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Understanding planning for effective decision support

A cognitive task analysis of nurse scheduling

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'There are no more promising or important targets for basic scientific research than understanding how human minds, with and without the help of computers, solve problems and make decisions effectively'.
(H.A. Simon, 1987, p.12)

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Planning in organizations is for all times. Coordination of organizational activities is needed not only to improve the overall performance of the organization but also to survive a competitive environment. Changes in the organizational environment, and technological developments (among others) require an adaptive allocation of resources amidst all kinds of uncertainties. Planning has always been an important success factor and is becoming ever more important within the organizations. Whether the objects of planning are machines, goods or personnel, making a plan or making a schedule[1] is a strenuous job for the planner. Attaining an 'optimal' schedule is becoming more and more difficult since on the one hand, the number of aspects of the problem to be taken into account increases, and on the other hand, the scheduler is restricted in his/her cognitive capabilities. A computerized system that supports the planner in the making of a schedule is seen as a solution to conquer the difficulties of planning. Developments in such systems continue to take shape as the power of information technology increases, making it possible to develop powerful computerized systems in order to support complex problem solving in the organization (Cash, McFarlan & McKenney, 1988; Jelassi, 1987; Keen, 1987; Sol, 1987; Stabell, 1987). Developing decision support for planning tasks is interesting both from a practical and a theoretical point of view.

Within the Dutch project DISKUS different planning problems are under consideration. DISKUS is an acronym for Dynamic Interactive Knowledge Utilization Systems. The aim of this project is to research different planning problems to identify common building blocks for decision support. The hypothesis is that a combination of Operation Research and Artificial Intelligence techniques is a fertile ground for the development of more advanced computerized systems (Jorna, 1992; Kornblum, 1992). The project Diskus contains three pilot projects, each of which investigates

[1] Planning is here considered as determining a sequence of actions whereas scheduling is considered as assigning resources (machines, employees) to specific times. An action could be the scheduling of nurses in the night shift.

one specific planning domain (production, network and manpower planning). This thesis is related to the manpower planning project, in particular, nurse scheduling. In this research an investigation into the task performance as seen in this planning domain is performed from a cognitive point of view, and the ZKR nurse scheduling system has also been built on the basis of these results.

1.2 DECISION SUPPORT

The subject of this study concerns improving the problem-solving capabilities within nurse scheduling by employing decision support. Developing decision support within the natural setting of an organization is closely linked to the field of decision support systems (DSS). Historically, decision support systems developed along two distinctive lines (Eiben, 1991; Verbeek, 1991). Along the first line the idea of the decision support system originated from management information systems as another type of computerized system with the purpose '*to denote the other aspects of information processing, namely the provision of information for supporting management decision*' (Keen & Scott Morton, 1978, p. 3). The second historical line from which Decision Support Systems emerged was the field of Operations Research/Management Science. The emphasis was on developing quantitative models for the representation of a problem (Hillier & Liebermann, 1967) along with understanding the decision-making problem from a normative and rationalistic point of view as how to attain the 'best' decision (Klein & Methlie, 1990; Vlek, 1990). Since then decision support systems developed as a distinctive research field, which is defined by Keen and Scott Morton (1978, p. 2) in the following:

- 'The impact is on *decisions* in which there is sufficient structure for computer and analytic aids to be of value but where managers' judgment is essential.
- The payoff is in extending the range and capability of managers' decision processes to help them improve their *effectiveness*.
- The relevance for managers is the creation of a *supportive tool*, under *their own control*, which does not attempt to automate the decision process, predefine objectives, or impose solutions'.

It is clear from the above description that an active cooperation between the computerized system and the manager's decision making is recommended. This means that in order to accomplish such a cooperation not only are ideas about the design of a computerized system needed but also an understanding of the human problem-solving and decision-making processes. However, such a comprehensive definition appeared to be too premature, since the main focus in research up to now has been on the design and the development of a computerized system (Angehrn, 1990; Bots, 1989; de Jong, 1992; Verbeek, 1991; Verbraeck, 1991; Zarate, 1991). Hofstede (1992) noticed the one-sided emphasis on the computerized system as well, and states that '*There is a general agreement among DSS researchers that the D in DSS has not received proper attention*' (p. 115). Decision support was approached by emphasizing the function of a computerized system as indicated in the following definition by Keen and Scott Morton (1978, p. 1):

> 'decision support implies the use of computers to:
> - assist managers in their decision processes in semi-structured tasks;
> - support, rather than replace, managerial judgment; and
> - improve the effectiveness of decision making rather than its efficiency'.

This definition reveals a one-sided emphasis on the function of the computerized system compared with the other definition. The approach for designing a DSS was worked out by Spraque and Carlson (1982), among others. Though, the importance of the role of human aspects in decision making is stressed again by Keen (1987), and others since then, who put forward '*the basic ideas of DSS: Here is a perspective on the use of computers and analytic methods. That is very different from the traditional assumptions and practice of Data Processing and Management Science. It* ***meshes human-judgment and the power of computer technology*** *in ways that can improve the effectiveness of decision making, without intruding on their autonomy*' (p. 253).

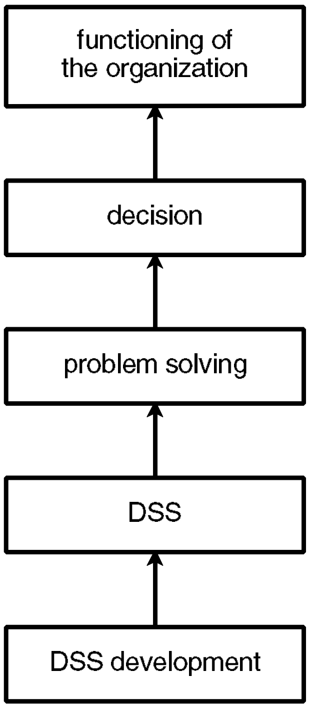
Despite the greater amount of attention paid to the design of a DSS, the relevance of human aspects have also received attention in the research in the meantime. A few examples will illustrate this notion. Verbeek (p. 39) states that '*human aspects determine the usability of a DSS*'. Bots (1989) discusses a third megatrend for information technology which will be aimed at improving human performance (p. 2), while Angehrn and Lüthi (1990) advocate a key role for the user in designing a DSS. Timmermans (1992) criticized the type of approach to designing a DSS that starts from the complexity of the problem and scarcely takes the problem solver's point of view and cognitive capacities into account. There is a need for a deeper understanding of human aspects within decision support. In order to give shape to human aspects in decision support, insight into the way humans solve complex problems is needed by describing their knowledge and skills.

An important impulse for pushing attention toward human aspects has been given by Artificial Intelligence (A.I.) the main topic of which is understanding human problem solving and reasoning in order to build intelligent systems. Barr and Feigenbaum (1981) defined A.I. as '*the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding, language, reasoning, solving problems, and so on*'. The starting point for applying A.I. is to explicate human knowledge used in the problem-solving processes. Further on, after formalisation of the knowledge, it will be implemented. Attention to knowledge and skills implies more and more user involvement. Doukidis (1988) stated that it is worthwhile broadening the scope of DSS because by using Artificial Intelligence a DSS will become more efficient and effective. Accordingly, Doukidis (1988) argued that in the near future '*Expert System user support tools, and more specifically the intelligent interfaces, are becoming critical components in the decision-making and problem-solving process!'* (p. 346). Er (1988) also points out that '*decision technology should be centred on problem solving (with experience, intuition and knowledge) supplemented by information technology*' (p. 360). As a way of putting the tendency of Artificial Intelligence's involvement in the field of DSS into practice, new names are generated for DSS like Intelligent DSS, knowledge-based DSS, and expert support systems (van Weelderen, 1991; Klein & Methlie, 1992). Moreover, such systems seem promising for the next decade of DSS (Scott Morton, 1991).

By introducing A.I. into the DSS field a 'new' perspective on the involvement of users is attained by investigating the knowledge and skills underlying human problem-solving. Such a perspective was lacking in the early days in the field of DSS. It means that the issue at stake is the problem solver him/herself, despite the capability to automate several activities. Moreover, it underlines the notion in the definition of Keen and Scott Morton, that the manager's judgment should be supported and not replaced.

There are at least two reasons which lead us to believe that research on human problem solving will have a broader impact on decision support in the organization. The first reason concerns the relevance of 'problem solving' within the organization, illustrated in the DSS quality chain (Hofstede, 1992). Understanding problem solving contributes to the quality of a DSS. The aspect of quality refers to effective decision support by improving the problem-solving capabilities (Klein & Methlie, 1990). The quality chain is depicted in figure 1.1. The figure is rotated by which means the 'right-hand link' becomes the bottom link and the 'left-hand link' becomes the top link.

Figure 1.1 THE QUALITY CHAIN OF DSS



Hofstede explains the DSS quality chain as follows: '*The relationship between the links of this chain is that the quality of the right-hand link is one of the determinants of the quality of the left-hand link..... The DSS is central in the present context' (p. 108). 'The quality chain is also, in a way, a process - product chain. Starting at the righthand side, the process of DSS developments results in the product 'DSS'. With this DSS, a decision maker can carry out a process of problem solving resulting in the product 'decision'. This decision then co-determinates the processes that constitute the functioning of the organization*' (p. 108). He concludes that: '*high-quality processes of DSS development and of problem solving are crucial if DSS are to be really used'*. This quality chain supposes a causal relationship between the components. As can be seen in the quality chain, insight into problem solving with decision support works on two directions: it offers feedback on the DSS development and on the design of DSS as well, and it can make clear the influence of decision support in the organization.

The second reason focuses on the implications of decision support for the problem-solving and decision-making tasks of human beings in organizations. The situation with decision support is different from the foregoing situation without decision support. In order to understand the changes in problem solving and decision making with decision support, it is necessary to determine **what** is it that has been supported? A thorough analysis of the problem-solving situation without decision support is therefore needed in order to make a comparison possible. The next paragraph explicates further the problem-solving view dealt with in this study.

1.3 HUMAN PROBLEM SOLVING

For the overwhelming majority of planning tasks the planner tries to accomplish a goal but does not know exactly how to attain it. Finding a solution for the problem would therefore not be a straightforward activity. This implies that the planner needs to do some problem solving; however, human beings are restricted in their problem-solving skills. In this paragraph first human problem solving is discussed from a theoretical point of view, and then the cognitive limitations significant in problem solving are indicated.

Newell and Simon (1972) contributed to the understanding of problem solving with their theory of human problem solving. Problem solving assumes a task environment, an intelligent agent and actions that result from the interactions between the agent and the task environment. The task environment refers to an environment combined with a goal, a problem or a task (Newell and Simon, 1972, p. 55). The task environment is embedded in the organization. They defined the task environment as '*a constraint on the behaviour of the problem solver that must be satisfied so that the goal can be attained*' (p. 79).

Problem-solving behaviour is therefore partially shaped by the task environment. This means that when a problem solver performs a task, the interpretation of the manifest problem-solving behaviour gives information about the task environment. Moreover, problem solvers are adaptive to the demands of the task environment and in this sense they are considered intelligent agents. Problem solving may embody all kinds of intelligent actions like reasoning, thinking, and deciding. Thus, problem-solving behaviour is shaped by the requirements of the task environment (Simon, 1990).

The task environment is represented in a set of possible situations: initial state, end state and goal state. The initial state consists of a description of the situation in which the objects, features and restrictions of the problem are indicated. The goal state is defined as a desirable state of a situation as defined by a problem solver. A goal state will always be the end state, while an end state need not be the goal state. In order to perform a task a number of phases can be distinguished within the problem-solving processes (Newell & Simon, 1972). The first phase of problem-solving is then to build an appropriate representation of the problem. A problem space, in which the problem-solving activities take place, will be created by means of a representation of the begin and the end state. The problem space is completed with other necessary information needed to solve the problem. For instance, it may comprise relevant information retrieved from long-term memory, extra information collected about the task to be solved from the task environment or instruction of the problem. Representing the task environment is thus an important part of building a problem space. Ultimately, all relevant knowledge is available to perform the task. When creating a problem space, all possible solution paths are herewith depicted going from one problem state to a next problem state. However, not all paths may lead to a successful solution of the problem or will reach a goal state.

The second phase of problem solving is characterized as searching through the problem space by selecting operators. An operator is a rule or procedure that transforms one state into another problem state. A problem state is each state as a result of the problem-solving process; this means that the begin and end state represented in the problem space are problem states as well. When the problem space is large, a heuristic search is needed since it is impossible to check all solutions paths and then decide which path will lead to the best solution. Therefore, executing a heuristic rule may lead to a problem state nearer to the goal state more quickly but it does not guarantee a solution. An algorithm, on the other hand, does guarantee a solution because it is more systematic in searching the problem space. Heuristics differ from algorithms in the type of solution: an algorithm gives the optimal solution whereas an heuristic provides a satisfactory solution. Though, as Simon (1990) puts it: '*Since we can rarely solve our problems exactly, the optimizing strategy suggested by rational analysis is seldom available. We must find techniques for solving our problems approximately, and we arrive at different solutions depending on what approximations we hit upon*;' thus, '*intelligent systems must use approximate methods to handle most tasks. Their rationality is bounded*' (p. 6). Another characteristic of a heuristic search is that it processes information from the task to find a solution: '*Hence a prime characteristic of heuristic search, is that the system gradually takes on the form and behaviour that is requisite to adapt it to the environment in which it finds itself*' (Simon, 1980, p. 36).

The third phase of problem solving is the implementation of selected operators, which effects the transformation to the next problem state. The transformation is executed by actions caused by a chosen operator. The execution of an action results in a problem state that more closely resembles the goal state.

The last phase concerns the evaluation of the present problem state compared with the goal state. If these states coincide then the problem is solved; otherwise, the problem solver needs to go back to the second step searching for a new solution path.

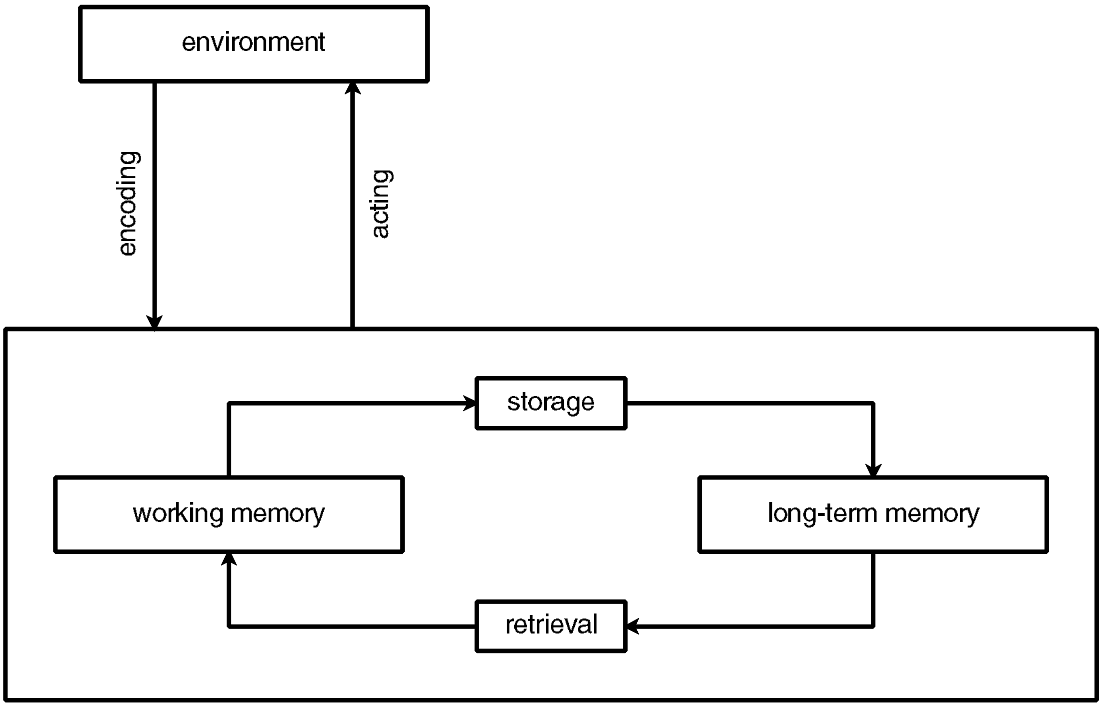
The sequence of the four steps in problem solving is not obligatory.

In general, '*problem solving can be conceived of as a search through a problem space*' (Anderson, 1983, p. 257). The representation of a problem and searching in the problem space for solutions can be demanding for the problem solver. These two aspects cause most of the difficulties in problem solving (Waern, 1989). This is true in particular when the problem is ill-structured, since then the number of possible solutions is very large, the actual solutions are not concentrated on a small scale but dispersed, and the comparison between many possible solutions to search for the best one, as well as the generation of new solutions, can cost much effort and time (Newell and Simon, 1972). Ill-structured problems are hard to solve because of the problem solver's cognitive limitations. Attention is required every time in order to find a solution. The problem solver is viewed as a cognitive system in this sense. The functioning of the cognitive system is the second aspect by which problem-solving behaviour is shaped, and will further be discussed in the next paragraph.

1.3.1 The cognitive system

A cognitive system is considered a symbol-manipulating system (Anderson, 1983; Jorna, 1990; Newell & Simon, 1972; Newell, 1990). A symbol represents facts, events, or objects. The cognitive system is able to process these symbols intentionally in order to act in the environment. Such cognitive processes underlying human thinking and problem solving can therefore be considered as operators which manipulate symbols. Cognitive processing comprises several stages: encoding, storing, retrieving, and generating solutions. The cognitive system is depicted in figure 1.2.

Figure 1.2 THE COGNITIVE SYSTEM



Any kind of information perceived in the environment enters the cognitive system through sensory perception (the five senses are sight, sound, touch, smell, and taste). This perceived information is encoded and stored in the memory selectively. New information is processed in working memory and if necessary stored in long-term memory. Perceived information can also contain clues for retrieving stored information from long-term memory. After retrieving, it is processed in working memory which results in goal-directed action performed in the environment. Working memory differs from long-term memory in two ways. Working memory has a restricted capacity: it can hold about 7 plus or minus 2 pieces of meaningful information. The other characteristic is that information can be stored temporarily in working memory. On the other hand, the capacity of long-term memory is more or less unlimited and the storage of information is more or less permanent. Waern (1989) explains that '*the limitations of working memory are probably the most important factor to be considered in trying to achieve a "user-friendly" system*' (p. 42).

Two types of long term-memory are distinguished which contain either declarative or procedural knowledge. Declarative knowledge concerns 'knowing what' whereas procedural knowledge concerns 'knowing how' (Anderson, 1983). Knowledge about general facts as well as knowledge about specific events is declarative. Knowledge about performing tasks and solving problems is procedural. Procedural knowledge therefore plays an important role in the learning of tasks (Jackson, 1992, p. 66). A characteristic of procedural knowledge is its immediate availability. This means that the cognitive effort, i.e. the mental load, will be low when applying procedural knowledge. The cognitive effort is high during problem solving when declarative knowledge is processed (Mulder, 1992). Working memory and long-term memory together with declarative and procedural knowledge play a significant role in performing problem solving.

The cognitive system reveals thus a restricted capacity available for the performance of a task. This means that problem solving is limited by the capabilities of the cognitive system. Performing several tasks will soon deteriorate the accuracy of the task performance. Each task requires a certain cognitive effort and so less capacity is left for the performance of the other tasks. Summarized, the restrictions of the cognitive system (Jackson, 1992, p. 68) are:

- the capacity of working memory
- cognitive effort is limited
- the speed of information processing

The cognitive limitations are computational in nature, especially those having to do with the speed in executing actions and the organization of a system's cognitive processes (Simon, 1990). The consequences of these limitations for problem solving are pointed out by Jackson (1992, p. 70): *'De beperkte resources van het menselijk informatieverwerkingssysteem en het menselijk vermogen tot leren geven, zo is aangetoond, vorm aan de menselijke taakuitvoering en bieden zo een -gedeeltelijke- verklaring voor het gebruik van bepaalde strategieën bij de uitvoering van cognitieve taken'*[1]. Thus, the cognitive restrictions fix the range of the variety of the performance of a task by a problem solver. Naturally, this aspect should be taken into account in the design of the computerized system. This is however not common practice. Moreover, compensating for such cognitive limitations needs to be the aim of decision support (Timmermans, 1991), because then the usability of a DSS is adequate and effective decision support has been reached. Roth and Woods (1989) underline this aspect by pointing out that: '*While A.I. tools increase the potential power of decision-aiding systems, the fundamental challenges facing designers of support systems remain the same: defining the cognitive demands that make the problem situation challenging; understanding what knowledge and problem-solving strategies allow*

[1] It has been shown that the limited resources of the human information-processing system and the human capacity to learn give form to human task performance and offer a--partial--explanation for the use of certain strategies in the performance of cognitive tasks.

human experts to perform well; understanding what kinds of errors of performance occur and the basis for those errors; and specifying what information or advice would reduce those errors and make for effective decision support' (p. 258).

A cognitive perspective on problem solving reveals the knowledge processed in order to perform a task. Rasmussen (1986) distinguished three levels of performance: skill-based, rule[1]-based, and knowledge-based performance. They differ in the amount of task experience and training as well as conscious attention needed. Skill-based behaviour takes place without conscious control and is acquired after much experience, while rule-based behaviour is '*consciously controlled by a stored rule or procedure that may have been derived empirically during previous occasions, communicated from other persons' know-how as an instruction or cookbook recipe, or it may be prepared on occasion by conscious problem solving and planning*' (Rasmussen, 1986, p. 102). When the problem solver meets an unfamiliar situation, '*the control of performance must move to a higher conceptual level, in which performance is goal-controlled, and knowledge-based behaviour*' (p. 102). Often, because of the ill-structuredness of a complex task, problem solving requires conscious attention, and because of a dynamic task environment of tasks embedded in the organization, problem solving depends on rule-based and knowledge-based performance: '*Then knowledge-based information processing is a goal- and concept-controlled search for proper rules for action, while rule-based processing will be the stereotyped use of such rules'* (Rasmussen, 1986, p. 138). Rules in knowledge-based behaviour are merely based on cues from the task environment and thus rather task-specific. The performance of the nurse scheduling task will be characterized for the most part by knowledge- and rule-based behaviour.

In order to understand the demands of the task environment within the nurse scheduling domain and the cognitive processes underlying the task perform-ance, first more insight is required into generic aspects of the planning domain, e.g. manpower planning in organizations. This will be discussed in the following section.

1.4 THE DOMAIN OF PLANNING

In an organization many different activities are performed by many participants. The aim of this is to improve the performance of the organization. Organizational

[1] The meaning of rule as used in rule-based behaviour refers to cognitive processes underlying the task performance. This meaning needs to be distinguished from rule as a representation formula.

activities differ in nature: either they indicate a primary production process or they refer to the coordination of production processes. Planning is such a coordinating activity. Several definitions of planning can be found in the professional literature. Anthony (1965) defines the organizational planning domains by distinguishing three different levels of planning: strategic, tactical and operational planning. These three levels differ in the scope under consideration. Strategic planning refers to the decisions made with respect to the organizational policy and the organizational goals. This is often determined by the competitive environment of the organization. Tactical planning concerns the acquisition and use of resources in the most efficient and effective way, in conjunction with the organizational objectives. Operational planning is the direct assignment of operational tasks to be carried out immediately and to be done in the most efficient and effective way. These three levels are hierarchically linked whereby the higher level yields the objectives and constraints of the lower level. All three levels are related to a specific time horizon: the strategic level to long-term planning, the tactical level to medium-term planning and the operational level to short-term planning. It is important to notice that Anthony's definition refers to different distinguished domains within the organization. Nurse scheduling is regarded an instance of the domain of manpower planning at the tactical level.

