Chapter 2
Decision Making in Planning and Scheduling: A Field Study of Planning Behaviour in Manufacturing

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Abstract Production planning and scheduling (PPS) requires human decision making. In this chapter, we introduce two theoretical models of Naturalistic Decision Making (NDM). Their applicability to the PPS domain has not been investigated to date. A field study in a Swiss manufacturing company is described, using existing NDM methods to study 'real world' decision making. The findings indicate that planners are using substantial amounts of general production and business-related knowledge to identify and solve decision problems. In their daily work, they are very much dependent on a supportive socio-technical environment that allows efficient information provision, diagnosis and interpretation of the state of affairs, and the development of expertise. The chapter closes with a discussion of NDM-related theoretical and methodological issues, as well as some implications of our research for decision support design.

2.1 Introduction

Production planning and scheduling (PPS) involves a substantial amount of human information processing and decision making. More complex business processes create more demanding work for today's planners and schedulers. Even equipped with highly developed PPS software tools, the complexity a human decision maker can handle is limited. Furthermore, many information technology (IT) solutions *create* additional complexity for the user and increase the challenge of decision making.

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In order to investigate decision making as a central cognitive activity of human planners, we used a Naturalistic Decision Making (NDM) approach to study *real world* decision making in PPS. Based on field research in fire fighting, military command, and aviation domains, NDM claims that in many such environments, expert human decision making is largely non-algorithmic, following heuristics based on experience rather than analytical deliberation of expected risks and utilities. NDM suggests that experts in general tend to use decision strategies that save time and reduce effort while preserving sufficient accuracy.

After a brief introduction to the psychological background, this chapter presents findings from a field study of decision making in planning and scheduling at a Swiss manufacturing company. It concludes by discussing an integrated perspective on theoretical and practical issues, and relating findings to the design and development of decision support tools for planners.

2.2 Psychology of Decision Making

Decision making research has revealed that human decision making behaviour differs somewhat from the predictions and prescriptions of rational decision-making theories. In response to experimental observations of ‘irrational’ or ‘biased’ behaviour, behavioural models of human decision making have been formulated, most prominently by Tversky and Kahneman (Tversky and Kahneman 1974). Such models suggest that humans use contextual information in choosing between alternatives, for example weighing potential losses more heavily than potential gains or over/under-estimating probabilities. Although these models suggest that human decision making is quite fundamentally different from predictions of economically rational normative models, they retain an algorithmic perspective. Subjective biases are taken into account, and rationality is somewhat questioned, but decision making in behavioural perspectives remains a cognitive process of choosing between alternatives through rational deliberation – however *bounded*.

Other decision researchers have moved away from a strictly algorithmic view on decision making towards a non-algorithmic or heuristic understanding of human decision making. Central to the non-algorithmic stream of research is the assumption that everyday human decision-making does not entail calculating probabilities, subjective values, and expected utilities. In their overview of research on non-algorithmic decision making (‘Simple Heuristics that Make us Smart’), Gigerenzer and Todd (Gigerenzer and Todd 1999) claim that such decision making *is* rational in the sense of being well-adapted to the natural human environment. Meanwhile, there is a large non-algorithmic decision making body of research based on field studies and laboratory experiments, which have led to a series of descriptive as well as predictive models (cf. Gilovich et al. 2002; Hardman and Macchi 2003; Plessner et al. 2008).

In order to develop a better understanding of *expert* or *routine* decision making in particular, researchers have described decision behaviour in real-world work

Table 2.1 Classical compared to naturalistic decision making research

Classical decision making approach	Naturalistic decision making approach
No expertise necessary	Expertise extremely important
No time pressure	Very often time pressure
Complete information is given	Often incomplete or ambiguous information
Well-defined decision goals	Ill-defined or conflicting decision goals
Risks can be calculated	Risks are difficult to calculate
Low emotional impact	High emotional impact
E.g. consumer decisions	E.g. decisions of pilots, fire-fighters
Research objective:Context-invariant decision models	Research objective:Context-related decision models

settings. Several decision making models have been developed since the 1980s as models of *naturalistic decision making* (cf. Zambok and Klein 1997). Their common claim is that expert human decision making is not algorithmic in nature but heuristic, holistic or intuitive (cf. Klein 1998; Svenson 1996). More recent work considers different *modes of thinking* and proposes a more process-oriented view of decision making (cf. Plessner et al. 2008). The differences between the classical and NDM approaches are summarized in Table 2.1.

In NDM models of decision making, deciding is considered to be a highly context-dependent process of sequentially transforming knowledge states until a decision is made. Most models also include a strategy selection of *how to decide*. Decision making as a cognitive activity is perceived as highly adaptive. Correspondingly, major assumptions for a framework of adaptive decision making (Payne et al. 1993) are:

- Strategies are characterized by different levels of accuracy, contingent on task environments.
- As a result of prior experiences and training, a decision maker is assumed to have multiple strategies available to solve a decision problem of any complexity.
- The selection of a strategy is sometimes a conscious choice and sometimes an instant (learned) association between elements of the task and the relative effort and accuracy of a specific decision strategy.

