The Human Factor in Planning and Scheduling

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Chapter #??

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1. INTRODUCTION

In this chapter, the term scheduling will be used for any decision task in production control that involves sequencing, allocating resources to tasks, and orchestrating the resources. Depending on the degree of granularity, scope, and authority, this view covers dispatching, scheduling, and planning. Unless noted, the basic issues and concepts discussed in this chapter apply to all three activities. This common view is also taken because in practice, it has been the authors' experience that in many cases, a single individual will be doing some planning, some scheduling, and some dispatching - all depending on the situation at hand and it is not possible to identify or specify clean boundaries between the three.

The gap between theory and practice in scheduling has been noted since the early 1960's and has been discussed by a number of researchers (Buxey, 1989; Dudek et al., 1992; Graves, 1981; MacCarthy and Liu, 1993; Pinedo, 1995; Rodammer and White, 1988; Crawford and Wiers, 2001). There are many possible reasons for the gap and each contributes to the difficulties associated with improving the effectiveness and efficiency of production.

One of the reasons for the gap has been speculated to be the lack of fit between the human element and the formal or systemized element found in the scheduling methods and systems (McKay et al., 1989; McKay and Wiers, 1999). This specific lack of fit is what we will call the human factor in the success or failure of scheduling methodology.

With very few exceptions, there is some component of human judgment and decision making in the production control of real factories. The human element might be responsible for the majority of sequencing and resource allocation decisions from the initial demand requirements, or might be responsible for initial parameter setting for algorithms and software, or might be involved in interpretation and manipulation of recommended plans generated by a software tool. It is very hard to think of a situation where the mathematical algorithms and planning logic are self-installing, self-setting, self-tuning, and self-adapting to the situational context of business realities. Unfortunately, the role and contribution of the human element has been largely ignored and under-researched compared to the effort placed on the mathematical and software aspects (McKay et al., 1988).

In this chapter, we will review the research conducted on the human factor in planning and scheduling. Specifically, the positive and negative aspects of the human factor will be discussed. We will also discuss the consequences when these aspects are ignored or overlooked by the formal or systemized solutions. Section 2 presents a discussion on scheduling and sequencing from the perspective of schedule feasibility. Section 3 presents a review of the human scheduling research focusing on the scheduler as an individual. Section 4 reviews the research on the task nature of scheduling. Section 5 proposes a set of concepts for how to better design decision support mechanisms which incorporate the individual and organizational aspects of planning and scheduling. The concepts presented in Section 5 are integrated in a design model for scheduling decision support systems in Section 6. Finally, Section 7 presents our conclusions.

2. SCHEDULING AND SEQUENCING

Encapsulated in mathematical logic or software, the scheduling problem is presented as a sequencing problem. This view dates back to the early 1960's and was explicitly expanded upon in the seminal work of Conway, Maxwell, and Miller (1967). The mathematical dispatching and sequencing rules focus on what to select from the work queue at any specific resource. In academia, *Theory of Scheduling = Theory of Sequencing*. At a higher level, this also includes what to release into the manufacturing process. During the past four decades, various sophisticated algorithms have been developed that attempt to find the best possible sequence given a number of constraints and objectives (e.g., Pinedo, 1995). The implicit or explicit goal of the research has been to create sequences of work that can be followed, and by this following of the plan, the firm will be better off. The ultimate goal is to use information directly from a manufacturing system, run the algorithms without human intervention, and have the shop floor execute the plans as directed - without deviation. This goal has been reasonably obtained in a number of industries, such as process, single large machine equivalents, highly automated work cells, and automated (or mechanically controlled) assembly lines. For these factories, the situation is reliable and certain enough for plans to be created and followed for the required time horizon.

The acceptable time horizon is one in which a change can take place without additional costs and efforts. For example, a, b, and c is the planned schedule and instead of picking a, we decide to work on c. If this decision does not incur additional costs and efforts as the rest of the plan unfolds, then the change does not matter. It might be that changes in the plan can be made without penalty two days from now. In this case, a good schedule and scheduling situation would be one that could be created and actually followed for today and tomorrow. Here, the *Theory of Scheduling = Theory of Sequencing*. For rapidly changing job shops or industries, plans for the immediate future might be changing every half hour or so. It has also been observed in the factories which have been studied that the objective functions and constraints change almost as quickly. In unstable situations such as these, sequencing is only part of the problem and the *Theory of Scheduling <> Theory of Sequencing*. The ability to reschedule and perform reactive scheduling does not really solve the problem either if the changes are being made within the critical timing horizon. Reactive re-sequencing may incur additional costs and wastes within the window if the manufacturing system does not have sufficient degrees of freedom with which to deal with the situation. In this chapter, the focus is on the situations where sequencing is only part of the scheduling problem and the challenge is the short term time horizon during which any changes might be problematic.

When sequencing is only part of the problem and the human scheduler is expected to supply the remaining knowledge and skill, other issues may remain. One issue relates to the starting point provided the human. That is, using the model, data, and algorithms in the computer system, generate a starting schedule for the human to interpret and manipulate. An extreme level is that of 100% - either accepting the proposed sequence or rejecting it. At one field site, it was reported that the schedulers started each day with deleting the software generated plan and starting from scratch manually. This is an example of 100% rejection. An automated work cell capable of reliable and predictable operation without human intervention might be an example of 100% acceptance. The quality of a starting plan might be considered the degree of acceptance - how much of the plan is acceptable.

The human might reject a plan, or part of a plan, for two major reasons. First, the plan (or sequence) is not feasible and is not operational. These are the decisions that can be considered 0-1 decisions - e.g., "That cannot happen." Second, operationally feasible sequences may be rejected because they are considered suboptimal or not desirable. These sequences could be executed on the shop floor, but it would not be a good way to use the firm's resources. One sequence is preferred over another. The feasible and infeasible criteria, and the preferred and not preferred criteria can be examined by what is included in the traditional models and methods.

In the *Theory of Sequencing*, what is a feasible plan? First, one test of feasibility is whether or not a resource is planned to do something it cannot do. That is, if a machine can only drill one thing at a time, is only drilling assigned, and is only one item scheduled at a time? This is basic feasibility. Second, another test of feasibility is to perhaps include a time pattern of availability; a machine can only be scheduled work when it is possible to schedule work. Third, precedence constraints can dictate order of tasks and how the tasks relate to each other. Fourth, assuming forward loading is being performed, work cannot start before it is available to be worked on. If a sequence satisfies these four conditions, it is generally assumed to be mathematically feasible. The parameters into the mathematical structure include information such as: routings, sequencing relationships between tasks, machine capability, machine availability, set up criteria, processing times, earliest start dates, due dates, possibly penalties and possibly yield. Once it is possible to generate a feasible plan given the input parameters, the next task is to create a good sequence. In mathematical terms, a good plan is one that would attempt to maximize (or minimize) one or more quantitative metrics that can be derived from the interpretation of the plan. The mathematical approaches either use heuristics and algorithms to guide the creation of better schedules while considering feasibility (e.g., traditional OR) or use methods for generating multiple feasible sequences and then have methods for selecting the better sequences. There are reasonably clear definitions and understanding about what *feasible* and *better* means in mathematical sequencing research. Feasible and better are usually explicitly discussed in the research publications. Other, less obvious, assumptions are not. Ten key, implicit assumptions we have observed in mathematical formulations are:

- the relatively small set of facts about the scheduling problem handled by the mathematical model or algorithm are sufficient to capture the main characteristics of the problem.

- the objectives or measurement metrics do not vary over the time horizon being sequenced.
- the feasibility constraints defining the problem do not vary over the time horizon.
- time can be modeled as an abstract time series with t(i), and t(j) and that sequencing is not dependent upon a Monday effect, a shift effect, a holiday effect, or a time of year effect.
- any routing or processing requirements are also independent of state or context for the planning horizon.
- the resource capability and output is largely independent of time (after learning is achieved).
- resources are largely insensitive to the work (in terms of causing problems to the machine).
- work is largely insensitive to the state of the machine upon which the work is performed.
- work can actually be late - numbers of late jobs, degree of lateness being common objectives in the scheduling research.
- operations, routings, quantities, and such do not dynamically change based on the current state of manufacturing.