1.4.1 The domain of manpower planning

As defined by Glover and McMillan (1986) manpower planning is characterized by the linking constraints between blocks of time periods, a large number of shift types, non-homogeneous employees with limited availabilities, management rules. These features stem from the need for working hours that exceed the individual working hours within the organization, because of the fact that work needs to be performed every day of the week. This means that extra attention needs to be given to the individual working hours of personnel which is formalized in the management rules. Within manpower planning the 24 hours of a day are divided into restricted time periods related to different shifts. Personnel are assigned to such time periods. The need for staff in the organization may also fluctuate according to the hour of the day, the day and the season. Each shift has thus a certain quantity of staffing. Last but not least, staff can only be interchangeable to a certain extent because the labour guidelines impose special requirements on the education and experience of personnel (Patrikalakis & Blesseos, 1988). Manpower planning aims therefore at the utilization of scarce resources of staff in quantitative and qualitative respects within a restricted time period, whereby both organizational objectives and the interests and potentialities of staff have to be taken into account. The concrete tool for management is the schedule in which personnel is assigned to specific times.

Different types of schedules are operational for manpower planning (Jansen, 1987). The distinction between different schedules is based on two dimensions, namely, 'continuity in working hours' and 'repetition of specific shift patterns'. In the 'continuity' dimension three different types of schedule exist. First, a discontinuous schedule which contains only day and evening shifts, no night shifts and no weekends. Second, a semi-continuous schedule contains day, evening and night shifts and there is a break in the weekend. Third, a fully continuous schedule means that there are no interruptions among shifts, without even a break in the weekends. In the 'repeat' dimension two different types of schedule exist: a cyclic schedule and a schedule resulting from scheduling by exception. A cyclic schedule means that, after a certain time period, the same pattern of shifts rotate among personnel. Thus, personnel will be assigned to the same patterns of shift and such a pattern will be repeated during the whole year. A cyclic schedule implies thus that personnel know their scheduled shifts in advance and that it is not common to alter the cyclic nature of the schedule. Scheduling by exception is quite a different story. Scheduling by exception means that for each time period a new pattern of shifts is assigned to personnel. In such a schedule there is hardly any regularity in the patterns of shifts. Such a schedule includes much flexibility in order to adapt to changes in the environment. It also means that personnel can take the opportunity to state their wishes for a particular shift. Moreover, the schedules differ among the personnel. A cyclic schedule is more common in industries, whereas scheduling by exception is more common in the service industries. Nurse scheduling is such an example of scheduling by exception.

The problem-solving activity required in the manpower planning domain is thus the making of a schedule. The task of making a fully continuous schedule by scheduling by exception is very difficult in comparison with the task of making a cyclic schedule, since the number of variables typical of such a schedule increases the complexity and difficulty of the problem solving. Actually, making a schedule is considered a planning task. Planning as it refers to problem solving is explained in the following definition by Thierauf (1982): *'planning is an analytical process which encompasses an assessment of the future, the determination of desired objectives in the context of the future, the development of alternative courses of action to achieve such objectives, and the selection of a course or courses of action from among these alternatives'* (p. 186). In this definition it is clearly emphasized that, irrespective of the level, planning is a problem-solving activity. Hayes-Roth and Hayes-Roth (1979) also stress the problem-solving aspect of the planning: *'the predetermination of a course of action aimed at achieving some goal'* (p. 275).

Planning starts with a representation of the begin state and the final goal state. The problem solver generates a plan that when applied to the begin state will lead to the goal state. Gomes (1993) defined a plan as *'an organized collection of operators'* (p. 94). It describes actions in a particular order to be performed within the planning domain. Actually, a plan is thus the solution for a problem. The challenge for a planner is to find such a plan by searching through the problem space, that is, mostly guided by using heuristics as a search technique. Planning is a problem-solving activity aiming at reducing searching, resolving goal conflicts, and providing a basis for error recovery (Cohen & Feigenbaum, 1982, p. 516). Planning such as performed by the problem solver in a real setting is also a cognitive activity, however, the planner as problem solver has not received much attention in research (Matsuda & Hirano, 1982). This is also pointed out by Rasmussen (1986, p. 5) in the following: '*Unfortunately, in spite of a long tradition of research in management decision making, a generic model of the information processes implied does not exist*'. More attention to the cognitive processes may help shed light on problems planners have with planning in order to be able to design adequate computerized systems for decision support of planning.

1.5 RESEARCH QUESTIONS

We noted that more attention needed to be paid to the cognitive perspective on decision support, which was further explained by focusing on problem solving. Winograd and Flores (1986, p. 8) justify the role for a cognitive perspective with regard to decision support in the following: '*The alternative we pose is not a position in a debate about whether or not computers will be intelligent, but an attempt to create a new understanding of how to design computer tools suited to human use and human purposes'*. Specifically, this means that for my study I am not concerned that the support should be 'intelligent' but that it should be suited to the problem-solving capabilities. Thus in order to design such a decision support system, research needs to be done on problem solving from the human perspective. This implies that the performance of the planning task needs to be investigated in the working practice of the problem solver. This study therefore deals with the following questions:

1. Which skills, knowledge and rules underly the task performance of the planning task in nurse scheduling?

2. What role do skills, knowledge and rules play in the task performance of

nurse scheduling with and without decision support?

3 What is the operational relevance of the skills, knowledge and rules for designing decision support for this planning task?

A cognitive task analysis aiming at understanding the problem solving underlying the task performance is performed in order to answer these research questions. Making the nurse schedule is investigated for experienced schedulers as well as for so-called novices who had no experience with such a task. In chapter 3 this is discussed in detail along with other relevant methodological considerations.

1.6 OUTLINE OF THE THESIS

The present chapter has set up the research problem. The main issues in the domain of nurse scheduling, along with literature on decision support for nurse scheduling are reported in chapter 2. Chapter 3 discusses the methodological foundation and the research approach of this thesis for investigating the problem-solving processes. In chapters 4 and 5, the outcomes of the problem-solving behaviour underlying the task performance in a natural setting are presented. In chapter 6, the schedules as the outcomes of the task performance are discussed. The problem-solving processes underlying the task performance in a decision-supported setting are discussed in chapter 7. In the last chapter, chapter 8, I draw conclusions and discuss the comparison between the problem-solving processes both with and without decision support in order to understand the effectiveness of decision support on the task performance by the scheduler, or to put this in other words, revealing the improvements in problem-solving capabilities the use of the nurse scheduling system provides.

CHAPTER 2

THE DOMAIN OF NURSE SCHEDULING AND THE ROLE FOR DECISION SUPPORT

2.1 INTRODUCTION

This study is about understanding the performance of the nurse scheduling task in hospitals. The present chapter therefore discusses general characteristics of the nurse scheduling domain. The hospital's particular characteristics impose special requirements on the availability of nursing personnel. In hospitals, staff planning issues are described in the nurse scheduling policy. Typical features of the hospital and the nurse scheduling policy determine the organizational context of the nurse scheduling task. Moreover, the performance of the nurse scheduling task is regarded a difficult and time-consuming activity because of the processing of many data and looking for acceptable combinations of nurses and shifts in order to achieve a feasible schedule. In chapter 1 the application of computerized systems is recommended as a solution for nurse scheduling, since information technology has been applied to the support of decision-making processes. This chapter reports on the different computerized systems used for nurse scheduling in the literature.

2.2 NURSE SCHEDULING

Nurse scheduling should provide for 24-hour staffing because of the continuous character of patient care in hospitals. Fully continuouq scheduling means that each day is split up into day, evening, and night shifts. In hospitals the primary care is focused on the day shift, though providing sufficient patient care in the evening and night shifts should also be guaranteed. Working irregular shifts at different times of day aggravates both the mental and physical health of personnel (Jansen, 1987). Job satisfaction and social life may be under a great deal of pressure. In order to keep such aspects under control, care is taken to define labour agreements as well as to offer other facilities to nursing personnel; for example, personnel are allowed to indicate their individual preferences for a shift. In a nurse schedule personnel are thus assigned to shifts whereby the organizational objectives of the hospital, the labour agreements and the interests and competence of individual personnel are taken into account.

2.2.1 The hospital

A hospital displays the characteristics of a professional bureaucracy (Mintzberg, 1979). In a professional bureaucracy three main segments are distinguished: professionals, support staff and the administrative structure. The professionals attend to the primary processes in a hospital concerning the nursing and treatment of patients. Professionals have acquired knowledge and skills in their speciality. In a hospital the professionals are the nursing and medical personnel, respectively, the nurses and the physicians. Professionals are divided among many specialties, for example, those working in surgery, internal medicine, or dermatology. This results in a variety of different wards. Thus each ward has its own specific group of professionals. The implication for nurse scheduling is that each ward is responsible for its own staffing problem and has its own schedule separate from other wards. In this sense the organizational objectives are subordinate to those of nurse scheduling. The second segment in a hospital is the support staff, consisting of laboratory and secretarial personnel. In fact they support the primary processes as performed by the professional staff. Finally, the administrative structure of a hospital comprises the managers of the medical and supporting divisions (personnel, salary administration), the board of the hospital and the board of directors.

2.2.2 Nurse scheduling policy

General guidelines for nurse scheduling are written down in the nurse scheduling policy. The nurse scheduling policy aims at the regulation of nursing personnel among different wards in a hospital in order to achieve feasible schedules. It concerns the regulation of nursing staff, the prediction and control of staffing problems, along with the formal rules and agreements, as well as the workload (Nurse Scheduling Handbook, 1989; de Vries, 1984).

Ward formation is determined by both the quantity and quality of staff needed in a shift in order to guarantee enough patient care. The quantity of staffing expresses a specific number of staff members in a shift, whereas the quality of staffing denotes the division within a shift of personnel according to education and experience. The number of staff arrived at partly depends on the quality of staff. The formation is designed to fulfil the requirements of the demand of patient care. The value of the quantity and quality of staffing varies among day, evening and night shifts but it may also vary among different wards, and among days of the week for a particular shift. From the formation the net number of staff can be calculated per time period, after subtracting holidays, days off and courses. The determination of a ward formation may lead to problems of under- or overstaffing. This can be of a quantitative nature but a disproportionate division among personnel in function and experience can also occur. These results are undesirable since understaffing necessitates modification of the formation because the demand of patient care could not be fulfilled. Overstaffing, on the other hand, is a luxurious problem; however, most schedulers try to minimize overstaffing in order to maintain the desired workload necessary for an adequate job performance.

The second aspect described in the nurse scheduling policy concerns the formal rules and agreements which regulate the working hours of personnel in order to prevent excessive labour. For the most part, it involves collective labour agreements which are related to the Labour Act (National Scheme of Conditions of Service). A summary of the major formal rules in nurse scheduling is given below.

FORMAL RULES IN NURSE SCHEDULING

- Full-time personnel are allowed to work for a maximum of 40 hours a week.
- Yearly 12 short time days (ATV) are assigned to personnel. It is obligatory to assign 2 days in three months.
- If the staffing is adequate, short time should be connected with days off in the schedule.
- Student nurses have 84 hours unpaid leave a year (oladagen).
- Personnel receive 4 days off in a fortnight. Exception: when changing shifts this rule may be overstepped twice in 28 days.
- Personnel receive at least 22 weekends off during a year.
- At least 10 hours rest has to be given to change between two shifts.

- While changing from a day to a night shift the resttime may be reduced to 6 hours.
- Each public holiday or feast-day which does not coincide with a Satur- day or a Sunday will be compensated for by an extra day off.
- Part-time workers may shift according to a fixed pattern.
- When sickness occurs during short time, short time lapses.
- A compensation for inconvenience like a compassionate leave will be assigned in certain circumstances.

Often the hospital thinks it desirable to define additional rules that are often derived from the labour agreements. An example of such a hospital rule is to allow eight days of continuous work instead of the maximum of ten days in the collective labour agreement. Besides these formal rules and agreements and the hospital rules, other informal rules can be present on a specific ward; however, these are never allowed to interfere with the nurse scheduling policy.

The third aspect of the nurse scheduling policy, the workload of personnel, is related to the total amount of patient care needed. However, the demand for patient care is variable and often unpredictable. It can only be adequately evaluated over a longer period of time. At the time of creating the schedule the actual workload can only be estimated and may need to be adjusted later. Keeping the workload balanced evenly among personnel is controlled by defining goals that are directly or indirectly linked to it. A summary of the goals is given below. In brief, the first goal aims at the equal distribution of workload among the personnel in different shifts. The second through fifth goals aim at the satisfaction of the personnel with their scheduled working hours, whereas the sixth and the seventh goals guarantee the quality of patient care. Since the goals aim at different aspects, the realisation of one goal may conflict with that of another. Therefore, achieving all goals in one schedule could be difficult. The role of goals in nurse scheduling is further discussed in chapter 4.

NURSE SCHEDULING GOALS

- To distribute the qualitative staffing proportionally
- To distribute the quantitative staffing proportionally
- To distribute shifts among personnel proportionally

- To distribute shifts and days off
- Honouring wishes
- A pleasant working atmosphere on the ward
- Continuity between and over days

It is obvious that the design of the schedule will be based on the nurse scheduling policy. However, in empirical research into designing schedules it became evident that physiological aspects of human beings were hardly taken into account. Jansen (1987, p. 22 and 23) investigated the physical healthiness in irregular work and formulated the following recommendations to be processed in the schedules:

- ‘Een rooster moet weinig opeenvolgende nachtdiensten bevatten.
- De ochtenddienst moet niet te vroeg beginnen.
- De wisseltijden moeten flexibel zijn.
- Korte intervallen van vrije tijd tussen twee diensten moeten worden vermeden.
- Volkontinuroosters zouden enkele vrije weekenden moeten bevatten met op zijn minst twee opeenvolgende dagen vrij.
- Bij volkontinuroosters gaat de voorkeur uit naar voorwaartse rotatie’[1].

These recommendations imply that, for instance, a schedule of seven consecutive night shifts would put too heavy a strain on the nurse's physical health. Fortunately, there is already the tendency in hospitals to split up the number of consecutive night shifts into three and four nights. Forward rotation means that the order of shifts to be scheduled for a staff member should be day-evening-night. Although it falls outside the scope of this study, translating such generic recommendations into practical guidelines would lead to improvements in nurse scheduling.

1
- 'A roster should contain few consecutive night shifts.
- The morning shift should not begin too early.
- The times of shift changes must be flexible.
- Short intervals of free time between two shifts should be avoided.
- Fully continuous rosters should contain several free weekends with at least two consecutive days free.
- In fully continuous rosters preference is given to forward rotation’.

2.2.3 The nurse schedule

In the schedule nursing personnel are assigned to different shifts for a restricted time period. Figure 2.1 depicts the framework of a schedule.

Periode:1	1							2							3							4							
Naam Persoon	M	D	W	D	V	Z	Z	M	D	W	D	V	Z	Z	M	D	W	D	V	Z	Z	M	D	W	D	V	Z	Z	
Arends																													
Bol																													
Cuiper																													
Duis																													
Everts																													
Flokstra																													
Gul																													
Hansen																													
Idema																													
Jansen																													
Koster																													
Lang																													
Middel																													
Noot																													
Ochterop																													
Prins																													
Ritsema																													
Smid																													
Tak																													
Vleugel																													
Totaal:																													

Figure 2.1

The physical representation of the schedule is a framework from which two dimensions and an interactional dimension can be identified. There is a vertical dimension consisting of the nursing staff, a horizontal dimension referring to a specific scheduling period and an interactional dimension where the horizontal and vertical axes cross. The latter is represented by the cells in the framework.

In the vertical dimension of a schedule all individual staff members are ordered with respect to their education and function. The common categories used in nurse scheduling are the head nurse, the assistant head nurse, trained nurses and student nurses. Within a category a further distinction can be made in the amount of experience and training of a nurse. Thereafter, the characteristics of different labour contracts are given for each employee since a nurse can be hired on a part-time or a full-time basis and only be available for a specific kind of shift. Specific attention is given to the student nurses who are not available on the ward full-time because of their educational program of obligatory hours at school. Also in the creation of a schedule, they need special attention when being assigned to a shift, since their work needs to be supervised by an experienced nurse.

The scheduling period on the horizontal dimension is divided into days. Mostly, the scheduling horizon covers a four-week to three-month period.

The interactional dimension is in some way considered the third dimension. The cells contain all the different shifts in the broadest sense which can possibly be present in a hospital. For instance, it contains the three major parts into which the day on the horizontal axis is divided, the day, evening, and night shifts. Because of the irregular working hours in a hospital obligatory days off are given to recover from work after a continuous period of work. The days off are also presented in the cells. With respect to the student nurses their courses are denoted in these cells as well. Actually, each activity arising from working in a hospital is presented in the schedule.

The two most relevant characteristics typical of nurse scheduling are present in the schedule: the day, evening, and night shifts in the schedule denote that there is continuous patient care, while scheduling by exception is illustrated in the schedule by the diversity in the alternation of shifts. Scheduling by exception means that the schedule needs to be adapted to accommodate changes in the environment such as courses or other particular wishes, which means deviating from the plan of the previous period. All the employees may tender their personal wishes for a specific shift and days off which are then processed in the production of the final schedule. The schedule should therefore display an enormous flexibility. Moreover, this feature of the schedule is necessary since fluctuations in patient care as well as unexpected illnesses among personnel frequently occur in hospitals and adaptations are thus needed in the schedule. By offering flexibility in the schedule, personnel are more attracted to the irregular work in hospitals, which will increase not only their work satisfaction, but also the quality of patient care (Fluharty, 1988). However, scheduling by exception is under discussion since, on the one hand, it is a complicating factor in the creation of a schedule, and on the other hand, it is well-entrenched perquisite. A fixed schedule with a cyclic nature, as commonly applied in industries, has therefore been advocated in nurse scheduling (Rosenbloom & Goertzen, 1987). A cyclic schedule is characterized by a work pattern which is repeated during a fixed time period of four to six weeks.

The last aspect mentioned in the description of the schedule are the nurse scheduling goals. The schedule needs to realize several goal functions. These are derived from the nurse scheduling policy and they concern the labour agreements and the quantitative and qualitative staffing requirements of a shift as well as the objectives of nurse scheduling. The goal functions play an important role in the problem solving that will be further discussed in chapter 4.

2.3 THE NURSE SCHEDULING TASK

2.3.1 Making a schedule

The head nurse, as the manager of the ward, is responsible for the making of the schedule. Although the scheduling task is only one of the many management activities of head nurses, it is an important as well as a complex and time-consuming task. In this study only the scheduling task is investigated; therefore, the head nurse is henceforth called the scheduler or the planner.

The making of the schedule is usually done with pencil and paper and with a framework of an empty schedule either on a piece of paper or on a planning board on the wall. When observing open-mindedly the performance of the scheduling task the behaviour of the planner seems chaotic. At first glance, the scheduler is busy placing names and shifts on the schedule, counting shifts and personnel, correcting less desirable solutions, searching for specific appointments on pieces of paper during the scheduling period as well as negotiating with personnel about assigned shifts. The question arises: what is really going on?

The scheduler starts with a chaotic amount of data from which a well-arranged schedule has to result. The challenge is to process all available information while positioning the different shifts on the empty framework, hereby striving for the realization of the different goals in the schedule. The variety of data to be taken into account makes the scheduling task a difficult one. Moreover, it is hard to know in advance which choice will lead to a feasible schedule. The planner conducts a heuristic search whereby it is uncertain whether it will lead to a solution. Actually it can be regarded as trial and error. When a solution cannot directly be established, the planner tries different options in the hope that one of them will lead to a final solution. Often the scheduler needs to go back in his or her reasoning processes and chose another path. It can be imagined that the making of the schedule is a time-consuming activity. In practice the achievement of a feasible schedule seems to be the primary criterion.

2.3.2 Bottlenecks in the nurse scheduling task

A first bottleneck in making schedules concerns the lack of clear guidelines. Handbooks about nurse scheduling as well as the nurse scheduling policy only discuss general recommendations about making schedules. They do not provide practical guidelines for the making of a schedule. Schedulers will acquire their expertise in nurse scheduling through ‘learning by doing’. A scheduler develops his/her own way of planning into which the management of the hospital, responsible for the nurse scheduling policy, hardly gets any insight, let alone schedulers from other wards.

It might be clear that understaffing complicates the making of a schedule. This is often solved by borrowing nurses from another ward or hiring nurses from an agency.

Although the making of a schedule is a repetitive task, each planning period is a fairly new situation. The scheduler is alert to changes in patient care and staffing personnel, wishes, courses, etc. to which the current schedule needs to be adapted.

The degree of difficulty of the task corresponds to the number of variables taken into account because of the greater variety and number of possible solutions. Larger numbers of personnel result in more comparisons when finding a solution. Also, overseeing all feasible solutions where larger number of employees are involved is difficult. The tendency of personnel to decrease their working hours, so-called shortage and part-time workers, as well as the opportunity for personnel to give their preferences for specific shifts, complicate the making of a schedule (Bots, 1990). The different, and sometimes conflicting, goals in nurse scheduling interfere with the performance of the task. Taking all the different aspects of the task into account burdens the working memory beyond the human working memory capacity and it requires much effort and attention on the part of the scheduler to keep the task under control. Cognitive limitations thus influence the making of the schedule. One consequence of cognitive limitations is that an enormous amount of time is required to make a schedule. On average one or two complete working days are needed before a satisfactory schedule has been created. The added burden of being pressed for time makes creating a schedule a strenuous exercise.

Obviously, the lack of guidelines for making a schedule, the dynamic environment of nurse scheduling, as well as the several complicating factors which are inherent to nurse scheduling itself, and the cognitive limitations of the scheduler, are all bottlenecks which interfere with the performance of the nurse scheduling task. Moreover, the bottlenecks indicate that the manually performed scheduling task is not only time-consuming but also rather imprecise and prone to errors-key reasons why decision support can be of help.

Nurse scheduling comprises thus a complex and difficult task where the scheduler appears to be the knowledge source for the understanding of the performance of this task and the specific difficulties herewith. This means that this description of the domain of nurse scheduling does not offer complete insight into the scheduling task. It merely contains an observation of several aspects of the nurse scheduling domain, whereas following chapters will provide a closer look at the task performance, that is to say, the problem-solving behaviour underlying the planning in nurse scheduling.

2.4 DECISION SUPPORT IN NURSE SCHEDULING

A review of the literature indicates that several researchers investigated the potentialities of a computerized system for decision support in nurse scheduling (Arthur & Ravindran, 1981; Bell, Hay & Linang, 1986; Fitzpatrick, Farrell & Richter, 1987; Okada & Okada, 1988; Ozkarahan & Bailey, 1988; Rosenbloom & Goertzen, 1987; Smith & Wiggins, 1977). Recently, decision support has been given increasing interest in the domain of nurse scheduling (Courbon, 1992; DISKUS, 1988; Esaki & Courbon, 1992; Jorna, 1992; Mietus, Jorna & Simons, 1990).

The research on decision support in nurse scheduling resembles the general issues of decision support as discussed in chapter 1. Decision support has developed along three approaches, which are the Operation Research/Management Science (OR/MS) approach, the Decision Support System (DSS) approach, with emphasis on interactivity, and the knowledge-based approach, influenced by Artificial Intelligence (AI). The roles of the different approaches relevant for decision support are discussed in relation to nurse scheduling by looking at how the researchers dealt with the complex nurse scheduling problem vis-à-vis problem decomposition, the typical model and heuristics. Different types of schedules used in the domain of staff planning are discussed for their applicability to nurse scheduling. In making a schedule the scheduler plays an important role as we have already seen. Therefore attention to the role of the scheduler in building computerized systems is an important criterion for the present discussion of the three approaches. Moreover, the scheduler may still be important in determining the usability of the system because of the dynamic environment and in judging the feasibility the schedule. This means that manual adaptation by the scheduler still needs to be provided. Examples of nurse scheduling systems will be discussed in relation to the above-mentioned aspects.