Scholars who are striving to understand the role of expert knowledge in decision making therefore need to study specific contexts, and adapt their models accordingly (Klein 1998; Klein 2009).

2.2.1 Two Models of Naturalistic Decision Making

If human planners are experts in their work domain and are making decisions in relatively uncertain and dynamic environments, under time pressure, and with incomplete information, the NDM approach is an appropriate theoretical framework for the study of decision making in PPS. Two prominent naturalistic decision making models, *recognition-primed decision making* and the *decision-ladder* will provide a theoretical background for our approach to the field study, the data analysis, and the discussion of our findings.

2.2.1.1 Recognition-Primed Decision Making

Klein's (Klein 1998) recognition primed decision making model (RPD) describes decision making processes in naturalistic environments as integrating (1) perception of the situation, (2) knowledge about the situation, and (3) knowledge about actions. In the RPD model, pattern recognition is central to decision making. Human expertise allows recognition of patterns in the information available for a certain situation. Such expert pattern recognition supports the diagnosis of the situation. Without expertise, the diagnosis is poor, the matching of situation and action is weak, and the decision maker is not able to identify adequate actions.

According to Klein (Klein 1998) experts' understanding of a situation depends on:

- Goals of the decision maker
- Critical cues
- Expectations about future developments of the situation
- Typical actions within such situations

Situational patterns are defined as sets of relevant situational cues that are interrelated to each other by conditional, causal or temporal relations, and reflect goals, constraints and expectations. Situational patterns are thus part of the planner's knowledge, and are substantial to his expertise. RPD suggests that planners use such patterns to identify critical system states and to reduce the system complexity to a number of cues sufficient to recognise prototypical situations (Klein 1998). Non-algorithmic human PPS decisions are therefore based on a pattern matching process, where actual information is compared to patterns stored in the human planner's knowledge and where a possible course of action can be retrieved immediately.

A decision is made when the preferred action path has been affirmed by what Klein calls *mental simulation*, i.e. the mental anticipation of the consequences that are to be expected when following the retrieved action path (Fig. 2.1).

2.2.1.2 Decision-Ladder

Rasmussen, Pejtersen, and Goodstein (Rasmussen et al. 1994) studied decision making and problem-solving of expert engineers and technicians. Their work revealed that these experts did not follow a linear information-processing structure, but instead took *shortcuts* using associations based on expertise when working on a familiar problem. They described these shortcuts as *shunts* from a data-processing activity directly to a knowledge state, or *associative leaps* between knowledge states. Both depend on using stereotypical knowledge stored in the experts' memory.

Their model of decision making, which is referred to as the *decision-ladder* due to its common graphical representation in the form of a ladder (cf. Fig. 2.2), can

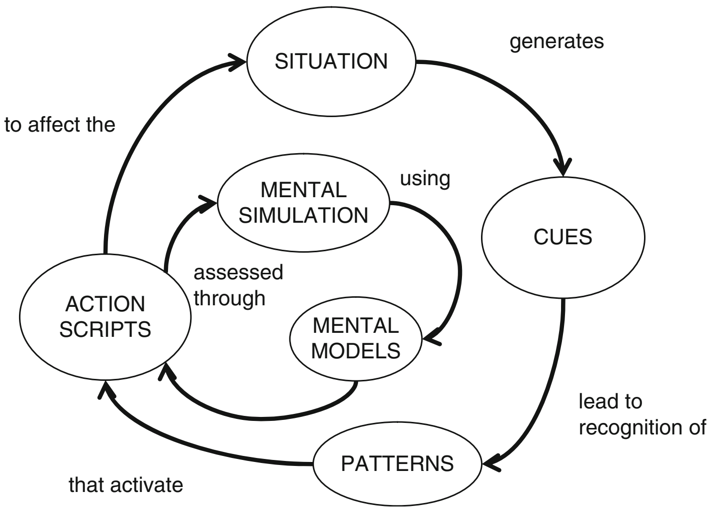

Fig. 2.1 A simplified representation of the RPD model, adapted from Klein (Klein 2009, p. 90)

nevertheless be understood as a linear model. The decision maker is step by step looking for answers to the following questions: What's going on? What lies behind? What's the effect? What goal to choose? Which is the goal state? Which is the appropriate change in operating conditions? How to do it?

According to the model, various data-processing steps are involved in decision making, each one transforming a knowledge state into another. Depending on the strategy the decision maker is using, more or less data-processing is taking place. For example, if the task is a regular routine triggered by a reminder, then the first step is activation, followed by observation. Depending on the strategy used, an observed pattern might associate directly with a procedure for execution. Or, as another example, it might lead to a knowledge state that requires interpretation, evaluation and refined task definition.

