. Introduction
Our research question in Chapter 1 asks how day-to-day planning in food processing industries can contribute to more flexibility. In Chapter 2, several reasons are given why flexibility is hampered by current planning practice. This can be translated to the view of planning as a decision hierarchy. For a number of decisions, it is advantageous if planners have information early, for example in order to assemble orders into runs of the same family and to create production sequences that avoid cleaning time. If planners do not have actual orders, they must make estimates which can prove false or unfavorable at a later time. But, due to the limited information processing capacity, there is not always enough time to reconsider decisions if the actual information replaces the estimates. In this sense, hierarchical planning opposes flexibility. Therefore, we will approach the research question by analyzing and reassessing the hierarchy in which planning decisions are taken.

To analyze the flexibility in the decision hierarchy, we will use the model in Figure 5.4, as discussed in Section 4.3.3. In this model, there are essentially four activities that constitute a decision. The first is to take the decision itself within the restrictions that are received from the higher level. This consists of generic decision making activities such as generating alternatives, evaluating alternatives, and choosing (Simon, 1960). Second, sub-decisions that have common constraints must be coordinated (arrows 3 and 4). Third, a decision maker must assess the consequences of a problem (the ‘problem’ arrow 2), communicate again horizontally, and possibly refer the problem upwards itself. Fourth, the decision must be communicated to lower hierarchical levels (the ‘constraint’ arrow 1).

![Figure 5.4. Basic hierarchic decision model](image)

Our line of reasoning is based on the premises that (1) making a plan is a form of decision making, (2) decision making is a form of information processing, and (3)
the information processing capacity of planners/decision makers is limited. As Simon (1985) indicates, a successful hierarchy should be nearly decomposable. If the decision hierarchy is not nearly decomposable, decisions have mutual dependency in the short term, and must be coordinated frequently. This process costs information processing capacity, which is, as we argued, limited.

We can now formulate the conflict between market characteristics, production system characteristics, and planning in small and medium sized food processing industries as follows. The planning hierarchy is not accommodated to handle changes with the frequency and lead time that is required by the market. Decisions can not always be reconsidered when needed because it takes too much information processing capacity to incorporate a change into the schedule (which can cascade through the whole schedule), or even to check the consequences that a change might have. This means that events that require a change in the schedule are not processed properly. In this section, we will explore how planning and flexibility are related, describe a way to increase the flexibility, and describe the prerequisites that follow from that.

5.4.2. Definition of flexibility
The term flexibility has been used several times now, but without a precise definition. Therefore, we will first look how the flexibility of a manufacturing system is related to the planning.

A flexible organization is an organization that possesses requisite variety in its control mechanisms to deal with the variety in the environment (Ashby, 1984; Gazendam, 1993). Volberda (1992, p. 96) provides a classification of types of flexibility. Strategic flexibility is the ability to react to long term changes in the indirect environment, organizational flexibility is about medium term changes in the direct environment, and operational flexibility deals with short term reactions in a stable environment. The former two kinds of flexibility relate to structural changes in the environment, whereas the latter kind relates to the natural flux that exists in an environment. It is this last kind of flexibility that we deal with if we talk about the relation between flexibility and day-to-day planning. The way in which this kind of flexibility is approached in manufacturing organizations will be the subject of this section.

Production/operations management literature provides ample definitions of and approaches to flexibility. Koste & Malhotra (1999) discern ten flexibility dimensions in a literature overview (Table 5.1). These dimensions can be separated in two kinds. Machine, labor, material handling, routing, operation, and expansion flexibility are internal for the manufacturer. Volume, mix, new product, and modification flexibility are, in addition to internal consequences, also external in the sense that these are the kinds of flexibility that the customer is confronted with. In a way, internal flexibility is only apparent from the outside via flexibility of the second kind.
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<thead>
<tr>
<th>Dimension</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Machine flexibility</td>
<td>The number and heterogeneity (variety) of operations a machine can execute without incurring high transition penalties or large changes in performance outcomes</td>
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<tr>
<td>Labor flexibility</td>
<td>The number and heterogeneity (variety) of tasks/operations a worker can execute without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td>Material handling flexibility</td>
<td>The number of existing paths between processing centers and the heterogeneity (variety) of material which can be transported along those paths without incurring high transition penalties or large changes in performance outcomes</td>
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<tr>
<td>Routing flexibility</td>
<td>The number of products which have alternate routes and the extent of variation among the routes used without incurring high transition penalties or large changes in performance outcomes</td>
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<tr>
<td>Operation flexibility</td>
<td>The number of products which have alternate sequencing plans and the heterogeneity (variety) of the plans used without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td>Expansion Flexibility</td>
<td>The number and heterogeneity (variety) of expansions which can be accommodated without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td>Volume flexibility</td>
<td>The extent of change and the degree of fluctuation in aggregate output level which the system can accommodate without incurring high transition penalties or large changes in performance outcomes</td>
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<tr>
<td>Mix flexibility</td>
<td>The number and variety (heterogeneity) of products which can be produced without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td>New product flexibility</td>
<td>The number and heterogeneity (variety) of new products which are introduced into production without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td>Modification flexibility</td>
<td>The number and heterogeneity (variety) of product modifications which are accomplished without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
</tbody>
</table>