2.4.1 Operation Research/Management Science approach

Operation Research (OR) is the application of mathematical techniques to the solution of complex decision making (Simon, 1987). The aim of OR is to improve the quality of decision making in order to benefit the organizational processes. Aspects typical of OR are that the problem is represented in an algorithmic model which emphasizes the quantifiable aspects of the problem, and that the solution of the model is directed to optimization (Ackoff, 1979). Next, the developed algorithm is implemented in a computerized system. A few examples illustrating the application of OR in nurse scheduling are given below.

An example of this approach is the work of Arthur and Ravindran (1981). In order to overcome the problems of conflicting goals in nurse scheduling, they employed Goal Programming in their models, which is a mathematical technique typical of Operation Research. With Goal Programming the scheduling problem is solved by offering the scheduler the opportunity to assign priorities to different goals. In this respect Goal Programming seems an advantage above many generally applied mathematical models, which often lack such a flexibility in determining priorities and, thereby, restrict the interaction with the environment. However, the application of this Goal Programming technique alone failed to generate complete nurse schedules. Therefore, Arthur and Ravindran decomposed the nurse scheduling problem into two subproblems in order to control the mathematical complexity of the problem space. Each sub problem is now solved separately, whereby optimality is no longer guaranteed. In the decomposition they were thus guided by technical considerations instead of others like social and problem-solving aspects. This is illustrated in the following: their problem decomposition was based on *'the benefit of previous approaches, i.e., the optimizing characteristics of mathematical programming models and the speed of heuristics'* (Arthur and Ravindran, 1981, p. 56). The modelling of the nurse scheduling problem was dominant in their view.

The first subproblem concerned the assignment of each employee to days on which a person had to work and to days on which he or she would be off duty. In this way a preliminary schedule with a day-on day-off pattern was generated which, according to Arthur and Ravindran, was considered *'as a first step in constructing the final schedule'* (p. 60). The assignment of the personnel to working days was irrespective of the shift which they had to perform. This was the main issue in the second subproblem where employees with a day-on designation were assigned to the different shifts. The Goal Programming technique was applied in the first subproblem whereas a heuristic procedure was used to solve the second. The notion of the optimal solution is herewith abandoned. Despite having developed their nurse scheduling model thus far, they stated explicitly that the generated output still needed manual corrections: *'Once the output from the shift assignment procedure has been obtained, the Director and the Staff should make any necessary adjustments'* (p. 60).

Goal Programming was also applied by Ozkarahan and Bailey (1988) in modelling nurse scheduling; however, there are differences in comparison with Arthur and Ravindran. Ozkarahan and Bailey attempted to solve the issue of conflicting goals in a dynamic model with the Goal Programming technique included. They justify their choice by stating: *'The solution space should consist of various models with changeable coefficients each serving a different need'* (p. 306). Actually such a model generates alternative optimization models which *'accommodate flexible work pattern and integrate the time of day and day of week problems'* (p. 306). By these means the nurse scheduling problem is not solved through problem decomposition but by offering several coefficients, variable parameters, which can be used with great flexibility by the scheduler. The consequence of the proposed dynamic model is that the computerized system provides the possibility to interact with the scheduler: *'The choice of the right model and correct coefficients could be properly driven by an expert system front end'* (p. 306). After computing a solution, the planner is offered the opportunity to change parameters in the model. The so called *'expert system front end'*, i.e. the user interface, appeared to play a major role in their computerized nurse scheduling system. However, Ozkarahan and Bailey (1988) also admitted that the generated schedule needed manual adaptations. Although the scheduler in their model is more involved compared to the work of Arthur and Ravindran (1981), the mathematical technique in the work of Ozkarahan and Bailey (1988) still dominates the modelling of the nurse scheduling problem.

Smith and Wiggins (1977) as well as Rosenbloom and Goertzen (1987) criticize the strict OR approach, illustrated in the examples before, in the modelling of the nurse scheduling problem. They state that large and expensive computers are needed to perform the time-consuming computations of these mathematical models, although, nowadays this argument is becoming less urgent. Their other point of concern is that these models solve a limited number of aspects of the nurse scheduling problem since the generated schedules are only applicable after manual corrections. Therefore, Rosenbloom and Goertzen chose a cyclic solution procedure, whereas Smith and Wiggins preferred a heuristic approach to deal with the nurse scheduling problem.

Rosenbloom and Goertzen (1987) developed an algorithm which was able to generate a complete schedule within a short time. In this sense their approach seemed successful. However, their model is only suitable for one specific type of schedule, a cyclic schedule. Since nurse scheduling is mostly characterized by a flexible alternating scheduling pattern, which contrasts with the features of a cyclic schedule, the system they developed does not seem to be very useful in the daily practice in nurse scheduling. The use of cyclic scheduling models in nurse scheduling has also been criticised by others (Choi, 1988; Fluharty, 1988).

Smith and Wiggins (1977) advocated a heuristic approach in modelling the nurse scheduling problem in which they emphasize the problem-oriented nature of the model. This is illustrated by their comment that *'nursing supervisors seem also to require a completed tentative (rough) schedule to help them articulate the remedial action required in particular instances. This feature of the problem, and the* *difficulties in adapting purely mathematical structures to incorporate the complicated constraints involved, caused us to adopt a heuristic approach utilizing list processing and problem-oriented data structures'* (p. 197). Their heuristic approach is linked with the ill-structuredness of the nurse scheduling problem. They argued that the provision of a technical utility is needed to adapt the model to specific demands, while the scheduler must be able to correct the schedule according to his or her personal view. This is an interesting example of decision support for nurse scheduling since it reveals a change from the accent on developing models to problem representation, and from an optimizing method to a heuristic method that leads to a satisfying solution.

As is illustrated by the examples, in the framework of OR the emphasis is on modelling the nurse scheduling problem in order to generate solutions. Hereby the optimization of a solution is not strictly followed, which would be expected on the basis of the principles according to OR. However, the scheduler with his/her knowledge and skills related to the problem representation as well as the design of the computerized system does not receive much attention within the OR approach.

The major criticism on the application of mathematical models as used in Operation Research is the ignorance of the complexity of the problem. As pointed out by Bell, Hay and Liang (1986, p. 136) *'an algorithm can fairly easily generate many feasible schedules, but incorporating workers' preferences and the soft and dynamic elements of the problem into an optimizing model that can be understood and used on the shop floor, is a formidable task'*. Thus OR neglects the more qualitative aspects such as the social and psychological aspects of the problem, in particular, the scheduler as a knowledge source for understanding the problem (Matsuda & Hirano, 1982). For nurse scheduling this means that there is still a gap between *'the academic literature on manpower planning and what manpower planners and personnel managers actually do by way of real-life manpower planning'* (Edwards, 1983, p. 1031). Because of this shortcoming the mathematical model would not perfectly represent the problem. In addition, qualitative aspects are difficult to capture in a mathematical model. This implies that *'the optimal solution of a model is* ***not*** *an optimal solution of the problem'* (Ackoff, 1979, p. 97). Moreover, when the soft aspects of a problem, for instance the judgment of the scheduler itself, play a significant role in the solution, then the best solution would not necessarily coincide with the optimal solutions. The aim of searching for the optimal solution of a problem might be questioned.

Although the mathematical models are often rather sophisticated, they are only useful for clearly distinctive well-structured subproblems derived from the entire problem which has to be solved (Courbon & Esaki, 1992). Operation Research techniques would therefore be less suitable for solving complex, ill-structured problems.

Courbon and Esaki (1992) have a different criticism of OR as well: *'Rarely do these techniques allow fully functional systems to be built, although they can be useful for local optimization within a more comprehensive system'* (p. 384). This shortcoming of OR contributes also to the fact that the developed models are not very widespread in practice (Edwards, 1983; Glover & McMillan, 1986). Usability of the computerized system and the generation of feasible solutions are important criteria for the success of decision support (Bell, Hay & Liang, 1986; Okada & Okada, 1988; Esaki & Courbon, 1992). This means that an adequate problem representation is of the utmost importance, requiring the use of an interactive computerized system. This shift in attention is in fact the main topic of the Decision Support System approach which will be discussed next.

2.4.2 The Decision Support System approach

Actually, the DSS approach is a logical response to the shortcomings within OR. In general, the aim of this approach is improving the decision-making and problem-solving capabilities by the use of computerized systems (Klein & Methlie, 1992). The scope is broadened to an organizational perspective on decision making (see Keen & Scott Morton, 1978). Bell, Hay and Liang (1986) favour the DSS approach for nurse scheduling as *‘an alternative approach to allow for the semi-structured nature of the problem by implementing an algorithm within a DSS, so that the scheduler can quickly and easily review and modify the schedules derived by the algorithm’* (p. 136). The emphasis is initially placed on understanding the complexity of the nurse scheduling problem instead of modelling the problem. Moreover, the computerized system provides possibilities for the solutions to be manipulated by a scheduler. Within the DSS approach the cooperation between operator and machine is a core principle. This means that the development of a computerized system is not aimed at replacing the decision maker but at supporting him/her. The design of the DSS is for the time being central to this approach (Spraque & Carlson, 1982). An example for nurse scheduling follows next.

Bell, Hay and Liang decomposed the nurse scheduling problem by the following argumentation: *‘the nurse scheduling problem is potentially so complex that no single formulation or algorithm can provide a workable solution for every possible variation of the problem’* (p. 143). Since their developed algorithm resulted in incomplete schedules, adaptations were needed for the specific requirements of nurse scheduling like quantitative staffing of a shift and breaks between shifts. These adaptations were accomplished with the heuristics method, which together with the applied algorithm, are typical of the OR approach. However, their DSS approach becomes clear when they present the generated schedules on a graphical interface to the scheduler. Because of the visual nature of the nurse scheduling problem a visual interactive model was designed by Bell, Hay and Liang. In this visual model the generated schedules were displayed and the scheduler was allowed to manipulate these schedules by using the user-friendly interactive interface. After making the necessary corrections, the model was able to run again after which the new results were presented. The visual model was easily understood and the application led to satisfaction among the schedulers. The attention which was given to interactivity in building the nurse scheduling system, as employed by Bell, Hay and Liang, turns out to be a great advantage of the DSS approach, though the emphasis is still on representing the problem in an OR model. The DSS approach stresses the operator-machine cooperation in decision making and problem solving. Hereby it reveals the importance of the judgment of the scheduler in cooperation with the computerized system, though less attention was given to the 'decision' beforehand and more to the aspects of 'support' and 'systems'. This means that less attention was given to the decision maker him/herself. It marks the change to the knowledge-based approach.

Other examples of nurse scheduling systems developed within a commercial setting are the Dutch so-called W3 system (BVA) and the SQUARE system (Wolf Informatica). These two systems resemble more the OR and DSS approach than the knowledge-based approach. The latter generates a cyclic schedule while both represent the nurse scheduling problem according to an OR algorithm. Examples of the DSS approach carried out for other types of planning problems are Production planning (Verbraeck, 1991), Manpower planning in an air line (Verbeek, 1991) and Trip planning (de Jong, 1992).

2.4.3 The Knowledge-Based System approach

The Knowledge-Based system approach shifts the attention to the scheduler who has acquired expertise in performing decision making. The central role of the scheduler is the most important difference with the DSS approach. The expertise forms the basis for understanding the problem, while the computerized system incorporates the elicited knowledge and then processing it by symbolic reasoning, provides it to the user. The system incorporates this extra aspect in comparison with the DSS approach; moreover, the knowledge and rules are available and accessible for other schedulers as well.

Two examples are given in the following. The first example illustrates this approach in its attention to the manual way of scheduling, while the second example illustrates the completion of the DSS approach by the Knowledge-Based approach. Although the nurse scheduling system used in this study also comes under this approach, it will be discussed further in chapter 7.

Okada and Okada (1988) conceived the difficulty *'of defining the concept of an "optimal schedule" in a strict sense'* (p. 54). This was complicated because of the many allowable solutions; therefore, they argued that a mathematical method would be inappropriate for the nurse scheduling problem. They chose therefore a heuristic method, which, however, is of a different kind in comparison to that of Smith and Wiggins (1977). It is *'aimed at solving the problem by applying the procedure which is similar to a manual method'* (p. 54). This means that Okada and Okada did not direct their problem representation through mathematical considerations but based it on distinctive subproblems according to the manual procedure such as was performed by the scheduler. The content of the model resembles thus the manual situation. This is in contrast to the previously described mathematical models of the nurse scheduling problem, which did not reveal such a clear link with the manual situation. Rather, the computerized system they developed presented the schedule whole, so that the generated subsolutions of the schedule could not be traced back by the scheduler.

Courbon and Esaki (1992) have investigated the value of a hybrid between the DSS and Knowledge-Based approach in the domain of nurse scheduling. Their criticism towards the DSS approach is that it capitalizes on interactivity by means of *'the possibility to experiment through manipulation of a visual representation of a problem'* (p. 384). Therefore, Courbon and Esaki prefer to extend the DSS approach with a Knowledge-Based approach when they remark *'it started from the pure interactivity approach and incorporated knowledge incrementally later on'* (p. 384). In their view, the Knowledge-Based approach represents the opportunity to incorporate knowledge during the development phases of the nurse scheduling model. For the most part, this means that the knowledge of schedulers is elicited from the performance of the schedulers with the prototype system. Thereafter, they built an object-oriented model consisting of objects and classes of these objects. Nurse scheduling, in their model, was represented in a hierarchy of classes which inherits objects and properties from other classes. An advantage of object-oriented modelling is that new objects can easily be added to the model, which is in essence the Knowledge-Based approach. In contrast to several of the aforementioned researchers, they did not decompose the nurse scheduling problem but their DSS computed the complete schedule at once. The schedulers also worked interactively with the DSS in order to make necessary corrections in the schedule. They emphasized the importance of participation of schedulers in building a DSS. Only through having schedulers participate in the early phases of the system by letting them work with the prototype can the Knowledge-Based approach be adequately performed. A slightly different approach, strongly influenced by cognitive science, is the elaboration of the Knowledge-Based approach as performed in this thesis. A summary of the different examples of nurse scheduling discussed is given in table 2.1.

Table 2.1 OVERVIEW OF NURSE SCHEDULING SYSTEMS

	Smith & Wiggins 1977	Arthur & Ravindran 1981
approach	OR	OR
model	algorithm	goal programming
heuristic	yes	yes
problem decomposition	two phases	two phases
scheduling pattern	flexible	flexible
manual adaptation	yes	yes
scheduler	-	-
software	Fortran	-

	Bell, Hay & Liang 1986	Fitzpatrick, Farell & Richter 1987
approach	DSS	OR
model	algor, visual interactive	mathematical model
heuristic	yes	-
problem decomposition	two phases	three phases
scheduling pattern	cyclic rotational	fixed pattern
manual adaptation	yes	no
scheduler	-	-
software	software package, database software	Lotus 1-2-3 spreadsheet

	Rosenbloom & Goertzen 1987	Okada & Okada 1986
approach	OR	knowledge-based
model	algorithm	-
heuristic	no	yes
problem decomposition	three phases	manual
scheduling pattern	cyclic	flexible
manual adaptation	no	no
scheduler	-	+
software	Basic, Pascal	Prolog

Table 2.1 OVERVIEW OF NURSE SCHEDULING SYSTEMS (continued)

	Ozkarahan & Bailey 1988	Courbon & Esaki 1992
approach	OR	DSS / knowledge-based
model	goal programming	object-oriented
heuristic	yes	no
problem decomposition	two phases	none
scheduling pattern	flexible	flexible
manual adaptation	yes	yes
scheduler	-	-
software	-	Smalltalk

	Diskus 1992
approach	AI / knowledge-based
model	object and rules
heuristic	yes
problem decomposition	many phases
scheduling pattern	flexible
manual adaptation	yes
scheduler	++++
software	Nexpert, C, MS Windows

2.5 CONCLUSION

The discussion of the nurse scheduling domain reveals the position of nurse scheduling in the organization and it also reveals the influence of the organizational environment on the nurse scheduling task. The scheduler responsible for taking into account all the various aspects of nurse scheduling plays a very important role in the making of the schedule. In practice, the scheduler is content when a feasible schedule has been attained. The management of the hospital hardly get any feedback on the role of the nurse scheduling policy. Decision support may be of help for the scheduler in generating schedules. The expected role of decision support is underlined by the different illustrations of the nurse scheduling systems from the research literature. The three different approaches applied by researchers form a logical transformation stimulated by technical and theoretical developments in information technology. It offers possibilities for more in-depth considerations about decision support in nurse scheduling. However, there is less research performed which follows the knowledge-based approach in the nurse scheduling domain. This study elaborates on this aspect. In chapter 3 the research approach used within the Knowledge-Based approach is further explained.

CHAPTER 3

THE METHODOLOGICAL FOUNDATION AND THE RESEARCH APPROACH

3.1 INTRODUCTION

The present chapter discusses the methodological foundation and the research approach used to find an answer to the research questions addressed in this study. The research questions determine the requirements for the research approach. Firstly, understanding the knowledge and rules in the nurse scheduling domain requires an empirical research approach. This is related to the scientific aim of the study. Secondly, there is a need to investigate the knowledge and rules of the scheduler in a practical setting. The results illustrate the practical relevance of the study. The combined play of theory and practice will continuously be attended to in this study. The capriciousness of a practical setting along with the methodological strength of scientific research bear upon the character of this study. This is a challenge which may well be typical of research in the field of management and organization.

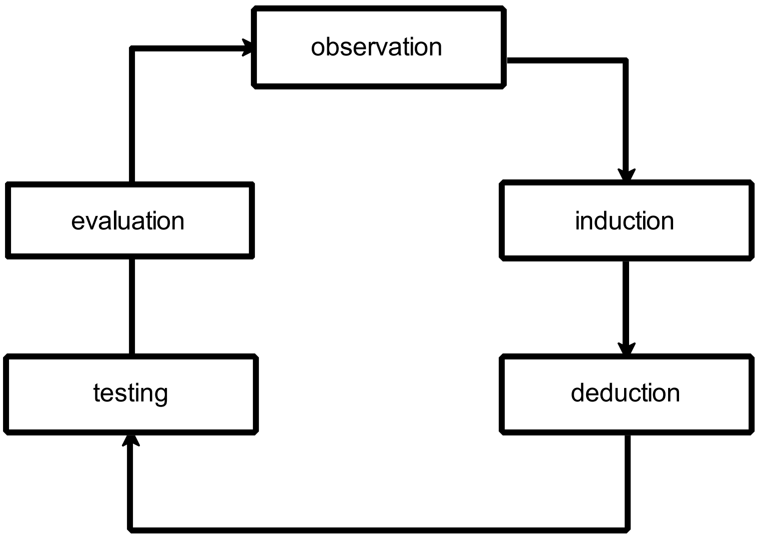
The empirical research as applied in this study is anchored in the behavioural sciences. The empirical approach is explained by discussing two relevant methodological models, viz. the empirical cycle (de Groot, 1961) and the regulative cycle (van Strien, 1975, 1986). It involves reflecting on the value of scientific statements on the one hand and providing more practical guidelines for researchers on the other hand. The former concerns primarily the way of reasoning that is related to the more philosophical aspects of methodology (see Hofstee, 1980; de Groot, 1961; Koningsveld, 1976; Lakatos, 1970; Popper, 1959; van Strien, 1975). The latter concerns the practical guidelines that deal with method and techniques that are necessary to organize research efficiently and effectively (see Meerling, 1980; Neale & Liebert, 1980; van der Zwaan, 1990).

My research closely follows both the empirical and regulative cycle in order to make recommendations for an effective decision support design based on understanding human planning. Such a use of the two cycles in one study could increase the value of research in the field of management and organization. This is further elaborated by discussing the two models first and then examining their possible role in the discipline of management and organization in general.

3.2 THE EMPIRICAL CYCLE AND THE REGULATIVE CYCLE

The empirical cycle will be discussed first. The empirical cycle aims at developing theories within a dominant paradigm. A theory refers to a body of knowledge consisting of a particular number of coherent rules. A theory is used for prediction and explanation of relationships among variables. It is attained by testing hypotheses with empirical data in order to reach general statements. The empirical cycle represents the hypothetical-deductive research approach. It includes several phases which are depicted in figure 3.1.

Figure 3.1 THE EMPIRICAL CYCLE



In the *observation* phase the emphasis is on the collection of empirical facts. In the next phase, *induction,* the aim is to specify explicitly the hypotheses on the basis of the observed facts. Hypotheses need to be defined in measurable variables in order to derive concrete predictions. This is the main focus in the *deduction* phase. Next, these predictive statements are checked in the *testing* phase by collecting new empirical data in order to examine whether the relationships among variables as predicted can be found in the new data. In the last phase, *evaluation,* the results are interpreted within the framework of the specified hypotheses and theories. The *evaluation* phase is interpretative by nature, generating ideas for new hypotheses and research. The *evaluation* phase runs smoothly into the first phase of the empirical cycle. Ideally, all phases should be run through in any research and it is worthwhile aiming for this goal. This need not happen in every type of research. Sometimes relationships among variables cannot be predicted because theories are lacking for the problem under consideration. Then the research is mostly of an explorative nature and only some of the phases would be run through. Moreover, the different phases would not be executed separately as presented in the model. The way the empirical cycle is applied depends mostly on the type of research.

Inductive-empirical research applies the empirical cycle in a strict sense following the requirements of the scientific method, while other types of research, such as descriptive research or explorative research, apply only one or a few of the phases, mostly in a less strict order (de Groot, 1961). The emphasis in these last two types of research is on the first two phases, *observation* and *induction*. Because of lacking theory and insight into the nature of the problem, the researcher is not able to specify the relationships between variables as clearly. On average it is difficult or even impossible to specify hypotheses beforehand. The research questions put forward in explorative and descriptive research are therefore not aimed at testing hypotheses. Naturally, on the basis of the results hypotheses could be specified afterwards which can then be tested in research. Descriptive research stresses the description of a variable whereby the relationships between variables are subordinate (Janssens, 1982), whereas in explorative research the researcher has suppositions about the nature of the problem. Both explorative and descriptive research address understanding such variables as measured in these types of research. It can be considered a first step in validating concepts. This study uses explorative research. This means that variables and relationships among variables which describe the manual performance of a planning task can not be determined in advance.

The last characteristic aspect of the empirical cycle is that the researcher is a spectator who is not a part of the problem being studied by means of personal involvement. This implies that there is a separation between the researcher and the research object.