When these assumptions do not hold, the ability of the mathematical model or software system to create a feasible plan is challenged. As the number of invalid assumptions increases, the more difficult it will be to create a feasible plan. These assumptions illustrate why the *Theory of Scheduling* is not always the same as the *Theory of Sequencing* (McKay and Wiers, 1999). When an assumption fails, either additional logic or manual intervention is required to bridge the gap - creating a feasible schedule. In McKay (1992), these assumptions were investigated and the types of information needed to bridge the gap were analyzed in a case study. While a large portion of the enriched data could be conceptually encoded, programmed, and added into algorithms, approximately 30% of the data used to bridge the gap was not considered to be easily computerized (or legally computerized). For example, scheduling decisions were observed that depended upon knowledge regarding a crew's attitude during training. This particular fact was only important on one day, for one job, on a specific shift and was not relevant for any other decision on the planning horizon. However, it was important enough to force the pertinent job to a specific place on the schedule. In hindsight, an analyst can say that this could be programmed (ignoring practical aspects of the challenge). Another example decision involved a worker's alcohol problem and how the scheduler wanted to avoid this worker's effort on any critical job. Legally, this type of information would be a challenge to include. While this could be coded, it might open up human resource issues and lawsuits.

Hence, human interpretation and enhancement of the scheduling problem is required when the assumptions cannot be satisfied by mathematics or software. While not needed in every factory situation, many factories fail to satisfy, or come close to satisfying the implicit assumptions of sequencing theory. The next section discusses the research that has been performed on the human element in scheduling.

3. THE HUMAN ELEMENT

3.1 Introduction

The first question to ask is “What can humans do that computers and/or mathematics cannot?” The answer is that there is much uncertainty in the physical world. It is humans who are very well equipped to cope with many ‘soft,’ qualitative task elements, as well as, any creative problem solving that might be needed in order to create a feasible or better schedule. Empirical field studies have suggested that humans are superior to existing scheduling techniques and information systems regarding the following characteristics (McKay et al., 1989):

- *Flexibility, adaptability and learning*. Humans can cope with many stated, not–stated, incomplete, erroneous, and outdated goals and constraints. Furthermore, humans are able to deal with the fact that these goals and constraints are seldom more stable than a few hours.
- *Communication and negotiation*. Humans are able to influence the variability and the constraints of the shop floor; they can communicate with the operators on the shop floor to influence job priorities or to influence processing times. Humans are able to communicate and negotiate with (internal) customers if jobs are delayed, or communicate with suppliers if materials are not available as planned.
- *Intuition*. Humans are able to fill in the blanks of missing information required to schedule. This requires a great amount of ‘tacit knowledge.’ At the time of collecting this knowledge it is not always clear which goals are served by it.

While the human’s ability to deal with uncertainty is important, it is also important to consider the human’s ability to create the sequences of work that form a schedule. The seminal article by Sanderson (1989) summarizes and reviews 25 years of work done on the human role in scheduling. Two types of studies are discussed in the review: laboratory studies and field studies. Sanderson also discusses methodological and conceptual aspects of the literature reviewed. The laboratory studies summarized in Sanderson's review have mainly focused on three themes: comparing unaided humans with scheduling techniques, studying interactive systems of humans and techniques, and studying the effect of display types on scheduling performance. However, there have been very few studies replicated or performed in such a way for the results to be generalized. The tasks studied in the research have been quite varied, as have the study methods. Moreover, the research questions which mainly focused on comparisons of humans and techniques might not be as relevant today with the large number of scheduling software tools available (e.g., over one hundred scheduling tools are available, see LaForge and Craighead, 2000). In addition, the majority of field studies prior to 1990 focused on highly experienced schedulers with very little decision support.

Sanderson concludes with the observation that more and better coordinated research on the human factor in scheduling is required. The research reported in Sanderson's review were widely dispersed over a variety of research journals and the reported works were often carried out in isolation from each other. She also notes that a common research question that what was addressed in much of the literature reviewed—i.e., which is better, humans or algorithms—was no longer relevant (even in 1989). Her conclusion was that humans and algorithms seem to have complementary strengths which could be combined. To be able to do this, a sound understanding of the human scheduler was considered necessary. In the following two subsections, recent literature on empirical research and cognitive scheduling models is discussed.

3.2 Recent Empirical Research On Scheduling

Although Sanderson identified the need for extensive field studies on the scheduling task and scheduler, relatively few studies have been performed on the human scheduler in the time since. With the emergence of commercially available computer technology and scheduling decision support systems in the 1980s, a different stream of research evolved. In this stream, researchers were driven by the differences between Operations Research-based scheduling theory that formed the basis of most of the software, and the real-life scheduling process as decision makers conducted it. Inspired by the real-world complexities of the human scheduler (McKay et al., 1988; McKay et al., 1989), researchers spent much time in factories, using descriptive qualitative research methods. Accordingly, subsequent to

Sanderson's review, most of the work studying the human factor in planning and scheduling has been of an exploratory and qualitative nature (see Crawford and Wiers, 2001, for a review) and has served very well the purpose of documenting actual scheduling behavior in production organizations.

Several interesting and novel results have been reported in the qualitative studies, such as the heuristics used by schedulers to avoid future problems, or the temporal aspect and the role of resource aging (McKay, 1992). A major contribution of these studies has been to move the field of study from the laboratory to the factory, with extensive qualitative empirical studies having been conducted, mostly based on ethnographic or case methodologies. Most studies have relied on relatively short observation or data collection periods to collect the empirical data. For example, one or two weeks might be spent with each factory doing an intense analysis and data collection. There have also been several longer term studies performed.

McKay (1992) performed two six month longitudinal field studies on the schedulers' cognitive skill and decision making processes. These two studies on the scheduling task are reported in the context of research on the effectiveness of the hierarchical production planning (HPP) paradigm in dealing with uncertainty. A task analysis at a printed circuit board (PCB) factory was used to identify the decisions made in response to uncertainties in the manufacturing system. The human scheduler turned out to be especially important in managing uncertainty (see also McKay et al., 1989). The field study in the PCB factory is also reported in McKay et al. (1995a). In this paper, the formal versus the informal scheduling practices are compared in the context of managing uncertainty. Several interesting aspects of the scheduling practices are mentioned in this study. First, it was observed that the scheduler worked with multiple schedules: a political schedule for the world to see, a realistic schedule, an idealistic schedule, and an optimistic schedule that was orally communicated to the line. This suggests that any field observations or field studies involving schedulers might be sensitive and aware of this possible multi-plan situation. This phenomenon has been observed in every factory situation the authors have been involved in. Second, it was observed that the scheduler did not accept the current situation as fate; instead, he endeavored to influence the amount and allocation of capacity, the amount of customer demand, the technical characteristics of machines (e.g., to minimize setups). The scheduler employed a large number of heuristics (more than one hundred) to anticipate possible problems and take precautionary measures.

Another exception to the short study is a nine year field study in which real world planning and scheduling has been researched (McKay and Wiers, 2003b). In this field study, flow shop and job shop systems were developed based on ethnographic methods for understanding the requirements and the systems have evolved with the requirements of the plant. In this effort, the schedulers' ontology or mental mapping of the problem was used to create a custom interface using their vocabulary and meta-functions. The focus of the research work was on task analysis to obtain deeper insights regarding the differences and similarities between scheduling, dispatching, and planning (McKay and Wiers, 2003a). The job shop part of the factory was structured in a hierarchical fashion with multiple individuals involved. The job shop was pulled just-in-time from the assembly area which was managed in an integrated way with one individual performing the three planning tasks. Weekly or bi-weekly visits to the plant have been made for the duration of the nine year study and have permitted many insights to be gained about the evolution and usage of scheduling technology as the plant itself evolved.