2.2.2 Summary

The recognition-primed decision making model and decision-ladder model postulate that experts use their rich experiences to reduce problem complexity, spare limited cognitive resources, and increase efficiency in decision making. Although from different backgrounds, the models clearly have parallels. Central to both models are decision making through situational pattern or stereotype recognition, and memory-driven associations. While the decision ladder allows representation of more individual variances in decision strategies, the RPD model is specific to certain contexts, usually involving high stakes and time pressure. Some of the information processing activities are quite similar in both models, such as recognition processes

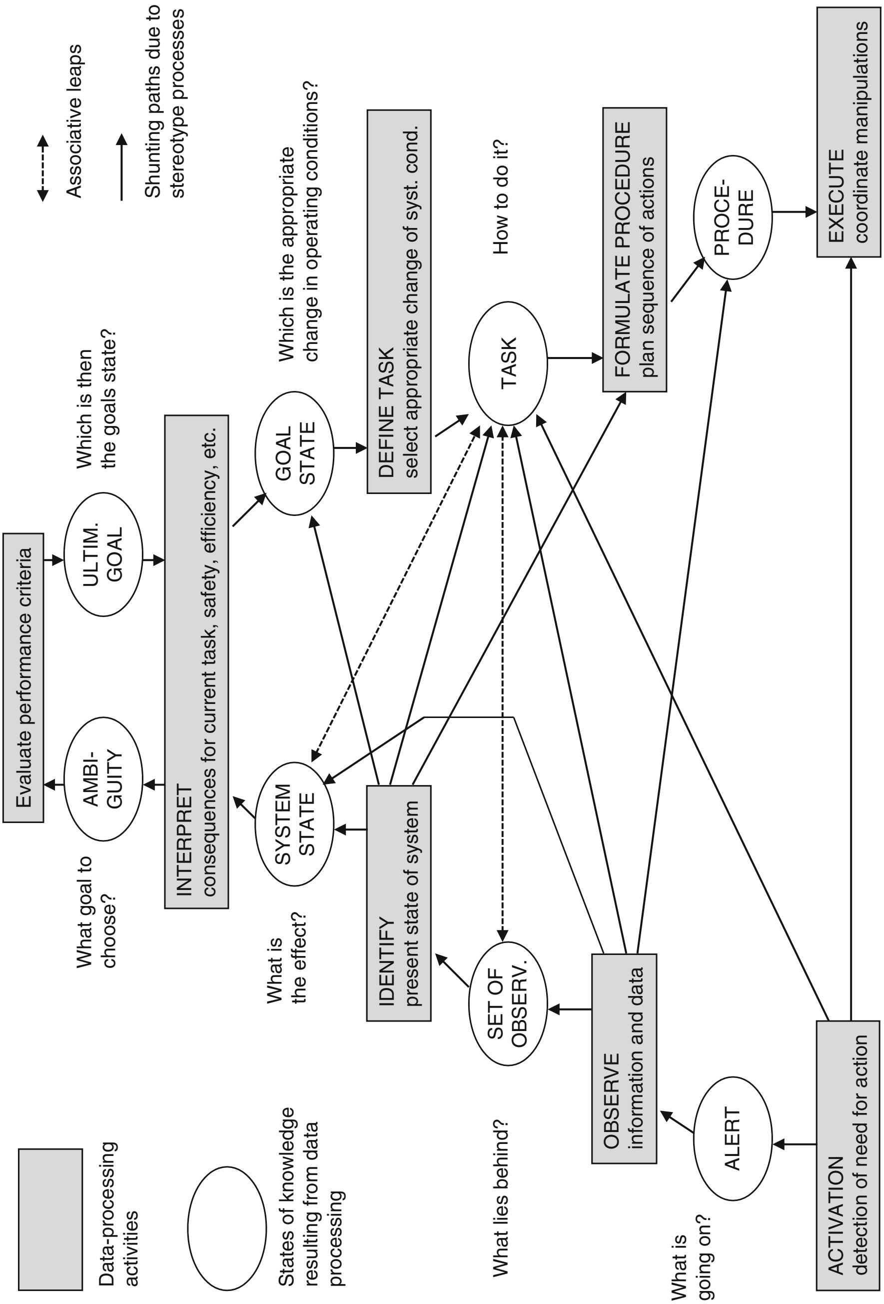

Fig. 2.2 Rasmussen's decision ladder model adapted from Vicente (Vicente 1999, p. 189)

involved in situational diagnosis, or more conscious mental processes to confirm, evaluate and redefine action paths and tasks. Both models describe expert decision making, allowing for non-algorithmic, experience-based, context-dependent strategies in a variety of complex, work-related decision situations. Hence, they both provide a useful theoretical framework for research on decision making in PPS.

From a methodological point of view, the decision ladder has mainly been used to capture think-aloud protocols in problem-solving activities, whereas there are more structured methods available for the RPD model. Some of these RPD methods were used by Crawford, MacCarthy, Wilson, and Vernon (Crawford et al. 1999) to investigate the role of industrial schedulers in organizations. The decision making and expertise involved in particular cognitive activities *within* industrial schedulers' daily routine tasks have received less scholarly attention.

2.3 Manufacturing Field Study

The aim of the field study presented below was to describe and interpret the reasoning and expert decision making behaviour of planners and schedulers as it occurs in real-world PPS rather than in artificial scheduling experiments. In order to better understand such behaviour, some preliminary questions about the organisational context were addressed: What are the roles and tasks of the persons involved? What kind of decisions do they take and how can the decision making processes be described?

Next, using the NDM approach to expert decision making, the study investigated decision situations: How do human planners and schedulers make use of information? What is the role of knowledge in their decision making? What kind of information is used to diagnose situations? How do human planners and schedulers decide on possible actions? How are information processing and expertise intertwined?