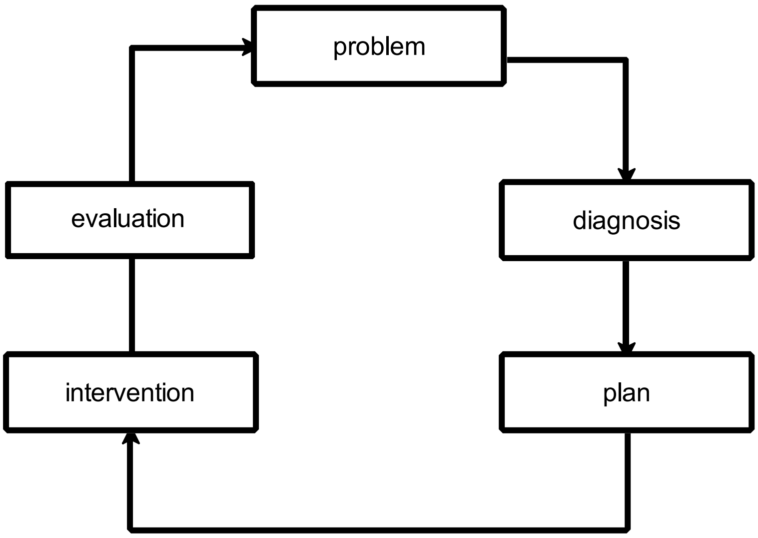
The empirical cycle is a stringent scientific method. The inductive-empirical approach uses the empirical cycle in order to understand and explain problems with the emphasis on the development of theories. In order to fulfil the requirements of the approach an artificial situation is created which often bears little resemblance to a natural situation. In such a case the empirical cycle would not seem workable for all types of research. Difficulties may arise when the problem being studied is embedded in a natural setting. This is the case for this study. Often such a problem does not conform to the rigidity of the research model. Despite striving to follow the cycle as strictly as possible, the researcher needs to make some concessions in the use of it. Unexpected things might happen because of which a strict control on collecting data cannot be maintained or because of which a person cannot spend as much time taking part in the research. In addition, the aim of the research could be that a problem needs to be solved by generating a concrete solution. In practice many problems exist which need to be solved by a realistic design; for example, a decision support system needs to be designed to support a planner, or a method for organizational diagnoses needs to be developed to help a manager. Typically the result of such research is that some intervention in practice will take place. The empirical cycle does not deal with this aspect.

Van Strien (1986) developed the regulative cycle which aims at intervening into practice by making a plan in which the focus is on solving an individual problem in particular circumstances. There will be a clear client organization which has a problem and which is involved during the whole cycle. This means as well that the researcher is also involved with the problem situation. The problem situation and the research are influenced by each other. The developed plan is often only suitable for that specific situation. In this respect the regulative cycle does not aim at general statements or at developing theories. The important criterion is the adequacy of the solution. However, it could be tentatively defended that a theory about a design for solving a problem has been developed. Also, the choices made in the development of the design are justified by arguments and rules.

The regulative cycle consists of the following phases as depicted in figure 3.2.

The first phase comprises the identification of a problem which is further diagnosed in the second phase. In the next phase a plan is developed in order to solve the problem. In the intervention phase the plan is implemented in practice, which is evaluated in the last phase in order to check whether the problem has been solved. This phase may lead to new problems which means that the cycle starts again. The first three phases in the regulative cycle are characterized for the most part by thinking, whereas the last two phases consist of doing. It is sensible to display a critical attitude by reflecting on the results of performed acts. Moreover, the transformation between two phases, from a diagnosis to a plan, takes place through theoretical reflections.

Figure 3.2 THE REGULATIVE CYCLE



The regulative cycle is normative in the sense that the development of a design or plan is guided by an objective derived from the problem under consideration. Next, the developed plan functions as the norm for solving the problem. This normative character is included in each phase because there is a problem which needs to be solved in order to create better conditions. For example, the problem solving is directed by an organization model. The regulative cycle could therefore be useful for design-oriented research.

The stringency of the scientific requirements as in the empirical cycle could hardly be met because of the immediately active character of the regulative cycle. This means that the situation being studied is continuously involved in the research process. The researcher cannot just step out of the situation.

An overview of the differences between the empirical cycle and the regulative cycle is given in table 3.1.

It should be noticed that these two models lie at both ends of a continuum. Although these two models are mostly separately applied in research, de Groot (1961) and van Strien (1975) both indicate a relationship between the two different models: a theory as result of the empiric cycle can be processed in phases of the regulative cycle in order to act effectively. In this sense these two cycles benefit from each other. Moreover, theoretical insights are transformed into practical usability, and feedback from the design in practice stimulates a better understanding of theories. Besides being able to use the results of each cycle within the other cycle, it would also be possible to integrate (phases from)

Table 3.1 COMPARING THE TWO RESEARCH CYCLES

the empirical cycle	the regulative cycle
explaining	acting
theory	design
predictive	normative
researcher is spectator	researcher is actor

the empirical and regulative cycle within one research project. This could be achieved, for instance, by executing the *observation* and *induction* phases and thereupon grounding design guidelines for decision support. This refers to the *plan* phase. The *observation* and *induction* phases act as substitutes for the *problem* and *diagnosis* phases. This study uses a comparable integration of different phases from the two cycles.

3.3 THE ROLE OF THE EMPIRICAL AND REGULATIVE CYCLE IN THE DISCIPLINE OF MANAGEMENT AND ORGANIZATION

The discipline of management and organization cannot lean upon a research paradigm of long standing. The research object concerns the processes of management and organizations to be viewed from an interdisciplinary problem-oriented view and directed to management (de Leeuw, 1991). Defining the scope of research has consequences for the structure of the research. First of all, the influential role of the problem owner's links with the organization being studied must be taken into account. It is namely a perceived problem. Research will therefore often originate in an actual problem situation. Consequently, the practice of the organization has a great impact on the structure of the research. In solving the problem the main focus is on the practice and thus the role theory plays is of minor importance. The research process is merely guided by qualitative data and subjective judgments, though from a multidisciplinary point of view. Second, the researcher would not be an outsider any more. He/she is personally involved in communication with the problem situation. Third, the aim of research is to deliver so-called knowledge products which can be applied to solve the problem (de Leeuw, 1991), knowledge products which should be suitable for use in the organization in future, such as, for instance, a method for understanding management processes.

It is not surprising that the most frequently applied type of research is design-oriented research (Eynatten, 1989; den Hertog & van Assen, 1988). This type of research is addressed to design organizations in the broadest sense: for example, the implementation of a management information system, development of product innovations, and adaptation of organizational changes. Design-oriented research is based on the regulative cycle, whereby attention to the empirical cycle has been neglected. Consequently, the development of theories and generic knowledge about organizations will be moderate. The choice to emphasize the utility of the regulative cycle, whereby the empirical cycle is put aside, is prompted by de Leeuw (1991, p. 19) who states that the empirical cycle '*is hoofdzakelijk relevant bij zuiver wetenschappelijk onderzoek*'[1]. De Leeuw's opinion regarding the great distance between the empirical and the regulative cycle does not agree with those of de Groot and van Strien. When starting research with the aim of finding a concrete solution for a problem the one-sided emphasis on design-oriented research is understandable; however, it does not justify paying less attention to the scientific point of view. Moreover, a synthetic research approach consisting of a scientific method in combination with design-oriented research has been advocated in the discipline of management and organization. Volbeda's recent thesis (1992) as well as this thesis are examples of such a synthetic approach in which theories determine part of the research process. By following the scientific approach the role of the problem owner will be less influential in doing research, though practice imposes specific requirements which are difficult to keep under control due to uncertainty and lack of time. In spite of this it should be a challenge and a necessity to maintain a scientific approach in the discipline of management and organization. If the empirical cycle is abandoned, then the building of theories is left to coincidence and the knowledge derived is founded on obscurity. Actually, the choice of a specific type of research should be postponed and it should be guided more by the nature of the research questions instead of by the problem owner.

In this study the starting point concerns the problems the scheduler has with making schedules in daily hospital practice. The practical issues are interpreted using insights from problem-solving theory in order to formulate the research questions. The role of the scheduler as the problem owner has first been put aside, because the aim was to acquire insight into scheduling that can be applied to other hospitals as well and that can be used for the design of the computerized nurse scheduling system. By choosing a specific research design (see 3.4) it is possible to derive recommendations for effective decision support.

3.4 RESEARCH DESIGN

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[1] is mainly relevant in pure scientific research

The execution of the different phases of the two cycles is supported by available methods and techniques. Which methods and techniques have been applied is described in the research design. The design of a research study determines its validity, whether it can reasonably be transplanted to other situations. Besides the external validity, the internal validity signifies that the measurements can be ascribed to the effects of the manipulated (independent) variable (Neale & Liebert, 1980). It is important therefore that the research be performed in a controlled setting. In order to make comparisons between different situations a quasi-experiment was chosen which contains two different experimental settings and different groups of subjects. The collection and the interpretation of data measured in the two settings is served by the cognitive task analysis. The present paragraph reports the research design applied in this study.

3.4.1 Three groups of subjects

Several hospitals participated in the DISKUS project. Some of them cooperated in this research by offering scheduling expertise. Eighteen subjects agreed to participate in this study after receiving an explanation of its purpose. They were classified as either an expert or a novice in the field of nurse scheduling on the basis of their experience with this task. The expert group consisted of six head nurses who were acquired from two hospitals. All of them had performed the monthly-recurring task for longer than four years. For the most part their knowledge and skills in this field were learned by doing. Although they had access to practical handbooks on nurse scheduling, these books were consulted only occasionally.

The novice group consisted of twelve student nurses who were all studying at the same school: six of them had already gained practical experience in their future profession while the other six student nurses only had theoretical experience with nursing. These two groups were denoted respectively the novice- practical training (novice-p) and novice-no practical training (novice-np) group. None of them had ever performed a nurse scheduling task and in case of the novices-p, they only knew this domain by being scheduled during their practical training periods.

Except for four novices who finished their education at the school for nursing, all participants were involved in both studies where the nurse scheduling task was investigated in the manual situation and under conditions of decision support.

3.4.2 Mixed design

The study consisted of a mixed design which, in accordance with Neale and Liebert

(1980), was designed so that the three groups did not overlap. This implies that the subjects of the expert group and the two novice groups were not interchangeable with respect to their experience in the field of nurse scheduling because the experts were familiar with this task and the novices were not. This means that the degree of experience was a subject-related variable. It also means that there is not a control group as required in an experimental setting. Lastly, the subjects did not receive a particular treatment but are placed in two different settings. This study is therefore regarded a quasi-experiment.

The task performance of the scheduler, i.e., the dependent variable, was investigated under the different conditions of the scheduling task, i.e. the manipulated variable. The schedulers made a schedule in the manual scheduling condition first. About one year later, or sometimes more, the scheduler made a schedule in the decision-support condition. The nurse scheduling system was built during the intervening period.

A mixed design yields within-subjects comparisons of the expert group and the novice groups as well as between-subjects comparisons (Table 3.2). Therefore, a mixed design reveals the general applicability of the experimental effect of the manual and the decision-support conditions.

The number of participants is indicated in the cells.

3.4.3 Cognitive task analysis

Cognitive task analysis (Roth & Woods, 1989) is the method used to reveal

Table 3.2 A MIXED 2x2 DESIGN

	experts	novices
manual	6	12
decision support	6	8

the knowledge and rules of the expert and novice subjects. Those knowledge and rules are elicited that underlie the task performance when the subject makes a schedule. It sets up the data for interpretation within the framework of problem-solving theory. In addition, it results in an interpretation of the cognitive demands of the scheduling task. The cognitive demand refers to the cognitive processes which are required when a task performer accomplishes a planning task and it is determined by the complexity and difficulty of such a task. This is in accordance with Roth and Woods (1989, p. 247): '*a cognitive task analysis is used to derive a description of the cognitive demands imposed by a task and the sources of good and poor task performance*'. These 'sources' refer to the knowledge and rules of a scheduler that influence the level of the task performance. Thus, the outcome of a cognitive task analysis is a generic model of cognitive processes on which the design of decision support should be based (Rasmussen, 1986).

A cognitive task analysis comprises both a knowledge acquisition and a knowledge representation phase, but for the most part it concerns the first one. Before explaining in more detail the knowledge acquisition phase, which is stressed in this thesis, I will briefly describe the knowledge representation phase. Knowledge representation as part of the cognitive task analysis means a formal presentation of knowledge in production rules, frames or scripts, semantic networks, or conceptual graphs (Jorna, 1992; Luger & Stublefield, 1989). This phase is an important phase in building knowledge-based systems because it is the transformation to the implementation phase (Luger & Stublefield, 1989). 'Knowledge representation' in this sense should be distinguished from 'representing knowledge', which is comparable with knowledge modelling. The meaning of 'knowledge' in 'representing knowledge' refers to the carrier of knowledge, a human cognitive system. Knowledge in computerized systems differs from knowledge in human cognition: the latter could be uncertain and incomplete or even contradictory, whereas the same would cause problems in computerized systems (Jorna, 1989, 1992).

The knowledge acquisition phase embodies a systematic approach to gathering and interpreting different types of knowledge. In the field of Artificial Intelligence this phase is often denoted as the most essential phase for building knowledge-based systems and expert systems (Hayes-Roth, Waterman & Lenat, 1983; Luger & Stublefield, 1989). Presently, knowledge acquisition is also becoming more influential in the field of management decision making (Paul & Doukidis, 1986; Kim & Courtney, 1988).

The aim of knowledge acquisition is to obtain and structure systematically the knowledge of an expert (Wielinga, Bredeweg & Breuker, 1988). In this study knowledge acquisition is also applied in the case of the novices. Knowledge acquisition is performed by a number of steps. In the first step the emphasis is on acquiring insight into the problem. On the basis of this insight the knowledge and rules are more systematically investigated in the second step and in the last step the elicited knowledge and rules are interpreted and properly described. These three steps are respectively denoted as problem formulation, knowledge elicitation and knowledge modelling, and are further discussed below. The person in charge of a knowledge acquisition phase is called a knowledge or cognitive engineer. He or she is responsible for performing adequately these three subphases when investigating the knowledge and skills as well as for revealing the cognitive demands in a specific domain. This is often considered a time-consuming and difficult job.

The first phase of knowledge acquisition: problem formulation

The problem formulation phase is a generic orientation in the domain to begin the knowledge acquisition. The aim of the problem formulation phase is to portray a general overview of the domain under consideration embedded in the organization besides the environment of the task. It concerns forming an impression not only of the information needed to perform a specific task and of the various problems met by practitioners, but also of the organizational context of the domain under consideration. Consequently the researcher becomes acquainted with the domain under consideration as well as with the planner. The task performance of the problem solver is only slightly under consideration because this is the main object of the next phase. The results of the problem formulation offer insight into the domain which is processed in a design for the knowledge elicitation phase. Herewith analysis of the domain and the task performance are not performed in isolation. The unstructured interview is a good tool for investigating the domain in as unbiased a way as possible by asking broad and open questions. A design for the knowledge elicitation phase is based on the results of this phase. Knowledge elicitation is focused on the task performance.

Second phase of knowledge acquisition: knowledge elicitation

The knowledge elicitation phase applies several knowledge elicitation techniques in order to elicit the knowledge and rules of an expert or novice efficiently. Knowledge elicitation techniques differ from one another in the type of knowledge elicited. For example, an interview elicits knowledge of objects and relations among objects in the domain, whereas a thinking aloud protocol uncovers the reasoning processes underlying the task performance in a special domain. This means that not every technique is equally suitable for eliciting all types of knowledge. Therefore it is recommended that more than one knowledge elicitation technique to be applied the domain under consideration. Several readable overviews have been written about knowledge elicitation techniques by Burton and Shadbolt (1987), Boose and Gaines (1990) and van der Werff (1992). We applied three of these knowledge elicitation techniques.

The following three knowledge elicitation techniques were employed in this research: interview, observation of the task performance, and thinking aloud protocol.

Interview

The interview is used to obtain a general overview of the content and the nature of the domain under investigation as well as a description of the objects in this domain and the specific problems met (Bainbridge, 1985; Davies & Hakiel, 1988; van der Werff, 1992). It goes further into the matters mentioned in the unstructured interview by asking specific questions about those subjects. However, the value of the interview is limited because it does not result in a complete understanding of how knowledge is used during task performance. Other knowledge elicitation techniques are chosen in order to complete the picture.

Observation of the task performance

This knowledge elicitation technique is used to understand the actual performance of the task. Each scheduler is observed in the hospital when he or she is making a schedule for the ward. At the same time, the scheduler is asked to think aloud in order to reveal his or her reasoning processes. If needed, questions about the performance of the task are asked, for instance, in the case of scheduling the evening shift, asking why a specific nurse is assigned to that shift. Interrupting the scheduler should be restricted, however. The advantage is that a realistic insight into the specific problems of the ward are acquired in this way. There are two restrictions to using the observation of the task performance. Firstly, a precise comparison among the different schedulers cannot be made because of the differences in their wards and thus, in their specific scheduling problems. Secondly, observing the task performance gives a limited insight into the cognitive processes. From a methodological point of view it is not possible to control for artifacts, in contrast to an experimental situation. In order to investigate more precisely how the scheduling task is performed, a thinking aloud protocol was chosen.

Thinking aloud protocols

'Thinking aloud' is a useful knowledge elicitation technique for exploring the cognitive processes underlying the task performance of an expert or novice (Breuker, Elshout & van Someren, 1986); therefore, the thinking aloud protocol has been a generally accepted technique in research on problem solving for many years (Newell & Simon, 1972; Ericsson & Simon, 1984). In the thinking aloud protocol people are asked to speak aloud what they think while solving a specific problem. In other words an attempt is undertaken to verbalize the cognitive processes. (Elshout & van Leeuwen, 1992). Thinking aloud synchronizes thus with the cognitive processes. This differs from introspection where the cognitive processes have to be retrieved afterwards from memory. Verbalizations in a protocol are therefore more reliable. Another point is that when the task is well known to the subject, an accurate verbal report is obtained (Nisbett & DeCamp Wilson, 1977). Moreover, the thinking aloud protocol as a method gains power when offering a manipulated task, especially when such a task is offered to groups with different levels of expertise (Roth & Woods, 1989). Hayes-Roth and Hayes-Roth (1979) have already acquired experience with thinking aloud protocols in their research on a planning task for doing errands.

The 'thinking aloud' is tape recorded and transcribed literally afterwards. The outcome is thus a written document on which further analysis needs to be done, so-called protocol analysis. This gives an enormous amount of data which needs to be managed accurately. Often the interpretation of protocols is an iterative process (Bainbridge, 1985). On the other hand, the validity of a protocol analysis appears to be high. An elaborate description of the use and interpretation of thinking aloud protocols and a protocol analysis can be read in Newell and Simon (1972), Nissbett and DeCamp Wilson (1977) and Ericsson and Simon (1984).

Third phase of knowledge acquisition: knowledge modelling

The interpretation of the gathered data in the knowledge elicitation phase is realized in the knowledge modelling phase. The aim of knowledge modelling is to build a model of expertise which describes knowledge and rules involved in the task performance.

An interpretation scheme is needed to guide the process of structuring knowledge and rules adequately. The four-layer framework as distinguished in the KADS (Knowledge Acquisition and Documentation Structuring) methodology is useful for the further interpretation of the protocols (Wielinga, Schreiber & Breuker, 1991). KADS has been applied for describing diagnostic tasks. I consider KADS as a coding scheme to analyze the thinking aloud protocols.

This four-layer framework corresponds with four distinctive types of knowledge, respectively: *domain knowledge, inference knowledge, task knowledge and strategic knowledge*. This is depicted in table 3.3.

Table 3.3 KNOWLEDGE CATEGORIES OF EXPERTISE IN THE KADS FOUR-LAYER MODEL

knowledge category	elements	relationships with other knowledge categories
strategic knowledge	strategies meta-knowledge	controls task knowledge
task knowledge	task / goals	applies to inference knowledge
inference knowledge	knowledge sources meta-classes	describes domain knowledge
domain knowledge	concept relationships	

Domain knowledge contains static knowledge of the domain such as objects, properties, and relations between objects, for example, a nurse is either qualified as 'experienced' or 'inexperienced'. Further on, the domain layer is used by the so-called inference layer which contains *inference knowledge*. This type of knowledge processes objects from *domain knowledge*. Inferences refer to the basic actions of a domain as well as to the role of the domain objects. Examples of inferences are 'selection', 'abstraction', and 'refinement'. Special types of *inference knowledge* are knowledge sources and meta-classes. Wielinga, Schreiber and Breuker (1991) defines these as follows: '*A knowledge source performs an action that operates on some input data and has the capability of producing a new piece of information (?knowledge") as its output*' (p. 14) and '*A knowledge source operates on data elements and produces a new data element*' which is called a meta-class.

The task layer applies knowledge of the inference layer in order to attain the goals of a task. *Task knowledge* therefore controls how a goal is accomplished. The task layer contains knowledge of elementary tasks, which are defined by Wielinga (p. 18) as follows: '*a task is a composite problem-solving action*'. Further on, *task knowledge* consists of task, control terms and the task structure. The task structure is a decomposition into subtasks.

The strategic layer controls the task layer and it contains *strategic knowledge* which '*determines what goals are relevant to solve a particular problem*'(p. 21). The dynamic planning of the task execution is therefore organized by *strategic knowledge*. The model of expertise in KADS is a competence model. The KADS methodology does not provide an explanation of cognitive processes, which, in this study, is considered a restriction.

3.4.4 Procedure

The three phases of the knowledge acquisition belonging to the cognitive task analysis are part of the quasi-experiment. This is depicted in table 3.4.

The phase of problem formulation was only performed in the expert group under the manual condition, while the knowledge elicitation and knowledge modelling were performed for all subjects under both conditions.

In table 3.5 the sequence of knowledge elicitation techniques used in the knowledge acquisition phase are depicted for both the expert and novice groups. The unstructured interview, which was only performed in the expert group, focused on the role of nurse scheduling in the hospital in order to become acquainted with the nurse scheduling domain. Furthermore a structured interview was performed which comprised questions about the most relevant aspects of the nurse scheduling domain. The experts were interviewed twice for the problem formulation phase, the interviews taking about two hours each, whereas the interview with the novices took about 30 minutes and they were interviewed just

Table 3.4 DESIGN OF THE QUASI-EXPERIMENT

	manual condition		decision support condition	
	experts	novices	experts	novices
problem formulation	yes	no	no	no
knowledge elicitation	yes	yes	yes	yes
knowledge modelling	yes	yes	yes	yes

once, and less extensively, prior to the manual performance of the nurse scheduling problem. The interviews were performed by different interviewers.

The observation of the task performance was done to comprehend how the expert was making a schedule for his or her own ward. Based on the data derived from the interviews and the observation of the task performance, a manipulated task, i.e. a scheduling problem (see 3.4.6), was made for the actual thinking aloud protocol.

Table 3.5 KNOWLEDGE ELICITATION TECHNIQUES USED

	unstructured interview	structured interview	observation	thinkout aloud protocol
experts	yes	yes	yes	yes
novices	no	yes	no	yes

The actual quasi-experiment was run either in the private offices of the head nurses (the expert group) or for the novice groups in a quiet classroom at school. All subjects were asked not to exchange any information about the presented scheduling problem during the period the experiments took place.

The written scheduling problem was presented and the participant was asked to make a conclusive schedule. All the necessary information needed to generate a schedule had been offered. Each subject had as much time as was needed for making his or her definite schedule. During the task performance the participants were asked to think aloud, and this was recorded on tape (thinking aloud protocol) at each session.

3.4.5 Statistical analysis

A number of tests were used for the statistical analysis of the data. The Kruskal-Wallis test aims at testing whether the scores on a variable differ between groups. This was used when there were more than two groups. The variable should be measured on the ordinal level. The population to which the groups belong need not fulfil the normal distribution and the variances need not be the same either. When there were only two groups of subjects then the Mann-Whitney-u-test was used. The Fisher-eksact-test can be used to test the independence between variables. The scores are expressed in frequencies in a 2 x 2 table. The F-test was used to test whether the variance between the groups of subjects differs for a variable whereby the alpha needs to be chosen.