**Table 5.1.** Flexibility dimensions (Koste & Malhotra, 1999, p. 81)

As stated in Section 1.2, De Toni & Tonchia (1998, p. 1593) summarize the conditions that mostly determine the need for flexibility as follows:

1. “The variability of the demand (random or seasonal)
2. Shorter life-cycles of the products and technologies
3. Wider range of products
4. Increased customizations
5. Shorter delivery times”

The overview in Chapter 2 discussed how these factors appear in food processing industries. De Toni & Tonchia (1998, p. 1593) describe five mechanisms that can influence the flexibility:
1. “Products (wideness of the range, number of parts, etc)
2. Manufacturing processes (availability of general purpose machines, reduced set-up times for the machines, etc.)
3. Planning and control (policies of lotting, scheduling, storage, etc.)
4. Human resources (training, trade-union relations, etc.)
5. Relations with the suppliers (co-makership policies, etc.)”

Apparently, planning influences flexibility. There are two ways in which these measures and categorizations of flexibility can be related to planning of manufacturing systems. First, the planning is one of the mechanisms that influences the flexibility of the manufacturing system. For example, the latest moment at which an order can be accepted can be restricted by the fact that it costs time to incorporate it in the planning. Second, the planning can be seen as a production system itself, with information as input and a plan as output. Although not all flexibility dimensions are applicable to such a view, it might still provide an interesting analysis of the planning process. We will discuss both points of view.

5.4.2.1. The influence of planning on flexibility of manufacturing systems
To analyze the influence of planning on the flexibility of manufacturing systems, we use the flexibility dimensions that are mentioned in Table 5.1. Thereby, we limit ourselves to the external flexibility dimensions that can be influenced by the planning, since we are focusing on the relation between the external conditions that determine the need for flexibility, and the planning itself.

New product flexibility, modification flexibility, and mix flexibility are only indirectly influenced by the planning: if the planning cannot deal with more product types, the introduction of new products will stumble upon this planning bottleneck. The influence of planning on volume flexibility is much more direct because volume flexibility itself is noticeable on a day-to-day basis (note that Koste & Malhotra (1999) deal with volume flexibility as operational static flexibility and not the long term strategic kind). Slack et al. (1998) provide more refined way to define the volume flexibility: the extent to which the output volume can be changed (they call it the volume flexibility, but in a more restricting sense than Koste & Malhotra (1999)), and the ability to change the time at which products can be delivered (the delivery flexibility). These kinds of flexibility relate to orders. Because orders are the link between the factory and the customer, the planning of the orders directly influences the external flexibility of the production system.