The third longer study is the work reported in Wiers (1996). The decision behavior of four production schedulers in a truck manufacturing company was investigated by means of a quantitative model. This model consisted of three parts: performance variables, action variables and disturbance variables. The results showed that schedulers who control equal production units show quite different decision behaviors. Also, a 'good' schedule turned out to be no guarantee for good performance. Moreover, some scheduling actions worked positively in the short term but negatively in the longer term. However, the methodological discussion of the case made clear that it is very difficult to construct a reliable quantitative model of production scheduling. Den Boer (1992, 1994) also conducted a quantitative field study on the decision behavior of material requirements planners. The model was based on the paramorphic representation of judgment (Hoffman, 1960) and contained four elements: performance, actions, disturbances and environment. Based on this study, Den Boer concluded that planners suffer from a lack of feedback in setting parameters such as safety time and safety stock.

This leaves the field now with a substantial number of insights from empirical studies, along with the results from earlier experimental studies and those from scheduling theory. Furthermore, in the field of cognitive psychology, advances have been made over the past decades regarding the more general problem of understanding human decision making in complex problem settings.

3.3 The Decision Level - Cognitive Scheduling Models

The area of modeling cognitive processes in complex tasks—such as the scheduling task—still appears to be in a relatively preliminary stage. In a special issue of Ergonomics about cognitive processes in complex tasks, Van der Schaaf (1993) notes that the process of developing a cognitive task model is more useful than the model itself. In an article about task allocation, Price (1985) observes that there is no universally applicable 'cookie cutter' for task allocation decisions; moreover, the ultimate configuration of tasks in a specific situation has to be determined throughout the design cycle. According to Price, covert and cognitive information processing tasks have not been adequately considered in systems design, or by human factors scientists generally. However, the decision models of Rasmussen (1986) are mentioned by Price as being helpful in this respect. The decision ladder of Rasmussen has been used by many authors to model cognitive processes in complex tasks, and is used by Sanderson (1991) and Sanderson and Moray (1990) to construct a model of human scheduling (MHS). The decision ladder model was also used by Higgins (1999) to study a scheduling situation and to create a matching user interface for scheduling technology.

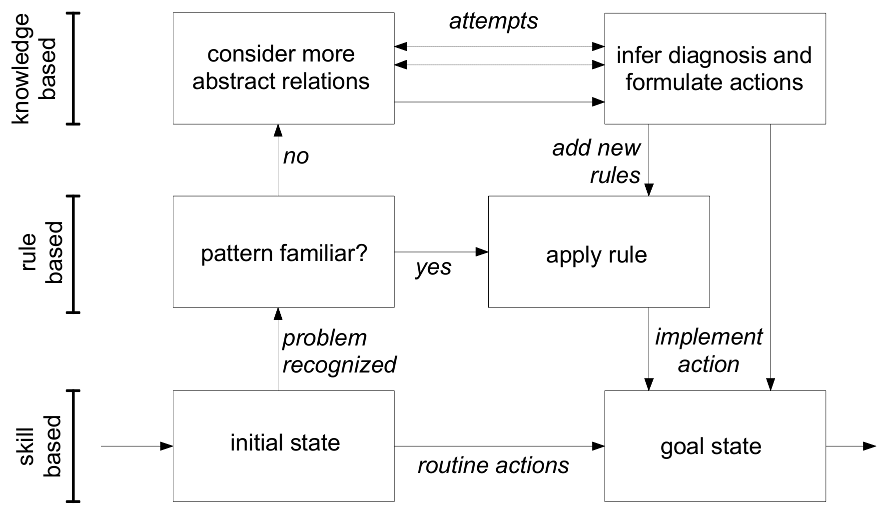

Figure #??-1. The GEMS model of human decision behavior (adapted from Reason, 1990)

The GEMS model (Generic Error Modeling System, Reason (1990)) is an adapted version of the decision ladder of Rasmussen. The GEMS model is depicted in the figure above. According to the model, humans reason with different levels of *attention* and *routine*. The more attention a task requires, the less routine the task, and vice versa. Tasks become more routine when they are repeated. The model distinguishes three levels of human information processing: skill based, rule based and knowledge based.

At the *skill–based* level, the actions are carried out almost automatically, i.e., without the need for conscious reasoning. Automatic progress of the activities is checked periodically, but as long as these checks are satisfactory, control stays at the skill–based level. If a difference between the expected and real outcome is noted, control passes to the *rule–based* level. At the rule–based level there are many *if–then* rules competing to become active. The pattern of the problem is matched with the *if* part of the rules. If this succeeds, a particular (set of) rules is applied. The predominance of a certain rule depends mainly on the match between the *if* part and the environment, and the strength of the rule as a whole. If there are no rules that match the environment, reasoning passes on to the *knowledge–based* level. At the knowledge–based level, problems are identified, analyzed and solved by combining novel and existing knowledge in a new way. First, a representation of the problem and its causes is built. Second, alternative solutions for the problem are generated. Third, a solution is evaluated, selected and implemented. Knowledge about the problem solving process is stored and can be re–used if a similar problem occurs. In this way new *if–then* rules are added to the rule base.

Limitations of human information processing capabilities stem mainly from two factors: (1) bounded rationality, and (2) incomplete problem representation. Bounded rationality is caused by limited mental capacities, and therefore, large real-world problem representations do not fit into memory. Even if mental capacities were large enough to encompass the problems mentioned, then incomplete problem representation, i.e., insufficient knowledge about the problem, would still impede the full understanding of the problem and its context. The relationship between bounded rationality and limited problem representation can be compared to a beam of light that shines on a screen with information. The size of the light beam on the screen represents bounded rationality; the fact that not all information is visible within the beam of light represents incomplete problem representation (Wagenaar et al., 1990).

Using frameworks such as this might assist in understanding and designing hybrid interfaces for human schedulers. It is important for the human to be able to identify infeasible solutions or parts of a proposed schedule which are infeasible. Understanding the limits of the cognitive process should assist in designing display content and tools that will augment and strengthen areas of weakness while at the same time avoiding negative impacts.

3.4 Issues Relating To The Use Of Formal Decision Processes

Kleinmuntz (1990) discusses why humans still prefer to use their heads instead of decision techniques, given the fact that cognition is bounded and that techniques can help humans to increase performance. A proposed explanation is that people are unwilling to settle for techniques they know are imperfect. Possibly erroneously, people also believe that increased mental effort improves performance. According to Kleinmuntz, this is particularly true for situations where they are confident about their expertise.

The issue of trust in automation has also been studied by Muir (1994) and Muir and Moray (1996). The former paper presents a theoretical model of human trust in machines. In the latter paper, two experiments are reported that examine operators' trust in the use of automation in a simulated supervisory process control task. Results showed that operators' ratings of trust were mainly determined by their perception of its competence. Trust was reduced following any sign of incompetence in the automation, even one which had no effect on overall system performance. Another finding of Muir and Moray's experiments is that operators' trust changes very little with experience; whereas Kleinmuntz concludes that the use of decision aids decreases with the subject's *belief* in his experience. Relating this back to schedule feasibility, if schedulers do not trust the feasibility of a proposed schedule, or if the schedulers observe repeated infeasibility, the decision support aids for scheduling might not be used or used as intended.

The question of how to improve the use of decision rules is studied by Davis and Kotteman (1995). They investigated the determinants of decision rule use in a production planning task. Decision rule use can be improved by offering feedback in which actual performance is compared to performance that would have been realized if the rule had been used. However, measuring the performance of production scheduling has recently been highlighted as a very complex problem (Gary et al., 1995; Stoop, 1996). Apart from basic criteria such as the absence of possibilities for minor improvements and feasibility, it is not clear that any objective criteria can be set. While performance feedback can be given by monitoring performance over time, this is likely to be of limited value when the manufacturing environment is unstable. Davis and Kotteman (1995) indicate that a somewhat less effective measure to improve decision rule use is to explicitly describe the performance characteristics (i.e., the way a certain rule affects a certain performance) to humans, in this way making the rule more transparent. According to Norman (1988), the transparency of a decision rule is especially important in situations where critical, novel or ill–specified problems have to be solved. In these cases, humans want to be in direct control, without the visible existence of a technique. This is referred to by Norman as 'first–person' interaction. On the other hand, if the task that has to be performed is laborious or repetitive, the visible existence of a technique is preferred. In these cases, humans give commands to the (computerized) technique which then solves the problem. This is referred to by Norman as 'third–person' interaction.

