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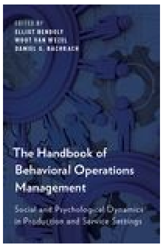
Published in:
The handbook of behavioral operations management

DOI:
10.1093/acprof:oso/9780199357215.003.0005

Publication date:
2015



The Handbook of Behavioral Operations Management: Social and Psychological Dynamics in Production and Service Settings

Elliot Bendoly (ed.) et al.

https://doi.org/10.1093/acprof:oso/9780199357215.001.0001

Published: 2015 **Online ISBN:** 9780190239336 **Print ISBN:** 9780199357215

CHAPTER

5 Outflanking Undecided, Ever-Changing Puzzles: The Role of Human Behavior in Scheduling

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https://doi.org/10.1093/acprof:oso/9780199357215.003.0005 Pages 56–96

Published: May 2015

Abstract

Scheduling determines the sequence and timing of activities in an organization. This involves, for example, decisions about priorities, timing, staff assignment, and allocating machines to manufacturing operations. These decisions have a considerable impact on performance in many organizations. Scheduling problems are well known for their numerical complexity and are typically approached mathematically. However, several features of scheduling necessitate human involvement. For example, information is ever-changing and needs to be interpreted, and stakeholders often need to be convinced to accept constraint violations. This chapter addresses the interplay between traditional scheduling research and a behavioral operations approach to scheduling, and describes two learning activities that can be played to comprehend some of the social and psychological aspects of the scheduling process.

Keywords: scheduling, numerical complexity, constraint, psychological, priorities

Subject: Behavioural Economics and Neuroeconomics

Collection: Oxford Scholarship Online

Overview

Scheduling encompasses the allocation of firm resources to various tasks and activities (Leung 2004; Pinedo 2012). This involves decisions about priorities, timing, staff assignment, and allocating machines to manufacturing operations. Most people will recognize the result from a scheduling process, which include, for example, Gantt charts, dispatch lists, and staff schedules. Scheduling is usually classified as a complex problem. Even small scheduling problems have a huge number of alternatives from which to choose. Because computers offer a very good means to evaluate and check many alternatives in a short time, since the 1960s scientific research in scheduling has been dominated by operations research. However, scheduling also is an organizational process where human planners perform a variety of activities such as information gathering and interpretation, communication, puzzle-solving, and negotiation with different stakeholders. In this chapter, we discuss the tasks and activities that human schedulers perform, how they cooperate and coordinate their work, and the role played by computer support in this process.

Schedules specify the timing of activities and determine, for example, which people work in what shift, when raw material is purchased, the moment that production of an order starts and needs to be finished, and how finished goods are ↳ transported to customers. Therefore, scheduling has a considerable impact on organizational performance. The combination of being a complex problem and having a large performance impact makes scheduling a popular research topic. Many thousands of articles and dozens of textbooks have been written on scheduling from various disciplines and perspectives. To introduce and anchor the role of humans in scheduling, we briefly describe a number of perspectives using the work of Gupta (2002), who summarizes the history of scheduling research by discussing various scheduling paradigms:

- "Might is right": there is no explicit deliberation on the scheduling problem; the decision-maker relies on organizational power and just tells employees what to do.
- "Don't keep the machine idle": scheduling is solved by accepting orders based on machine capacity, avoiding machine down time. Scheduling is centralized, using Gantt charts to schedule and track progress.
- "Tell them what to do": shop floor supervisors are given aggregate quantities (the "what") and are responsible for scheduling their own department (the "when").
- "Divide and conquer": the application of mathematics to scheduling problems. Because the problems are generally too complex to solve completely, assumptions are made that might not be realistic but that at least lead to scheduling problems that can be solved.
- "Too complex, too expensive": researchers realize that mathematics will not lead to solutions for all scheduling problems. Cases where the worst-case scenario would not be solvable were no longer subject to intense investigation.
- "Something is better than nothing": researchers working in the "too complex, too expensive" paradigms retained focus on analytic solution procedures to find optimal solutions for stylized scheduling problems. Simultaneously, others developed approximate solution procedures, such as heuristics for problems that could not be tackled analytically, working from the idea that some improvement in the objectives is better than nothing at all. This led to solution procedures that were practically applicable, increasing acceptance of scheduling research in practice.
- "Give them something to decide": the advent of enterprise resource planning (ERP) and decision support systems (DSS) gave scheduling algorithms a context. Decision-makers could now provide

input to the algorithms and interpret and change the output. This further increased the use of scheduling algorithms in practice.

- "Why bother": Because scheduling problems are too complex to solve, the production system should be designed such that scheduling is not needed. An example is just-in-time production.
- "Let the computer tell us": The complexity of scheduling problems provides a challenging context for
p. 58 approaches in artificial intelligence. Several techniques have been extensively researched for use in ↳ scheduling. These include, for example, rule-based expert systems, constraint satisfaction, and genetic algorithms. Although successful for some scheduling problems, these techniques have not shown general applicability.

The scheduling paradigms clearly follow scientific developments in management research, respectively management science, operations research, MRP/ERP/DSS, lean production, and artificial intelligence. Each paradigm is vulnerable to criticism. Analytic optimization approaches solve nonexisting problems, heuristics do not solve to optimality, automatic learning algorithms in artificial intelligence are black boxes that can give unpredictable results, and so on. However, I would like to emphasize that the paradigms are not mutually exclusive. Each still exists and each has its own specific context within which it can be employed successfully.

During the past several decades, parallel to these scientific developments, research in behavioral and organizational aspects of scheduling has been a relatively small but stable niche. Interestingly, a recurring theme is the gap between scheduling theory and scheduling practice, including, for example, Pounds (1963), Conway, Maxwell, and Miller (1967), Miller (1987), McKay, Safayeni, and Buzacott (1988), Buxey (1989), Kleinmuntz (1990), Waters (1990), Hofstede (1992), MacCarthy and Lui (1993), Higgins (1996), LaForge and Craighead (2000), Herrmann (2006), and Pinedo (2012). Although the influence of the various research paradigms is clearly present in practice, scheduling theory attends to only a small part of the work of human schedulers. Empirical research focused on scheduling situations—without exception—reveal that scheduling involves much more than merely solving a puzzle. Consequentially, quarreling over the best way to solve this puzzle is of essential, but limited, value to most companies. For example, an early description of the scheduling task explicitly notes that planners have to anticipate future difficulties and discount them (Coburn 1918). Anticipation does not fit well in any of the dominant scheduling paradigms, because it involves difficult-to-model things like imaginative speculation, creativity, weighing risk, and empathy with stakeholders.

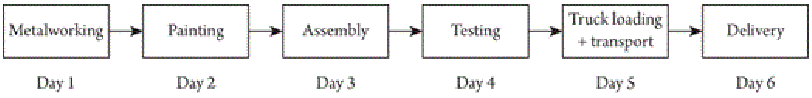
Although being in a relative research niche, behavioral research in scheduling has yielded considerable knowledge on how organizational scheduling processes take place in organizations and how human schedulers think and operate in these contexts. This chapter discusses results from a number of methodologies that have been applied, including, for example, longitudinal case studies, surveys, experiments, and cognitive task analyses.

Case Example

In contrast to other chapters in this text I will postpone theoretical discussions until after I've had a chance to set the stage with a short case example. The case exemplifies the activities involved in the creation of a schedule, based on an office furniture manufacturer (De Snoo et al. 2011; De Snoo, Van Wezel, and Wortmann 2011). This case is used in the scheduling game described later in the chapter.

p. 59 The make-to-order office furniture manufacturer processes about 150 client-specific orders each day. Twenty-five sales agents are responsible for order procurement. Roughly 30,000 product parts are purchased from a large group of suppliers and used in the three manufacturing departments: metalworking, painting, and assembly. The standard lead time of work in progress is five days (figure 5.1): one day for each of the manufacturing departments, one day for testing, and one day for loading and transport. The sixth day is used for delivery (figure 5.1).

Figure 5.1



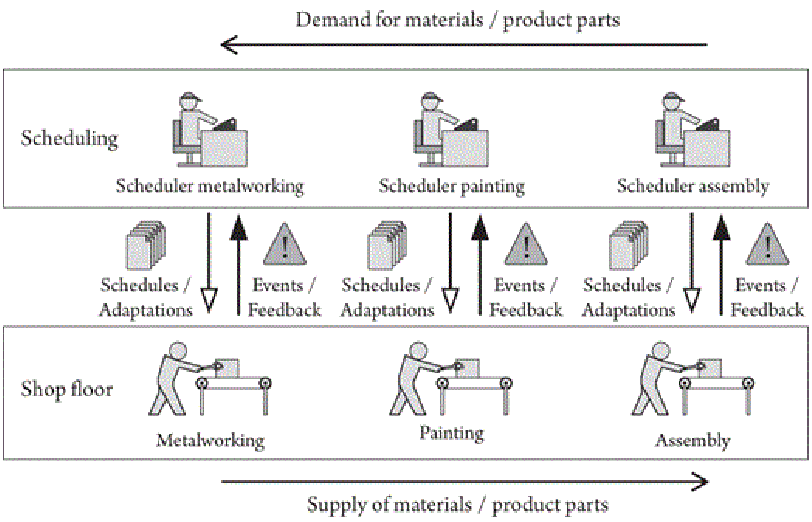
Lead Time for Departments

Over 200 operators work in the departments in multiple shifts. Each department is managed by a production manager and several foremen. The production manager is not involved in the daily operations, but is responsible for implementing long- and mid-term strategy and developing staff schedules. The foremen act as information hubs between the schedulers and the operators. They work as operators at the various workstations but have the extra responsibility to communicate information to and from the schedulers.