5.4.2.2. The flexibility of the planning process as a production system
In Chapter 4, we have looked at the process of plan creation. This process can be viewed as a production process that delivers a plan. Therefore, the dimensions of flexibility can be applied to this ‘production’ process. New product flexibility and modification flexibility are meaningless for day-to-day planning because they relate to long term changes to the structure of a plan (e.g., changing from a plan that only
assigns products and machines to a plan that assigns products, machines, and personnel). Material handling, routing, and operation flexibility have little or no meaning for the planning process because the process of plan creation typically has very few stages of ‘production’ with no alternative operations. Machine flexibility is meant to denote the variety of operations that can be handled by a machine. This is of little use in our analysis, because this variety is limited if we view computer support as the machine that is used for plan creation. The expansion flexibility expresses whether the capacity or capability of the planning can be extended. If this kind of flexibility is high, this means that more planners can be put to work at short notice, or that a part-time planner can increase the time he spends on the planning. The labor flexibility is about the number and variety of tasks that a planner can perform. This is the case if multiple planners work on a planning problem and they are flexible with respect to the tasks they perform. Volume flexibility denotes the output, where we can again split this in the output volume flexibility and the delivery flexibility. If the output volume flexibility of the planning process is high, it can process many events (e.g., new orders, changes to orders, machine breakdowns, etc.) in a short time if necessary. The delivery flexibility relates to the time that the plan is released. In this sense, flexible planning means that a plan can be made or adapted at short notice.

The research question in Chapter 1 asks how day-to-day planning in food processing industries can contribute to flexible product replenishment. In these terms, flexibility means to be able to respond quickly to a wide range of requests. By looking at theories about flexibility, we have identified a number of factors that determine the flexibility in two steps. First, one of the factors that determine the flexibility of the production system is planning. Second, we have analyzed the flexibility of the planning process as if it were a production system itself, and we showed how the flexibility of the planning influences the flexibility of the production system.

Our definition of the flexibility of the planning descends from the view of the planning process as a production system. We define the planning flexibility as the time until it is possible to make changes to the schedule. In other words, the planning flexibility is directly related to the latest moment that new orders or changes can be processed. This is the external flexibility of the planning process, since it can directly be expressed in the volume output flexibility and delivery flexibility of the planning process. In turn, volume and delivery flexibility are influenced (but not solely determined) by the (internal) labor and expansion flexibility of the planning process. In this way, the flexibility of the planning is defined by the volume and delivery flexibility of the planning process itself, and the flexibility of the production system is influenced by the flexibility of the planning (Figure 5.5).

Because the flexibility of the planning is one of the factors that determine the flexibility of the production system, We can now formulate a way in which the planning can contribute to flexible product replenishment and thereby provide an answer to our research question: if the flexibility of the planning increases, so does the volume and delivery flexibility of the production system, which enables
manufacturers to deal with shorter lead times and more orders. The factors that influence the flexibility of the planning process will be discussed in more detail in the remainder of this section.

5.4.3. Flexibility factors

There are two base factors that determine the latest moment at which events that might result in changes to the plan can be processed (Table 5.2 contains examples of events).

<table>
<thead>
<tr>
<th>Source</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>New order</td>
</tr>
<tr>
<td></td>
<td>Change of order</td>
</tr>
<tr>
<td></td>
<td>Cancellation of order</td>
</tr>
<tr>
<td>Product</td>
<td>Rejection of batch due to quality problems</td>
</tr>
<tr>
<td></td>
<td>Raw material out of stock</td>
</tr>
<tr>
<td></td>
<td>Packaging out of stock</td>
</tr>
<tr>
<td>Process</td>
<td>Process duration differs from planned (e.g., due to short</td>
</tr>
<tr>
<td></td>
<td>machine interruptions or processing uncertainties)</td>
</tr>
<tr>
<td>Machines</td>
<td>Breakdowns for longer periods</td>
</tr>
<tr>
<td></td>
<td>New capacity available</td>
</tr>
</tbody>
</table>

Table 5.2. Examples of events (copy of Table 2.5)
The first factor is the volume flexibility of the planning process, which corresponds to the number of events that can be processed. Processing changes requires information processing capacity in the form of people that must make decisions. We presume that this capacity is limited and scarce. Therefore, the number of events that can be processed is limited.

The second factor is the delivery flexibility, which is determined by the throughput time of processing the events. In other words, notwithstanding the time that is actually spent at processing an event, a longer throughput time will make the ultimate starting time for an event earlier and thereby the planning less flexible. The throughput time of planning decisions is longer than the processing time itself if decisions must wait, for example because they are made only once a day, or because a decision must be made by multiple persons that need to coordinate somehow.

Alteration of the planning after an event can cause a cascade of changes of which the magnitude is difficult to predict (Figure 5.6).