3.4.6 The scheduling problem

The scheduling problem offered to the subjects concerned a ward in a general hospital where sixteen registered nurses and five student nurses were working. All the data were derived from a real situation except for the names, for which fictitious names were substituted for reasons of confidentiality. The task of the scheduler was to make a schedule for a one-month period. An over-view of the characteristics of the registered and student nurses was presented with regard to full-time or part-time work, their function and their quality (expressed as more versus less experienced for the registered nurses). The student nurses were first through fourth year students. The ward was supervised by one head nurse and one deputy nurse. The quantitative staffing of the day, evening, and night shifts was presented as well as the staffing in the weekends. Additional information concerning recent night shift history, weekends off, courses, wishes, general agreements and vacation for each nurse was also given. All data were presented on written notes in advance, including an empty framework for a schedule, together with different coloured felt pens, as well as the different codes of each shift. The same scheduling problem was used with the ZKR system in the decision support setting.

3.4.7 The research design of this study

An overview of the research design applied in this study is given in figure 3.3.

This figure shows all knowledge acquisition phases that were passed through in this study and the data provided by each step. The boxes labelled 'manual' will give the answer to the first research question about the task performance, whereas the boxes labelled 'decision support' as well as the comparison between 'manual' and 'decision support' give answers to the second research question. The other three boxes refer to the answers to the last research questions. The top boxes refer to the first two phases from the empirical and the regulative cycles, viz. the observation/problem phase and the induction/diagnosis phase. The central part elaborates further on them whereas the right part of figure 3.3 is the working out of the design phase of the regulative cycle.

CHAPTER 4

THE TASK DOMAIN
AND
THE STRUCTURING OF THE DOMAIN KNOWLEDGE

4.1 INTRODUCTION

The notion of understanding the problem solving underlying the performance of a task is gaining more and more attention for designing decision support in complex domains (Howell, 1993), because in such so-called semantically rich task domains *'successful performance calls for specific knowledge as well as general problem-solving skill'* (Simon, 1979, p. 369). Moreover, dealing with an ill-structured task where problem solving is needed requires extensive knowledge (Voss & Post, 1988). In order to understand problem solving as discussed in chapter 1, a description of the task environment or task domain is essential.

The task domain sets up one of the three elements of any problem solving situation where the problem solver and the task as such being the other components. The nurse scheduler performs the planning task in the task environment whereby knowledge extracted from the task environment is processed. This 'knowing what' refers to domain knowledge consisting of entities, properties and relations among entities. Domain knowledge is therefore considered domain specific. What we understand commonly by domain knowledge is declarative knowledge (Anderson, 1983). This needs to be distinguished from procedural knowledge, which merely refers to 'knowing how', and explains the way the task itself is executed. Procedural knowledge is understood by inference, task and strategic knowledge which forms for the most part the underlying processes of the task performance.

The acquisition of domain knowledge is important for solving the nurse scheduling task adequately. A comparison between expert and novice schedulers offers insight into the role of domain knowledge. Generally speaking, along with the fact that experts and novices have different amounts of experience in the performance of the task, the content and structure of domain knowledge differ among them as well (Glaser & Chi, 1988). Experts not only have a greater domain knowledge but have also organized their knowledge into meaningful patterns or chunks (Schank & Abelson, 1977; Glaser, Strauss & Chi, 1988; Soloway, Adelson & Ehrlich, 1988). Such an organization of domain knowledge leads to more efficient problem solving.

As stated by Glaser and Chi (1988) there are *'strong interactions between structures of knowledge and processes of reasoning and problem solving'* (p. xxi). The task performance depends therefore partially on the content and the structure of domain knowledge (Schaafstal, 1991).

In the present chapter results are discussed concerning the domain knowledge in nurse scheduling. The domain knowledge was obtained from the interviews and thinking aloud protocols, described in detail in chapter 3 along with the handbook of nurse scheduling and other written materials. The data from each interview as well as each individual thinking aloud protocol were analyzed by using the four-layer model as given by KADS (knowledge acquisition and documentation system). This method, as described in chapter 3, results in an overview and abstraction of the domain knowledge related to the nurse scheduling task domain. In particular, the interviews were analyzed to determine to what extent the schedulers acquired domain knowledge, whereas the protocol analysis was intended to be used to reveal the specific relationships among domain entities referring to the structure of domain knowledge. First, the task domain of nurse scheduling is discussed in general, and second, a comparison between expert and novice schedulers with respect to their domain knowledge in nurse scheduling is made in order to get insight into the content and organization of domain knowledge.

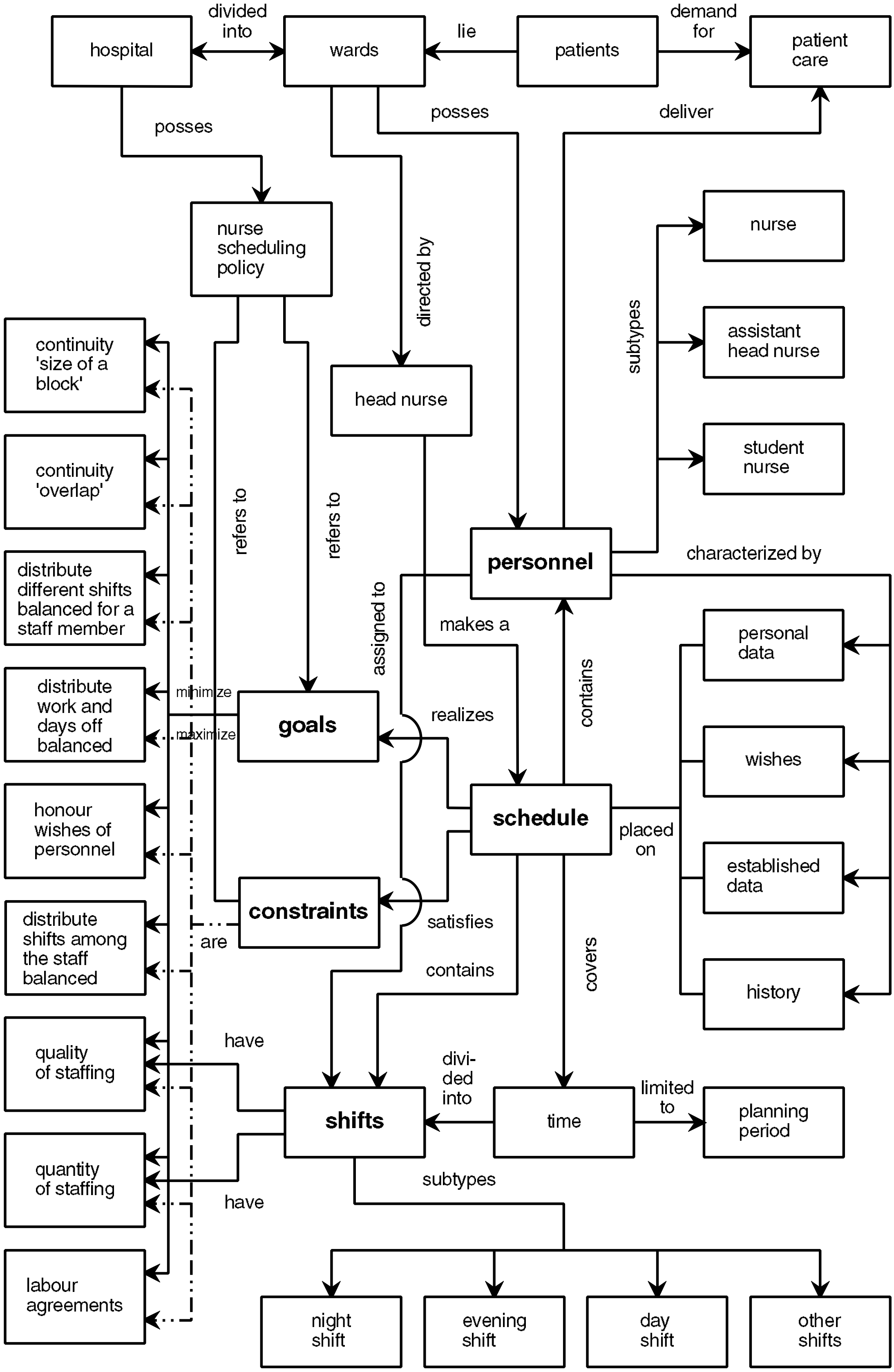
4.2 THE TASK DOMAIN VIEWED FROM THE TASK PERFORMANCE PERSPECTIVE

A description of the task domain denotes the several domain entities and their mutual relationships. This is depicted in the conceptual model in figure 4.1.

The conceptual model depicts the embedding of the nurse scheduling task in the organization. Besides, it refers to activities belonging to the nurse scheduling task. The domain entities hospital, nurse scheduling policy, patients and patient care were discussed in chapter 2. In the present chapter I discuss further those entities related to the task domain.

Different clusters of domain entities can be composed each referring to a particular aspect of nurse scheduling, viz. the schedule itself, the shifts, the personnel and the goals and constraints. A first cluster of domain entities is related to the schedule itself, namely *time, planning period, personnel, shifts, goals*

Figure 4.1 CONCEPTUAL MODEL OF THE TASK DOMAIN IN NURSE SCHEDULING



and constraints. A second cluster elaborates on a specific part of the schedule, and contains the domain entities *schedule and shifts, quantity and quality of staffing and the day, evening and night shift,* whereas the domain entities *the three subtypes of personnel, wishes, personal data, historical data and established data* make up a third cluster which further characterizes personnel. A fourth cluster refers to the different goals which primarily realizes acceptable solutions in the schedule. The allowable solutions of the schedule are specified by the last cluster referring to constraints needed to be satisfied in the schedule. These distinctive clusters are each considered to be a meaningful group of domain entities in nurse scheduling. It is assumed that a scheduler needs to acquire domain knowledge on such meaningful groups of domain entities for a proper fulfilment of any planning task. Therefore in this respect, they are further on denoted as knowledge of schedule, knowledge of shifts, knowledge of personnel, knowledge of goals and knowledge of constraints, respectively.

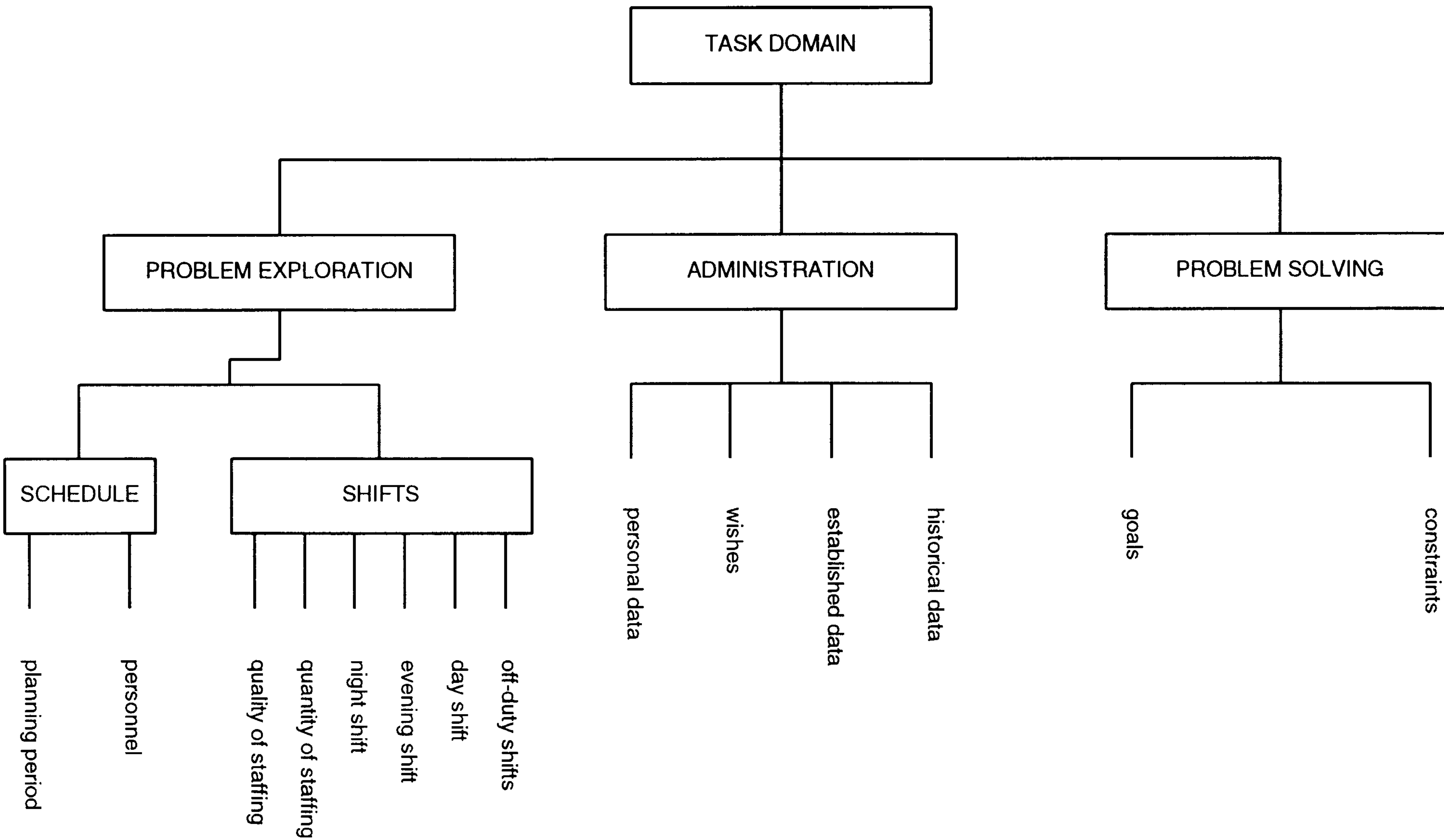
The conceptual model can also be viewed from a task performance perspective which results in a three-part division. The first part refers to the problem exploration which needs to be created by the scheduler in order to get a beginning state for starting the execution of the nurse scheduling task. It concerns especially knowledge of schedule and knowledge of shifts. The second part is the administration in which the different types of information characterizing personnel are processed. It concerns thus the knowledge of personnel. The third part of the conceptual model can be labelled as the problem solving, which refers especially to the scheduling aspects within the nurse scheduling task, in which the knowledge of goals and knowledge of constraints are processed. The task performance perspective is depicted in figure 4.2.

According to this partition from the task performance view, a detailed description of the domain entities of the task domain is given whereby their possible role in the nurse scheduling task is designated.

4.2.1 The ward

The nurse schedule is organizationally confined to a ward in a hospital. Information about the number of beds and the type of patients as a consequence of the nature of the illness are the typical aspects of a ward which are relevant for the accomplishment of a nurse schedule.

Figure 4.2 THE THREE-PART DIVISION OF THE TASK DOMAIN FROM THE TASK PERFORMANCE PERSPECTIVE



The ward is defined as follows:

domain entity ***ward***	
features	***value***
department of a hospital	neurology, surgery, internal ...
number of beds	10, 20, 30 ...

The implications for nurse scheduling of the department of a hospital, type of patients as well as the number of beds have been outlined in chapter 2. There is one schedule per ward. During the making of a schedule, the scheduler processes and arranges these different sorts of information, although in nurse scheduling, the number of patients and the demand for patient care are taken into account only to a small extent by schedulers.

4.2.2 The problem exploration

The schedule

The schedule is made by the head nurse. To start with, planning periods, shifts and personnel need to be placed in the empty framework of a schedule. This framework contains a matrix consisting of a horizontal and a vertical dimension, and the empty cells where these dimensions cross. The cells of this matrix are gradually filled during the performance of the task. The generated schedule needs to satisfy the constraints and the goals operative in nurse scheduling. The nurse schedule reveals an alternating pattern among shifts and one operational schedule covers a restricted time horizon (see also chapter 2).

Time

Time has a significant function in the nurse schedule: on the one hand, personnel is assigned to specific times of the day, and on the other hand, a nurse schedule is solved within the boundaries of a limited time horizon.

Planning period

The planning period denotes the scheduling horizon. At the beginning of the making of a nurse schedule, the scheduler fixes the time period to be scheduled which mostly consists of a four-week to three-month period. Therefore, the planning period is a constant factor in the generation of a schedule. The four to twelve weeks of the planning period are further divided into smaller parts, namely days of the week, which correspond to specific dates in the schedule.

domain entity ***planning period***	
features	***value***
month	January, February, March ...
week	week 1, week 2, week 3 ....
weekend	weekend 1, weekend 2, weekend 3
day	Monday, Tuesday, Wednesday ....

Personnel

The personnel are paramount in nurse scheduling because they need to fulfil the demand in patient care. Depending on the size of the ward, twenty to thirty employees are needed for adequate staffing. It should be noted that this number reflects the situation in Dutch hospitals. The personnel is a complicated factor in nurse scheduling because of the variety of information needed to be known in order to schedule personnel. First, the individual employees of a ward can be categorized according to their function into a head nurse, an assistant head nurse, a registered nurse or a student nurse. On the basis of these characteristics employees are placed in a ranked order on the vertical dimension of the schedule with the head nurse at the top and the students nurses at the bottom. Secondly, there are differences in education and work experience among employees. Therefore, the nurse scheduler qualifies registered nurses into experienced versus inexperienced, and student nurses into the capability of working independently versus dependently. Thirdly, employees differ with respect to their contractual hours and labour contracts. The specific assignment of an individual employee is formalized in the labour contract with the hospital. Personnel can be employed on a part-time basis with working hours ranging from 50 to 90% or employed on a full-time basis, i.e. 100% labour. Thereafter, labour contracts provide the opportunity for personnel to be assigned to specific shifts, for instance to work only in the evenings or nights. Finally, wishes expressed for specific shifts, such established data as courses and vacations as well as historical data are important information about personnel in the making of a nurse schedule. This will be further explicated in 4.2.3 and in chapter 5 as well. All the different properties of the domain entity personnel usually remain fixed for several consecutive monthly produced schedules, sometimes even for longer periods of time.

domain entity ***personnel***

features	*value*
function	head nurse, assistant head nurse, registered nurse, trainee
experience	experienced, inexperienced, independent, dependent
labour percentage	50%, 60%, 70%, 75% ...
wishes	day shift, evening shift, night shift, day off ....
education	course

The qualities of personnel play different roles in nurse scheduling (see chapter 5).

Shifts

In hospitals the 24 hours of the day are divided into a day, an evening and a night shift as main shifts. These shifts not only differ in the time of day but also in the demand on the quality and the quantity of staffing. The shifts to which personnel are assigned are denoted in the cells of the schedule. Apart from these three major shifts, there are also other shifts which only slightly differ with respect to working time. Therefore, these are not discussed further. Staffing the three shifts of a day causes irregular working hours for personnel which implies that special attention needs to be given to the resting hours for recuperation from work. Many precise rules about hours of rest are given in formal labour agreements. For instance, the completion of a night shift sequence should be followed by a period of two days off, which implies that an employee cannot be assigned to a shift in the schedule for two days. Other examples of schedule rules linked to specific shifts are the number of obligatory days off after working during Christmas so-called compensation days. Moreover, unpaid leave for trainees, short time and vacation have to be taken into consideration also.

domain entity ***shift***	
features	*value*
part of the day	day, evening, night
recover time	day off, vacation
special event	compensation day

4.2.3 Administration

Personal data

Personal data is related to individual staff members and the specific types were therefore discussed under the domain entity personnel. Personal data need to be accessible during scheduling, therefore some are placed on the schedule beforehand. Personal data form a criterion in the assignment of personnel to the different shifts. A student nurse who follows a course would not be available for a particular shift. A nurse working part-time should not be scheduled as a full-timer within a planning period because the extra working days should be compensated for in the next period.

Wishes

A wish is either a stated preference to work a specific shift or sequence of shifts on certain days or a dislike for a specific combination of shifts or days. All wishes are placed on the schedule. The role of wishes is a delicate aspect in the domain of nurse scheduling. The scheduler may decide on whether a wish is honoured or not during scheduling. Stating wishes by personnel is accepted as a most usual procedure and is often considered an acquired right for the employee in nurse scheduling.

domain entity ***wishes***

features	***value***
preference to combine specific shifts or work on particular days	day shift, evening shift, night shift, day off ....
statement by personnel that a combination of days or shifts is not preferred	day shift, evening shift, night shift, day off ....

Established data

Established data are mandatory in nurse scheduling because they refer to specific activities of personnel on days they cannot be assigned to shifts in the schedule. Examples are vacations and courses, which are often known for longer periods of time. It is necessary to collect this information before starting a scheduling job because schedulers are not allowed to change these data. Placing the established data on a schedule leads to part of the schedule being already complete. An illustration is the training of student nurses. When student nurses are at school to follow special courses or practise various skills, they are not available on the ward and cannot be scheduled. Thus, the educational program of the trainees on the ward has be known beforehand. Also, registered nurses follow courses to update their knowledge and nursing skills. Since these courses are considered as official working time, they have to be taken into account as established data in the creation of a nurse schedule.

Historical data

The historical progression of scheduled shifts for each nurse needs to be considered over an entire year. Historical data is important for deciding who is available for a shift. The historical data can be extracted from 'old' schedules and contains an overview of how many times an employee was assigned to different shifts as well as the date on which these shifts were performed. The scheduler continuously needs to update the historical data for each forthcoming schedule. This is particularly important for the scheduling of night shifts because night shifts cannot follow one another very quickly in sequence.

domain entity ***historical data***	
features	***value***
the last date of a shift	1-1-93, 2-1-93, 3-1-93 ...
how many times scheduled to a shift	0, 1, 2, 3, ...

Although this historical information can be objectively computed from old schedules, memory is often relied on in practice.

4.2.4 Problem solving

Constraints and goals

In the following, that type of domain knowledge is discussed that restricts the problem space during problem solving. The knowledge of constraints sets up the boundaries of the problem space. Moreover, it restricts the solution space. This means that solutions to the problem are situated in this space. During problem solving the constraints need to be satisfied in order to attain at least the minimal threshold for allowing solutions. For instance, two student nurses alone are not allowed to work in a shift. A satisfactory solution may be that one student nurse together with one registered nurse is scheduled for the night shift. Such solutions, however, may not be the 'best' solutions; therefore, the knowledge of goals indicates, on the contrary, the solutions regarded as 'better'. During problem solving the aim is to realize those goals; therefore, a goal function is derived from the goal. This goal function representing the goal state during problem solving, will be minimized or maximized, resulting in solutions considered to be optimal. If, however, the constraints are not met, they function as goals. Then only a satisfactory solution can be achieved.

The role of constraints and goals in problem solving is explained by means of domain knowledge about the quality of staffing in the night shift. The scheduler has a goal in mind about an ideal quality of staffing for the night shift, for instance, a team that consists of an experienced registered nurse and a student nurse. During scheduling the scheduler will try first to maximize this goal. When this fails for any reason, he/she will try to minimize the goal. For instance, the scheduler strives for a team that consists of two experienced nurses. In both cases success will give an optimal solution. If, however, when minimizing or maximizing, the goal function is not achieved, and thus the goal has not been attained, then the constraint related to the quality of staffing comes to the fore and functions then as the goal. Consequently, only a satisfactory solution can be obtained, for instance, a team that consists of one student nurse and one inexperienced registered nurse in the night shift.

Actually, the psychological order of the task domain that dominates the Artificial Intelligence view is realized here. Such a perspective differs from the view on goals and constraints common in Operations Research, which emphasizes the logical order of the task domain. The most important constraints and goals active in nurse scheduling are discussed below.

Labour agreements

The labour agreement aims at the regulation of on- and off-duty days, as a consequence of the irregular working hours in hospitals, for the most part. This means that it restricts the possible solutions. The labour agreement functions, therefore, mostly as a constraint within the problem solving. The collective labour agreement contains a number of regulations, the most interesting ones for the nurse scheduling task are discussed below.

Personnel receives four days off in a fortnight.