Metalworking consists of 40 workstations. Production orders have different routings, and orders are produced in batches. The batch size depends on order size and available capacity. The products from the metalworking department are painted and powder-coated at painting. Two powder-coating lines are available. One of these lines is highly flexible but not efficient, and one requires long cleanup and setup times but is faster and thus suitable for large batches. The assembly department operates seven assembly lines. Both self-produced components and purchased parts from suppliers are assembled into final products and packaged for delivery to customers.

Each manufacturing department has its own scheduler (figure 5.2). The main task for the schedulers is to cluster orders on certain dates and to assign them to work cells or production lines. Each department has a different preference for the sequence of production. For example, the painting department likes to combine all orders that need to be painted black because they have to clean the whole painting line when they switch colors. However, the metalworking department prefers to combine all orders that have the same material thickness so they have to set up their bending machine only once.

Figure 5.2



Flow of Material and Information

The resulting schedules are released to the shop floor daily. The schedules specify what work needs to be done on what day for each department for several days. In general, the order of activities during the day does not matter so departments can determine an efficient sequence for themselves. This is an example of the "Tell them what to do" paradigm as discussed by Gupta (2002). An exception is rush orders that need to be pushed through several departments on one day. These orders are discussed during a work meeting early in the morning.

In addition to creating schedules, the schedulers are confronted with many requests to change existing schedules because of all kinds of events like rush orders, p. 60 ↳ order changes, material supply problems, and machine failures. Based on new information from (among others) salesmen, product developers, suppliers, and foremen, the schedulers modify the schedules and communicate changes to the operators. De Snoo and coauthors (2011) measured all interactions on a typical day in the company and found that 220 interactions took place between schedulers and others, taking from two to four hours per day. Because the schedulers were not located on the production floor, most communications took place by phone. De Snoo, Van Wezel, and Wortmann (2011) reported that relocation to the production floor led to more face-to-face collaborative communication, which improved scheduling effectiveness.

Delivery reliability is the most important performance objective. A special job function, the "troubleshooter" or "order chaser," urges schedulers to schedule and operators to produce products that have to be delivered soon. The firm realizes an average delivery reliability rate of more than 95%.

In our case study, it is possible to have late orders, which is important. For some industries such as the automotive supply chain, it is not acceptable to create a plan that has any late orders, and constraint relaxation techniques are used to ensure that an assembly plant will not be shut down. If lateness is strictly forbidden, the relevance of traditional scheduling heuristics encompassing lateness is questionable.

The company faces various complex scheduling problems. Each of the 150 daily orders includes a multitude of operations. For example, a table needs legs that must be cut, bent, and welded in the metalworking department; cleaned, painted, and varnished in the paining department; and assembled in the assembly department. One order of 50 tables involves hundreds of activities. Multiply by 150 orders and the factory faces thousands of manufacturing activities per day, which is too many to create a detailed schedule for. The scheduling department resolves this limitation by first dividing the scheduling tasks over multiple schedulers. Second, the problem is made smaller by not scheduling every activity. p. 61 ↳ For example, the schedulers do not specify an exact starting and ending time, but rather specify the day on which a production order needs to be completed. Rather than determining all start and end times for each activity in a department, they only have to specify which orders need to be produced on a given day.

Theoretical Perspective

Why Scheduling Problems Are Difficult

Since the advent of computers, scheduling research has been dominated by operations research (Muth and Thompson 1963; Pinedo 2012). Computers can compare thousands of alternative schedules per second and can identify constraint violations in schedules that are too large to comprehend by human schedulers. Five basic properties of information make it impossible to investigate all possible scheduling solutions.

- The first is related to *numerical complexity*. Many scheduling problems are "NP-complete." Such problems always need an approximation algorithm to solve in reasonable time (Pinedo 2012). Using approximation means that the solution found is not necessarily the optimum solution. This results in a trade-off between speed and solution quality. The major focus of scheduling research is related to this trade-off.

- The second is *timing disparity of information*. Sometimes, a decision is needed before all required input is available. For example, the lead time of raw material of a manufacturer might be longer than the lead time offered to customers. The result is that supply and demand need to be decoupled.

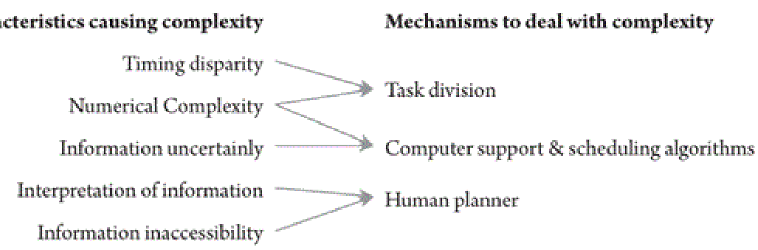
- The third is *information uncertainty* or inexactness. For example, a recipe in a cookie factory might specify that ingredients need to be mixed for two minutes, but this could be an average. The actual time can depend on the quality of raw material, temperature, humidity, and so on. For scheduling, it is important whether we know the characteristics of uncertainty or not. Scheduling algorithms can take this into account by combining the various uncertainties and by calculating worst-case and best-case scenarios.

- The fourth is the *interpretation of information in its social context*. This subtle and perplexing property is best expressed through example. In one of our visits to a factory, a machine needed an emergency repair at 4:00 p.m. The customer needed to be informed because the order would be shipped late. When we asked the scheduler why he did not immediately inform the customer, he told us that he would wait until 6:00 p.m. His manager would have left for home, and he would call the customer himself. The schedulers at the customer would also have left, and his call would be forwarded to the warehouse. By p. 62 experience he knew that the warehouse would not have a problem with a late ↳ delivery. If he called his own manager now, the communication with the customer would follow the official route, which would lead to commotion and a dissatisfied customer. These circumstances are very specific to the time of the machine disruption and the specific customer. This kind of information is often time related, dynamic, and based on personal relationships and gut feelings, which makes it impossible to quantify, formalize, and put into formal procedures or use in scheduling algorithms.

- The fifth is information *inaccessibility*: information needed to create a schedule is unavailable at the time that the planning organization and support are designed. Many assumptions need to be made in the face of incomplete information. Decisions are made with best guesses about what is actually where, what the quality is, and how much has been completed.

These five properties underlie scheduling. Roughly, the following mechanisms are used to handle these complexities (figure 5.3).

Figure 5.3



Complexity of Scheduling

A first is *task division* of scheduling tasks aligned to the time horizon or cognitive workload. To reduce numerical complexity and to mitigate timing disparity, companies have traditionally used hierarchical decision-making (Anthony 1965). This means that first decisions are made in aggregate for times in the future. This is the planning, scheduling, dispatching hierarchy first documented in the early 1900s and still used today. Within any time horizon, task division can also be related to numerical complexity. The problem can simply be too large for one scheduler to handle for any time period. The second mechanism is *scheduling algorithms*. Algorithms follow prespecified steps to create schedules, can very quickly compare multiple schedules, and can calculate these with compound uncertainties better than humans can. The third is the *human planner*. The first two mechanisms can be designed and formally structured into day-to-day processes. However, using inaccessible or context-sensitive information in a design is by definition impossible. This results in the need for human planners to regulate and handle information flows that cannot be prespecified. The fact human planners play a role in the scheduling process implies that the other mechanisms (hierarchy, task division, algorithms) need to incorporate this role, which is where behavioral operations comes into play.

Table 5.1 describes some examples of each of the complexity factors for different kinds of scheduling.

Table 5.1. Examples

	Manufacturing scheduling	**Transportation scheduling**	**Project planning**
Timing disparity	Lead time of purchasing raw material is longer than lead time of own delivery.	Logistics companies need to hire trucks and drivers before actual transportation orders are known.	People often work in multiple projects simultaneously; they need to reserve capacity before activities start.
Numerical Complexity	N jobs on M machines	What product in which truck? Sequence of stops.	People (being aresource constraint) work in multiple projects simultaneously.
Information uncertainty	Speed and yield of chemical processes	Speed of trucks; traffic jams	Task duration
Interpretation of information	Responsibility for meeting due dates if multiple departments are involved	Delivery time windows	Quality of the outcome of activities
Information inaccessibility	Exact available capacity; maintenance schedules	Flexibility of timewindows at customers; options for overutilization of trucks	Possibilities for overtime of employees

 Information inaccessibility and interpretation require that human schedulers be included in the scheduling process. The next section describes the results of empirical research on the human role in planning and scheduling.

Behavioral Aspects of Planning and Scheduling

A Comprehensive Model of Scheduling

Despite the advantages of scheduling algorithms, they often are underutilized. Tenhiälä (2011) reported that only 25 of 89 companies in his survey used finite loading techniques, and a survey reported by Jonsson and Mattsson (2003) showed that only 20 of the 54 manufacturing companies used finite capacity scheduling. This theory/practice gap orbits the following (provocatively stated) positions. On the one hand, operations researchers take the position that modeling unsolvable problems is useless. On the other hand, this claim is refuted by organizational scholars who state that it is useless to solve nonexistent problems. To bridge these opposing views, we need to frame scheduling not only as a problem to solve but also an organizational
p. 64 process that needs to be managed. ↳ Scheduling resembles a sociotechnical network (Wäfler 2001), where the social element consists of human planners and others who, while having no formal role in planning, nonetheless have an impact on planning (e.g., shop floor supervisors or warehouse clerks). The technical element consists of IT systems (e.g., ERP and advanced planning systems).

Scheduling encompasses a variety of tasks and activities including information gathering and interpretation, communication and negotiation with different stakeholders, puzzle-solving, decision-making, and problem-solving (Jackson, Wilson, and MacCarthy 2004; Kreipl and Pinedo 2004; MacCarthy and Wilson 2001a; McKay, Safayeni, and Buzacott 1995b; McKay and Wiers 2006; Van Wezel, Van Donk, and Gaalman 2006). In practice, there are no clear-cut design criteria that prescribe how scheduling processes should be organized. To anchor theory that describes scheduling task design, we first describe what the typical week of a human scheduler might look like in the office furniture factory described in the case example.