These concepts of transparency and packaging have been applied in a custom decision support system (McKay and Wiers, 2003a) where various groupings of decision rules and functions have been structured. The scheduler can have micro level control when needed, or slightly decomposed or macro-function level decisions selectively applied. The scheduler can also choose to apply more highly-packaged functionality and have many decisions automatically performed. In all cases though, the output of the decisions in the form of reports or task allocation decisions can be manually manipulated. Training was also performed with the schedulers using the system to ensure that transparency of the decision rules existed. This was important for creating the trust level for feasibility. The transparency was also necessary for the three levels of management above the scheduler who were involved in some way with reading and interpreting plans created by the scheduler. The scheduler trusted the system, but the second level manager did not and continually challenged the feasibility of the solutions. To address the trust aspect special reports and the ability to expand or collapse information supporting the decisions was necessary. Based on this experience, a flexible approach using Norman's first and third person concepts might be appropriate if multiple users of the scheduling output exist.

Apart from problems regarding the measurement of performance in production scheduling, there might be another reason against offering certain types of performance feedback to human schedulers. While performance feedback has been found to improve decision rule use, it has also been found to impair effective learning in complex tasks (Johnson et al., 1993). Though feedback about the effectiveness of behavior has long been recognized as essential for learning in tasks, and, as found more recently, stimulating decision rule use, such feedback at least has to be specific and timely to be effective. In complex tasks where the relationship between actions and outcomes is unclear, only offering feedback about performance may be counterproductive. This is because outcome feedback might cue a focus on evaluating one's competence rather than on increasing competence, which could result in a maladaptive behavior pattern (Johnson et al., 1993). Furthermore, because action–effect relations in production systems are very hard to grasp, mental models of schedulers are prone to become inaccurate and variable. This is confirmed by Moray (1995), where a supervisory task controlling a simulated discrete production system was studied. The study of the individuals' behavior showed that there was variability between individual operators in system intervention. Some operators decided to manually schedule parts of the system even when no faults were occurring, possibly to prevent faults from occurring, while others decided to leave the scheduling decisions to the system.

However, there appears to be consensus in the literature that to improve decision behavior in complex tasks, some form of cognitive feedback is required (e.g., Brehmer, 1980; Jacoby et al., 1984; Early et al., 1990; Johnson et al., 1993). In an experiment by DeShon and Alexander (1996) this need for feedback was confirmed for tasks with implicit learning. However, in tasks with explicit learning, they found that setting specific goals appeared to gradually increase performance. Tasks with implicit learning can be characterized by the acquisition of knowledge through repeated exposure to problem exemplars without intention or awareness. In these tasks, it is very difficult for the subject to verbalize the rules used. In tasks with explicit learning, the first step in the solution of any problem is the development of an internal representation of the problem. The internal representation would consist of the perceived initial state of the problem, a goal state, allowable transformations for achieving the goal, and boundary conditions (Newell and Simon, 1972). DeShon and Alexander (1996) state that while explicit learning requires cognitive resources and is sensitive to distraction, implicit learning is relatively resource independent.

3.5 Individual Differences

Though believed to be of great importance, there is still insufficient knowledge about the effect of individual differences on the use of computers in general, or on the use of scheduling information systems in particular. According to Wærn (1989), individual differences that influence human–computer interaction from most stable to least stable are: personality factors, cognitive styles, learning styles, and personal knowledge (i.e., user experience). Wærn (1989) argues that user experience is both the most important and the least stable aspect of individual variation. In studies of a supervisory task in a simulated discrete production system, Moray (1995) also found that differences in mental models, which are built by experience, caused differences in decision behavior.

In Levy et al. (1995), a production scheduling task in a laboratory setting was used to study feedback seeking behavior. More specifically, the effect of individual differences and situational characteristics on feedback seeking intent, reconsideration of intent and modifying of intent was studied. The results showed that seeking feedback depends on the perceived privacy of the feedback seeking process and the context in which it is performed. For example, individuals in organizational settings may want feedback but those in public contexts may be very concerned about how they appear to others, especially for individuals with high self–esteem. A finding that relates to individual differences is that people with high public self–consciousness and social anxiety desire feedback more than others.

Self–efficacy, which refers to beliefs in one's capabilities to mobilize the motivation, cognitive recourses, and courses of action needed to meet certain situational demands, is also frequently found to determine computer usage. Individuals who consider computers too complex and believe that they will never be able to control these computers will prefer to avoid them and are less likely to use them. The effect of self–efficacy on computer usage was studied in Igbaria and Iivari (1995) through a survey of 450 microcomputer users in Finland. It was found that self–efficacy influences computer usage through perceived ease of use and perceived usefulness. Also, computer experience and organizational support appeared to increase self–efficacy.

4. CONTEXT OF SCHEDULING IN PRACTICE

4.1 Introduction

While "What is sequencing?" is relatively easy to answer, "What is scheduling?" is not. Dealing with feasibility in sequences and crafting sequences that can be actually executed is part of scheduling, it is not the whole story. In this section, scheduling will be placed in the context of day to day scheduling activities.

When studying human schedulers, it is often difficult to distill the conceptual scheduling and sequencing problem from what human schedulers are actually doing. Because the content of scheduling tasks can vary over organizations, different field studies have consequently focused on different scheduling elements.

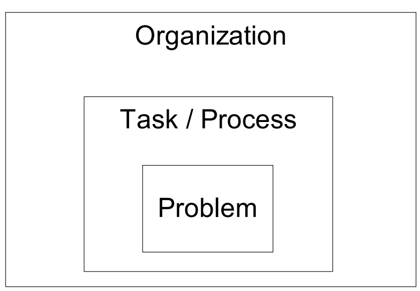

Figure #??-2. Scheduling context

The figure above illustrates three perspectives on scheduling that will be described in this section. In practice, a scheduling *problem* is often tightly coupled with an individual employee: a scheduler who executes the scheduling *process* and hence carries out a scheduling *task*. The human scheduler is part of an *organization* that provides the inputs for, and requires the results from the scheduling process. Unfortunately, the task concept can itself become an issue since different schedulers may draw task boundaries differently and this will vary with experience and skill.

The scheduling *problem* as currently defined in the academic literature highlights a specific part of the scheduling task - the sequencing. Therefore, in the next subsections, the task and organizational perspective will be used to provide an extended definition for scheduling.

4.2 Organization perspective

An operational view of scheduling can be partially derived by studying its context with other organizational production control functions. It is often difficult to make a single schedule for the whole production system of a company. Therefore, production systems are often decomposed into a (more or less) hierarchically organized planning and control structure to reduce the complexity of the scheduling problem. This approach is also known as Hierarchical Production Planning (HPP). For example, Bertrand et al. (1990) distinguish between goodsflow control, which concerns planning and control decisions on the factory level, and production unit control, which concerns planning and control decisions on the production unit level. The goodsflow control level also coordinates the various underlying production units.

The HPP paradigm is widely used and has become an accepted planning and control strategy for many medium to large manufacturing organizations. The HPP decomposition results in official tasks, task scope, authority, and responsibility. Although the decision model should fit the business requirements of the moment (Robb, 1910), the organizational structures in most firms are reasonably static and inflexible. This results in decision models being used that do not fit the decision problem. Unfortunately, the adoption of the HPP paradigm within a firm usually results in scheduling being done in an hierarchical fashion regardless of the appropriateness of the concept (McKay et al., 1995b).

Wiers (1997) identifies four types of control that are associated with planning, scheduling and dispatching:

- *Detailed control*. Dispatching is seen to be the most detailed control level dealing with the shortest planning horizon in the company. Dispatching answers the questions relating to: What do we do now? What do we do next? How do we fix the mess we are in? Scheduling control refers to work that is planned for the immediate horizon and the scheduler makes the predicted matching of time, resource, and work to be performed. This might also include the release of work to the factory floor. Planning's direct control refers to the ability of the decision maker to accept, interpret, and possibly modify demand. The planner might also be able to orchestrate personnel levels and resource capability - issues usually not possible to manipulate on very short notice.