This regulation implies that 10 days of continuous work are allowed but should be followed by four days off. However, ten days of continuous labour in a hospital is considered hard to fulfil. Therefore, this rule is often not used but is transposed to assigning two consecutive days off to every five days of continuous work. On the basis of the foregoing regulation it is possible to let personnel work every weekend; however, this possibility is excluded by the following labour agreement rule which regulates weekends off:

Each person receives twenty-two weekends off in a year.

The time horizon of this rule covers a whole year and thus goes beyond the mostly used four weeks to three months scheduling period. According to this regulation it is allowed to assign four weekends within a delineated scheduling period but this should be compensated sooner or later in the year. Therefore, the scheduler needs to record the number of weekends off. It may be obvious that a proportional spreading of the assigned weekends is preferred in order to prevent problems at the end of the year. The following regulation strongly influencing the scheduling task is:

At least ten hours of rest has to be given between shifts.

In practice it is easy to implement in a nurse schedule. However, if a day shift follows an evening shift this is only allowed when this day shift starts later in the morning. The last regulation from the labour agreement to be mentioned is:

Every year 12 short time days (ATV) are assigned to each person who works full-time or else a proportional part will be assigned to part-timers. Two short time days have to be scheduled every three months. However, when an employee is sick on an assigned short time day, his or her short time goes out of date.

This regulation has implications for the scheduling task because the scheduler has to know how many short time days a person welcomes and how many of these days have already been assigned. Therefore, these data need to be recorded and kept by the scheduler. The following regulation is an elaboration of the former:

Short time days (ATV) should be connected to days off, whereby the quantity and quality of staffing should have attained the required minimal level.

This regulation induces specific patterns in a schedule as depicted in figure 4.3.

Besides the formal labour agreements, there are so called optional agreements which are defined by the management of a hospital or a ward. Although these agreements are considered to be of equal importance, they are allowed to

Figure 4.3 SHORT TIME EMBEDDED IN AN ALTERNATING PATTERN

	days of the week						
	S	M	T	W	T	F	S
nurse A	e	e	**st**	do	do	d	d
nurse B	d	d	do	**st**	n	n	n
nurse C	do	**st**	d	d	d	d	d
nurse D	do	d	d	d	d	**st**	do

legend: e = evening shift d = day shift
st = short time n = short time
do = day off

be weakened by the scheduler when a solution for the schedule can otherwise not be fulfilled. In this respect these constraints are dealt with as 'soft' conditions in the nurse schedule because they do not consequently have to be satisfied in the completion of the schedule, in contrast to the 'hard' constraints from the labour agreements which have an obligatory character. An example of such a 'soft' formal rule which may be violated from the optional agreement is:

> ***On a ward it is preferred that personnel work no more than eight days consecutively.***

The implementation of this rule satisfies a desired solution for the personnel. It illustrates the general character of soft constraints, implementation of which benefits the working atmosphere on a ward and the job satisfaction of individual staff members, in contrast to the formal labour agreements which are considered the minimal constraints in the generation of a schedule and determine the variety of allowable solutions, which are not always the most desirable solutions.

Quantity of staffing

The quantity of staffing denotes a specific number of staff members for a shift in the schedule. The scheduler strives for a balanced division of the quantity of staffing during the planning period. A balanced distribution of the quantity of staffing denotes that over several sequential shifts the number of employees remains stable. This is depicted in figure 4.4.

Figure 4.4 DISTRIBUTE THE QUANTITY OF STAFFING PROPORTIONALLY

day shift	balanced					unbalanced				
	days of the week					days of the week				
	M	T	W	T	F	M	T	W	T	F
nurse A	x				x	x	x			x
nurse B	x	x	x		x x	x	x	x		x
nurse C	x	x	x	x		x	x	x		x
nurse D	x	x	x	x			x	x	x	x
nurse E				x	x		x		x	x
nurse F		x	x	x					x	x
total number	4	4	4	4	4	3	5	3	3	6

A balanced distribution of staff members benefits the workload demand and the working atmosphere on a ward.

A minimal norm for the quantity of staffing in a shift is denoted as well. If the quantity of staffing is under this norm then patient care is not guaranteed sufficiently. In this respect the quantity of staffing functions as a constraint in a nurse schedule, though it is desirable to exceed the minimal norm.

Quality of staffing

The quality of staffing denotes combinations composed of different qualified staff members. The scheduler strives for a balanced distribution of differently qualified staff members among shifts during a planning period. A balanced composition of the qualitative staffing means that several consecutive shifts have a comparable distribution in the quality among the personnel during a planning period, as depicted in the figure 4.5.

A balanced distribution of staff members benefits the workload demand and the working atmosphere on a ward, comparable with the quantity of staffing. A minimal norm for the quality of staffing in a shift is denoted as well. If the quality of staffing is under this norm then patient care is not guaranteed sufficiently. In this respect the quality of staffing functions as a constraint in a nurse schedule, though it is desirable to exceed the minimal norm.

Figure 4.5 BALANCED COMBINATION OF QUALITY OF STAFFING

day shift	balanced							unbalanced						
	days of the week							days of the week						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S
exp. nurse	x						x	x	x			x		
exp. nurse		x	x					x			x	x		
exp. nurse				x		x		x			x	x		
inexp. nurse	x	x	x			x					x	x	x	
inexp. nurse	x			x	x	x	x			x	x		x	x
student nurse 1	x			x	x				x				x	x
student nurse 2		x	x				x		x	x			x	x
student nurse 3		x	x				x		x	x				x
student nurse 4				x	x	x		x		x				

legend: exp. = experienced
inexp. = inexperienced

Continuity of personnel within one shift

Continuity of personnel within one shift means that patients are looked after by the same nurse or nurses over several days. In the nurse schedule this type of continuity is attained by the "size of a block" for a shift. In figure 4.6 the patterns resulting from this type of continuity are depicted.

By achieving continuity of personnel within one shift, a crew thus works together in the same shift for several successive days. This continuity is directed towards the patients whereby a nurse can take care of one group of patients for several days in a row. This goal can be realized in a schedule by generating specific patterns and consequently assigning staff members to such a pattern.

Continuity of personnel among days for a shift

This is the second type of continuity whereby overlap of personnel between days is realized. Hereby, a crew of persons changes gradually person by person from one day to the other. The patterns that result from this type of continuity are depicted in figure 4.7.

Figure 4.6 CONTINUITY OF PERSONNEL WITHIN ONE SHIFT

	days of the week						
	S	M	T	W	T	F	S
nurse A	d	d	d				d
nurse B	d	d	d				d
nurse C				d	d	d	
nurse D				d	d	d	d
nurse E	d	d	d				
nurse F	d	d	d				
nurse G				d	d	d	
nurse H				d	d	d	d

legend: d = dayshift

This goal actually aims at an efficient and a reliable transfer of medical and nursing information to new persons coming into a team. It should be noted that these two types of continuity cannot ideally be attained at the same time: in fact they can only be realized at each other‘s expense.

The nurse scheduling goals discussed so far aim at efficient patient care and differ from goals which aim at work satisfaction among personnel. The goals aiming at efficient patient care should be fulfilled in every schedule during each planning period, whereas this is not always necessary for the goals which aim at work satisfaction among personnel.

Honour wishes of personnel

This is another example of a scheduling goal which aims at work satisfaction among personnel. The scheduler strives to honour the wishes of those employees who have declared a strong preference or dislike for shifts on particular days in the scheduling period.

Figure 4.7 CONTINUITY OF PERSONNEL BETWEEN DAYS FOR A SHIFT

	days of the week						
	S	M	T	W	T	F	S
nurse A	d	d					d
nurse B	d	d	d	d			d
nurse C			d	d	d	d	
nurse D					d	d	d
nurse E	d	d	d	d			
nurse F	d	d					
nurse G			d	d	d	d	d
nurse H					d	d	d

legend: d = dayshift

Distribute the different types of shifts in a balanced way for an individual staff member

Balancing the different types of shifts aims at an equal distribution of the different shifts during the scheduling period for each employee. For instance, when an employee has to work five evening shifts in a specific scheduling period, it is preferable to assign three evening shifts in the first week and two evening shifts in the third week instead of assigning these five evening shifts to a one-week period. In figure 4.8 this goal is represented for the day shifts in a four-week schedule.

Distribute work days and days off in a balanced way

A balanced distribution of working days and days off for full-time nurses results in a scheduling pattern whereby two days off together are assigned to every week. Part-time personnel obtain days off in accordance with their labour percentage. For the most part this goal is embedded in, and thus derived from, the formal labour agreements as discussed earlier. It is represented in the schedule pattern of figure 4.9.

Figure 4.8 BALANCED DISTRIBUTION OF SHIFTS

number of day shifts in one planning period		week 1	week 2	week 3	week 4
balanced	nurse A	3	3	4	3
	nurse C	4	3	3	4
unbalanced	nurse B	2	5	5	1
	nurse D	1	6	3	3

Distribute shifts among the different staff members proportionally

In contrast to the goal whereby the different shifts for an individual staff member had to be balanced over the scheduling period, this goal aims at an equal distribution of the different shifts between staff members. However, the total number of shifts an employee is assigned to depends on the percentage of labour and also on the individual labour contract. An example of a proportionate and disproportionate distribution of shifts for different percentages of labour, is depicted in figure 4.10.

Herewith the several domain entities indicated in the conceptual model are discussed. The conceptual model was viewed from two perspectives: first, a particular group of domain entities, referring to a specific type of domain knowledge as denoted in the beginning of this paragraph; second, the task performance perspective, referring to a particular type of domain knowledge. In the following paragraph the acquisition of domain knowledge is considered for the expert and the two novice groups.

4.3 RESULTS AND DISCUSSION: THE CONTENT AND STRUCTURING OF DOMAIN KNOWLEDGE

A scheduler has to learn different types of domain knowledge in nurse scheduling; these are knowledge of the schedule, knowledge of personnel, knowledge of shift, knowledge of goals and knowledge of constraints. The structure of domain knowledge is revealed by relationships among the different types. For

Figure 4.9 BALANCED DISTRIBUTION OF WORK DAYS AND DAYS OFF

	days of the week						
	S	M	T	W	T	F	S
balanced							
nurse A	w	w	w	o	o	w	w
nurse B	o	o	w	w	w	w	w
unbalanced							
nurse C	w	w	o	w	o	w	w
nurse D	o	w	w	w	o	w	w

legend: w work day
o day off

Figure 4.10 PROPORTIONAL DISTRIBUTION OF SHIFTS FOR ONE PLANNING PERIOD

	labour percentage	proportionate	disproportionate
nurse A	100 %	10 day shifts	10 day shifts
nurse B	50 %	5 day shifts	10 day shifts

example, the quantity of staffing is related to shifts as wells as to goals and constraints. The frequency of occurrence of different types of domain knowledge among the experts (Experts), novice with (Novice-p) and without practical training (Novice-np) derived from the interviews, are presented in table 4.1.

Although this study was meant to be exploratory, some testing on the data in table 4.1 is possible. The results should be interpreted tentatively. A comparison among the three groups for each type of knowledge was performed in order to check whether the experts, the novice-p group and the novice-np group differ in the content of domain knowledge. The Kruskal-Wallis test revealed a significant difference (Chi-square = 5.82, df = 2, $p < 0.05$) in respect to the knowledge of schedule. Thus, the three groups differ in the content of knowledge of the schedule. It is due for the most part to the novice-np group who lack some knowledge of the planning period and personnel in relation to the schedule. There is also a significant difference (Chi-square = 9.30, df = 2, $p < 0.009$) for the knowledge of shift. This means that the expert group, the novice-p group and the novice-np group differ in the amount of knowledge of shift. The novices and in particular the novices-np did not fully acquire domain knowledge about the shift, in particular they did not acquire much knowledge about the quality of staffing. A comparable significant difference (Chi-square = 10.3, df = 2, $p < 0.005$) was found in the knowledge of constraints. Again, the novices-np reveal a lack of knowledge about the quality of staffing. According to the Kruskal-Wallis test statistic there is a significant difference (Chi-square = 13.5, df = 2, $p < 0.001$) between the experts and the two novice groups for the knowledge of personnel. The same goes for knowledge of goal, which amounted to a significant difference, Chi-square = 9.4, df = 2, $p < 0.008$, as well. The significant results imply that the experts' domain knowledge is outstanding compared with the novices' domain knowledge, in particular the novice-np group. They had acquired less domain knowledge.

The novices and in particular the novices-np lack knowledge about some domain entities. It concerns the knowledge of goals as well as the quality of staffing related to both knowledge of shift and knowledge of constraints. With regard to knowledge of personnel they reveal a lack of knowledge concerning historical data. The explanation may be that knowledge of goals is acquired when making the nurse schedule. This implies that it is related more to the task than to the schedule itself. The tendency is for novices to acquire domain knowledge related to the schedule first. This is also illustrated by the differences in acquiring knowledge of the quality of staffing in comparison with the quantity of staffing. The latter is more visible in the schedule and consequently easier for the novice to acquire. The differences in domain knowledge may be reflected in the task performance. Due to lack of domain knowledge the novices-np may perform worse for that part of the nurse scheduling that processes that comparable kind of domain knowledge. This means that they can be expected to have less difficulty with honouring wishes compared with the *continuity* goal of personnel for a shift. In addition, they perform the administration more or less adequately but are unable to perform problem solving adequately. The novice-p should perform between the novices-np and the experts in problem solving since they have acquired more domain knowledge.

Table 4.1 FREQUENCY OF OCCURRENCE OF DOMAIN KNOWLEDGE

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
knowledge of schedule			
schedule	6	6	6
planning period	6	3	2
shift	6	6	5
personnel	6	6	2
knowledge of shift			
quantity of staffing	6	6	3
quality of staffing	6	4	1
knowledge of personnel			
personal data	6	4	0
wishes	6	6	3
established data	6	2	1
historical data	6	0	0
knowledge of constraints			
labour agreement	6	6	1
quantity of staffing	6	6	3
quality of staffing	6	2	1
knowledge of goals			
quantity of staffing	6	2	1
quality of staffing	6	4	1
continuity over days	6	2	0
continuity between days	3	1	0
distribution of shifts			
• per employee	2	0	0
• among employee	3	1	0
work days and days off	6	3	2
wishes	6	4	4

Besides a quantitative analysis of differences in domain knowledge, a qualitative comparison among the three groups is performed to get more insight. The experts and the two novice groups were more or less comparable with respect to the entities of knowledge of schedule, the quantity of staffing from knowledge of shift, the wishes from knowledge of personnel, the quantity of staffing from knowledge of constraints, and honouring wishes from knowledge of goals. The novices-p in particular had acquired a reasonable amount of domain knowledge; however, in contrast to the quantity of staffing from the knowledge of constraints, the quality of staffing of this category was only present in two of the novices-p. The several entities in relation to knowledge of goals were only present in a few novices-p. The fact that most of the novices had not yet acquired knowledge of goals could be due to the nature of this domain entity. On the one hand, goals are not perceivable in the schedule beforehand and, on the other hand, a goal is often an aggregated domain entity denoting a relation between different domain entities. The novices only mentioned those goals which were related to and could be derived from observable entities in a schedule. For instance, the goal *honouring a wish* was mentioned very often by the novices whereas the two *continuity* goals were rarely mentioned. The first goal is easily derived from a schedule, in contrast to the *continuity* goals, which combine domain entities.

The differences in domain knowledge support the conclusion that novices, especially the novice-np group, acquire their knowledge by perceptions based on observable things in the schedule (Forbus & Gentner, 1986). This explains why the novices had knowledge of domain entities which were directly related to the schedule itself, in contrast to the knowledge which could be derived from the relations between domain entities. In this sense the differences in content of domain knowledge between expert and novice schedulers implies that novices' knowledge of domain entities is a surface-oriented feature whereas that of the experts represents knowledge on a deeper level (Glaser & Chi, 1988, p xix). It is expected that the task performance of novices would greatly be guided by the visible structure of the schedule.

The differences between novices and experts concerning the lack of domain knowledge about the more complex types are related to differences in representation of domain knowledge in these groups (Jeffries et al., 1981). Novices make fewer relations among domain entities, resulting in the organization of their domain knowledge being ill-structured (Anderson, 1981; Chi, Glaser & Feltovich, 1988; Schaafstal, 1991). Experts, on the other hand, impose several relations on domain entities, by which more meaningful patterns are created (Schank & Abelson, 1977). In this sense experts in nurse scheduling reveal greater domain knowledge, which a novice has yet to acquire. Although the organization of domain knowledge was mentioned in passing, the structure of domain knowledge and how it is related to the problem solving needs further investigation.

Whereas the differences in content and structure of domain knowledge among the three groups are not regarded as serious - since it is expected that the two novice groups can easily acquire domain knowledge - they do have implications for decision support. Investigating domain knowledge leads to a thorough understanding of the content and structure of domain entities which can be processed into the design of decision support. The differentiation among types of domain knowledge in the problem solving means that they serve different roles in the task performance. Knowledge of the schedule can be used to design the user interface, whereas knowledge of the goals will be prominent in the problem solving by the computerized system.

CHAPTER 5

PLANNING SKILLS IN NURSE SCHEDULING

5.1 INTRODUCTION

The nurse scheduling task is a planning problem in itself. With an empty framework to start with and all necessary information available, the first planning problem faced is namely how to manage the scheduling task in general. All the necessary data have to be transferred to the appropriate places in the framework to form a well-organized and complete schedule. The planning nature of the nurse scheduling task implies that the challenging aspect in handling this task is the determination of tasks (Thierauf, 1982). Johnsons (1988) defines a task as *'an activity that is undertaken by one or more agents to bring about some change of state in a given domain'* (p. 164). Dealing with the activities refers to the problem solving. Along with the task environment, investigating the problem-solving processes of an actor underlying the task performance in that environment is thus the other important aspect for understanding the making of a schedule (Newell & Simon, 1972). This merely refers to the deployment of different types of knowledge in order to achieve a goal that concerns task-, strategic-, and inference knowledge as distinguished within KADS (see chapter 3). Task knowledge acquired plays a dominant role in decomposing the task; strategic knowledge arranges the goals related to tasks resulting in an overall sequence; inference knowledge consists of rules directed to the execution of the task.

Dealing with the nurse scheduling task encourages the decomposition and arrangement of tasks. The decomposition of an ill-structured task needed to deal with the complexity of the task is a generic problem-solving principle (Newell & Simon, 1972). Decomposition is a process of refinement of tasks into smaller manageable subtasks (Jeffries, Turner, Polson & Atwood, 1981). Consequently, it unburdens the working memory load by making a more efficient use of the capacity. In this respect, an adequately performed task decomposition reduces the complexity of the task (Leplat, 1988). The performance of task decomposition, however, depends on the task knowledge and skills of a problem solver.

Since task decomposition results in a number of subtasks, it implies that an arrangement of subtasks is needed in order to perform the nurse scheduling task systematically. The arrangement of tasks is deployed by strategic knowledge that results in a specific sequence in which the subtasks are going to be executed. The arrangement of tasks may depend on the nature of the task decomposition. A vertical task decomposition will impose a hierarchic structure among the tasks that are mutually interdependent. This implies that the sequence in tasks is more or less fixed. In contrast, a horizontal task decomposition reveals a sequence of tasks that are mutually independent, implying that the sequence of tasks is free. Moreover, it depends on preferences from a problem solver. Taken together, the process of decomposition into smaller directly executable subtasks and the arrangement of these subtasks in a specific sequence for successive execution indicate the scheduling strategy as seen in the task performance. Card, Moran and Newell (1983) pointed out that, in handling complex tasks, the decomposition as well as the arrangement are important to investigate for the understanding of the task performance.

The characterization of the scheduling strategy is understood by pursuing Cohen and Feigenbaum (1982) who consider human planning in two manners: script-based planning and opportunistic planning. Script-based planning consists of skeleton plans which are recalled from a store of plans instead of generated (Schank & Abelson, 1977). The plan guides the planning systematically. In opportunistic planning, however, the planner has no underlying plan, which implies that planning is performed less systematically. Hayes-Roth and Hayes-Roth (1979) characterize human planning as opportunistic and multi-directional as well, although the criticism of their research is that the subjects involved can be regarded as novices because the subjects do not have any experience in performing the presented task.

In order to understand the nurse scheduling strategy theoretically and empirically a general description of the several tasks in the nurse scheduling domain are abstracted from the thinking aloud protocols that are depicted in the task structure and next, a comparison between expert and novice schedulers with respect to their task performance is made. Lastly, the execution of tasks is discussed in relation to scheduling illustrated by some protocols. The questions addressed concern into which tasks the nurse scheduling task is decomposed by experts and novices. And in which strategic way do the schedulers organize the tasks?

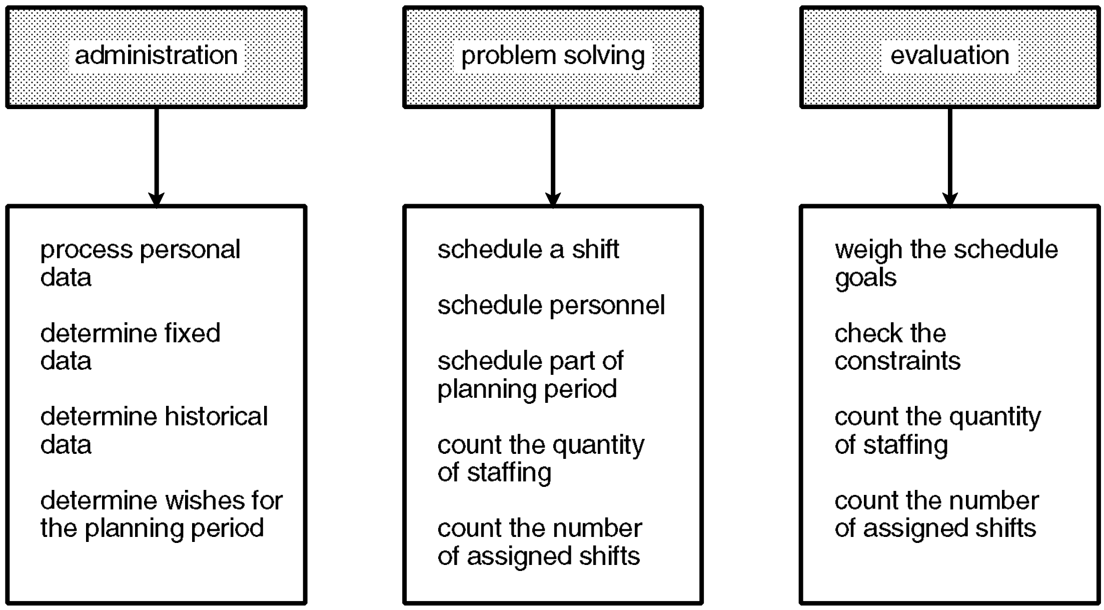
5.2. THE TASK STRUCTURE OF NURSE SCHEDULING

Clancey (1985) distinguished several types of problems by heuristic classification. He made a generic distinction in synthetic tasks and analytic tasks. Planning is an example of a synthetic task whereas diagnosis belongs to the latter. Typical of a synthetic task is that it can be decomposed into different subtasks. This is, actually, a process of categorizing. Following Clancey (1985) *'The categorization is not based on purely essential features, but rather is primarily based on heuristic, non-hierarchical, but direct associations between concepts'* (p. 342). Heuristic classification is a description of how a complex task is solved by the problem solver that is independent of implementation in a computerized system. The different tasks and the relationships among them are represented in the task structure. A first step in the specification of a task structure is to indicate activities related to the domain entities discussed in chapter 4. The connection of a domain entity and an activity refers to a task within the nurse scheduling domain. These tasks can be clustered into groups which refer to more generic tasks at an aggregate level. It results in the following tasks. The task *making a schedule for the ward* resembles the goal of the nurse scheduling task in general. While the tasks *determine the wishes for the planning period*, *determine the historical data*, *process the personal data* and *determine the fixed data for the planning period* refer to administrative activities. This cluster is denoted as the aggregate task *administration*. The aggregate task *problem solving* is abstracted from the activities *schedule personnel, schedule shifts, schedule planning period*. The activity *counting* is part of the scheduling task as well as being performed within the problem solving and in the evaluation. Lastly, the activities which *check the constraints* and *weigh the schedule goals* refer to the evaluation of the schedule regarded as the aggregate task *evaluation*. The three tasks in relation to their subtasks are depicted in figure 5.1 and discussed next.