- On Monday/Tuesday the scheduler starts to collect all the data needed to create a schedule for the following week. Information about goals and constraints the schedule should obey is needed. This includes actual and expected orders, delayed production from the previous week, available inventory, expected deliveries, machine availability, staff availability, and expected results from this week.
- On Wednesday, a preliminary schedule is made. Various departments can set different and often conflicting goals and constraints, regarding production lead times, service costs, and staff workload. Schedulers have to balance these different interests and communicate and negotiate with these stakeholders. Alternative schedules are developed and choices are made. The starting point is the due dates promised to customers; minimizing due date violations is often a primary concern. A hard constraint is that all material must be available. Somewhat softer constraints are the availability of operators, hours of overtime, scheduled maintenance, and so on. Material availability can be a soft constraint if delivery can be expedited by the supplier.
- On Thursday, the preliminary schedule is discussed with the operations manager, the sales manager, and the shop floor foremen. Decisions must be made bearing on what orders will miss the due date, how maintenance will be scheduled, what setups are necessary, and how much time they take.
- On Friday, the schedule is released and the shop floor can start to prepare for the next Monday.

In many factories, there is a stark contrast between tasks as they are described and the activities that are actually performed. In past decades scheduling has been analyzed using various paradigms, including natural decision-making, sociotechnical system design, and cognitive ergonomics. The late 1980s and early
p. 65 1990s saw a surge of empirical research in planning and scheduling, including Crawford and ↳ coauthors (1999), Higgins (1999), McKay (1992), McKay, Safayeni, and Buzacott (1995a; 1995b), Mietus (1994), Nakamura and Salvendi (1994), Stoop and Wiers (1996), Wiers (1996), and Van Wezel (2001). Collections of

papers can be found in the edited volumes of MacCarthy and Wilson (2001a) and Fransoo, Wäfler, and Wilson (2011). In this section, we describe a model that encompasses many of these empirical models. The model is based on the framework reported by Jackson, Wilson, and MacCarthy (2004) and has three parts: a categorization of tasks that the scheduler needs to perform, the roles in which these tasks are performed, and the schedulers' external environment.

Jackson, Wilson, and MacCarthy (2004) describe three kinds of tasks:

- Formal tasks: the tasks as formally specified in the job description
- Maintenance tasks: informal activities that the scheduler performs to maintain his or her position, for example, check sources of information
- Compensation tasks: glitches in the formal structure need to be mitigated; for example, wrong information in the information system, people that refuse to work together, and so on
Jackson, Wilson, and MacCarthy (2004) propose that the work of the scheduler also has multiple roles:

- Interpersonal role: This role represents the human scheduler who needs to maintain his or her position in the interpersonal network, for example, exchanging favors or mediating between stakeholders.
- Informational role: The scheduler holds a central position in the information hub; formal and informal information is needed to create a schedule that is accepted by stakeholders. Because of this, organization members know that the scheduler has a clear sense of the state of the factory, the order portfolio, and production progress.
- Decisional role: Three types of decision-making include predicting and solving problems, allocating resources (i.e., creating the actual schedule), and handling disruptive events.

The task categorization does not describe what schedulers actually do. The tasks they describe are collections of related activities that are goal directed. Scheduling activities are usually depicted as problem-solving, and the most basic view is that schedulers follow a Plan-Do-Check-Act problem-solving cycle. Although a scheduling problem is rarely unique, it is also rarely exactly similar to a previously solved problem. Meystel (2006) described a multilayer, multiresolutional recursive "elementary loop of functioning," with a cycle of (1) sensing, (2) sensory processing, (3) building a model based on a combination of the sensory input and both generic and specific knowledge, (4) generating behavior, (5) enacting the behavior, and then (1) sensing the new state again. Hoc (2006) provided a conceptually similar model based on Rasmussen's step ladder (Rasmussen, Pejtersen, and Goodstein 1994), which includes anticipation and abstraction in the reasoning processes during planning.

p. 66 We follow the activities in the cycle, noting that multiresolutional recursion, anticipation, and abstraction can be part of each activity:

- Problem formulation, opportunity identification, and isolation: why are we planning? An issue, demand, or opportunity to address? (skills in this activity, and the process involved are discussed in Volkema 1983).
- Outcome definition: what are we planning? A company reorganization, a new product launch, or a production run in the factory (e.g., Caves 1980)?
- Quality of outcome (goal) specification: what are the factors that define success? Will it be cost, improved time to market, delivery targets, market share, shareholder value, or quality goals? Will the expected outcomes include nebulous concepts such as innovation (e.g., Mumford, Bedell-Avers, and Hunter 2008)?

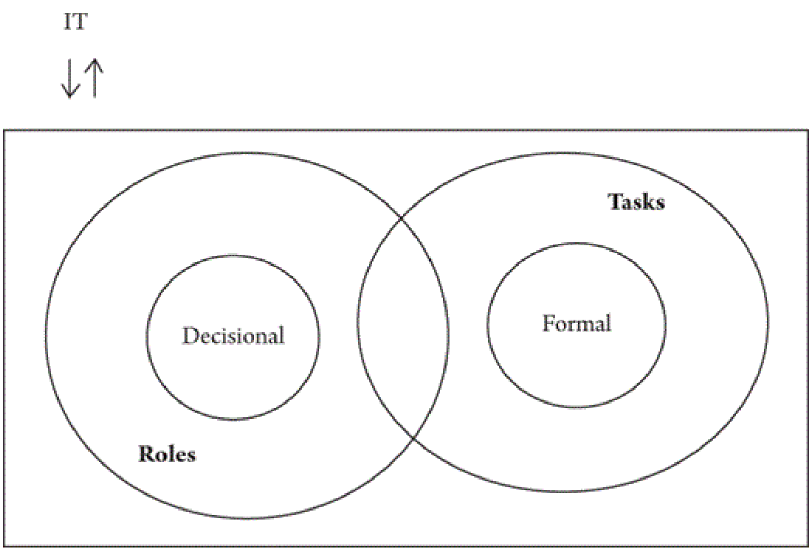
- Generation of the plan: the most effective and efficient sequence of actions and activities for organizational resources to follow that will achieve the desired goals, taking risks and uncertainty into account.
- Plan evaluation, approval, and project launch: a particular plan is agreed upon and activities are launched.
- Implementing, monitoring, and maintenance of the plan: as time proceeds, how good is the plan? Does the plan need modifications and, if so, what are the changes? What are the links between plan evaluation and implementation (e.g., Nutt 2007)?
- Closure of the plan: knowing when the outcomes are achieved (or will not be) and understanding the quality of the planning and execution. Knowing what to do next, if there is a "next."

Note that, similar to tasks and roles, the activities do not include any domain specificity. The activities are necessary in all kinds of planning environments (e.g., manufacturing, routing, staff scheduling). Jorna (2006) showed that such an abstraction is viable. His research shows that human schedulers solving scheduling problems in different domains used comparable tactics and activities, for example, counting, checking constraints, relaxing constraints, using visual aids, and so on. Hoc (2006) similarly showed that operators in different domains apply similar strategies (abstraction and anticipation) while rescheduling under time pressure. This is not to say that schedulers can easily transfer from one domain to another, but does indicate that lessons learned in one context can apply to other contexts.

Tasks, roles, and activities are all aspects of the work of individual schedulers. Because no single individual does all of the planning/scheduling in an organization, planning often is not an individual task but is distributed across several human planners that can be organized into a dedicated planning department or distributed throughout various units (e.g., each manufacturing department has its own dedicated planner). There are four important organizational elements in schedulers' tasks: (1) how do schedulers divide their work if there is more than one scheduler, (2) how are their tasks are integrated into the overall
p. 67 organization, ↳ (3) how is the quality of their work measured by management, and (4) how is scheduling supported by decision support systems.

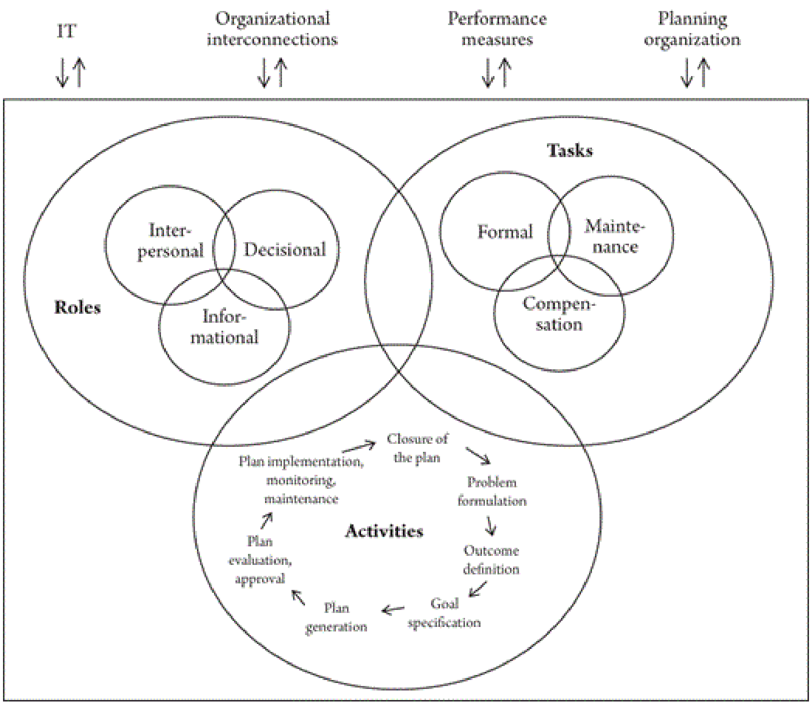
Figure 5.4 depicts the traditional view on scheduling. A scheduler makes and adapts schedules using IT. Figure 5.5 shows the comprehensive scheduling model. Although definitive models cannot be provided, we discuss existing empirical research contributing to the model.