From an application-oriented perspective, we expected some insights concerning the design of support tools: How and to what extent is the human planner's decision making supported or impeded by the working conditions? What kind of support for PPS decision making is needed from a NDM-perspective? How should an information system need to be designed to support and enhance specific processes or phases in PPS decision making?

2.3.1 Company Description

The company – based in Switzerland – has approximately 500 employees and a yearly turnover of around 120 million Swiss francs[1], producing products for

[1]Approximately 80 million Euros

building and construction markets worldwide. A wide range of around 1,000 products and 4,000 versions consisting of close to 15,000 different parts are produced, assembled and shipped to hardware stores, wholesalers and building enterprises.

Manufacturing processes range from casting to surface treating. About half of the parts are produced in-house, while the rest are purchased from around 200 suppliers. Some 250 employees are working in six production units, another 50 in the assembly unit. Based on forecasts of the sales unit, PPS is performed centrally, supported by an up-to-date IT system. The parts are produced according to a production plan (make-to-stock), whereas assembling is driven by orders (assemble-to-order).

2.3.1.1 PPS Environment and Processes

The company's products are positioned in the upper price range, and delivery reliability is an important success factor on the market. A strategically defined lead-time of three days is achieved in 97% of all customer orders. The planning horizon is 12 months, with forecasts by the sales department and seasonal differences on the building market taken into account.

Production resources are generally predictable, except some raw materials like copper and steel which are affected by market cycles or scarcities due to political or other influences. External disturbances result from changes in supplier delivery reliability, raw material quality, and import/export regulations. Internal disturbances include variances in the casting processes, machine breakdowns, workflow bottle-necks, testing of new manufacturing processes, introduction of new products, and other complexities of the production processes.

A central PPS department is responsible for production planning (i.e. program planning), master scheduling, detailed production scheduling, and stock management. Key planning stages are (1) production planning, (2) scheduling of production and purchasing, (3) releasing of production and purchasing orders, and (4) central and local sequencing, dispatching and control. Goals of maximizing responsiveness and minimizing stock capital lockup are always conflicting. Scheduling hotspots include order prioritisation in casting, and the management of bottle-necks. At bottle-necks, job sequencing is centrally managed by the PPS department. Therefore, only limited amounts of scheduling and sequencing activities are done by foremen on the shop floor. Within the job shop production environment, dispatching and control of the job progress is done mainly by the foremen, who regularly report their progress to the PPS department. There is generally little distributed decision making, since most decisions are taken within the PPS department, without substantial contributions by the production units (cf. Wäfler 2002). However, there are weekly production meetings where planning-related issues and problems are discussed with the foremen. The PPS department also interacts with the sales and engineering departments to coordinate sales activities and product releases with production and purchasing activities.

Within the PPS department, there are three teams, located in the same open-space office. The planning team focuses on medium to long-term production planning, the purchasing team orders parts and raw materials, and the scheduling and dispatching team schedules and releases production orders. The third team also sequences orders for some of the production units (casting, bottle-necks) and monitors the work progress for critical (urgent) orders. The compact layout of the PPS department allows for quick cross-functional communication and coordination. This is especially important in case of major disturbances or urgent production orders.

Planners in the planning team consider setting parameters in the enterprise resource planning (ERP) software system the most difficult task. It involves many decisions, such as the method for scheduling or the optimal batch size and production lead time. Especially challenging is the introduction of new models, when the planners struggle to avoid backlogs for the new model as well as remaining stocks of the old model, while considering all interdependencies, constraints, and goals. Schedulers in the scheduling and dispatching team find the releasing of orders most difficult, e.g. when two similar orders are due within a relatively short time frame.

The company provides a good environment for a field study of decision making in PPS. Its structures and processes are comparable to many medium size manufacturing companies in Europe. When making decisions, the company's planners and schedulers are facing substantial complexity in the form of dynamics and uncertainties of the production environment.

2.3.2 Decision Making 'in the Wild'

2.3.2.1 Methods

Scope. A qualitative research approach was used for the field study. The retrospective *decision probe method* was developed by Crawford and her colleagues (1999) to describe decision processes in PPS based on earlier work within the RPD framework (Lipshitz and Strauss 1997). The method consists of systematic observations, structured interviews, and a structure-laying technique. The scope of our data collection and subsequent analysis extended beyond the production planning unit to other units and individuals involved in PPS activities, such as foremen and purchasing agents, to cover the whole 'secondary work system' of planning and scheduling (Wäfler 2001). Accordingly, following initial workshops and interviews on the management level, four planners were selected for workplace observations and decision probe interviews. Their roles and tasks included program planning, purchasing, scheduling, order releasing, and dispatching. They had worked for the company between 7 and 22 years (average 17 years) and all them had been in their actual positions for at least 7 years. Their average age was 46.8 (39–56).