The aggregate task *administration* aims at the updating of information about personnel available on a ward, before starting with problem solving. The scheduler decides which data are relevant to the new schedule, where to obtain the relevant data and where these data need to be put in the schedule. Some data are put in a cell of the schedule, for instance the wish of a staff member or the courses of student nurses, while other data are placed on a separate piece of paper. The administrative task is a straightforward activity but time-consuming. For instance, the history of an individual staff member for the scheduled shifts is easy to compute but when it needs to be done for thirty staff members then it will take a lot of time. The administration is actually the preparation for the problem solving. The task *administration* results in a temporarily fractional schedule that is the starting point for the task *problem solving*.

In the problem solving decisions need to be taken on the assignment of staff members to shifts in the planning period, whereby the different constraints

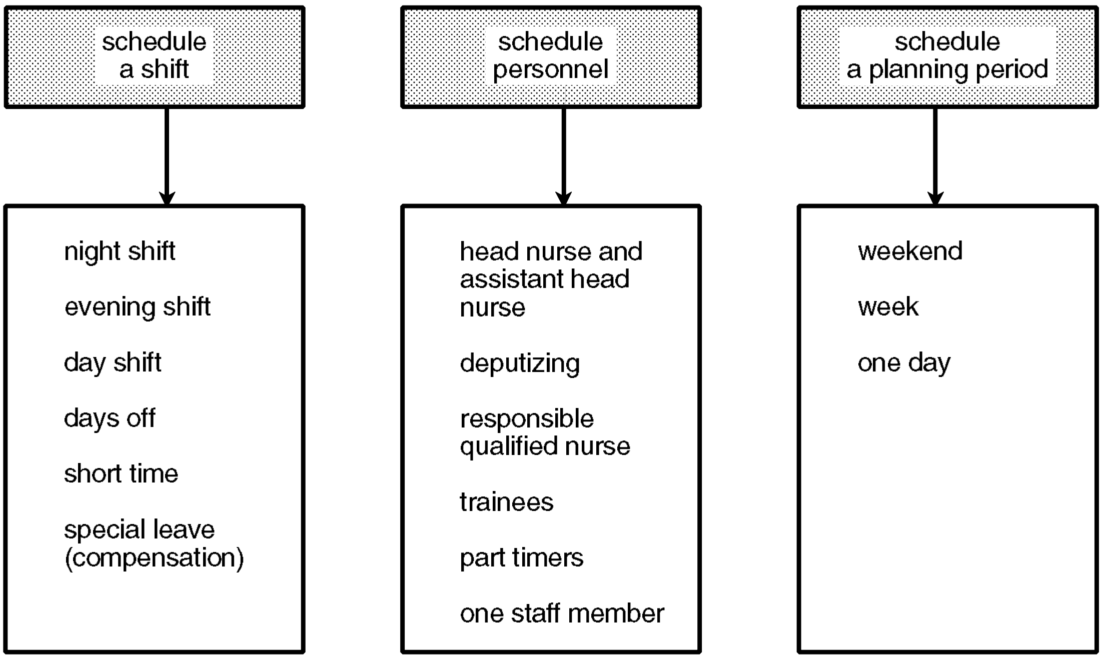
Figure 5.1 THE THREE CLUSTERS OF GENERIC TASKS



are taken into account, along with attempting to achieve the schedule goals. The three distinguished tasks related to problem solving are not feasible as such, in contrast with the task *administration* which can be executed right away on the basis of their division. These tasks are further refined on the basis of the values of the dimensions. The refinement is depicted in figure 5.2.

A characteristic feature of these distinctive tasks is that they cover a specific part of the framework of the schedule instead of the framework wholly, that is to say, that such a smaller specific part of the schedule is lifted out and selected to be scheduled separately. The focus is on the selected part. The scheduling of one of the personnel types extends in the horizontal direction, while the scheduling of a part of the planning period extends in the vertical direction. For instance, executing the subtask *schedule trainees* means that one specific type of personnel that is placed as a group on the schedule is chosen to be scheduled. On the other hand, scheduling one of the shifts does not cover such a compact part of the schedule framework. Often, scheduling one of the shifts is therefore combined with a specific part of the planning period. The task decomposition required within the problem solving results thus in feasible, well-structured tasks that make dealing with the complexity of the task possible. For problem solving this means that the problem space is more restricted and easier to deal with and consequently, the number of possible solutions decreases, so that less searching

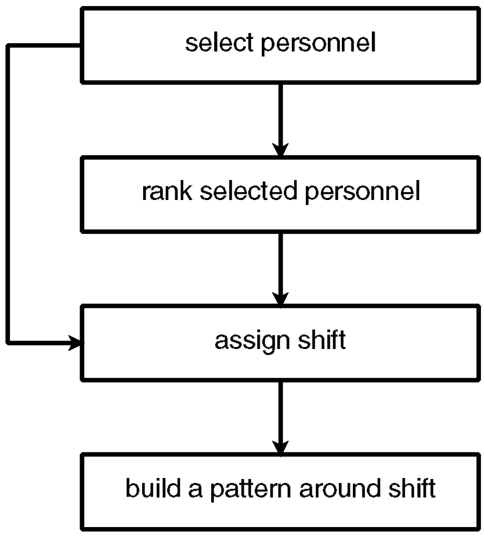
Figure 5.2 THE REFINEMENT OF TASKS RELATED TO PROBLEM SOLVING



is needed to achieve the final solution. For instance, when scheduling the student nurses only, all solution paths with registered nurses can be excluded. The execution of these tasks results in a complete schedule for personnel on a ward. However, some of these subtasks may overlap in the part of the schedule they cover, which means that it is not necessary to perform every task in order to complete the whole schedule. The easiest subtask will be that task which covers the smallest part of the schedule, and that is, scheduling the staff members one by one, since this task reveals the smallest problem space. Days off, short time and special leave are credited as time worked although these are off-duty shifts. Scheduling these shifts is summarized in the task *schedule the off-duty shifts*.

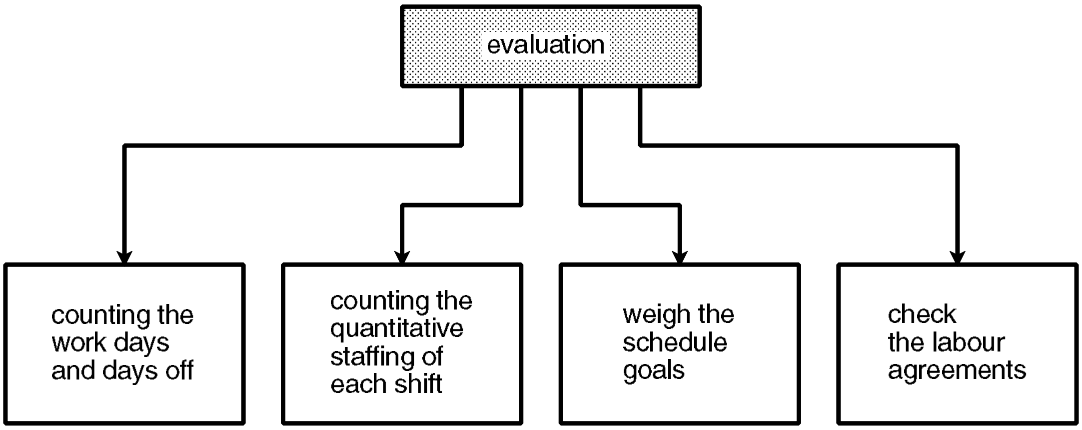
The smaller tasks related to the problem-solving part of the nurse scheduling task are executed according to the same scheduling procedure; moreover, the execution of the scheduling procedure is the scheduling itself. The scheduling procedure contains the following activities or tasks: select personnel, rank selected personnel, assign a shift and build a pattern around the shift. Thus, the assignment of personnel to a shift happens within the scheduling procedure. The aim of the activity *select personnel* is to sort out from the whole set of personnel a subset of personnel who are in principle available for that specific part of the schedule. Herewith disallowable solutions are excluded. Next, a decision has to be made about who is preferred for a shift assignment. This is done by the activity *rank selected personnel*, in which a hierarchic structure is imposed on the availability set. The activity *assign shift* chooses the 'best' person, who is then assigned to a shift. Lastly, a schedule pattern tuned to the assigned shift is constructed around the assigned shifts of an employee. Finally, these four activities result in a scheduled part of the schedule. Within these four scheduling activities it is often necessary to count the number of staff of a specific shift as well as the number of scheduled shifts of a particular staff member required in order to be in line with the labour percentage. Suppose that an average ward contains about twenty employees which need to be checked. It can be expected that counting consumes much time and moreover, mistakes can be easily caused by miscounting. The scheduling procedure is depicted in figure 5.3.

Figure 5.3 THE TASKS OF THE SCHEDULING PROCEDURE



However, it is difficult to keep a general overview of the schedule when all tasks are executed separately. Therefore the aggregate task *evaluation* is an important task in the making of a schedule. The evaluation of the schedule is more a diagnostic task which searches for less desirable solutions which need to be improved. The scheduler examines the schedule by weighing the several nurse scheduling goals and checking on the constraints. It is therefore diagnostic because the schedule is checked on less desirable solutions or on violating the constraints which the scheduler attempts to adapt to more acceptable solutions. Also, counting is performed in order to check the quantity of staffing as well as the number of shifts assigned to a staff member for the whole schedule. After the performance of the task *evaluation* the scheduler will reschedule a part of the schedule, if necessary, by backtracking. The task *evaluation* is depicted in figure 5.4.

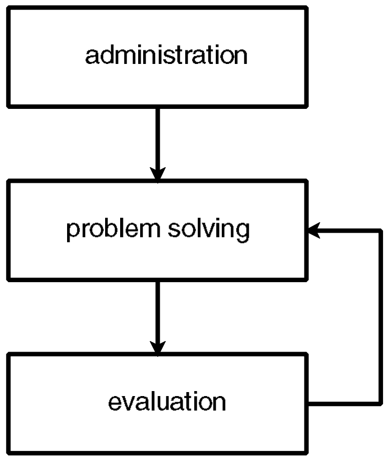
Figure 5.4 THE ACTIVITIES OF THE TASK EVALUATION



In conclusion, the three aggregate tasks reveal a mutual dependency. The results from the first task handled are necessary to perform the next one. The function of the aggregate task *administration* is the preparation of data needed to be processed in the task *problem solving* that is in fact the core of the planning problem. Feedback on the outcome of this task is the main function of the task *evaluation*. The three generic tasks are depicted in figure 5.5.

The subtasks related to the aggregate tasks are depicted in the task structure in figure 5.6. The task structure reveals that a planning task consists, most importantly, of designing tasks and activities in order to solve this complex task. The scheduler proceeds through the task structure by choosing tasks to be executed. Passing through the task structure depends on problem-solving processes, namely, the task decomposition and the task arrangement, as performed by the scheduler. Moreover, the sequence of tasks is indeterminate and not all tasks need to be performed to achieve a complete schedule. In the next two paragraphs the task decomposition and the arrangement of tasks by expert and novices schedulers as revealed in their thinking aloud protocols, is reported.

Figure 5.5 THE THREE AGGREGATE TASKS IN THE NURSE SCHEDULING TASK

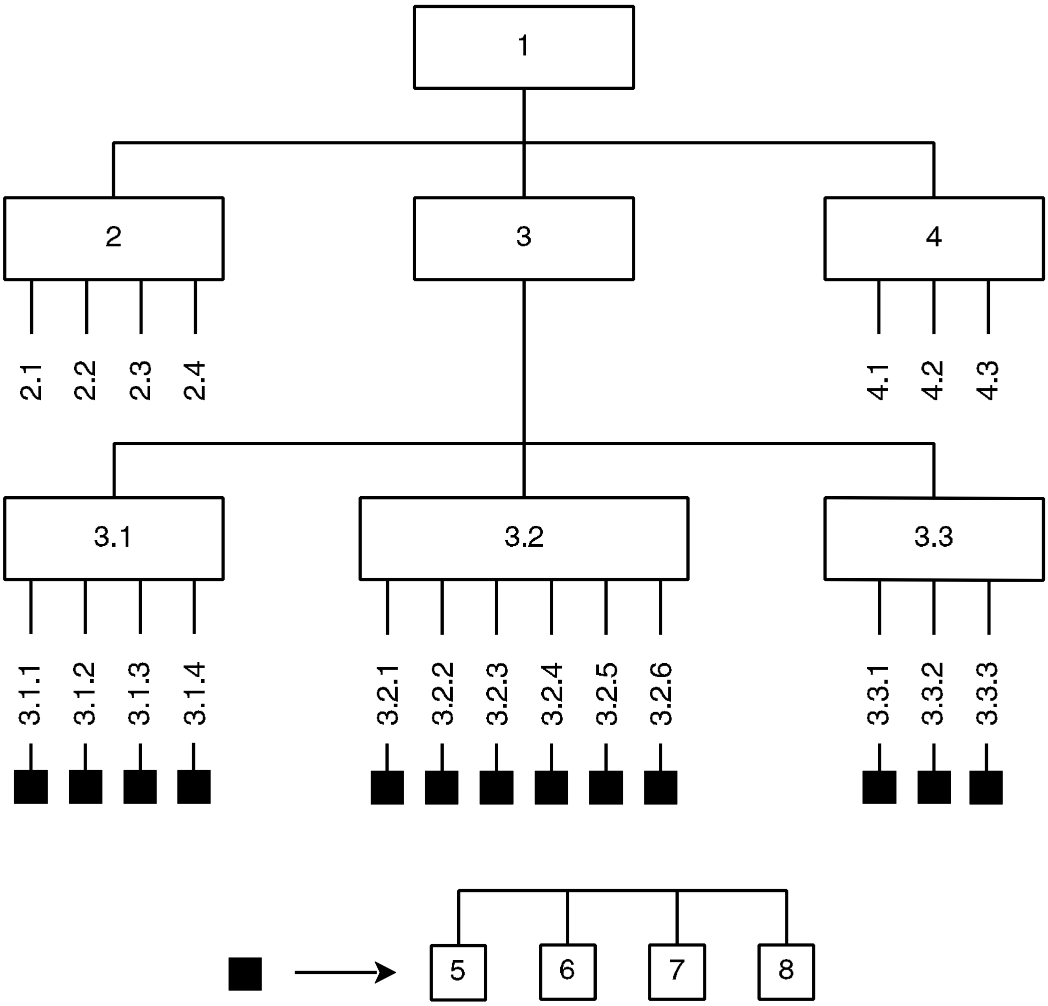


5.3 COMPARISON OF THE TASK DECOMPOSITION BETWEEN EXPERTS AND NOVICES

The protocols were traced to identify the tasks resulting from the task decomposition by expert and novice schedulers when making a schedule. Tables 5.1 to 5.3 depict the results concerning the decomposition of the tasks *administration, problem solving and evaluation* by the experts and the two novice groups.

All the experts performed the four tasks belonging to administration, and the novices also revealed a comparable task decomposition, with the exception of the task *determine the historical data*. Half of each novice group did not perform this task, while the other half of the novices noticed the relevance of this task in nurse scheduling. The determination of historical data appears to be less recognizable in the nurse scheduling task in comparison with the other three tasks belonging to the administration part of nurse scheduling. Personal data, wishes and established data are easily recognized as being relevant in the nurse scheduling task because these data are coupled with the personnel. Because of the considerable similarities between experts and novice schedulers in the task decomposition of the administration tasks, it is concluded that this will not cause difficulties in the performance of the nurse scheduling task.

The heart of the overall nurse scheduling task is the problem solving task. The task decomposition as regards this task reveals a less homogeneous picture. The results are depicted in table 5.2.



1 making a schedule
2 administration
3 problem solving
4 evaluation

2.1 process personal data
2.2 determine fixed data
2.3 determine historical data
2.4 determine wishes

3.1 schedule a shift
3.2 schedule personnel
3.3 schedule the planning period

4.1 weigh the schedule goals
4.2 check the constraints
4.3 counting

5 select personnel
6 rank selected personnel
7 assign a shift
8 build a schedule pattern

3.1.1 schedule the day shift
3.1.2 schedule the night shift
3.1.3 schedule the evening shift
3.1.4 schedule the off-duty shift

3.2.1 schedule the head nurse and assistant headnurse
3.2.2 schedule the deputizing
3.2.3 schedule the trainees
3.2.4 schedule the responsible qualified nurse
3.2.5 schedule the part-timers
3.2.6 schedule one staff member

3.3.1 schedule a weekend
3.3.2 schedule a week
3.3.3 schedule a day

Figure 5.6 TASK STRUCTURE OF THE NURSE SCHEDULING TASK

Table 5.1 THE DECOMPOSITION OF THE TASK ADMINISTRATION PERFORMED BY EXPERTS AND NOVICES

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
process personal data	6	6	6
determine fixed data	6	6	6
determine historical data	6	3	3
determine wishes for planning period	6	6	6

All the experts consent to the four tasks belonging to the task *schedule a shift*. However, more variety in task decomposition among experts is shown for the task *schedule personnel* and the task *schedule a planning period*: for instance, not every expert prefers to schedule trainees separately. Thus, together with a resemblance among experts in task decomposition, expert schedulers also develop their personal preference for decomposing a task. The two novice groups reveal comparable results in their task decomposition. They agree in the task decomposition of the task schedule a shift and partially in the decomposition of the two other tasks. The differences between the two novice groups are rather small.

A comparison between the expert and novice schedulers for the task decomposition revealed the following results. According to the Kruskal-Wallis test statistic, there is no significant difference among the three groups, Chi-square = 2.26, n.s., for the task *schedule a shift*. This implies that the experts and novices reveal the same task decomposition. There was no significant difference found among the three groups, neither for the decomposition of the task *schedule personnel*, Chi-square = 3.04, n.s., nor for the task *schedule the planning period*, Chi-square = 2.43, n.s. Obviously, the differences between the experts, the novices-p and the novices-np are not very overwhelming in their task decomposition, although a closer inspection of the task decomposition reveals that novices decompose the tasks *schedule personnel* and *schedule the planning period* into smaller tasks in comparison with experts, as illustrated by the tasks *schedule one staff member* and *schedule one day*. This task decomposition is only performed by the novices and not by the experts. What these two tasks have in common, is that they comprise the smallest separate part on the dimension *personnel* and *planning period* of the schedule, which are the easiest tasks to

Table 5.2 THE DECOMPOSITION OF THE PROBLEM SOLVING PERFORMED BY EXPERTS AND NOVICES

schedule	experts (n=6)	novices-p (n=6)	novices-np (n=6)
a night shift	6	6	6
an evening shift	6	6	6
a day shift	6	6	6
off-duty shifts	6	4	5
head nurse and assistent head nurse	6	5	5
the deputizing	6	-	-
the responsible qualified nurse	2	1	-
trainees	1	-	1
the part-timers	1	-	-
one staff member	-	3	4
a weekend	3	3	5
a week	4	4	4
one day	-	2	4

handle. These results reveal that problem solvers decompose a task into smaller tasks until he/she is able to manage the task. Comparable results are found by Jeffries et al (1981) who investigated a design task by letting novices and experts design a computer program. Apparently, novices are less competent than experts, who are able to manage more complex tasks than novices. This difference between experts and novices reveals that cues from the perceivable dimensions of a schedule appear to govern the task decomposition for the novices (Forbus & Gentner, 1986). Novices addressed more the layout of the empty framework of the schedule, while the experts had acquired task knowledge on a more abstract level, which can be seen in that they are able to schedule bigger parts of the schedule. Their knowledge is packed more in so-called chunks. A chunk is any stimulus that has become familiar, hence recognizable, through experience (Schank & Abelson, 1977). Despite the great resemblance between the experts and the novices in their task decomposition, the organization of the novice's task knowledge has not achieved that of the experts.

The decomposition of the task *evaluation* by the schedulers is depicted in table 5.3

Table 5.3 THE DECOMPOSITION OF THE TASK EVALUATION PERFORMED BY EXPERTS AND NOVICES

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
counting the working days and days off	6	5	5
counting the quantitative staffing of each shift	6	5	5
weigh the goals	-	-	-
check the constraints	-	-	-

The experts and the two novice groups hardly differ in the decomposition of the task *evaluation* of the schedule. The experts and the novices both perform the two types of counting tasks, whereas it is more difficult to recognize the evaluation of the achievement of goals and of satisfying the constraints as distintive tasks in the task performance of the schedulers. The experts perform these two evaluation task by inspecting the schedule generally during scheduling. Often the evaluation by means of counting is performed during the problem-solving task as well. Counting the shifts and days off, or counting the quantitative staffing of a shift, in particularly the day shift, is regarded a control mechanism on the results of the problem solving. The conclusion of these results is that all experts and novice schedulers reveal a comparable decomposition of the nurse scheduling task into the task *administration*, the task *problem solving* and the task *evaluation*. The task decomposition into administration, problem solving and evaluation is derived from the input/output data relation among these tasks. The output of the administration is further processed in the task problem solving and the input for the evaluation is the result of the task problem solving.

The task decomposition of the problem-solving part as seen in the experts and novices reveal a number of tasks in which the experts and novices agree: schedule a night shift, schedule an evening shift, schedule a day shift, schedule the off-duty shifts and schedule the head nurse and deputy. The task *problem solving* was thus primarily performed by executing the subtasks from the task *schedule a shift*. The common task decomposition among experts and novices is considered the invariance of the task performance in nurse scheduling. The utility of recognizing invariance in the task performance is pointed out by Simon (1990, p. 2) who stated: *‘ Psychology does not much resemble classical mechanics, nor should it aim to do so. Its laws are, and will be, limited in range and generality and will be mainly qualitative. Its invariants are and will be of the kinds that are appropriate to adaptive systems. Its success must be measured not by how closely it resembles physics but by how well it describes and explains human behaviour’*. Moreover, the invariance of scheduling behaviour therefore needs to be processed in designing decision support because it may be displayed and recognized by other schedulers as well.

The task decomposition reveals some differences among experts and novices as well. Some tasks are only performed by either an expert or a novice. Such a difference between experts and novices refers to the role of knowledge and skills in the task decomposition. Experts decompose the task *personnel* into schedule the deputy and even some of the experts prefer to schedule the trainees, the responsible qualified nurse and the part-timers separately. Such tasks are more related to an expert level while the tasks *schedule one day* and schedule *one staff member* are salient at the novice level since these tasks were only performed by novice schedulers. That novices acquired less knowledge and fewer skills also makes it clear that their task decomposition is based on cues from the nurse scheduling task, particularly the schedule itself. It is concluded from the results that within the task decomposition an expert and novice level are indicated, along with an invariant part of the task decomposition.

5.4 THE ARRANGEMENT OF THE DIFFERENT TASKS

In the present paragraph the task performance of the scheduler is held up against the empirical task structure with respect to the sequence of tasks performed, that is, the arrangement of tasks. Schedulers may differ in their opinion of the successively performed tasks and thus in their scheduling strategy. Such an arrangement of different subtasks of the nurse scheduling task is discussed for the experts and the two novice groups.

All subjects agree on the sequence administration first, problem solving next and evaluation last. The arrangement of tasks related to each aggregate task is discussed in the following section.