Figure 5.4



Traditional Model of the Scheduling

Figure 5.5



Behavioral/Organizational Scheduling

source: Adapted from Jackson, Wilson, and MacCarthy 2004.

p. 68 **Individual Planning Task Performance**

Cognitive models of planning show how problem-solving, planning, and information processing relate. Several approaches in scheduling have been inspired by the way in which humans solve personal planning problems such as making a shopping list, planning a holiday, or playing chess (Van Wezel, Jorna, and Meystel 2006). Das, Karr, and Parrila (1996, 27) stated that "it is the plan that controls human information processing and supplies patterns for essential connections between knowledge, evaluation, and action." This generic description can be extended by the approach reported by Newell and Simon (1972). They described planning as a system of heuristics used by their general problem solver (GPS) "to construct a proposed solution in general terms before working out the details. This procedure acts as an antidote to the limitation of means-ends analysis in seeing only one step ahead" (428). Planning heuristics are used to guide action when a problem is too difficult to solve by means-end analysis. Newell and Simon assume the following steps in planning (1972, 429):

1. Abstracting by omitting certain details of the original objects and operators.

2. Forming the corresponding problem in the abstract problem space.

3. When the abstract problem has been solved, using its solution to provide a plan for solving the original problem.

4. Translating the plan back into the original problem space and executing it.

Complexity is reduced by leaving out details and reasoning by analogy. In this sense, planning is a way to solve problems. Earlier models of planning presume that planning is always a hierarchical process that proceeds according to successive refinement. Sacerdoti (1975) implemented such an approach in his computer program NOAH. In this view, planning is performed by recursively decomposing goals into subgoals until a subgoal can be reached by elementary action. This paradigm is contradicted by Hayes-Roth and Hayes-Roth (1979). They argued "that planning processes operate in a two-dimensional planning space defined on time and abstraction" (312). In these terms successive refinement always works top-down from high to low levels of abstraction and forward in the plan time frame. Thinking aloud protocols from different subjects that perform planning tasks shows that this is not always the case. Hayes-Roth and Hayes-Roth reported what they called "opportunistic planning." Individuals switch in levels of abstraction and move both forward and backward in time in successive reasoning steps. Hayes-Roth and Hayes-Roth (1979) proposed a theoretical framework for cognitive planning that incorporates this behavior. They found that reasoning often takes place heterarchically; plans are created incrementally on multiple hierarchical levels simultaneously where decisions at a detailed level can invalidate plans at a higher hierarchical level. They argued that strict hierarchical planning can rule out good solutions, and that humans compensate for
p. 69 this by opportunistic planning: "the bottom-up component in multi-directional processing provides ↳ a potentially important source of innovation in planning. Low-level decisions and related observations can inspire novel higher-level plans" (1979, 306).

Riesbeck and Schank (1989) argued that planning is based on scripts. Instead of conceiving new plans for each problem, humans try to find a plan that was used for previously solved comparable planning problems. Then the basic planning activity is more adaptation than construction. In this paradigm, planning is about memory, indexing, and learning (Hammond 1989), which are interrelated. Plans should be stored in memory so that it becomes easy to find an existing plan from comparisons of new goals with previously handled goals. Here solutions must be remembered so that they can be used for new problems, and a failure to execute the plan suggests that the knowledge the planner has of the execution world may be faulty. Thus, script models can be seen as adding learning to the paradigms already discussed.

To handle complexity, humans apply abstraction hierarchies, heuristics, scripts, and opportunistic planning. Van Wezel, Jorna, and Meystel (2006) described how these mechanisms can also be found in organizational planning by denoting the similarities and differences between planning for yourself versus planning for others. For example, according to Hayes-Roth and Hayes-Roth, the choice of a planning strategy depends on three variables: the problem characteristics, expertise, and individual differences. These can be found in the industrial scheduling literature as well.

First, regarding problem characteristics, Cegarra (2008) discussed a scheduling typology with seven dimensions that shape the scheduling task from a cognitive perspective:

- Uncertainty: the inability to predict future events.
- Process steadiness: disturbances in the scheduled process that can be anticipated.
- Time pressure: whether there is a need to react instantly or can events be processed later.
- Cycle synchronicity: operators, machines, sales, and schedulers themselves can have different preferred cycle times.
- Process continuity: discrete processes such as found in job shops are more difficult to schedule than continuous processes
- Complexity: the numerical complexity of the scheduling task at hand.
- Multiple and contradictory objectives: schedulers might face different objectives from, for example, sales and manufacturing. Even within a manufacturing department, objectives might differ per person, machine, or process.

The dimensions can exist independently of each other and each dimension can lead to different scheduling task characteristics. This implies that in practice many different possible combinations can emerge. Once they occur, however, the dimensions can interact, which further complicates the structure of the scheduling task. Fransoo and Wiers (2006) showed that the complexity of planners' actions increases with the p. 70 complexity and number of actions conducted. This ↳ finding is quite intuitive, but contradicts the reasoning that complexity leads to mental overload and thereby to a reliance on routine decisions. Experiments of Moray and coauthors (1991) showed similar results. Although time pressure resulted in increased perceived workload, operators kept working with a constant level of effort, decreasing the number of scheduled tasks. This effect is demonstrated in our traveling salesman learning activity that can be found at the end of the chapter.

Second, expertise influences task performance. Mietus (1994) and Guerin, Hoc, and Mebarki (2012) showed that planners change their strategies with experience. Experts use a higher level of abstraction and more top-down reasoning than novices.

Third, individual differences lead to differences in task strategies and views on the problem structure; furthermore, these change over time with increased experience. Kiewiet, Jorna, and van Wezel (2005) showed with card-sorting and graph-positioning methods that planners who work in the same company on the same planning task can have very different cognitive maps. Jorna (2006) investigated the problem-solving strategies of 34 planners and found that differences within domains were larger than between domains, and that culture (i.e., Indonesian versus Dutch planners) was an important factor in the differences found.

Performance Metrics of Planning and Scheduling

Traditionally, scheduling research measures performance as the number of constraints that are violated and the extent that scheduling goals are realized. These metrics are related to the projected execution of the schedule. For example, in production scheduling, these can include total completion time, lateness, earliness, tardiness, and machine utilization (Hoogeveen 2005). In workforce scheduling, metrics include total penalty cost due to violating shift balances and total satisfaction of employees' preferences (Cheang et al. 2003), and in patient appointment scheduling, these include doctors' productivity and idle time, total waiting time, and average patient time flow (Cayirli and Veral 2003). Several authors have criticized this approach as being too narrow. For example, MacCarthy and Wilson (2001b) remarked that "objective measurement in planning, scheduling and control must account for the process by which plans are generated and executed, the people who are instrumental in generating them as well as the actual realization of plans and schedules over time" (312). Likewise, Jackson, Wilson, and MacCarthy (2004) noted that the performance measures in their case studies "took the form of contextual expectations generated by other business personnel. Such performance measures represented the way that schedulers were expected, for example, to be good communicators, to share accurate and up-to-date information, to solve problems, and to have a proactive view of requirements" (548). Thus, in addition to typical performance measures, social concepts such as fairness and punctuality also are important. De Snoo, Van Wezel, and Jorna (2011) found three kinds of performance criteria. The first category relates to the effect that executing the schedule will have:

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- ↳ Number of constraint violations, for example, regarding promises to customers, use of capacity, and labor regulations.
- Costs of schedule execution; for example, batching products of the same family will reduce setup time, and thereby, increase capacity utilization.
- The number of employees' preferences and wishes that are honored.
  The second category includes the following:
- Numbers of errors in the schedule, for example, using wrong processing times.
- Robustness and adaptability of the schedule; does it need to be changed after each deviation or can it absorb some unexpected events? If it must be changed, will the changes cascade like a snowball, or will the effects on other parts of the schedule be minimal?
- Understandability of the schedule and of schedule changes: can operators and foremen comprehend the schedule, for example, if their department will have low efficiency due to the schedule, can they understand why?
  The third category consists of criteria that are related to the scheduling process:
- Timeliness and reliability of initial release: is it released in time so operators can start to prepare?
- How flexible are schedulers regarding schedule adaptation?
- Accessibility of schedulers and communication and harmonization quality: can the schedulers explain their choices? Can they empathize with operators that must execute the schedule? Can they negotiate without starting conflicts? And so on.
- Cost/efficiency of the scheduling process. Do the planners themselves work efficiently? Do they use their tools correctly?

Organization of the Planning Tasks

Planning is typically distributed across multiple people, and many will not have scheduling as their full-time job (Wäfler 2001). Planning therefore often should be designed as a collaborative task.

The first step in task division is usually driven by timing disparity, numerical complexity, and uncertainty. A clear example is described by Meal (1984), who described the planning organization of a tire manufacturer with multiple divisions developed over the course of decades. Before computers could be used for data processing, planning was decentralized and customer-driven. Each division of the tire manufacturer did its own planning. This led to high stock levels. Noting these stock levels, the company wanted to switch to centralized planning. Although by then this could be facilitated by computers, several disadvantages were found: a complete combined detailed schedule was too large to be reviewed by humans (numerical
p. 72 complexity), the authority of local managers was taken ↳ away (inaccessible information could not be accessed anymore), and the forecasts on which the plan was based were not reliable at the item level (timing disparity and uncertainty). The company then decided to segregate the plan in several hierarchical levels. Rather than making a centralized detailed schedule in which all individual customer orders were allocated to production facilities, the company decided to incorporate multiple stages in the scheduling process. At the corporate level, senior management decided which regions would be served by which factory based on aggregated yearly demand by item and by region. At the plant level, the plant manager used monthly demand by product type to determine seasonal patterns. Finally, each shop floor manager determined detailed schedules. This method of hierarchical production planning is now common and facilitated by enterprise resource planning (ERP) systems. For each subplan, different knowledge and expertise is needed. At the corporate level the planners need to know market trends, and on the shop floor the planners know each operator and machine.