![Diagram showing effects of an event in a hierarchy]

**Figure 5.6.** Effects of an event in a hierarchy
This is especially the case if an event at a certain hierarchical level requires changes at a higher level, because changes at higher levels cascade to all lower levels. In this sense, a decision can cause the necessity to take a lot of other decisions, which is of course coherent with our definition of planning as a decision hierarchy. In this way, it is easy to see the relation between hierarchical planning and the flexibility of the planning. As an illustration, consider the following example:

A rush order can not be put in the planning because the batch of that product type is already full with other important orders. Thus, the event can not be processed at its own hierarchical level. At a higher hierarchical level, the planner can decide to increase the batch size for that product type. This has implications for the batches of the other product types. One or more will have to decrease or be postponed. Thus, the planner must search for orders in other batches that can be postponed.

It is not uncommon practice that different hierarchical levels are organized as distinct tasks that are performed by different people. This means that a change that effectuates multiple hierarchical levels possibly must be assessed by several people. Their work must be coordinated. For example, the production manager might be the one that makes the decision whether a batch will be increased or not. If (in the previous example) the planner must wait for the production manager to decide on the batch size, the throughput time of the decision might become too long to be useful for a rush order. Thus, both the number of events that can be processed and the throughput time are influenced by the fact that the planning process is hierarchically organized. Figure 5.7 contains a decision tree with a simplified decision process that occurs after an event occurs. This decision model results in five states that an organization can be in if it is confronted with a new order or other event (Table 5.3; Van Wezel et al., 2001). If the number of events increases without an increase in information processing capacity, and the planner has not enough time anymore to handle all events timely, the planner will find himself more often in state 1,2, or 3. In other words, events can not always be accumulated because they require immediate attention. For example, if a planner has not enough time to find out if a new order can be put in the schedule, the new order will be declined (state 2).

Clearly, state 5 is always preferable. However, from the perspective of the planning, state 4 is also acceptable, as long as the planning department is not the cause that state 5 is not reachable. Therefore, our definition of flexibility leads to the following statement: the later the moment that planners can be in state 4 or 5 after an event that requires a planning action, the more flexible the planning is. This provides a summary of the relation between flexibility, decision making, and planning organization. If the planners can process more information, or if the information processing is better organized, it might be possible to become more flexible. It also gives the direction in which the research question in Chapter 1 will be answered: the flexibility is a function of information processing capacity and throughput time of planning decisions.
Is it known what must be done to decide about the event?

Are the efforts to make a decision about the event acceptable?

Is the throughput time to make the decision smaller than the required lead-time?

Do we make a decision anyway?

Do not process the event

Make a decision

Incorporate the event

Decline event

Do not process the event

Figure 5.7. Decision tree of event processing

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>It is not known what effort is needed to assess the consequences that the event has.</td>
</tr>
<tr>
<td>2</td>
<td>The efforts to find out what the consequences are are too great.</td>
</tr>
<tr>
<td>3</td>
<td>The efforts to consider the consequences are acceptable but the throughput time for considering the consequences is longer than the lead-time that is required (i.e., a timely answer can not be given).</td>
</tr>
<tr>
<td>4</td>
<td>The consequences of incorporating the event are known to be too costly (e.g., a rush order would require overtime, or current production must be interrupted).</td>
</tr>
<tr>
<td>5</td>
<td>The event will be incorporated (the plan will be adjusted) because it is profitable (e.g., because another order can be postponed or because it is an important customer).</td>
</tr>
</tbody>
</table>

Table 5.3. States after events (Van Wezel et al., 2001)

The state that the planner is in after an event depends on the kind of event and the state of the production system that the event relates to. Figure 5.8 shows a timeline with six activities in time that are important for planning in production organizations. This figure could be extended with activities such as staff planning and capacity
determination, but these are left out here for the sake of simplicity. Furthermore, we have outlined the phases in which events are expected to happen normally for each of the event categories from Table 5.2 (e.g., events from the customer are expected in phase 1 and phase 2). These activities signify seven periods or phases that an event can relate to. For example, a new order can be received when the planner has not yet ordered raw material or allocated capacity to product families for the period that the requested delivery date of the new order falls in. Then, the phase of the event in Figure 5.8 is phase 1. If this new event would relate to a period (say, next week) for which the planner has already started to make a detailed plan (assigning orders to runs, assigning runs to production lines, and determining the sequence of production), then the phase of the event in Figure 5.8 would be phase 3. The state in which the organization would find itself after the event would differ whether it is received for phase 1 or for phase 3. The figure already indicates that such an event is usually not expected at such short notice.