Observations and interviews. Within a period of 6 weeks, 13 observation sessions of 1–2 h were arranged with the four participants. During the observations, the

Table 2.2 Decision probe interview questions (adapted from Crawford et al. 1999)

No.	Question
1	Describe this decision episode in your own words
2	What would an appropriate title be for this decision?
3	What caused you to have to make the decision?
4	What was it that you thought about in order to make the decision?
5	What information did you use to make this decision?
6	What knowledge did you use to make this decision?
7	Did you have to communicate the outcome of this decision to anybody else?
8	How would you rate this decision? (difficulty, time pressure, need for advice)
9	Does a documented procedure exist for this type of problem?
10	Overall, do you consider this decision to be a typical type of decision?

observer identified *decision points* without disturbing the work process if possible. In order to clarify and identify all relevant decision points within the observation period, the participant was interviewed immediately after the observation. During the first observation sessions, typical and frequent decisions (as perceived by the participants) were selected for further analysis, in order to get an overview of the variety of decisions. Subsequently, the most complex decisions were selected for further examination. All selected decisions were then examined in structured interviews consisting of a set of ten questions (see Table 2.2). In total, 90 decision points were identified during 15 h of observation. Following the observations, 30 decision probe interviews were conducted, ranging from 4 to 10 interviews per person. Out of the 30 decision probes, ten were excluded because of incomplete documentation or other shortcomings such as descriptions of workflows instead of decision making. Accordingly, the remaining sample of 20 decision probes was further analysed.

Analysis. The analysis first focused on the information 'elements' used by the decision maker in order to evaluate the need for a decision and to take the decision, i.e. to choose or to confirm an action. Potential cues for situational patterns and situation diagnosis-related processes were extracted from the decision probe interviews. The decision probes were transcribed by using an adapted notation structure proposed by Crawford and colleagues (Crawford et al. 1999). Table 2.3 shows the categories that were described within the structure. In the second step of the analysis, relations between information elements were extracted and categorised as either conditional or causal. The decision descriptions were then cross-checked by two co-researchers. Additionally, the resulting notations were validated by the interviewees.

In addition to these *structural* properties of decisions, we also considered the *process* of deciding in terms of sequentially performed cognitive activities by the decision maker and her surrounding socio-technical environment. This aspect of decision making is relevant for our study especially with regard to the design of PPS IT systems. Each sub-process can be understood as an activity that is transforming knowledge states, finally leading to a decision. From such a process-oriented perspective on decision making, a set of processes involved in decision making can be defined. According to the decision-ladder model proposed by Rasmussen and his colleagues (Rasmussen et al. 1994), up to eight information processing

Table 2.3 Categories of the decision description

Category	Specification
Context	History of the decision and trigger for actual episode
Situation	The actual decision situation/task at hand
Information	Used information during the decision process
Knowledge	Used knowledge for the identification of the decision need and the evaluation of the situation
Decision need	Result of a pattern matching process comparing the actual situation (as perceived) with knowledge about similar situations and the implications arising from deviations of the ideal state
Action options	A set of possible action paths with a preference for one of them as a result of a pattern matching process between the actual situation and the knowledge about action paths that might be feasible
Decision	Result of the decision about action paths
Communication	How and to whom was the decision communicated?
Values	Values or superordinate goals influencing the decision process

activities can be distinguished in a decision making process. These do not include psychologically-relevant processes such as learning or more perception-related processes (e.g. awareness and filtering). Therefore, we chose to use the following sub-processes in order to describe decision making in PPS:

1. Information acquisition
2. Filtering of information relevant to decision problem
3. Weighing of relevant information
4. Linking of information and activation of context-specific rules
5. Generation and selection of action paths (options)
6. Learning of decision-relevant patterns and rules (knowledge generation)

2.3.2.2 Findings

As an example, one typical routine decision concerning the planning of raw material is presented in the box below.

The planner characterised this particular decision as not very complex, not under time pressure, and without any required advice. A documented procedure for this kind of decision does not exist within the company. From this example, nine information elements and three associated relations were extracted, representing the situational pattern and the knowledge used by the planner while taking the decision. Figure 2.3 shows a schematic representation of the situational pattern that was extracted from that example. In our notation, we distinguished between (1) information elements, (2) relations between them, and (3) general rules related to the situation. Information elements consist of a variable and a related value, e.g. the variable ‘consumption’ incorporates the values ‘low’, ‘moderate’, and ‘high’. Conditional or causal relations between information elements are indicated with dotted lines, without further specification. Furthermore, situation-specific rules depending on such values and their actual values can be formulated, e.g. if copper is scarce on the market, the supplier’s reliability is affected.