The second step in task division is driven by information inaccessibility. Managers often prefer to have a separate scheduler for each department, even if it does not result in full-time jobs. There are cognitive limits to knowing the details and history of each machine and operator. Further, particularly for confidential information, operators need someone that they can trust to represent their interests. Both are facilitated if the department has a dedicated scheduler, especially with someone who has previous experience as an operator.

A third relates to the complexities involved in scheduling and rescheduling. In operations research, these two are like two different worlds, each with own methods, techniques, and tools (Pinedo 2012). In practice the distinction often is not clear. Scheduling and rescheduling overlap and often are done in parallel. During scheduling interdependencies between schedulers can be managed with simple rules and agreements. If issues arise, there is sufficient time available for schedule adaptation, feedback, communication, and coordination. The organizational design of coordination modes can be based upon an analysis of predictable and stable interdependencies. During rescheduling, the situation is quite different. Schedules are released to the operators and are being executed. Events disrupt schedule feasibility and often require an immediate response. Generally, it is uncertain when an event will happen and what its impact will be on one or multiple scheduled operations and resources. Complete rescheduling is usually impossible because of time constraints or is undesirable because it can cause tumult on the shop floor. Therefore, schedules are typically adapted partially (Vieira et al. 2003; Aytug et al. 2005; Subramaniam, Raheja, and Rama Bhupal Reddy 2005). Nevertheless, changing one schedule can easily require modifications to another schedule. For instance, alternative sequencing of operations in one department can be a prerequisite to solving a material shortage problem within someone else's schedule. To find solutions quickly, communication and deliberation between schedulers is necessary (Van Wezel, Van Donk, and Gaalman 2006). Consequently, the design of coordination structures for rescheduling differs from the coordination design for scheduling. Rescheduling poses specific requirements on the task design of the schedulers, especially regarding the
p. 73 design of coordination modes ↳ to manage task interdependencies. Although scheduling and rescheduling

can be done by the same person, and in many organizations this is the case, there are also cases where these tasks are split.

Task division based on hierarchical planning layers, departments, and scheduling/rescheduling can still result in tasks that are too extensive for one person to handle. So a third reason to divide tasks is simply numerical complexity.

Companies tend to distribute planning tasks, but interestingly, De Snoo and Van Wezel (2014) found that collaborative scheduling (i.e., working as a team without task division) can result in better schedules (figure 5.6), suggesting that synergy can improve scheduling when it is done collaboratively.

Figure 5.6

Collaborative Scheduling

The Organizational Interconnectivity of Planning and Scheduling

Extensive research has focused on the organizational design of coordination as an instrument to manage interdependencies between decision-makers (Albino, Pontrandolfo, and Scozzi 2002; Crowston 1997; Molleman and Slomp 2006; Olson, Malone, and Smith 2001; Thompson 1967; Van de Ven, Delbecq, and Koenig 1976). However, the traditional approach of developing coordination structures based on an analysis of predictable and stable interdependencies appears to have limited applicability within organizations operating in high-velocity environments (Crossan et al. 2005; Faraj and Xiao 2006; McPherson and White 2006). Scheduling, and especially rescheduling, provides a clear example of such an environment. The variety and unpredictability of this environment lead to variety in types and criticality of interdependencies. Conditions of high uncertainty and fast decision-making challenge the assumption "that the environment is predictable enough to characterize existing interdependencies and that predefined mechanisms can be designed for various contingencies" (Faraj and Xiao 2006, 1156). The analysis of performance criteria shows that managers and planners who work in dynamic environments consider process criteria (e.g.,
p. 74 communication, negotiation, flexibility, understandability of the ↳ schedule, and the employees' wishes) more important than a good schedule (De Snoo, Van Wezel, and Jorna 2011a). Interestingly, these are criteria that relate to the interaction of a scheduler with other departments, for example, purchasing, sales, production, quality, finance, human resources, industrial engineering, and IT (McKay and Wiers 2006).

Berglund, Guinery, and Karltun (2011) described the tasks performed at this interface: clarify, negotiate, and joint problem-solving. De Snoo, Van Wezel, and Wortmann (2011) investigated the effects of the relocation of the scheduling department to the center of the shop floor. Their analysis showed that the effectiveness of such interface tasks increased when schedulers and operators were able to communicate more face to face. Concerning performance criteria, Nauta and Sanders (2001) showed that the focus of manufacturing is on efficiency and quality, of planners on delivery performance, and of marketing on customer service. An important conclusion from Nauta and Sanders is that perceived goal differences increase the frequency and seriousness of conflicts between departments.

Berglund and Guinery (2008) investigated the power relations between planning on the one hand and commercial/production departments on the other. They found that planners primarily use informal power versus formal power. Because planners do not have formal power, they must negotiate to find a balance between the goals of sales versus manufacturing. During this process, schedulers tended to work with multiple scenarios in parallel; for example, a political view that is made public, a realistic view that the scheduler think will actually happen, and an optimistic schedule that is communicated in the bartering process (McKay, Safayeni, and Buzacott 1995b).

Nauta and Sanders (2001) explored the relation between personality characteristics and four kinds of planners' negotiation behavior (table 5.2). They concluded that collaborative problem-solving occurs more when individuals are extraverted and agreeable, and when employees perceive high interdepartmental interdependencies. Contending occurs more when individuals are extraverted and disagreeable. Yielding occurs more when individuals perceive a power advantage versus the other department. All kinds of negotiation occur less when organizations have a low-cost strategy.

Table 5.2. Negotiation Strategies

Problem-solving	Negotiation partners consider both their own goals and the others' goals.
Yielding	The partner adjusts to the demands of the other.
Contending	The partner imposes preferred solutions on the other.
Avoiding	The partner neglects the conflict.

From an organizational design perspective, McKay and Wiers (2006) described two kinds of connections that planning can have with other departments: structural and functional. Structural interconnections depend on the scheduling task division; what aggregate layers do we distinguish, and how are the p. 75 corresponding scheduling and rescheduling tasks divided between the schedulers and the ↳ shop floor? Related aspects are information visibility, decision depth, and decision breadth. Functional connections describe the flow of information, which depends on the scope and formalisms used (e.g., the number of participants in the process and how they communicate), and the solution space (i.e., the density and elasticity of constraints). Wiers (2009) offers an example, discussing how autonomy depends on uncertainty (probability and extent of unforeseen events) and human recovery (the ability and latitude of operators to handle the disturbances themselves):

- *Smooth shop*: little uncertainty and little need for human intervention. The scheduler can make the schedule and focus on optimization.
- *Social shop*: little uncertainty, but there is frequent need for human intervention in the production process. Detailed scheduling decisions should therefore be allocated to the operators, which means that the schedule of the scheduling department should allow for some decision latitude.
- *Stress shop*: much uncertainty, but no possibility for the shop floor operators to handle this, because the uncertainty is caused by external factors. The schedulers will handle all rescheduling.

- *Sociotechnical shop*: a high level of uncertainty, but also a local need to be able to handle exceptions. There is little utility in making a detailed schedule as the operators will not be able to execute it anyway.

Due to specific characteristics of scheduling, customized coordination theories need to be developed. The decision latitude of sales, planners, and shop floor operators, and the appropriate coordination mechanisms between these departments, must be determined. However, theory to support these organizational design decisions is limited.

Computer Support for Planning and Scheduling

Scheduling problems have always been an important application area for decision support systems (DSSs) (Eom and Lee 1990; Eom and Kim 2006; Eom et al. 1998). A DSS improves the quality of decisions pertaining to unstructured and large-scale problems by coupling the cognitive resources of individuals with computer capabilities (Keen and Scott-Morton 1978). However, in scheduling systems, while a great deal of emphasis has been placed on large-scale problems, the user has been somewhat neglected. Framinan and Ruiz (2010) proposed a generic architecture for manufacturing scheduling systems and describe the following functionality:

- Scope of the system: the system can support one or more aggregate layers (planning, shop floor control, reactive scheduling, and so on).
- Problem modeling: the system can detect the suitable model (combination of objects, constraints, goals) itself, adapt it to the specific situation, and be able to represent the solutions.
- p. 76 ↳ Problem-solving: creating the actual schedule using algorithms or heuristics, on the appropriate level and within the model chosen.
- Solution evaluation: analysis of the solution, for example, analyzing scenarios with multiple objectives and uncertainty.
- Capacity analysis: the detection of bottlenecks before and during scheduling.
- User interface: entering parameters, representation of the schedule (e.g., a Gantt chart), displaying constraints and goals, and interactions with the user.
- Integration with existing information systems: for example, ERP systems for orders, bills of material, recipes, stock positions, and so on. But also interact with shop floor control systems and systems of customers.

Framinan and Ruiz (2010) essentially mitigate human expertise in their scheduling system. However, scheduling, and especially rescheduling, is subject to extemporized information that is unavailable at the time of the design of the system. Additionally, scheduling decisions need to encompass interpretation of information by stakeholders, which is not necessarily stable. For example, Conway, Maxwell, and Miller (1967, 3) argued that “much of the research literature in sequencing refers to the job-shop scheduling problem and uses the terminology of manufacturing: job, machine, operation, routing, and processing-time. In fact, the work is based on this type of idealized pure-sequence abstraction of such a manufacturing shop and the results are equally applicable to problems in transportation, communication, services, etc. Actually one might say that the results are equally inapplicable, since this idealized model is not an exact representation of any real job-shop.” McKay, Pinedo, and Webster (2002) specifically noted that the dynamic nature of scheduling gives the human scheduler an important role in the scheduling process. Therefore, we should explicitly consider the role of the human in the design of scheduling support. Below, we will outline factors that can be used to determine the kinds of interaction between the human and the computer, and when these interactions are appropriate.