![Figure 5.8. Phases in planning](image)

The seven phases are discussed in Table 5.4. In order to be as flexible as possible, the moment until orders or other events are not accepted anymore should be as late as possible. This can now be further specified with the states that are described in Table 5.3 and the discrete events that are depicted in Figure 5.8. The states that are described in Table 5.3 have to do with information availability, information processing capacity, and throughput time. The phases in Figure 5.8 make clear the following (ceteris paribus) conclusions. First, the information processing capacity that is needed could be higher for events that occur further to the right. The rationale behind this is that an event might invalidate work that already has been done. For example, a new order can be accepted without much consideration in phase 1 (a
rough cut capacity check would do) whereas it might cause rescheduling activities if it occurs in phase 3 or later. Second, the predictability of the information processing capacity that is needed is lower for events that occur further to the right. The rationale is the same, namely that it might not be clear whether previously made decisions will be invalidated or not. Third, the throughput time that is available to make a decision is lower for events that occur more to the right.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before the capacity has been allocated or raw material has been ordered, events can be processed without much consideration, although in the case of new events or long machine breakdowns a rough capacity check will be needed to make sure the total available capacity will not be exceeded.</td>
</tr>
<tr>
<td>2</td>
<td>After raw material and packaging cannot be ordered anymore (because the procurement lead time is longer than the period until the production order must be started), it must be checked whether an event does not lead to shortages (e.g., a batch is rejected and must be remade so the usage of raw material is higher than expected; or a new order cannot be accepted because there is not enough packaging and new packaging cannot be delivered before the requested delivery date).</td>
</tr>
<tr>
<td>3</td>
<td>If the making of the plan is started but not yet finished, an event can disrupt the planning process. Before phase 3, orders can be collected and dealt with by creating a detailed plan from scratch. If the making of the plan is started, then events must be incorporated in an existing plan (or the planning must start again from scratch, which is usually not an option due to the time it costs).</td>
</tr>
<tr>
<td>4</td>
<td>When the making of the planning is finished, but the execution has not been started yet, reconsideration of the planning is possible but often not an issue because all parties have agreed with the plan and changes would cost much time. Still, some events cannot be neglected, for example, machine breakdowns and unexpected stock-outs of raw material.</td>
</tr>
<tr>
<td>5</td>
<td>In this phase, not only customer, product, and machine related events can occur but also process related events. The process can take longer or shorter than expected, batches might be rejected for quality reasons, and machines might be temporarily disrupted. If the executing of the planning is started, the required reaction time might be extremely short. But, because a plan specifies multiple orders that are not all started immediately when the plan execution is started, there are still possibilities for adjustments to the plan.</td>
</tr>
<tr>
<td>6</td>
<td>In principle, the planning of a batch could be altered even if preparations of a batch (collection of materials, preprocessing) have begun. However, this is not done likely in practice because the consequences cannot be assessed timely.</td>
</tr>
<tr>
<td>7</td>
<td>Food processing industries often do not allow preemption, so a batch that is started must be finished.</td>
</tr>
</tbody>
</table>

**Table 5.4. Phases that an event can apply to**

With Table 5.3 and Figure 5.8 it is possible to characterize the planning flexibility of an organization. Flexibility was defined as the time until it is possible to make changes to the schedule. This can be measured by specifying the combinations of types of events, states, and phases of an organization, with the underlying presumption that the organization will respond always in the same way on events in a particular phase. For example, a certain organization might always refuse changes
to orders that are requested for phase 4 or later, because it finds itself in state 3 if that situation. This also enables us to determine when an organization becomes more flexible: higher flexibility means that higher numbered states occur in later phases. In this way, the definition of flexibility (‘the time until it is possible to make changes to the schedule’) is qualified by dividing ‘until’ into different time blocks (Figure 5.8), by specifying what kinds of ‘possible’ exist (Table 5.3), and by seeing decisions about events as ‘changes’. Figure 5.9 contains an example of the relation between states and phases for an event.