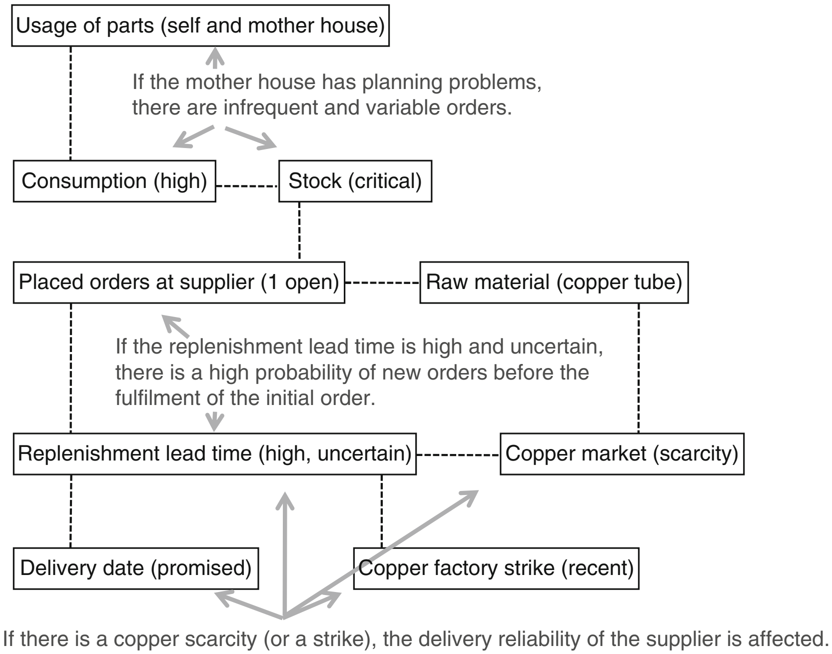

Fig. 2.3 Example of a situational pattern and relational knowledge extracted from a decision description. Information elements are displayed as *grey boxes*, *doted lines* represent relations between information elements, and relating situation-specific rules are printed in *black* with *arrows* pointing to concerned information elements

We used the above method on the sample of 20 planning and scheduling decisions and extracted 64 information elements linked by a total of 137 conditional or causal relations. The resulting situational patterns consist of between 4 and 15 information elements and they contained up to 18 relation links, with an average of 9.5. Relations were predominantly classified as conditional, with a minority of causal links (average 2.0 per pattern).

A closer look at these relations between information elements unfolds a wide body of PPS expert knowledge. The participating experts used information elements originating from local to global sources and linking them through relational knowledge adapted to the specific decision or task context. Such knowledge was applied to link seemingly independent information elements, making sense of the situation at hand. Some examples of such relational knowledge are: “If two parts require more or less the same tools on the robots, it saves cost and time to produce them right one after the other.” – “If supplier X does not have sufficient raw material, the delivery cannot be advanced.” – “If a part is novel, the production times need to be adjusted to allow for disturbances and tests.”

Classifying the information elements according to the company’s planning stages shows that almost half are related to the production order release stage. The sum of categorised information elements per planning stage is shown in Table 2.4.

Table 2.4 Classification of extracted information elements according to the planning stages (N = 64, multiple categories possible)

Planning stage	No. of information elements
Production planning	5
Material requirements planning/master prod. scheduling	14
Detailed scheduling/production order release	29
Detailed scheduling/purchasing order release	17
Sequencing/dispatching/control (centralised)	7
Sequencing/dispatching/control (local)	12

Table 2.5 Classification of relations between information elements according to knowledge domains within the company (N = 137, multiple categories possible)

Knowledge domain	Percentage of relations (%)
Marketing and sales	19
Production planning/MPS/MRP	31
Detailed scheduling and order release	62
Supply/purchasing	21
Sequencing/dispatching	19
Production processes	31
Environment	12

Classifying the relations according to correspondence with knowledge domains shows that more than 60% are linked to scheduling and order release (Table 2.5).

All of the observed planners used situation-specific rules from multiple knowledge domains. Interestingly, those involved in scheduling and order release were frequently linking rather distant knowledge domains – e.g. sales with production or scheduling with (supplier) environment.

To account for a process-oriented perspective apart from structural aspects, the decisions were described using six typical sub-processes of decision making. To illustrate that, Table 2.6 shows a *process-oriented* representation of the example decision about the procurement of raw material mentioned in the box above.

Central to the notion of decision making as a *process* is the development of action alternatives. Initially, there might be just one option to consider, i.e. to do or not to do something. After a phase of information gathering and weighing, another option might become apparent, which again requires more information and so on. As mentioned above, we did not assume a linear information processing sequence. Non-algorithmic strategies and shortcuts as well as algorithmic deliberation must be kept in mind.

To sum up the findings, we would like to point out that planners and schedulers are using extensive knowledge about their work domain, the company and its environments. Even for seemingly simple decisions like changing the batch size when releasing a production order or setting a parameter in the ERP system, they are considering many interdependences and relationships within and beyond the production system.

While not documented in detail, we observed human planners and schedulers frequently changing and modifying the outputs of the ERP system. In our view, it is

Table 2.6 Example of a process-oriented decision description

Process	Description
Trigger	The decision was made after a request by the electro-plating shop. Its foreman wanted to know if there was a possibility to start with a regular large job ahead of time in order to use underemployed resources
Information acquisition, filtering	The job that he proposed required raw material, which led the planner to check stocks and orders of the required parts
Weighing	He quickly realised that the consumption of these frequently used parts was high as normal, and that there was an open order at the supplier to get new material
Linking	He knew that the required parts are made out of copper, what in the current situation on the world market might lead to supplier-side delivery delays. In addition to general copper scarcity, a strike had recently taken place in a nearby copper factory had recently taken place, causing even more problems with copper supply
Activation of rules	Although the supplier promised to deliver on time, a decision was necessary to avoid problems due to backlogs
Linking	The risk of a backlog was high because of planning problems at the mother house of the company. The mother house, which used the parts prepared by the electro-plating shop, is known to order enormous amounts at unpredictable times
Generation of action paths	The preferred action was therefore to increase the order that was already filed to the supplier and to start working on the job (as proposed by the foreman)
Selection of action path	The decision was to charge someone else in the PPS team with inquiring at the supplier if it was possible to get more parts within the actual order

crucial to understand this decision making behaviour in order to improve the interaction between the software and the users. We next present a psychological perspective on supporting and impeding conditions for human PPS decision making that suggests potential improvements to socio-technical system design.