Behavioral Effects of Using Scheduling Algorithms

There is general recognition that scheduling algorithms need to support rather than replace the human scheduler because constraints and goals are usually too complex to fully consider in an algorithm or heuristic (Sanderson 1989). However, using an algorithm that contains simplifications like neglecting constraints and optimizing a single goal in a multicriteria scheduling problem results in new tasks for human schedulers such as the need to check the schedule for errors. These changes can have unintended side-effects. For example, the human scheduler might be overloaded with too much information (Baek 1999), system input and output can be difficult to understand (Sanderson 1989; Higgins 1992), and the introduction of a system can result in boredom, demotivation, or complacency (Parasuraman et al. 1993). p. 77 The success of decision support systems depends not ↳ only on the objective quality of system output but also on user-related factors such as the perceived usefulness, ease of use, and job relevance (Sabherwal, Jeyaraj, and Chowa 2006; Venkatesh and Bala 2008). Technology acceptance, postadoptive behavior, and use risks of decision support have seen extensive attention in literature, but are essentially ignored in the design of scheduling algorithms (Chopra et al. 2004; Hoch and Schkade 1996; LaForge and Craighead 2000; Singh and Singh 1997).

Nakamura and Salvendy (1994) argued that the computer "must have models of the human operator so that it can infer the possible actions that the humans might take for any system state" (342). Haider, Moodie, and Buck (1981) showed that an interactive scheduling system can only be effective if a scheduler can relate the objective that is being optimized with the information about the jobs and the shop being displayed. Further Baek (1999) showed that in complex job shop scheduling situations operators "performed significantly better when working with initial solutions that were generated by themselves. This implies that computer aiding that is incoherent to human problem-solving strategies may be less effective than commonly expected." If the goals pursued by the algorithm have no clear link to the objectives of the planner, or algorithms are not understood by the decision-maker, the subsequent inability of the person to gain insight into the problem contributes to information overload (Sharit, Eberts, and Salvendy 1988) and poor performance.

In line with this reasoning, Prietula and coauthors (1994) proposed that the human planner and the scheduling support system should work in "coincident problem spaces." The models themselves need not be similar, but at the points of interaction understandable communication must be possible. Hence, successful use of an algorithm is not only determined by the quality of the solution procedure and the quality of the mapping, but also by the way in which results are communicated in the user interface. This is confirmed by experiments of Cegarra and Hoc (2008), who found that result comprehensibility is necessary for good performance, but that understanding the algorithm itself might lead to lower performance due to higher cognitive costs. Chenoweth, Dowling, and St Louis (2004) showed that cognitive feed-forward (such as instructions or training) and cognitive feedback (i.e., not only feedback on the outcome itself but also on the system and the decision strategy that it used) increase awareness of the improved accuracy that complex models offer. Explanation increases perceived usefulness and acceptance. However, differences in reasoning patterns and cognitive maps between individual schedulers performing the same task (Mietus 1994; Kietwiet et al. 2005; Guerin, Hoc, and Mebarki 2012) complicate representation issues.

The role of the human scheduler is to process extemporary information. Because it is by definition impossible to predict when and where such information will emerge, the scheduler needs to understand the schedule at all times, and must be able to intervene at each decision moment. A mismatch between schedulers' mental models and the reasoning and communication process of the support system can lead to three risks: trust, complacency, and loss of skill and adaptability due to loss of situation awareness.

p. 78 If schedulers do not trust the system, they will neglect it. Because of the introduction of automation, the role of the human changes from active controller to supervisory controller (Lee and Moray 1992). Arkes, Dawes, and Christensen (1986) and Lee and Moray (1994) showed that operators tend to use automation if trust exceeds self-confidence, and that manual control is used if self-confidence exceeds trust. Dixon, Wickens, and McCarley (2007) showed that reliance on the system decreases with increasing system failures, and that compliance (i.e., response time and accuracy of the operator's reaction if the system indicates a problem) decreases with increasing numbers of false diagnoses. De Vries, Midden, and Bouwhuis (2003) highlighted the importance of error feedback on trust, self-confidence, and whether humans choose to use automatic planning. They concluded that transparency of process feedback can increase initial trust and acceptance of new technology. Riedel and coauthors (2011) showed that while good performance increases trust, performance variability decreases trust, concluding that high performance is more important for trust than low variability.

A second risk is overreliance or complacency. Cegarra and Hoc (2008, 613) defined complacency as "an unjustified assumption of satisfaction in which a human accepts suboptimal performance because of the cognitive cost of evaluating or correcting the machine's proposal." They show that complacency can be avoided by increasing result comprehensibility, but that grasping the internal workings of an algorithm does not reduce complacency. Complacency can also lead to nonvigilance based on an unjustified assumption of a satisfactory system state (Inagaki 2003). If the introduction of an algorithm changes the task of an operator from problem-solving to monitoring, it must be taken into account that humans cannot maintain effective visual attention for more than about half an hour (Bainbridge 1983). Therefore, Kuo and Hwang (1998, 166) proposed to "leave some thinking space to human schedulers" in the design of an interactive scheduling system.

A third risk is loss of skill and adaptability due to reduced situation awareness (Hoc 2000). Introduction of a system can lead to "cognitive starvation," and, as a consequence, human planners cannot deal with exceptions anymore (Wiers and Van der Schaaf 1997). Van Nimwegen and van Oostendorp (2009) reported that performance aided by an interface providing guidance was worse than performance aided by an interface without guidance, which attributed to proactive thinking. When properly designed, however, support can also improve situation awareness and adaptability because it can reduce workload and provide integrated information (Endsley and Kiris 1995).

Involving human expertise in the design of scheduling systems is essential. Support should not replicate human decision-making, but should account for usage effects such as trust, complacency, vigilance, and situation awareness. Therefore, the system design should account for the following design criteria:

1. The scheduling goals of the human scheduler and system need to be aligned. Misalignment of goals and variability in performance decrease trust.

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2. ↳ The system should communicate the decision strategy and schedule in a comprehensible way, which increases acceptance and trust and decreases complacency.

3. The system should account for human limitations such as short-term memory and attention span, and individual differences.

4. Human schedulers should be provoked to participate in the scheduling process, or risk losing their long-term mental model of system functioning and structure, and their ability to deal with exceptions.

These criteria imply that the requirements specification, which precedes design and development in the software engineering process, needs to be more than a mathematical formulation of a scheduling problem.

Design Methodology for Scheduling Support

Cegarra and Van Wezel (2012) described three properties that scheduling systems should have to address situational oversimplification and utilize cooperation skills, mental flexibility, and human scheduler creativity:

1. Adaptability: "accommodate medium- and long-term changes in the problem-solving environment."
2. Flexibility: "accommodate heterogeneity in the current (short-term) decision-making context."
3. Acceptability: "the ability to take into account the cooperative outlook of the humans who participate in the decision-making process."

Simple but understandable algorithms have low acceptability (Cegarra and Hoc 2008; Green and Appel 1981). Hence, algorithms should be able to solve complex problems. However, such algorithms are usually based on a one-off analysis of the scheduling problem, impeding the adaptability and flexibility needed for sustained user acceptance. Cegarra and Van Wezel (2012) argued that support should link to schedulers' mental models in two ways. First, the interface should use commonly accepted metaphors and make use of human pattern-recognition capabilities. Second, algorithms should capitalize on human abilities. To create adaptable, flexible, and acceptable systems, we need to uncover information on the scheduling problem to find applicable algorithms, but also information on the way the human schedulers work and think. Cegarra and Van Wezel (2011) compared three perspectives to analyze information requirement methods for scheduling:

1. Normative: it prescribes how the tasks should be done, e.g., hierarchical task analysis (Annett 2000; Annet and Duncan 1967).
2. Descriptive: it describes how the task is currently performed. An example is a Cognitive Task Analysis (Schraagen et al. 2000).
3. Formative: it provides an exhaustive description of the scheduled domain, including physical and functional interrelations (Higgins 1999).

p. 80 Cegarra and Van Wezel (2011) used Vicente (1999) to compare these information requirement approaches. The *device dependency* expresses to what extent the method depends on the currently used "devices" that execute the task (e.g., humans, computer programs, etc.). The *event dependency* specifies whether novel circumstances can be detected. The *psychological relevance* indicates how the schedulers' point of view is considered in the analysis. These aspects can be linked to the adaptability, flexibility, and acceptability of scheduling systems (table 5.3). Traditionally, DSS for scheduling follow a *normative* approach: an existing solution procedure is adapted to specific circumstances, and tasks are assigned to the scheduler. Such an approach is not device independent, event independent, or psychologically relevant. Thus, adaptability and flexibility are low and acceptability has two sides. High performance increases acceptability, but low psychological relevance decreases acceptability. A *descriptive* analysis is device dependent and event dependent, but psychological relevance is high. This decreases adaptability because new circumstances will by definition not be encountered in descriptive analysis. However, flexibility and acceptability are high. Finally, a *formative* analysis is device and event independent, but psychological relevance is low because it p. 81 analyzes the domain, not task performance. ↳ This makes adaptability and flexibility high, acceptability low because the current way of working is not considered.