- *Direct control*. Schedules are transferred to the shop floor without any intermediate control function between scheduling and the shop floor. That is, the scheduler is the person who is turned to for answers and direction. In a similar fashion, the planner transfers to the scheduler a plan for production (without detailed sequencing) and a scheduler to a possible dispatcher (a recommended schedule, but one that can be altered based on the situation).
- *Restricted control*. Short term issues relating to material requirements, material availability and available capacity are usually beyond the direct and immediate influence of the scheduling function and reside at the planning level. The scheduler can request or perform some expediting, additional shifts, and overtime, but in general, they have to live with the situation they have, and deal with the options in front of them for work assignment and operation execution. Each layer in the task structure has some form of direct and restricted control - the planner, the scheduler, the dispatcher.
- *Sustained control*. Each level has a form of sustained control over the level beneath it. For example, scheduling monitors the progress of production and solves problems if the actual situation deviates from the scheduled situation. The scheduler does not generate a release and sequence plan and then check on it the next day. The scheduler, when in the plant, is typically provided with or seeks out feedback as to schedule execution and fulfillment.

Each of these levels can be observed and documented. The activities and the characteristics of the activities for planning, scheduling, and dispatching can be isolated and studied. However, the titles and official positions of individuals can create difficulties. For the purposes of research, it is necessary to use the traits and types of control suitable for a level to identify the individual and placement of decisions. Someone having the types of control, duties, and interactions with the shop floor typical of what we consider a scheduler to be, is a scheduler, regardless of title or organizational affiliation. For example, the person might be called a planner, but is really a scheduler. The scheduler might be in another department and report to a Materials Manager, but in reality deals directly with the shop floor supervisors or machine operators. If a floor supervisor is making the detailed assignment and sequencing decisions, then the supervisor is a scheduler or dispatcher for the purposes of studying scheduling. If the supervisor is making longer term assignments and time/resource allocations - the supervisor is planning. If the supervisor or operator is deciding what to do next from a set of immediate options, they are dispatching.

Note that the types of control (i.e., detailed, direct, restricted, sustained), specifically help to clarify the distinction between planning, scheduling, and dispatching. The four types and their usage can be considered preliminary and exploratory at this time and further research is required to sharpen this aspect of the scheduling perspective. Clear (or somewhat clear) definitions and distinctions are needed if work is to be compared on equal footing, or if work is to be replicated.

4.3 Task Perspective

As noted, a relatively small number of studies have been conducted on real-world scheduling. In McKay (1992), the field studies captured the task specifics associated with what the schedulers were charged to do. The particular decisions associated with detailed, direct, restrictive, and sustained control were analyzed. As a result of looking at the task structure, it was documented that the schedulers' main function was to be a problem anticipator and solver, instead of a simple sequencer or dispatcher. The task analysis provided a clear view of what was being controlled, when it was controlled, and what feedback was used to execute and sustain control. In the field studies, control centered around uncertainty. It is interesting to note that the situation noted by McKay is similar to an early definition of what a scheduler was expected to do:

> "The schedule man must necessarily be thorough, because inaccurate and misleading information is much worse than useless. It seems trite to make that statement but experience makes it seem wise to restate it. He must have imaginative powers to enable him to interpret his charts and foresee trouble. He must have aggressiveness and initiative and perseverance, so that he will get the reasons underlying conditions which point to future difficulties and bring the matter to the attention of the Department Head or Heads involved and keep after them until they take the necessary action. He is in effect required to see to it that future troubles are discounted." (Coburn, circa 1918; pp. 172)

At one of the factories studied, the information and types of information used by the scheduler when dealing with operationally feasible (and desirable) schedules was gathered and analyzed. During the study period approximately 250 non-routine decisions were captured and encoded. These non-routine decisions were those that were not the obvious, straightforward material, job, resource, time decisions. The scheduler at the factory used many types of information for making decisions and was a key information hub - gathering and disseminating. In addition, the information was processed in an active fashion: collected, vetted, augmented, compressed, and reflected upon. Information acting as a cue or signal was used to control secondary information processing activities. Various categories or subject areas of information used by the scheduler are given in *Table #??-1*. Information used by planners, schedulers and dispatchers

.

Category	**Information used – examples**
Humans	expertise/skill, motivation, absenteeism, and various other individual characteristics of: operators, foremen, management, other schedulers, engineers, salesmen, suppliers, customers, transporters, technicians, subcontractors
Organization	goals, procedures, responsibilities, politics, gossip
Resources	capacity, flexibility, reliability, costs, location, state of maintenance, modes of operation (manual or automatic), age, and sensitivity of: machines, tools, fixtures, personnel, transportation equipment, buffers, pallets, subcontractors
Materials	due–date, required amount, customer, quality, processing time, age (regarding design), specifications, CNC programs, bills–of–material, routings, stability, batch size, stock level, risk

Table #??-1. Information used by planners, schedulers and dispatchers

The richness of the information illustrates the challenge made to the ten simplifying assumptions of sequencing theory. It is also important to note that the majority of the scheduler's time and effort related to anticipatory control based on risk assessment and mitigation - the types of activities difficult to assign to a decision support system.

The five field studies described in Wiers (1997) contained similar findings: the routine tasks could have be allocated to a decision support system, whereas the exceptional situations had to be handled by the human scheduler. Field studies conducted by Crawford (2000) also support the view of the scheduler being an information centre and problem rectifying resource. The two-stage control paradigm presented in McKay et al. (1995c) explicitly discusses a control theoretic role for the human in decision making.

Exceptional situations are those that can make a supposedly feasible plan, infeasible and possibly one not to be trusted. In McKay (1992), it was documented that approximately 10% of all of the scheduling decisions made by the scheduler were 'exceptions'. The majority of trigger events were considered to be routine by the scheduler – machine failures, wrong parts made, and so on – but the solutions, as represented by the final sequence of work to be done, varied in almost each case. This supports the problem solving view of the scheduler's role and the view of normal/exception information processing. The insights into exceptional decisions made by the scheduler also help to clarify the differences between sequencing and scheduling.

4.4 Daily activities

Previous sections have described the general task of scheduling and a number of different characteristics of the cognitive task. In this section, the daily routine of dispatchers and schedulers will be explored from an integrated perspective and we will use the term scheduler to refer to the combined task. For our purposes, the scheduler's daily routine comprises of what the person does each day at a high level of task description. This daily routine has been described in McKay and Buzacott (2000). The seven steps in a typical daily routine are depicted in

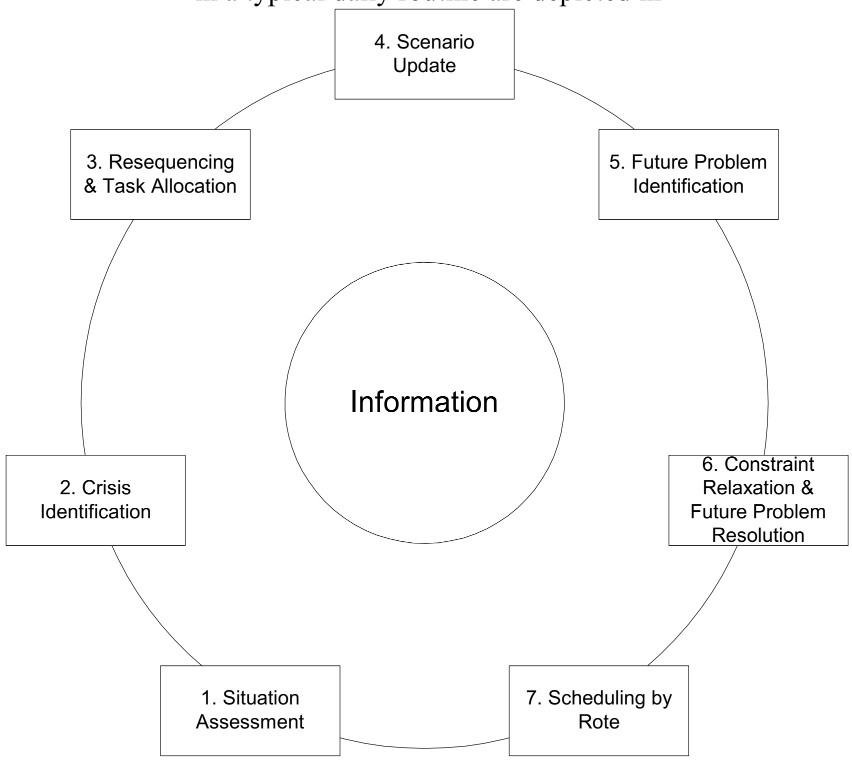

Figure #??-3. Seven subtasks for planning (adapted from McKay and Buzacott, 2000)

and will be briefly described:

1. The decision maker (i.e., scheduler) starts the routine by a situation assessment. For example, the individual might want to see what changes have occurred in the daily shipping requirements, what was built in the last twenty-four hours, and what the current inventory levels are. From this information, the problem definition is refreshed and updated. The decision maker also obtains the net changes in supply and demand and renews the view of what the problem is.
2. Subsequently, special problems or crises are identified. These are likely to be the most constrained or most important activities in the factory. In decomposing the problem, these are the anchor points and will be addressed first.
3. The special problems are sometimes addressed by resequencing and allocating tasks. They might also be addressed by dynamic changes to resources, processes, quantities, materials, dates, crews, operators, and anything else that can get the job done. While a decision support system

can help by resequencing, the ability to make and negotiate dynamic changes to the problem definition are currently in the realm of human capabilities.

4. The overall schedule is then updated around the anchors - wanting to see what the updated scenario means when compared to plans already in existence. By making the plan feasible for the hot jobs, the plan might now be infeasible for other work in the immediate future.
5. When the immediate problems have been discounted, the scheduler will identify future problems with the schedule or sequence - problems outside of the immediate dispatching horizon. These are the second order effects or issues that break the feasibility or desirability requirements.
6. The future problems will be attempted to be solved with sequencing or allocation strategies. However, if the problem cannot be addressed, the situation will be dealt with by relaxing constraints.
7. Lastly, the routine work that is not critically constrained is scheduled by rote, i.e., mechanically. This is the area of sequencing rules and systemized methods for coordinating the resources.

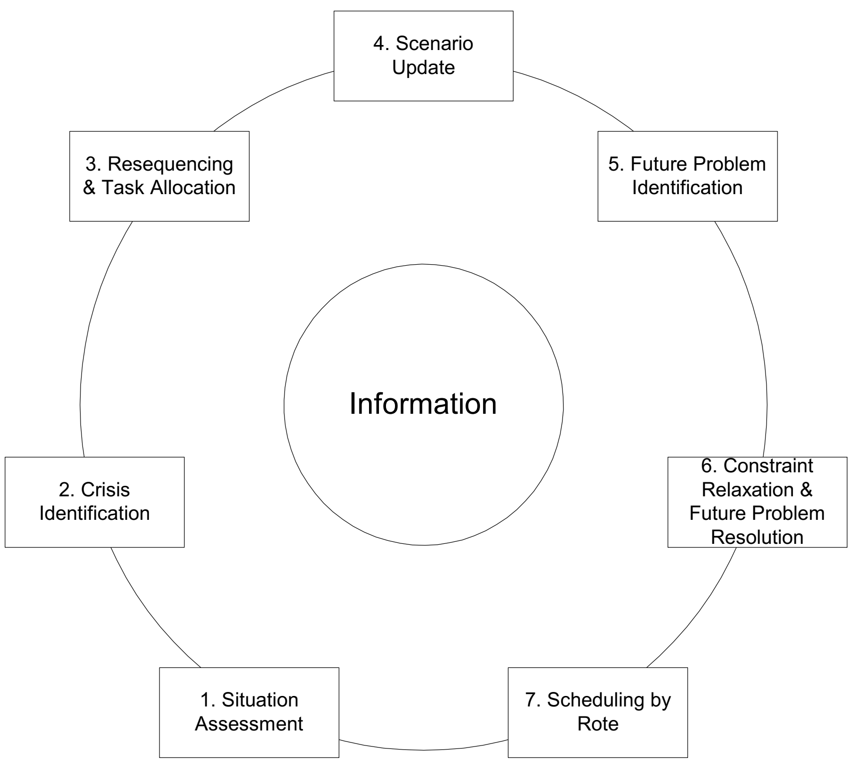

Figure #??-3. Seven subtasks for planning (adapted from McKay and Buzacott, 2000)

The daily routine will change somewhat when an unexpected change in supply, demand, or resource capability is sufficiently large enough to warrant major re-planning and re-analysis, i.e., when a crisis is identified. The daily routine will also vary depending on the day of week, week of month, and month of the year. For example, new short-term forecasts may be updated every Friday and the long term forecast might be updated the last week of the month.

Depending on the factory situation, the tasks might depend on information feeds from the manufacturing software systems (e.g., ERP), or on other activities in the plant. For example, tasks one and two (general situation assessment and crisis control) might be needed to be addressed before 6:30AM each day - before the day shift supervisors arrive. Resequencing and doing a scenario update might be needed to be performed between 6:30AM and 6:50AM - while the supervisors are available and before the day shift workers arrive at 7:00AM and before the 6:50AM production status meeting starts. The remaining tasks might need to be completed before the 8:00AM full production meeting. This is a real example from the field study which inspired the McKay and Buzacott model. It illustrates that the scheduler tasks are not always isolated, can be stressed by time and information requirements, and are affected by other tasks and activities. This is also part of scheduling.

5. INTEGRATING SCHEDULING AND SEQUENCING

The above sections have discussed how scheduling is composed of many factors, one of which is sequencing. While sequencing is mechanistic and algorithmic, scheduling in many real factory situations is not. An operational or practical view of scheduling takes into account operational feasibility and a required trust in the plan. If a scheduler decides to issue a plan that is known to be infeasible, then it should be consciously done, and not done by accident or by blind mandate. The human contribution to scheduling involves dealing with uncertainty, acting as in information hub, and anticipating problems before they occur. The scheduling task has also been discussed as having multiple phases or focus points and these tasks are not isolated or independent of the situation.

This section will take these various concepts and propose how they can be systematically integrated into decision support technology. The discussion focuses on the division of labor between the human and the planning technology and uses four concepts to guide the division and design of functionality: i) how well-defined the problem space is, ii) how much uncertainty exists in the operational environment, iii) problem complexity, and iv) transparency.

5.1 Well–defined vs. ill–defined Criteria

To distinguish between formalized data typically found in manufacturing information systems and data used by schedulers, it is possible to consider the following attributes (McKay 1992):

- completeness of information;
- ambiguity in the information;
- error/accuracy in the information;
- presence or existence of the information.

The dimensions can be further discussed as to the implication of high or low completeness, sporadic or pervasive ambiguity, certainty of values and data, and if there is much or only little of this type of information needed for decision making. Where there is incompleteness, ambiguity, errors, inaccuracy, and possibly missing information used in determining sequencing decisions, the decision is ill-defined. A decision that is only partially ill-defined, might still be a candidate for formal techniques, but decisions that exhibit many of these traits will be a challenge for any formalized process. It is also possible that ill-defined decisions can be considered those which contain enriched data – information that is not normally found in manufacturing information systems. Some of the information such as key historical data might be captured and included via enhanced rules, but information such as the current weather conditions at a border crossing or the health of a worker after an evening of partying cannot be practically included.

The GEMS model presented in § 3.3 can be tied to these characteristics by equating *routine*—the GEMS concept—to *formalization*— as shown in the following table.