2.3.3 Supporting and Impeding Conditions

Based on our analysis of PPS decisions, supporting or impeding conditions for the human planners' decision making can be postulated. These conditions include management and communication processes as well as features of the technology involved:

- Supporting conditions:
  - Decision-relevant information is made more available through the coordination of formal and informal information sources and by avoiding conflicting tasks or rules.
  - Immediate feedback (e.g. about changes in customer demands, sales activities, changes in the production process, service levels) provides planners with

decision-relevant information and support the learning, correcting, and adjustment of decision-relevant situational patterns.

- Impeding conditions:
  – Relevant information is sometimes unavailable, ambiguous, and uncertain. While this is the nature of PPS, nevertheless, information is often not provided though it is potentially available. Due to poor internal or external communication processes in the company, provision of information becomes time consuming and impeding for the decision process.
  – Relations between relevant information elements and situational cues are difficult to identify by less experienced planners within the actual socio-technical environment.

In Table 2.7, we present a more detailed account of impeding and supporting conditions derived from our field study. To compensate for impeding conditions, planners and schedulers create their own tools to facilitate their reasoning and decision making using either common office software or pencil and paper. At the same time, they establish formal and informal organizational structures, practices, and routines. Where such compensating activities have been observed, they are mentioned among the supporting conditions in the right column of the table.

Anticipatory Procurement of Raw Material

The decision was made after a request by the electro-plating shop. Its foreman wanted to know if there was a possibility to start with a regular large job ahead of time in order to use underemployed resources. The job that he proposed required raw material, which triggered the planner to check stocks and orders of the required parts. He quickly realised that the consumption of these frequently used parts was high as normal, and that there was an open order at the supplier to get new material. He knew that the required parts are made out of copper, which in the current situation on the world market might lead to supplier-side delivery delays. In addition to general copper scarcity, a strike had recently taken place in a nearby copper factory, causing even more problems with copper supply. Although the supplier promised to deliver on time, a decision was necessary to avoid problems due to backlogs. The risk of a backlog was high because of planning problems at the mother house of the company. The mother house, which used the parts prepared by the electro-plating shop, is known to order enormous amounts at unpredictable times. The preferred action was therefore to increase the order that was already filed to the supplier and to start working on the job (as proposed by the foreman). The decision was to charge someone else in the PPS team with inquiring at the supplier if it was possible to get more parts within the actual order.

Table 2.7 Impeding and supporting conditions for decision making sub-processes including observed compensatory activities/tools

Process	Impeding conditions	Supporting conditions and observed compensatory activities/tools
Information acquisition	High effort required to get decision-relevant information or the information needed is not accessible, even when potentially available	Using informal communication channels; Co-location of planners and schedulers; "overhearing" discussions and communications of colleagues; Planning board; Meetings; Inspections on shop floor
Filtering of information	IT provides a wide range of information – however, in a specific situation the desired information is not "at hand", but has to be collected and filtered from different software outputs; also, a rather large amount of information provided through colleagues and other sources needs to be filtered	Individually generated spreadsheets and tables, electronically as well as printouts; Printouts of screenshots, marked with highlighter; Planning board with visual elements (colour stamps, paper clips)
Weighing of information	ERP system does not support weighing of information, e.g. for the prioritisation of production orders. Pre-decisional, preparation steps that are mostly done as part of a routine are not supported by IT	Calculations with desk-top calculator; Print-outs of spreadsheets with hand-written notes; Paper-calendars; Planning board (order queue)
Linking of information	Relevant relations between information elements are not represented because of their complex, dynamic and intransparent nature; ERP system creates additional complexity because the underlying mechanisms and algorithms are mostly hidden to the user	Individually generated spreadsheets and tables, electronically as well as printouts; Planning board with visual elements; Inspections on the shop floor (including informal exchanges with foremen and team leaders); Formal planning and scheduling meetings
Generation and selection of action paths	Pre-conditions for the execution of a specific action path are not available – or all action paths are facing risks (e.g. for backlogs) without knowing the exact probabilities of these risks	Using informal communication channels; Inspections on the shop floor (including informal exchanges with foremen and team leaders); Co-location of planners and schedulers; Formal meetings with domain experts (e.g. engineers)
(Expert) learning	Critical relations between information elements are not represented in IT – which makes it more difficult to learn about system behaviours and dynamics. Because of missing or delayed feedback incomplete or false knowledge is built up and cannot be adapted to actual developments and conditions	Feedback about production costs per part (for every production order); Informal discussions with foremen; Inspections on the shop floor

2.4 Discussion

While the theoretical foundations of NDM and some of the methods developed by its proponents have proven useful for the study of decision making in PPS, more specific questions regarding the applicability of NDM models for this domain remain to be clarified. As the findings of our study indicate, linear or quasi-linear models of decision making like the RPD model or the decision-ladder are not quite suitable for the overall description of decision making *processes* in PPS. Nevertheless, the *structural* implications of these models concerning situational patterns and expertise are highly useful to explore expert decision making in this work domain. The situational patterns described above could be understood as networks of activation, although omitting the parallel activation of motives, goals, and personal preferences involved in routine decision making (Betsch 2005).