Table 5.3. Effects of Analysis Approaches

	Adaptability	Flexibility	Acceptability
Normative analysis	Low	Low	Low/high
Descriptive analysis	Low	High	High
Formative analysis	High	High	Low

Cegarra and Van Wezel concluded that all three approaches are needed to address the tasks and roles of human schedulers. However, exhaustive normative, descriptive, and formative analyses are likely to be time consuming and costly. Van Wezel, Cegarra, and Hoc (2011) proposed applying function allocation to mitigate these limitations. Per subtask the effects of automation (trust, complacency, loss of adaptability) constitute a risk—the higher the risk and the costlier the possible effects, the more important human involvement. This technique has its origin in cognitive engineering, where it is used to determine appropriate task division between human and computer in dynamic, high-risk situations. Table 5.4 shows an example with various levels of automation.

Table 5.4. Levels of Automation

1.	Human completes the job up to the point of turning it over to the computer for implementation.
2.	Computer helps by determining the options.
3.	Computer helps determine which steps human need not follow.
4.	Computer selects action, and human may or may not do it.
5.	Computer selects action and implements it if human approves.
6.	Computer selects action; informs human in plenty of time to stop it.
7.	Computer does whole job and tells human what it did.
8.	Computer does whole job and tells human what it did only if human explicitly asks.
9.	Computer does whole job and tells human what it did, and then the computer decides if the human should be told.
10.	Computer does the whole job if it decides it should be done, and if so tells human, if it decides the human should be told.

source: Sheridan and Verplank 1978.

In function allocation, the level automation that corresponds to the required level of human involvement determines the appropriate task analysis methods. For example, a subtask on level 1 would need no normative analysis, whereas a subtask on level 10 would need no descriptive analysis.

The involvement of humans in computer-supported scheduling orbits information that cannot be specified in advance. The computer model can get out of date or cannot capture the flexibility necessary to real circumstances. The human should always be able to tell the computer what can be done and the computer should accept it. For example, the scheduler can temporarily have one machine do two things at the same time, or assign work to a machine not listed in the computer as being possible.

Learning Activities

Game 1: Manufacturing Scheduling

Based on de Snoo and van Wezel (2014). (The game can be played physically with Lego bricks.)

The furniture-manufacturing case serves as the inspiration for a scheduling game showing the effects of cooperation in a dynamic scheduling situation. The game can be used to play a stylized simplified scheduling situation in approximately 30 minutes. It shows the effects of collaboration when schedulers need to solve complex problems in which they are simultaneously under time pressure and mutually dependent.

The scheduling situation can be characterized as a flexible job shop. There are three departments, and each has three similar machines (sawing, cutting, milling). The schedules are strongly interconnected. Each order consists of two operations. Processing times differ per operation. Transport times, setup times, and inventory are not taken into account. Participants are confronted with event information at different points in time (see table 5.5). Participants have a range of possibilities in changing a plan: schedule an order earlier or later on the same machine; move an order to another machine; add or remove an order. The schedulers are jointly responsible for the timely delivery of orders and the efficient utilization p. 82 ↳ of machines. Because of the routing of the orders, adaptation of one schedule quickly results in infeasibility in another order.

Table 5.5. Events Provided to the Participants

1.	**8:30 a.m.** The sales department has received a request from a potential client to deliver a trial product. If the delivery of this product is achieved on time, the client will likely place substantial orders in the near future. The management has therefore decided to fulfill this request. Order 13 has to be delivered at the latest at 17:00; the product first requires sawing (processing time three hours), and then has to be cut (processing time three hours).
2.	**8:50 a.m.** The distribution department reports product damage during onward delivery. The product has to be remilled. Milling is the only processing activity required for this “rush order” (processing time is two hours). Order 14 has to be ready by 15:00.
3.	**9:40 a.m.** The raw materials for order 12 do not meet quality standards. Therefore, these materials have to be resupplied. Order 12 is therefore postponed; it can be removed from the milling and sawing schedules.
4.	**10:10 a.m.** The shop floor notifies that the cutting department does not have the highly specialized skills required for order 4. Management decides to outsource the cutting activities for order 4. Order 4 only needs input from the sawing department.
5.	**10:40 a.m.** The production manager reports that sawing machine 1 requires attention. Maintenance activities will take place between 14:00 and 15:00. No orders can be scheduled on the machine during this hour.
6.	**11:20 a.m.** A rush order (order 15) is received that has to be delivered by 16:00. The product first requires cutting (processing time is two hours), and then milling (processing time two hours).

The game can be played simulating several alternative scheduling situations to demonstrate how communication and collaboration can influence the scheduling process:

1. Players start with an empty schedule. Participants need to create the schedule based on a description of products and their operations.
2. Players start with a complete schedule that will be executed tomorrow. The schedule is purposefully suboptimal so participants can immediately start to optimize. Events (e.g., order cancellations, new

rush orders; table 5.5) invalidate the schedule, and participants must coordinate to fix it.

3. Starting with the same schedule as in situation 2, but the schedule is currently being executed. Events invalidate the schedule, but as the game progresses, there are fewer opportunities to make changes. The scheduling decisions for orders that production has already started cannot be changed; preemption is not allowed. Therefore, the number of orders that can be moved decreases as the game p. 83 progresses. Time ↳ pressure is higher when the schedule has already been released since there is less time to react. For example, consider a rush order arriving at 8:50 a.m. (event 2 in \table 5.5). If the execution of the schedule has already started, three orders (numbers 6, 9, and 3) can no longer be moved. Moreover, at 11:00 a.m. two further orders are scheduled to start (orders 2 and 12), reducing yet further the number of movable orders. Although in this situation there are more constraints, the number of alternatives that have to be considered also is lower.

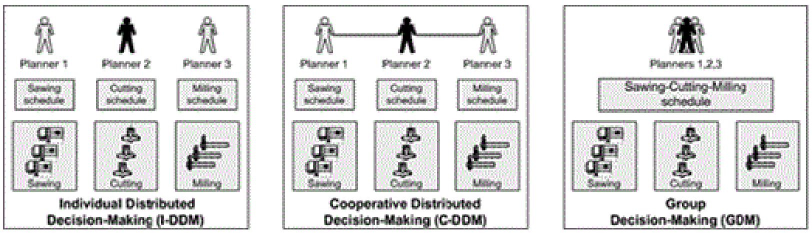
To express the organizational design options, collaboration can be organized in three ways (figure 5.7):

1. Individual decision-making: participants are physically separated from each other. They can only view their own schedule and can communicate changes to it by specifying the recipient scheduler's name and the change they propose. Deliberations about alternatives or decisions are not allowed.

2. Collaborative decision-making: participants are placed apart as in the individual setting and, again, each has his or her own schedule that may not be communicated. However, in this mode, the schedulers are allowed to communicate or deliberate with each other in face-to-face conference. Cooperation clearly has some costs: the schedulers have to leave their working places and, after deliberations, have to apply the agreed-on actions to their individual schedules (with a risk of errors due to poor recall).

3. Group decision-making: the three schedules are combined and the participants are physically located around the same table. They are instructed to handle all events jointly and to make all decisions together.

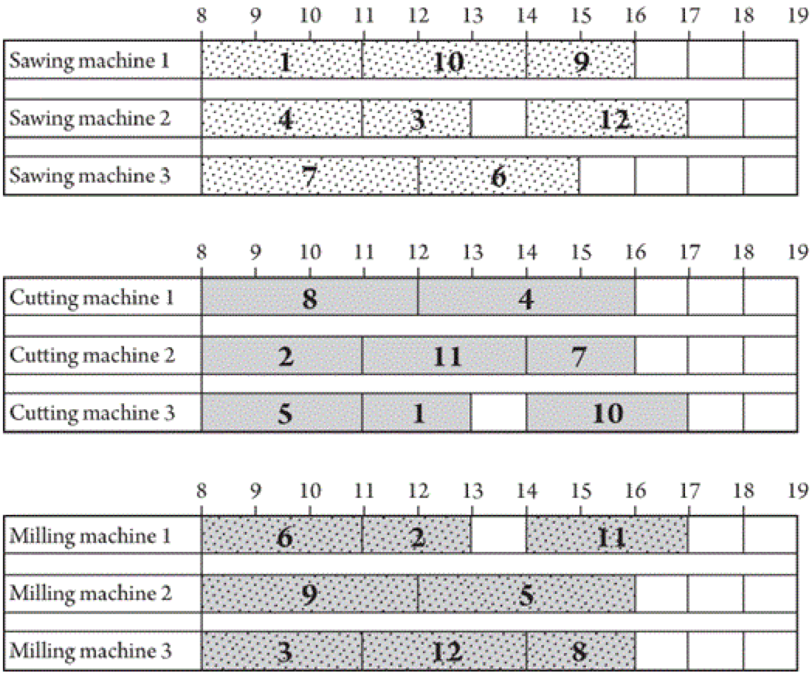
Figure 5.7



Coordination Modes in Scheduling

To play the game, the participants are provided with a Lego board with bricks representing scheduled orders, and an order book containing the delivery time and processing time per operation. The interdependencies within and between the initial schedules are the same for each pair of schedules; that is, each schedule contains the same number of orders with equal variance in processing times, the sequence dependencies between two production operations related to a single order are equal, and each schedule p. 84 contains the same ↳ amount of slack and redundancy (figure 5.8). At fixed points in time the groups are confronted with written information concerning an event (table 5.5). Players have 12 minutes to update and improve their schedules. These 12 minutes represent a four-hour period (8:00 a.m. till 12 noon); a digital clock shows the progress of time. In this way, complexities of scheduling reality are simulated. If there is time, participants can play the game a second time under different circumstances.