Human reasoning level	**Information used**
Skill–based	formalized data / well–defined
Rule–based	+ extended formalized data
Knowledge–based	Non–formalized data / ill–defined

Table #??-2. The relation between the human reasoning level and information used

The two central characteristics of this table are the amount of *routine* or *formalization* that can be achieved in a particular scheduling task; in other words, it can be used to characterize the information situation as well– or ill–defined. This notion assists in developing a first, general separation in the division of labor: it indicates when people are needed and when they are not. Humans are needed in production scheduling because they can solve ill–defined problems that cannot be modeled by systems designers (Sanderson, 1989). They can provide estimates for incomplete data, provide a judgment on ambiguous data, and correct data (McKay, 1987). A major contribution of humans is that they are social beings; they are continuously gathering information which is not instantaneously relevant to the scheduling task. Consequently, they can fill in blank spots of missing information using this 'tacit knowledge.' They also provide the interface to the non–formalized information needed when dealing with new situations or changing situations. Furthermore, they can provide information about constraint strengths, constraint relaxation, and penalties for constraint violations (McKay 1992). Thus, humans can outperform systems in problem areas where information is inadequate for any number of reasons. In essence, the humans are the interface to the environment in which the scheduling decisions will be executed and this includes the world at large and the factory itself.

If the situation has relatively few ill-defined aspects, the majority of decision making can rest in the decision support system at the skill-base level. The system should be capable of developing a reasonable starting point requiring few manual modifications. In such a situation, the richness in interpretation, representation, and manipulation functions can be minimized. It should also be possible to encode many of the enhanced or enriched aspects of the problems in rules or decision tables and further reduce the gap between feasible and infeasible schedules – the rule-base level.

If the situation is considered to be largely ill-defined, much of the control has to reside in the knowledge-base level. For example, a reasonable approach might be to use a simple loading heuristic (e.g., forward or backward loading with basic priority) to create a plan. The system should then focus on the added functionality needed to enhance interpretation, feedback, and manipulation. In such cases, the manipulation functions should allow the scheduler to effectively 'do what I say' and 'not what database says is possible'. If creative problem solving is used routinely to deal with ill-defined aspects of the problem, the scheduler will need complete freedom to say what can be done where, when, and by what – often violating what could be considered hard constraints. For example, the scheduler might assign a task to a machine not specified as being able to perform a task, and assign it at the same time as another job is running on the machine – effectively having the machine do two things at once. This particular example has been observed in the field studies. The machine in question was a two-stage process, normally bolted and welded together. The normally scheduled job was using one of the two stages and with a little bit of work, the single machine was soon two. There was not sufficient time to alter the scheduling and manufacturing database to create this unique solution and the scheduler wanted to make the assignment – immediately and create the necessary paperwork for the factory floor. We call this capability, the ability to lie to the computer. The job shop DSS tool in the longitudinal study by McKay and Wiers (2003b) has this ability and it is used routinely. Approximately 30% of the daily reports are modified daily – some very little, some more so. This particular job shop has many ill-defined problems and the majority of software development has been focused on supporting the knowledge-base of the scheduler and avoiding getting in the way of the scheduler.

5.2 Autonomy and Uncertainty

5.2.1 Shop types

The extent to which a certain scheduling task can be supported using decision support systems obviously depends on the characteristics of the underlying production system. As uncertainty in the production system increases, the ability of a 'smart' system to perform decreases. That is, *uncertainty kills smartness*. If a situation exhibits uncertainty, the smart features must be implemented in such a fashion as to effectively and efficiently complement the human tasks and additional functions must exist to support the human tasks. If the functions are not so designed and implemented, there will be a mismatch in requirements/solution – the solutions will not be close to feasible and the human will not be able to do the necessary tasks easily and this will ultimately lead to failure of the system. The smart system ignoring the uncertainty implications will either block the human's tasks, or not provide the information necessary to make a decision, or prevent the human from describing the solution.

One important aspect to consider before implementing any decision support system is the question where to deal with uncertainty: at the scheduler's level or at the shopfloor. This is the question of what autonomy to allocate to the shop floor regarding production control decisions. In Wiers (1997), a typology of production systems is given that describes the possible strategies in allocating autonomy to the shop floor. The typology is depicted in **Error! Reference source not found.**.

	No uncertainty	Uncertainty
No human recovery	Smooth shop	Stress shop
Human recovery	Social shop	Sociotechnical shop

Table #??-3. typology to allocate autonomy

The four categories attempt to capture the dynamic nature of the shop with the corresponding 'general' style of scheduling that can be expected. The uncertainty columns relate primarily to the information base and the rows relate to the ability of the shop to execute the plan – uncertainty in execution. The concept of *human recovery* indicates the positive role that human operators can play in the prevention of disturbances by using flexibility to compensate for uncertainty in the information space. Before linking the two together explicitly, we will briefly describe each of the four categories in the following subsections.

5.2.2 Smooth shop

In the *smooth shop*, there is little uncertainty in the detailed information or execution phases and as a result, there is little need for human intervention and problem solving, i.e., the recovery. Since the shop is stable, optimization can be performed with precise operation timing and sequences. It is likely that the scheduler's life will focus on tactical policies and fine–tuning of the optimization approach – it will not be dominated by exception decisions. A smooth shop is also likely to be considered relatively well-defined and offers the best promise for scheduling systems that provide full, automatic functionality and expect the shop to execute as planned. These types of situations are well suited for the skill-based and rule-based solutions.

5.2.3 Social shop

In the *social shop*, there is limited or non–existent uncertainty in the macro or aggregate levels and possibly some minor uncertainty in the detailed situation. In this case, the scheduler can lay out the basic schedule with sequences and timing, but allow for autonomy on the shop floor to tune the final work sequence at any resource. The scheduler provides an optimized recommendation, but acknowledges that some recovery or adjustment will be necessary. Ideally, the schedule identifies the operation sequence, recommended timing, and possible bounds for advancing or delaying the work. Because of their close relation to the production process, human operators are often faster and better able to react to disturbances than the scheduler. Obviously, the social shop is not as well-defined as the smooth shop. As a result, it is possible that if the humans can accept 'close enough' and if the decision support system is robust in terms of re-scheduling and recovery, a computer dominated situation can be achieved. This is possibly the third-best situation in which a scheduling system can be deployed. Depending on how well-defined the actual decisions are, these types of situations might also be well suited for the skill-based and rule-based solutions.

5.2.4 Stress shop

In the *stress shop*, there will be little uncertainty in the planning and state information, but substantial uncertainty in the execution phase – the schedule cannot be carried out as planned. The decisions themselves are not ill–defined and the proper reaction can be determined via rules and static properties. The necessary flexibility needed to resolve the problem can be identified and exploited via pre–specified algorithms and knowledge imbedded in the software. While not as stable as the smooth shop, the scheduling problem can still be considered relatively well-defined in terms of its structure. This is possibly the second-best situation in which a scheduling system can be deployed. It is highly likely that a skill-based and rule-based solution would be sufficient for the purposes of creating a feasible sequence.

5.2.5 Sociotechnical shop

In the *sociotechnical shop*, the worst of all possible worlds exists – substantial uncertainty in information and execution, and the problem is definitely ill-defined. This is the world explicitly studied by McKay (1987, 1992) and provides the most challenging environment for predictive and reactive scheduling. In this situation, it is not possible to *a priori* imbed the necessary flexibility into the system to identify or solve precise problems. It is impossible to know everything in advance when dealing with new inventions or situations and it is best to plan for unknowns and not pretend they will not exist. Appropriately designed decision support systems for supporting the ill-defined problem are required; helping to identify patterns, predicting future problems, and recommending possible solutions. The authors are not aware of any such system which has been developed commercially for these types of manufacturing situations.

5.3 Complexity

Decision support systems have a considerable advantage over humans when the skill-based reasoning is straightforward and the rule–based reasoning task is of sufficient *complexity* to make solutions less than obvious. That is, in order to gain advantage over a human scheduler, the problem domain should be complex in terms of reasoning rules and the number of possible, operationally feasible schedules to consider. A suitable situation for substantial computer assistance in scheduling could be a site such as a process oriented plant where the number of combinations is large; or a group of repetitive flexible manufacturing cells where the number of routings might be large, but where the manufacturing process is well known, stable, and well defined.