Relational knowledge – linked to application rules for a variety of situational contexts – is considered to be essential to expertise. However, this study was not intended to elicit planners' knowledge in a systematic way. The degree to which the method described here could be used as a dedicated knowledge elicitation method would require further work employing methodological triangulation to validate the method and to systematically test its reliability.

Decisions in PPS can be understood as non-linear series of information-processing activities, whereas some are rather short and others can be very long, depending on the complexity and the criticality of the given situation. Planners and schedulers are constantly working on multiple decision problems, relying heavily on colleagues and business contacts where information provided by the IT system is insufficient. General use of NDM methods to study expert reasoning and decision making in PPS has been fruitful in terms of identifying supporting and impeding conditions for expert decision making in a complex production environment. But within this study other potentially crucial influences on PPS decision making remain unexamined. Planners are positioned as 'information brokers' within a company, embodying an important role within a network that spans across the organization (Crawford et al. 1999). Within this role, they might also be concerned about procedural issues, and therefore value and prefer some procedures more than others. This perspective would add a more inter-personal dimension to PPS decision making behaviour from information gathering to action implementation. It could further explain how seemingly irrational decisions could be rational in another perspective, i.e. through the consideration of 'procedural utility' (Benz 2007).

The 'decision-script' approach developed by Hamm (Hamm 2003) in the field of medical decision making might provide further insights into PPS decision making characteristics and mechanisms. Although this approach cannot claim to be an established model of expert decision making, it provides a valuable perspective, interlinking cognitive psychology with behavioural judgement and decision making research. For application-oriented environments in particular, the 'decision-script' approach could help to devise more appropriate interventions and design efforts to support practitioners' decision making. For example, by gaining understanding of not only the decision situation in terms of information and knowledge involved, but also in terms of the typical 'script' or learned action path followed by decision makers in such situations, sub-optimal decision-scripts could be identified and new scripts could be written and implemented. The methodological issue here is that in order to discover decision-scripts in the first place, we need to observe many decision situations. And the more similar the decision situations, the more likely it would be to discover decision-scripts.

Our field study has been able to show the activity of planners and schedulers in making sense of complex decision situations. They constantly diagnose the state of affairs, seeking to identify potential planning or scheduling conflicts and thus decision problems. These decision situations very often involve information that clearly exceeds what is available in a computerised planning system. This substantial amount of knowledge concerns not only the specialised task of planning and scheduling, but also the production process, technologies, supplier relations, marketing, and engineering. From a process-oriented perspective, decisions involve multiple phases of decision making, without a distinguishable linear order. Further complicating matters, planners and schedulers are often working on multiple decision problems in parallel. In consideration of our findings, further research should not only address methodological issues, but also try to establish a more fitting decision making model for PPS or similar work environments. From an application-oriented perspective, the interplay of socio-technical design and the acquisition of expertise in PPS is a scholarly field that remains mostly unexplored.

2.5 Outlook: Implications for Decision Support Design

When identifying a critical system state or a need for a decision, planners aggregate information coming from different information sources, i.e. the PPS software, formal and informal organizational communication, planning boards etc. Their knowledge contains expertise about *which* cue from *which* source is relevant in a particular situation, *how* an element of information is interrelated to other elements of information, and *what* conclusions can be drawn from that in the form of situation-specific rules.

Our analysis shows that the human planners' decision making is facilitated – or impeded – by the socio-technical system around them, including management, cooperation and communication, as well as IT. In order to enhance the quality of decision making, we believe at least two fundamental cognitive processes should be better supported:

1. Continuous development of expertise, i.e. planners' PPS-related skills and knowledge.
2. Situational diagnostics (i.e. pattern recognition) by facilitating the availability and presentation of decision-relevant information in a way that is compatible to the planners' knowledge structures.

Accordingly, planners should be supported in identifying and selecting relevant cues from several information sources, and in constantly learning about relevant interrelations between these cues. This could be achieved for instance by implementing existing relational knowledge into databases and interfaces. Explicit and well-structured communication paths within the organization, as well as between the organization and its suppliers, could further support decision processes by making potentially available information readily accessible for the planners. Continuous feedback about the development of market demands and about the outcomes of PPS in terms of service levels and other operating figures (e.g. production costs, capital lock-up) should finally support the adjustment and correction of expert knowledge.

Understanding naturalistic decision making by human planners and schedulers provides a base for conceptual theories of an improved socio-technical PPS system. Central to this understanding is the way expert planners and schedulers are using their IT system and other resources when making decisions. Creating more supportive conditions through a better fit of the system design to the expert's way of working will most likely lead to a higher performance in planning and scheduling. Much research and design effort is still needed to achieve this goal.

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