A table as depicted in Figure 5.9 can be made for each event that can occur. The actual states, phases, and events are case specific, but the model can be used to analyze where the flexibility can be increased. In the remainder of this chapter, we will describe how the flexibility can be increased from the perspective of task performance, organization, and computer support of the planning with the use of the event/phase/state distinction.

| state | 5 | x | x | | | |
| 4 | x | x | x | x | |
| 3 | | | | | |
| 2 | | | | | |
| 1 | | x | x | |

| phase | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| event | new order |

Figure 5.9. Example of event / phase / state relations

5.4.4. Increasing flexibility
In Chapter 2 and Chapter 4 we have discussed that current planning practice takes place hierarchically. The time that it costs to react on events, the throughput time of the decisions, and the uncertainty thereof, are reasons to set a point in time after which an event will not be considered anymore, so the plan at that level can be used as constraints for lower level (more detailed) plans. Before this point, processing the event should require not much effort, for example because a mere capacity check suffices. After this point there are not only aggregate relations between orders and capacity, but the planning might be partially completed at a detailed level and preprocessing might even have been started. A very important contemplation is that if the information processing capacity would be high enough to assess the consequences of changes to a plan that is already partly finished, then the point after which events can be processed could be moved to the right in Figure 5.8, which would increase flexibility. In this way, information processing capacity is directly related to the number of events that can be processed, which in turn is one of the measures of flexibility. In the utopian situation of unlimited information processing capacity and a throughput time of zero (no waiting time), only state 4 or 5 in Table 5.3 would ever occur, no matter the phase or type of event. Although this is of course
not reachable, both increasing the information processing capacity and decreasing the throughput time will be discussed.

The total capacity that is needed to take planning decisions should be smaller than the capacity that is available. Although this is of course trivial, an interesting fact can be deduced if we state that this is also true for very short time periods. For example, if there are two simultaneous events that each require one hour of information processing capacity, then it is possible to answer both events within 2 hours. But if both events must be answered within one hour, one will be late, and in this case the planner finds himself in state 3 that is sketched previously. Events that do not require an immediate answer can be stacked, but others can not. Therefore, an increase in information processing capacity can enable an increase in the number of events that can be answered. Possible ways to increase the capacity are increasing the number of people that make decisions, educate planners, and apply appropriate computer support. Another way to increase the number of events that can be processed is to decrease the information processing capacity that is needed per decision. This can be done by, for example, using better decision procedures and by improving communication about decisions.

If the information processing capacity increases or the capacity that is needed to handle an event decreases, the throughput time automatically decreases because less time is needed per decision. But next to processing time, throughput time also includes waiting time. Waiting time is caused by periodic processing of events, e.g., once a day. If decisions are divided over multiple decision makers, such waiting times can occur multiple times for one decision. One of the reasons for task division is that a person has a limit to the amount of information that can be processed. If the amount of time that a planner must spend at decisions decreases, so might the need for task division (see the discussion about allocation levels in Section 4.3.3). This, in turn, can improve the throughput time. Alteration of the allocation of planning decisions can influence waiting time and throughput time of decisions in two ways. First, if decisions are not taken periodically but continuously, the waiting time disappears. Second, decisions that are taken hierarchically can be integrated to become one decision without a hierarchical structure. If decisions are integrated, the number of alternatives that can be assessed increases, so it will probably cost more capacity to take an integrated decision than to take it in a hierarchical fashion. This disadvantage might be offset if the decision only has to be taken once instead of multiple times (because of erroneous assumptions at the higher level).

Summarizing, we have described the relation between information processing capacity, event processing, and flexibility. We will propose computer support as a way to increase information processing capacity. Figure 5.10 summarizes the effects that this can have on flexibility.

The following section will describe how the planning in the food processing industries can become more flexible by proposing changes to the task strategy that is shown in Figure 5.2.
5.5. The task strategy for continuous planning

In Section 5.3 we stated that all decisions at all hierarchical levels should in principle be open to reconsideration. It does not mean that all events should always be incorporated in the plan. It means that there must always be some kind of weighing in two stages: first, whether a decision will be made about the event, and second, whether the event will be incorporated in the plan (Figure 5.7).