Figure 5.8



Start Schedules

During the debrief participants can reflect on several of their experiences:

- The difference between starting with an empty schedule and adapting an already complete schedule. When participants start with an existing schedule, they need to first grasp the interconnections, which is difficult when events are piling up. We regularly see that participants first remove everything from the schedule and then build it from scratch. This can be related to the use of scheduling algorithms; if the schedule is created by an algorithm, human schedulers find it more difficult to make changes relative to a schedule they made themselves.
- The effect of time pressure on task performance, and the difference between (offline) scheduling and (online) control.
- The consequences of changes on an already finished schedule. A lesson learned can be that in dynamic situations, detailed centralized scheduling is not always a sound choice, as changes will invalidate most of the previously made decisions.
- Perceived task interdependency, power struggles, and negotiation strategies can be discussed.
- p. 85 ↳ The need for communication and transparency of information. Especially the individual decision-making mode leads to schedule errors, for example, by scheduling operations of the same job on multiple machines simultaneously.
- The task division that appears in the group decision-making mode. Did one of the participants take the lead, or were all decisions made collaboratively?

Note that this game is played in the context of a "naive" or new scheduler, not a scheduler with years of experience. No game will teach all of the things expert schedulers know and do. Experienced schedulers have different tactics, know the other schedulers and politics, and so on, and would work in a collaborative situation differently than novice participants in this game. However, the game teaches some of the key concepts of behavioral operations in scheduling.

Game 2: The Traveling Salesman

Based on Bendoly and Prietula (2008).

Many antecedents to performance have nonmonotonic effects. Such antecedents suffer from the law of diminishing returns, which makes the relation between cause and effect asymptotic. For example, increasing the number of employees for a given task increases the need for coordination, which at some point can offset scale efficiencies. Sometimes the relation can even be curvilinear. Pierce and Aguinis (2013) call this the Too-Much-of-a-Good-Thing Effect. An example is workload of employees. A very low workload will result in boredom and nonvigilance of employees. A very high workload, however, harms performance as well. This inverted-U form of the relationship between workload and performance (or the Yerkes-Dodson Law; Yerkes and Dodson 1908) results from two opposing phenomena. The first, based on goal-setting theory (Locke 1968; Locke and Latham 1990), is that a limited amount of work pressure leads to a rise in motivation compared to no pressure at all. In contrast, too ambitious goals can lead to a decrease in motivation (Karasek 1979), as frustration and stress may cause individuals to exert less effort (Lawler and Suttle 1973; Erez and Zidon 1984; Locke and Latham 1984). Managing nonmonotonic relations is difficult because they differ per individual and can change over time. An example of this latter issue is the effect of skills on individuals' interpretation of a particular workload level. An experienced, highly skilled employee might not be deterred by a high workload as easily as an inexperienced employee.

The game described in this section demonstrates both phenomena: a too high and a too low workload are detrimental for performance, but highly skilled employees are less sensitive to workload than unskilled employees. The game is based on a well-known problem in operations research: the traveling salesman problem (TSP). In its most basic form it is a sequencing problem. A salesman has to visit a set of cities, starting and ending at his home address. He wishes to ↳ travel the shortest route possible. Similar to the manufacturing sequencing problem discussed previously in this chapter, this problem is NP hard. The game is played by showing a map with a number of dots that indicate cities to be visited (figure 5.9). The first dot that is clicked indicates the start of the route. Each subsequent dot clicked extends the route to include the corresponding city. There are two performance measures: the distance of the route, and the time participants need to create a route.

Figure 5.9

Map with Cities to Visit

Because the goal of the game is to show the effect of workload on performance, first a base speed rate needs to be determined for each individual. The base rate is determined by solving TSP problems until a stable solution speed is achieved. This can be detected by calculating a three-problem moving average reference frame. When the variation in the last five subsequent moving averages does not differ by more than 5%, the moving average of the last three decisions is the base rate.

Once the base rate is determined for all participants, the game itself can be played. There are two parameters that need to be manipulated:

1. The workload is simulated by a queue of TSP problems to solve. A problem that is solved is removed from the queue, and the solution time and travel distance are stored to calculate performance. Problems are added to the queue automatically in one of three speed levels:
    a. Much lower than the base rate. The participant is waiting until a new problem arrives. This is to show that boredom and nonvigilance lead to low performance.
    b. p. 87 ↳ A bit higher than the base rate. The participant must make more effort than during the calibration phase but manages to handle the workload.
    c. Considerably higher than the base rate. The participant must work much faster than during calibration, and might even be faced with a continuously increasing queue.
2. Expertise is manipulated by teaching participants a heuristic, for example the "nearest-next"

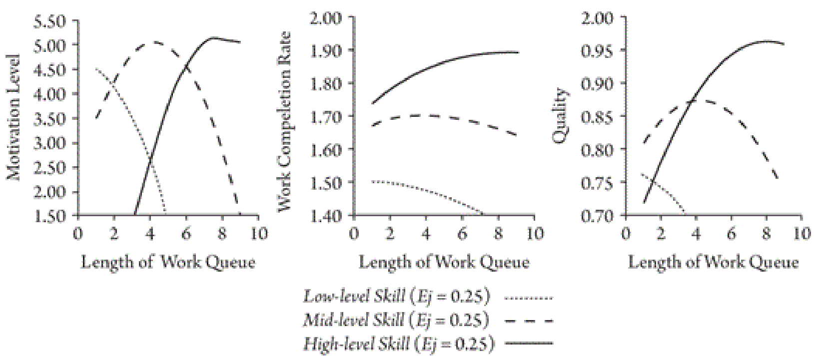
heuristic, where the next city in the route is always the city that is closest to the last city in the route. Applying this relatively simple trick often leads to decent routes in a short time, giving the participants the feeling they have mastered the task.

Depending on the teaching goal, the number of participants, and the available time, these settings can be played by each individual or distributed over multiple participants.

The debrief should focus on differences between the speed settings and the effects of skill:

- Figure 5.10 shows typical results that can be found for motivation, speed, and quality under the different workload settings. Increase in skill impacts perceptions of work pressure and shifts the level of workload most conducive to peak performance. Topics of discussion are, for example, how participants trade off quality for speed when workload increases, how this influences their motivation, and whether or not applying the heuristic mitigated the effects of an increased workload.
- Discussion can point out practical settings where workload can be designed. Students can reflect on their own experiences; what happens when deadlines for multiple courses are close together? Examples in manufacturing are assembly lines and project management, and in a service setting one can think of the difference between a central queue compared with a queue for each server.

Figure 5.10



Nonmonotonic Relations and the Effect of Skills

source: Bendoly and Prietula 2008.

p. 88 Curvilinear relations caused by the Too-Much-of-a-Good-Thing Effect are in general understated. The game can be used as a hands-on example and impetus to discuss other examples. The overview of Pierce and Aguinis (2013) can serve as a starting point.

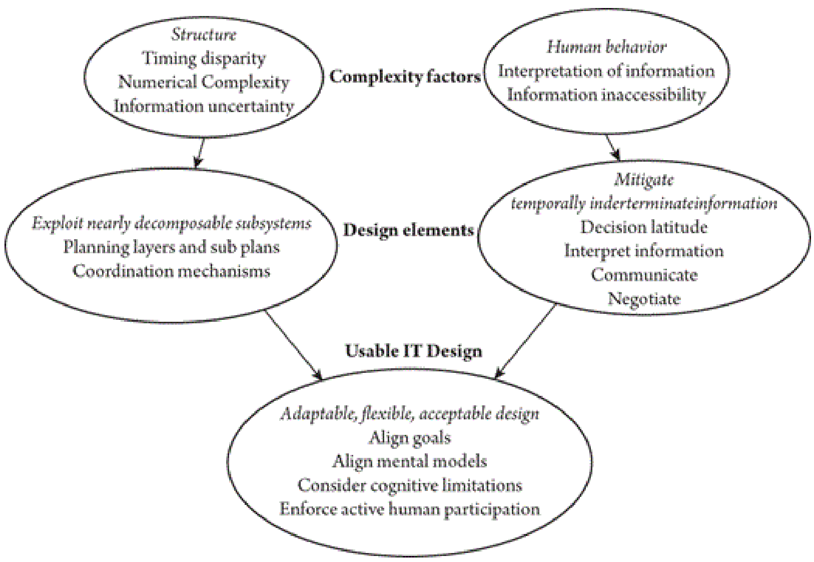
Discussion

Scheduling problems are traditionally handled by operations management as numerically complex problems that need advanced algorithms and computational power to find near optimal solutions. However, terms like *branch-and-bound* or *simulated annealing* have no meaning for human schedulers that need to solve these problems day to day in actual companies. Scheduling problems are puzzles: the schedulers start with many pieces and need to build a coherent whole. However, the desired end-state of a scheduler's puzzle is not precisely known. During the puzzle-solving process, the pieces of the puzzle change; they might be adapted or altogether disappear and new ones might be added. Additionally, information, goals, and rules can be interpreted differently by various stakeholders. One of the strategies that organizations employ to mitigate the effects of dealing with many detailed decisions simultaneously is to work with larger, more aggregate puzzle pieces. Each larger puzzle piece has one or more smaller puzzles within. For example, if the schedule specifies which orders need to be produced on what day, but not at what moment or in what sequence (as in our case description), small changes during the day can be handled within the departments.

 This highlights the role of human schedulers. They make the puzzle with the pieces that are available and deal with changes. A task division with nearly decomposable subsystems always needs coordination. Collecting missing information, communication, interpretation, and negotiation are especially prevalent when an event in one department invalidates that department's schedule, and a solution needs a constraint violation in another department. Human schedulers try to develop solutions that keep all stakeholders satisfied by searching for flexibility in established constraints. Often, however, the pain of constraint violations needs to be put somewhere. Since departments are evaluated on their departmental goals, they are not always immediately willing to accept a hit in their performance to solve another department's problems. Here the added value of the human scheduler is clear. Knowing when a department or individual can be pressured, keeping tabs on future compensation, and being convincing to colleagues, managers, and operators are at the core of the skills of human schedulers.

Figure 5.11 summarizes all the elements that are discussed in this chapter.

Figure 5.11



Elements of Human Behavior in Scheduling.

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