5.4 Transparency

In Wiers (1997), transparency of scheduling systems is discussed as an important factor for the amount of confidence a scheduler will have in the system. Especially in situations with much uncertainty, schedulers want to be in direct control, without visible interference of a system. Therefore, the need to be in direct control depends on the amount of re-scheduling required. For information systems to be helpful in re-scheduling actions, they have to be transparent. If many re-scheduling actions have to be carried out, an opaque information system is perceived to get ‘in the way’ of the human scheduler. The concept of transparency can be considered a research area; in a decision support system, how can the system be designed with variable and controllable degrees of transparency to deal with the routine situations and the exceptional conditions? The schedulers do not want to see the details or be concerned about the parts of shop which are running smoothly, but require complete and comprehensive control for the problem areas. To make a distinction in visualization between aspects that allow routine and exceptions is a major challenge for any kind of scheduling support system.

6. DESIGNING DECISION SUPPORT SYSTEMS

6.1 Design model

How can human schedulers be supported by scheduling information systems? This question is answered by presenting a design model for scheduling decision support systems, which is based on the criteria presented in the previous section and presented in **Error! Reference source not found.**.

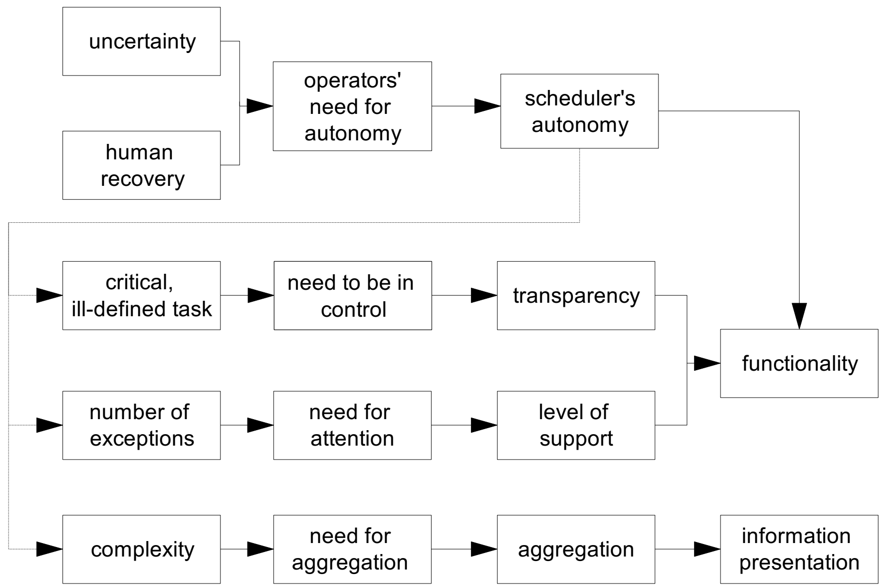

Figure #??-4. Model of designing scheduling decision support (Wiers, 1997)

The relationship between these concepts and the required scheduling information system is depicted in the figure above. The use of the system depends on the match between the required system and the actual system. The characteristics on the left side in **Error! Reference source not found.** and the scheduler's autonomy are given for a specific situation, although each practitioner probably suggests improvements on aspects such as uncertainty and complexity. Causal relationships are read from left to right in **Error! Reference source not found.**. From this perspective, it would have been appropriate to place the rectangles related to scheduler's autonomy to the left of the other characteristics, as the division of autonomy between the scheduler and the shop floor influences these characteristics. Instead, this relationship is represented by the dashed line.

In the design model, no relationship is assumed to exist between a scheduling information system's functionality and information presentation. However, in information systems, certain functionality might require or impede the presentation of certain information, and vice versa. For example, a low level of support of a scheduling information system's functionality is often combined with information presentation functions. Possible interactions between functionality and information presentation therefore have to be considered during the design of a scheduling information system in practice.

6.2 Semantics and the scheduler's ontology

A decision support system can be quite invasive and disruptive if the system forces the users to adapt to the system – what is done, when it is done, objects used, and the vocabulary employed. In order for the system to be quickly accepted and reduce the disruptive nature, it is possible for the decision support system to adopt the terminology of the users and support their meta-objects. For example, we have observed that the word 'job' has different meanings depending on the factory, as does crew, shift, and any other term possible to use in a scheduling situation.

If production control is viewed as a community and studied via ethnographic methods (McKay and Wiers, 2003a), the communication, interrelationships, and roles of the individuals are highlighted. One of the results of such a study is an ontology of the scheduler's objects and concepts – what they use when they talk about scheduling and what they use to communicate to others. The meta-operations of the scheduler are part of the ontology and are important for understanding the meaning or semantics of the situation. For example, is work effort described in hours, piece rates, shift capacity, or crew capability? It is possible that multiple meta-elements are used simultaneously or in certain situations.

In one field study, we observed and ultimately supported four different ways to describe the load being applied to a resource. Instead of having the human translate the four meta-values to a normalized standard, the system did it internally and preserved the meta-view for the scheduler and other users of the plan. This type of meta-support addresses part of the transparency issue as everyone would realize how the 2,200 for one day was derived – was it from a crew perspective, a rate perspective, etc.

6.3 Task support

Traditional software and systems are designed from a functional perspective – similar to word processing or spreadsheet menus. Schedulers may use their systems continually throughout the day, each and every day. The scheduling systems are not periodic or casual use items, they are mission critical. As noted in the sections on task identification, the schedulers and planners have specific processes they do regularly – each day or each week at roughly the same time, being done in the same way. By packaging functions together, it is possible to create user interfaces based on task allocation (McKay and Wiers, 2003b). In these systems, the interface might have selections for tasks done in the morning (e.g., special optimized interfaces for the 6AM, 6:30AM, 7AM, and 8AM activities), ones in the afternoon and so forth. The job shop system noted earlier has such menus and functions that reduce the user interaction to the bare minimum. Wherever manual, repetitive processes are noted, they are prepackaged. The flow shop system also alluded to earlier in the chapter has menus that change on Fridays (present different tasks and certain functions have enhanced processes). The menus and functions also change on the first of the month and are different if the system was not used on the first of the month and it is now later in the month. The task oriented approach assists when the regular decision maker is ill or on vacation, and when the backup scheduler or manager must use the system.

7. CONCLUSION

In summary, the research on the human scheduler is too meager for any general, quantitatively supported results to be stated in a predictive fashion. At best, the majority of work is descriptive with some insights about what might be reasonable to include in production control practices and decision support systems. At worst, the research is anecdotal without any rigor or scientific value. In this chapter, we have tried to indicate the research which has been done with generally accepted methodologies and from which contributions have been made to the body of knowledge concerning scheduling.

Regardless of methodology, short case studies are always subject to possible bias in what is observed and captured, and what is not. The most rigorous insights have been derived from extensive longitudinal studies which cannot be generalized per se. It is clear that additional, extensive studies are required in this domain. However, the existing studies support each other and general patterns can be observed. The themes of problem solving and task structures are prevalent. The need for transparency and support for dealing with uncertainty are also supported by direct and related research on the scheduling task. Decision support systems can be constructed that support these ideas and working industrial systems have been constructed. The next step is the generalization of the concepts and the inclusion of the ideas in widely available commercial form.

From a theoretical perspective, an enhanced *Theory of Scheduling* could include and embrace these and the other concepts described in this chapter as a starting point. Further research should either dismiss or support them, and possibly add additional concepts to the theory. In any event, the traditional view that the *Theory of Scheduling = Theory of Sequencing* is insufficient to bridge the gap between theory and practice.

This chapter has presented a number of guidelines to assist practitioners in designing decision support systems for production scheduling tasks. A design model was presented that is based on four key elements in the scheduler's task support: autonomy, transparency, level of support and presentation of information. Secondly, in the subsection on semantics and the scheduler's ontology, it has been discussed how scheduling decision support systems should speak the language of the scheduler. Lastly, it was emphasized that decision support systems should support a scheduling task, which goes beyond offering a number of functions that are in the eyes of the scheduler structured differently from the daily activities to be supported by them.

8. ACKNOWLEDGEMENTS

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