Hierarchical approaches often distinguish plan hierarchies in which aggregation of time, aggregation of other object types, and the moment to make decisions at a certain hierarchical level, are linked. For example, Anthony (1965) distinguishes strategic planning, management control, and operational control. Strategic planning deals with decisions on a high level of aggregation and a long time horizon. Operational control deals with very detailed decisions at short notice, and management control lies somewhere in between. The difference of our proposal with such traditional hierarchical approaches is that an event is not rejected because it relates to a period that is considered as fixed, but because it costs too much time to decide about, or (if a decision is made) because it is too costly to incorporate in the plan. In other words, the link between the different dimensions of aggregation is relaxed. To be flexible, it must be possible to make decisions about capacity groups and product families at short notice.

This kind of continuous planning does not mean that there will be no more hierarchical or periodic planning. Hierarchical planning is still necessary because sometimes planning decisions must be taken before all the required information is available. Periodic planning is still advantageous because it costs less time to collect events (e.g., accept new orders) and plan them in one planning session, than planning each event individually as it arrives. This kind of periodic planning (first accept new orders and then plan new orders) corresponds to hierarchical planning (see Figure 5.2). Ten Kate (1995) and Raaymakers (1999) show that the performance of the manufacturer (i.e., due date performance and production efficiency) not necessarily needs to suffer from this. The discussion in Section 5.4 with respect to flexibility in planning can be used to make some observations about and requirements for the use of the concept of continuous planning:
1. The considerations about planning capacity become negligible if it costs very little time to process an event. In other words, an increase in information processing capacity will result in the ability to make more decisions, and in the ability to process events in a later phase in Figure 5.8. Additionally, it uncovers that the allocation of sub-decisions over decision makers can be the bottleneck of the throughput time.

2. Even with high information processing capacity, a large throughput time hampers timely assessment of alternatives. Ideally, the planning should be organized in such a way that a decision does not have to wait for coordination. This is the case if a planner is authorized to take decisions at all hierarchical levels.

3. It must at all times be clear what the consequences are of implementing a change in the schedule so the advantages can be weighed with the consequences. In other words, states 1 and 2 in Table 5.3 must be avoided altogether, and state 3 must be avoided as much as possible.

These three observations (and their underlying assumptions) form the basis for the changes that we will propose for the task strategy as described in Section 5.2.

To enable a more continuous planning process, we propose to change the task strategy that was depicted in Figure 5.2. Decisions must allow continuous adaptation on all hierarchical levels. This also means a greater emphasis on feedback, because if events are always taken into consideration when they occur, there is a chance that the previously imposed constraints turn out to be too restricting (see also Figure 5.6). Such feedback must then provide information about the constraints that are too restricting and the event that has caused it, so this can be taken up at a higher hierarchical level. At that higher level, it can then be decided whether rescheduling at that level is possible and worthwhile (e.g., reshuffling a production order in such a way that there is room for another order).

Figure 5.11 shows the adapted task model. The main idea is that subtasks are not only carried out sequentially in time anymore (as in periodic planning), but also in parallel (as in reactive planning) (see also Giebels, 2000). Referring to the discussion about flexibility, this means that the volume flexibility and delivery flexibility of planning decisions must increase. This, in turn, means that high information processing capacity, short throughput time, and knowledge about the consequences of changes, are required. Referring back to Section 3.2.2, this model resembles what Hayes-Roth & Hayes-Roth (1979) have called ‘opportunistic planning’ of human individuals: making a plan beforehand, but also being able to react on events and perhaps adjust the plan. The way in which the tasks are carried out and the way in which they are supported, do not always allow to process feedback. Moreover, if feedback is allowed by the structure, there should also be time to process the feedback. We propose to deal with this in the following way:

1. Flexibility is hampered by periodic hierarchical planning.
2. One of the sources of periodic hierarchical planning is the limitation of information processing capacity.
3. An increase in information processing capacity can provide the means to reassess hierarchic decisions when needed (next to periodic planning) or to make some decisions not in a hierarchy at all.
4. One of the ways to increase information processing capacity of planners is computer support.

**Figure 5.11.** Task strategy for continuous planning

In Chapter 4, we have argued that a decision on a certain hierarchical level can always be seen as a complete planning problem, at least from the perspective of that level. In Section 3.2.2, we saw that humans are flexible when they plan for themselves because there is only one hierarchical level of planning that directly
controls the actions (due to the link between the brain and the motor cortex). Although this is of course not possible in organizations, it at least indicates that a limitation in allocation of hierarchical levels to decision makers influences flexibility.

There are four activities that can be performed with respect to hierarchical planning (see also Figure 5.4): (1) create a plan at a given hierarchical level from scratch, (2) provide feedback from a lower hierarchical level to a higher level, (3) change a plan at a given hierarchical level, and (4) assess the consequences of changes on lower planning levels. As said, creating a plan from scratch and changing a plan are different kinds of activities, which is also referred to as constructive versus reactive planning. The underlying assumption of this is that it is not feasible to create a plan from scratch after each event, no matter when that event takes place.

Computer support can provide assistance for each of these four tasks. The introduction of support has two effects. First, some decisions can be made faster. Second, decisions that could not be made manually at all can be made now. The distinction is a bit blurring because essentially all decisions can be made manually, but some require so much information processing that they are not considered as such at all. If we link this to hierarchical decision making, we can draw the following conclusion. Because the sequential hierarchical structure partly exists due to limited information processing capacity of planners, the structure can change with the introduction of computer support. The next section describes the functional requirements that are needed to contribute to the flexibility of the planning.

5.6. Planning support requirements for continuous planning

Computer support can provide faster information collection, computations, and plan manipulation. Therefore, the time to create or adapt a plan at any given hierarchical level can decrease. Computer support will not decrease the complexity itself, but rather provides the opportunity for the planner to spend more time on problem solving. Then, the planner can handle more complex problems. Plans that are decomposed or disaggregated into sub-plans for complexity reduction can possibly be made at one hierarchical level.

As said, changes to an existing plan can cause a cascade of changes to lower levels. A change at a given level alters the constraints for lower levels. Therefore, assignments that have already been made on lower levels can be invalidated or turn out unfavorably. It requires considerable information processing to figure out the consequences of a change. Computer support can help to analyze and assess these kinds of effects. If computer support makes feedback loops almost instantaneous, the question arises whether plans that are distributed over multiple persons in an organizational hierarchy can be made by one person in a task hierarchy, and whether plans that are made in a task hierarchy can be solved in a problem solving hierarchy of one task.

The concept that we proposed needs specific requirements with respect to computer support. Chapter 3 and Chapter 4 stipulated the following functionality for planning support:
On the basis of the analysis of flexibility, we can again add a requirement. If decisions must be able to be made in parallel, the effects of a decision on other decisions must be shown real-time. Thus, the planning support system should integrate support for all subtasks transparently. In this concept, it is especially important how constraints are shown in the user-interface, since the output of one task is seen as a constraint for another task. Furthermore, special attention should be paid to the way in which a task shows feedback from one of its subtasks. Integration of subtasks can be attained by using the inputs and outputs of the subtasks as the interface between the subtask support modules. In essence, we will apply the system architecture as it is depicted in Figure 3.8, with the addition that (a) several planning problems (i.e., hierarchical levels) can be worked on simultaneously, and (b) the relations between the decisions are always clear. The following chapter will show a prototype implementation of this system architecture with the added functional requirements regarding task support and flexible hierarchical planning.

5.7. Conclusion
After two chapters that deal with planning in a generic way, this chapter applies the framework of Chapter 4 to the research domain of food processing industries. Thereby, the research question is answered in a conceptual way by showing how planning can contribute to flexibility of the manufacturing system, and what requirements for computer support this results in.

The following aspects are discussed in this chapter. First, the planning domain and planning tasks in food processing industries are modeled with the SEC. Second, an analysis of flexibility shows how the planning influences the flexibility of the production system. Third, the flexibility analysis is used to propose some adjustments to the planning task strategy. The adjustments induce flexibility by allowing planning decisions to be made as late as possible. Fourth, it is argued that computer support can enable such a strategy by allowing decisions at different hierarchical levels to be worked upon simultaneously.

To conclude, the following line of reasoning shows how the planning can contribute to flexible product replenishment in food processing industries:

1. Flexibility is hampered by hierarchical planning.
2. One of the reasons of hierarchical planning is a limitation of the information processing capacity.
3. An increase in information processing capacity can provide the means to reassess hierarchic decisions more frequently or to make some decisions not in a hierarchy at all.

4. One of the ways to increase information processing capacity of planners is computer support.

The following chapter describes a prototype planning system that includes the requirements that are deduced from the planning concept that we have proposed in this chapter.