5.4.1 The task administration in experts and novices

The protocol analysis revealed that the experts and the novice-p group started with the aggregate task *administration* and they executed all the relevant tasks before another task was selected. Thus, they first refine and perform the administrative task. This is depicted in table 5.4.

Table 5.4 WHEN ARE THE ADMINISTRATIVE TASKS PLANNED?

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
gathered	6	6	2
dispersed	-	-	4

On the other hand, the novice-np group executed the administrative tasks more dispersedly. They performed these tasks, when they realized that the data provided by one of the administrational tasks, are needed for making a schedule. The dispersed performance of the tasks was due to their lack of strategic knowledge into conceiving that it would be beneficial to know the administrative data ahead of time. The planning behaviour of the novices-np indicates opportunistic planning. Hayes-Roth and Hayes-Roth (1979) investigated planning by subjects having to plan a day's errands. They pointed out: '*We assume that peoples's planning activity is largely* ***opportunistic****. That is at each point in the process, the planner's current decisions and observations suggest various opportunities for plan development. The planner's subsequent decisions follow up on selected opportunities*' (p. 276). The novices-np follow a bottom-up strategy which means that their problem-solving processes are directed by the presentation of the schedule currently available. The bottom-up way of planning is a significant aspect of opportunistic planning, although, problems with scheduling may arise further on. Then the scheduler has to backtrack, which involves replanning from the point that failed (Cohen & Feigenbaum, 1982, p. 520). It will take extra cognitive effort by the scheduler.

5.4.2 The task problem solving in experts and novices

The task schedule a shift

To investigate the strategic aspects of the task *schedule a shift* a quantitative analysis was performed with the following variables. The order in which the different day, evening and night shifts were handled is denoted as the sequence of tasks. The total number of alterations among the different tasks is denoted as the number of tasks. First the results with respect to the task *schedule a shift* are discussed. In table 5.5 the results concerning the sequence of tasks are depicted.

As can be seen in this table the expert group as well as the novice-p group started with the task *schedule a night shift*. Experts argued their choice to schedule the night shift first based on the tightness of the night shift, namely the strict constraints of the night shift and the fact that a night shift covers seven days sequentially and two days off, which should coincide with a weekend. They explained that these two things are hard to satisfy when the evening and day shift have already been scheduled. Moreover, it is easier to change a scheduled evening or day shift than a night shift. In problem-solving terms, the night shift has a quite strict number of allowable solutions in comparison with the evening and day shift. A solution path will sooner be found when the problem space is not curtailed by already scheduled shifts. Although it was elucidated from the investigations into the domain knowledge of nurse schedulers that schedulers considered the day shift as the most important shift to schedule because most of the workload of patient care is focused in the daytime and therefore the scheduler prefers the qualitative staffing in a day shift to be above the minimal norm, the achievement of the staffing in a shift is more difficult for the shift which is scheduled last. Thus, there seems to be a discrepancy between the preference and the planning abilities of the scheduler.

Table 5.5 THE SEQUENCE OF TASKS IN THE EXPERTS AND NOVICES

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
no fixed sequence	-	-	4
day → evening → night	-	-	2
day → night → evening	-	-	-
evening → day → night	-	-	-
evening → night → day	-	-	-
night → day → evening	-	-	-
night → evening → day	6	6	-

The novice-p group defend their choice by stating that they experience the night shift as an unpleasant shift for personnel. The novice-np group is in this sense unbiased since they have still not worked in the hospital. They chose a shift at random just to start with. They were not able to state the reasons for their opportunistic choice.

The question still remains whether the three groups really made a strategic choice based on their first task to schedule. This was further investigated by looking at the sequence in which the night, evening and day shifts were handled. All subjects in the expert group as well as the novice-p group used the same strict sequence in shifts, namely night, evening and day shift. It seems that the novices-p really did acquire strategic knowledge. Two illustrations of expert protocols with respect to the arrangement of tasks within their scheduling strategy are given below.

Example protocol of an expert: illustration of transformations between tasks in his/her strategy.

> All the wishes are filled in. Now I'm going to see who worked the night shift... (scheduled the night shift). I've finished planning the night shifts. Now, just the late starts and week-ends off. (pattern around the night shift). Now I'm going to plan the evening shifts in the same way.

Example protocol of an expert:

> I move on to the second week. First the weekend... I have two evening

> shifts completed. The rest are day shifts. Who all do I have? ... So, that's it for this week. Next week. Let's just see again how we're doing with the evening shifts...

In these protocols the consequent reasoning of the experts is revealed in their task performance in finishing a task and choosing the next task.

The novice-np group reveals no such strict sequence in scheduling shifts. They perform the task *scheduling a shift* in an opportunistic way since no sequence can be abstracted from their protocols. The differences between the two novice groups are striking because they only differ in the amount of practical experience working in hospitals. None of them had ever made a schedule.

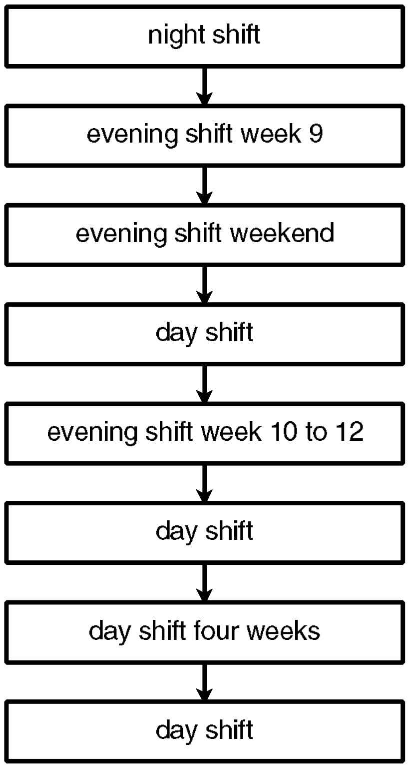
Table 5.6 THE MEAN NUMBER OF SHIFTS SCHEDULED SEPARATELY

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
mean number of shifts	5	10	18

The acquisition of strategic knowledge would not only lead to a strict sequence in scheduling shifts but also, as is expected, to a restricted, compact number of performed tasks. An experienced scheduler will finish the scheduling of the night shift before performing a new task, although, within the general scheduling strategy tasks can be repeated iteratively, for instance, scheduling the day shift per week. The total number of separately scheduled shifts are counted and this number is called the size of the scheduling strategy. This is depicted in table 5.6.

From table 5.6 it is concluded that novices reveal a less compact manner of scheduling compared with the experts. Novices do more repetitions in scheduling the same shift. Surprisingly, the novice-p group did not achieve as much as the experts. Despite the strict sequence by the novices-p, they were not able to keep their strategy under control. This may be due to the fact that they failed to keep their attention fixed on scheduling one shift before skipping to the next. For the novices-np it was even more difficult. Lesgold et al. (1988) discussed a comparable result for novices in their research as well. In this respect the cognitive demand is rather burdensome, which is reflected in the novice's scheduling strategy, which reveals disorderly, i.e. opportunistic, repetitions in scheduling the day evening, and night shifts. An example of such a sequence of shifts is given in figure 5.7.

Figure 5.7 AN EXAMPLE OF AN OPPORTUNISTIC STRATEGY BY A NOVICE



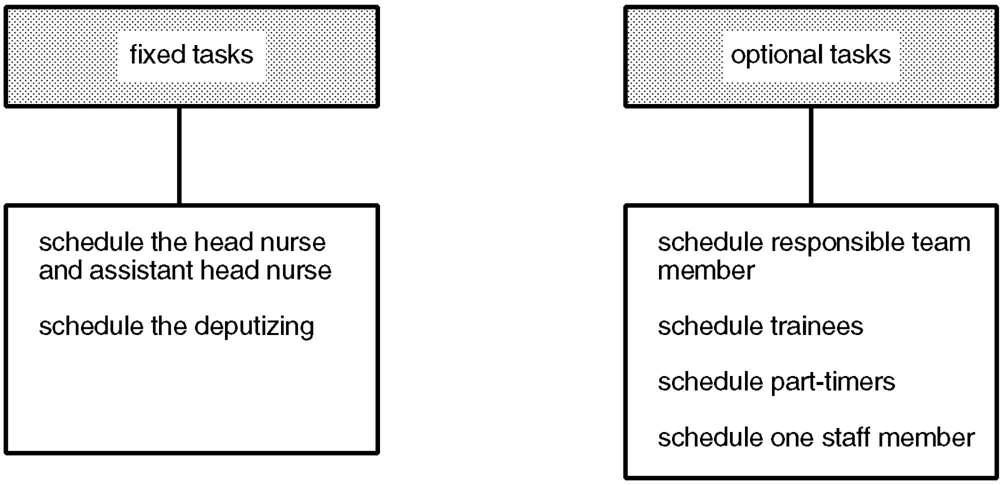
On the basis of a systematic strategy it was expected that the scheduler would schedule the evening shifts either in sequence for four weeks or per week. The novice skipped to the day shift during the scheduling of the evening shift and skipped back to the evening shift. In addition, the novice scheduler thought aloud in the protocol to schedule the day shift and decided further on that the day shift had to be scheduled for four weeks but changed some things for a person and began again with the day shift. The scheduler who was scheduling the day shift took the opportunity to schedule one staff member and then started again with the task *schedule a day shift*. Again, this illustrates that the task performance of the novices can be regarded as opportunistic planning.

It is concluded from the discussed results that the arrangement of tasks by novices is directed for the most part by the nature of opportunistic planning, while the experts perform the arrangement of tasks within the task *scheduling a shift* straightforwardly. They performed, in order, the tasks night, evening and day shifts. The task performance of the experts is explained by script-based planning. A so-called planning script underlies their task performance. Schank and Abelson (1977) defined a script as *'a predetermined, stereotyped sequence of actions that defines a well-known situation'* (p. 41). They explained the concept of a script by the well-known example of the restaurant script. The acquisition of knowledge will thus be stored in a script. It contains the outlines for solving the nurse scheduling task. An important function of the planning script is thus to provide a background in which the nurse scheduling task is carried out (Schank & Abelson, 1977, p. 49). Consequently, when an experienced scheduler has to make a new schedule, this script will be accessed. Novices have acquired less-developed scripts, which explains the differences between experts and novices in their task performance. Cohen and Feigenbaum (1982) showed that script-based planning is a top-down approach which means that during problem solving the abstracted actions in the script are filled with knowledge from the particular situation. Thus, the expert planning behaviour in the task *scheduling a shift* is called script-based planning while the novice planning behaviour for this task is called opportunistic planning.

The task schedule personnel

A well-organized arrangement of the tasks related to the task *schedule personnel* was not found in the scheduling strategies. The expert group perform first the task *schedule the head nurse and the assistant head nurse*, and then the task *schedule the deputizing*. These tasks were mostly performed at the beginning of the scheduling strategy, after the task *administration*, while the other tasks such as schedule *the responsible qualified nurse*, *schedule the student nurses*, *schedule the part-timers and schedule one staff member*, are optionally performed. This means that these tasks were either not positioned in a particular place within the scheduling strategy or were not even performed by the expert scheduler. These so-called optional tasks are considered a further refinement preferred by an individual scheduler in order to handle the complex scheduling task. In this sense it is referred to as the variant part of the task structure. In other words, these tasks can be positioned anywhere among the other tasks belonging to the invariant task structure. For instance, one expert scheduled the part-timers last to complete the schedule. More or less, she used the variable working days of part-timers to fill up the empty places in the schedule. Thus, there was no overall strategy in arranging the optional tasks by the experts. The results are depicted in figure 5.8

Figure 5.8 **THE ARRANGEMENT OF THE TASKS WITHIN THE TASK SCHEDULE PERSONNEL BY EXPERTS**



The novices did perform the task *schedule the head nurse and the assistant head nurse* but they did not do it in a systematic way within their scheduling strategy, and they hardly ever performed the other tasks. The novices focused for the most part on the task *schedule one staff member* within their scheduling strategy. An example is given in the following protocol:

> I'll put Isabel in the evening shift. No, I won't do that, I'll put a student in the evening shift. She's on evening duty and then Isabel a late start. And Juul gets a day off. This remains early day shift, and that too. Floor has a late start and Sonja has a late start, Isabel a day off, Juul has early day shift. Hillie a day off. Boukje from early day shift to... Door, what percentage does she work again? 50%. Door is also off-duty. Floor goes to the night shift, no to the evening shift. So! Hillie gets an early day shift or no, she [gets] the... And that stays the same, and this becomes off-duty. Renske again in the evening shift and this also remains evening shift. Anna has ADV and Boukje? Day shift? Christa and Floor, Door... this stays the same. Isabel stays in early day shift. Juul gets night duty. Renske stays in the evening shift. Then Saturday-Sunday. Sonja: two day shifts. Now, who's on night duty? Juul stays on night duty on the weekend. Then Floor again on evening duty. Then I have enough for the early day shift and evening shift and night shift. And the rest are off-duty. And the Sunday I do exactly the

same schedule.

This novice reveals a consistent way of planning: each person to whom shifts were assigned is directly based on a previous day. Hereby the focus is on the visible parts of the schedule. The novices have more difficulty executing a scheduling strategy thoroughly than the experts.

The task schedule the planning period

The arrangement of the tasks related to the planning period is investigated per scheduler since the decomposition of the task schedule the planning period as depicted in figure 5.2 revealed too many differences among the schedulers in the expert group. Each individual scheduler performed a specific arrangement consistently; for instance, a scheduler consistently schedules the Monday to Friday periods after completing the weekends. To give a second example, an evening shift is first scheduled only for the weekends for the whole planning period and then the rest will be scheduled. The several possibilities of the arrangement in task structure concerning the dimension planning period are depicted in figure 5.9.

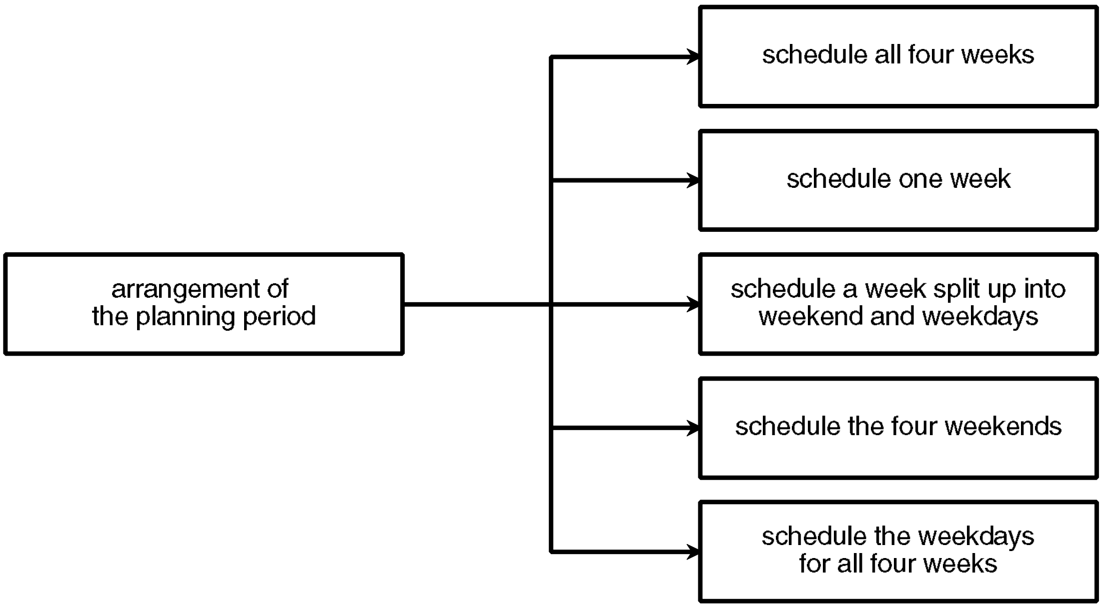
Often, a part of the planning period was tuned to the dimension shift depending on the preference of the scheduler; for instance, the night shift was always scheduled for four weeks or the days off were coupled with the weekends.

The novices did not acquire any systematism in handling the planning period. Often, they schedule per day, starting with the first day and working through the last day of the planning period. An example of scheduling per day is given in the following protocol:

Schedule per day

> Then I have Monday finished! She's off, her too. Tuesday, I start with the day shift. We have 5 of them, 1,2,3,4,5. There also has to be a late day shift. I had her yesterday, so today I'll give her a... Let's see, evening shift, code 5. One, two, so I have that, and two night shifts: one, two. So I have that too, the rest are off... Now Thursday, 1,2,3,4,5. Evening shift, here a 5, there a 5. Night shift, one, two. So, I have that too, so I'm finished fast. Friday...

Figure 5.9 ARRANGEMENT OF THE PLANNING PERIOD



The cognitive demand of the nurse scheduling task is illustrated in the example. By scheduling per day the novice scheduler is able to control this task, which is not the case for a more complicated task, such as schedule the day shift. The novices started with the more complicated tasks but did not succeed, which is one reason why they plan opportunistically. The performance of scheduling per day also illustrates that the memory load is reduced because the results of the problem solving cover a small part of the schedule, implying that they also have more control over the outcomes.

5.4.3 The task evaluation in experts and novices

The task evaluation is achieved by performing the distinguished tasks *weigh the goals* and *check the constraints* and *the counting* at the end. These tasks are interrelated, since a goal may be checked by counting the shifts. This implies that, on the one hand, weighing the goals may be rather invisible in the protocols, and on the other hand, that the arrangement of the evaluation tasks is not performed in a specific sequence. Note that counting is also done many times within the scheduling itself. The task counting in particular is performed by all experts as part of the evaluation. The two novice groups did not explicitly perform the task *evaluation* as such at the end. This does not mean that they assumed that their schedule was a feasible one. The task evaluation is an extra control on the results of the scheduling.

In conclusion, the results concerning the arrangement of tasks within the nurse scheduling task agree with the comparable observation in performing a planning task by Hayes-Roth and Hayes-Roth (1979) who state that the arrangement depends on characteristics such as decomposition, individual differences and knowledge and skills.

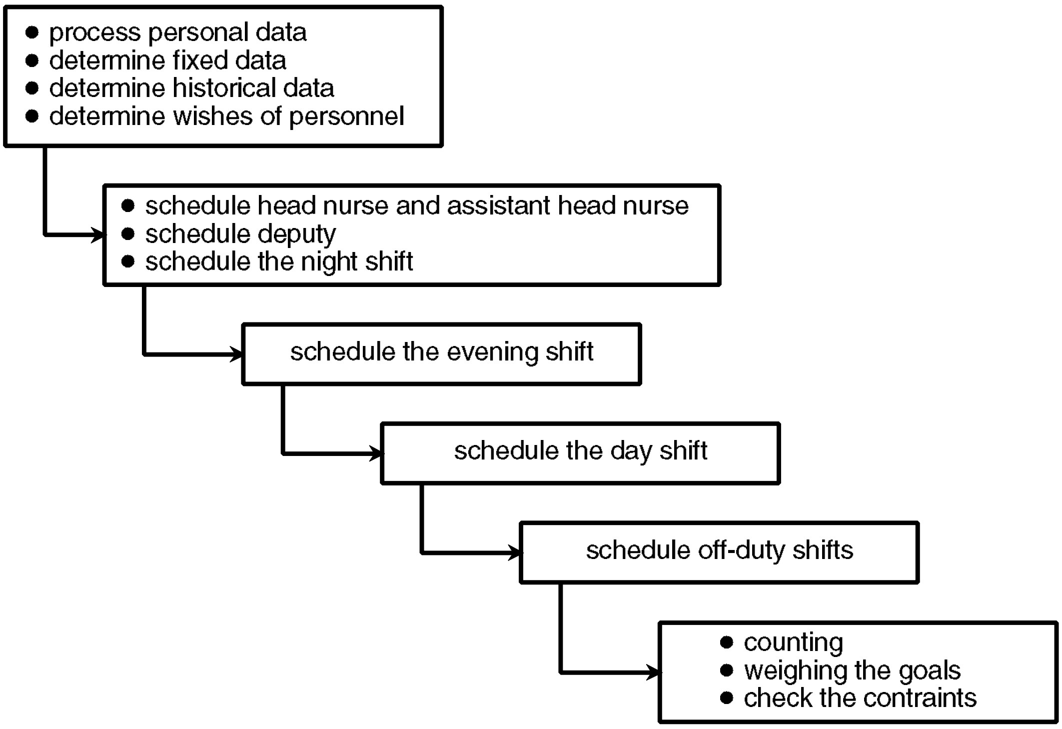
5.5 CONCLUSION TASK DECOMPOSITION AND TASK ARRANGEMENT

The task performances of the schedulers reveal some common aspects with regard to the decomposition and arrangement of the different tasks. This concerns first, the decomposition of the task *administration* together with the arrangement that these tasks are performed in the beginning of the whole nurse scheduling process. Second, the decomposition of the task *schedule personnel* into *schedule head nurse and assistant head nurse* and the task *schedule the deputy*. These tasks are performed after the administration activities. Third, the task *scheduling a shift* is decomposed and arranged respectively into the night, evening and day shifts. Fourth, the off-duty shifts (day off, short time and so on) will be scheduled and fifth, the task *evaluation* is performed by counting at the end. All six experts revealed a similar way of planning while the novices were only somewhat similar in this regard. This common part indicates therefore the invariant part of the task structure in nurse scheduling. From the results we can tentatively conclude that the novices acquired the invariant task structure first. Therefore, the common aspects of the task performance are abstracted to form one generic scheduling strategy. In figure 5.10 the generic scheduling strategy is depicted.

It can be seen in this figure that the first, second and last step contain more than one task because these tasks were always performed before the following tasks and were therefore considered as one step. However, the order of these tasks showed some variety among the experts. Logically, the other tasks that are left fall under the variant part of the task structure.

The distinguished scheduling strategy in the task performance refer to script-based planning guided by a plan. Schank and Abelson (1977) explain this as follows: *'Plans are where scripts come from. They compete for the same role in the understanding process, namely as explanations of sequences of actions that are intended to achieve a goal. The difference is that scripts are specific and plans are* *general. Both are necessary in any functioning system*' (p. 72). A plan is a representation of the scheduling strategy underlying the task performance, whereas a script is filled with context-specific knowledge like typical things on a ward. When a script is available, it will be chosen; otherwise a plan is chosen. Both guide problem-solving activity in the nurse scheduling task.

Figure 5.10 THE GENERIC NURSE SCHEDULING STRATEGY



The function of a plan is explained by Hoc (1988) who distinguished three main features of a plan: *'Guidance is heuristic. It can orient activity rapidly in the most promising directions without requiring fine or laborious analysis of the situation'* (p. 116) The heuristic nature of a plan means that the knowledge stored in a plan can be used in new situations and besides that, this knowledge is easily accessible. Second, *'The guidance provided by planning allows for* ***optimal use*** *of the* ***limited processing capacities*** *of the human cognitive system'* (p. 116). Plans serve to reduce the cognitive load by storing knowledge in meaningful patterns and anticipating the required processing of a task by structuring it. Third, *'Guidance raises the* ***control level of activity****'* (p. 116). A plan strictly guides the sequence of tasks performed.

Task decomposition and task arrangement are thus important problem-solving processes in dealing with the complex planning task. However, the aim of the nurse scheduling task, assigning personnel to the schedule, has still not been attained. The task decomposition and the task arrangement form a preparation for the actual scheduling of personnel since this results in manageable tasks. The execution of such a task forms the real scheduling activity as was briefly reported when the aggregate task *problem solving* was discussed. It is further discussed in the following paragraph.

5.6 THE SCHEDULING ACTIVITIES

Scheduling is the problem-solving process in which the assignment of personnel to shifts takes place on the schedule. It consists of the following activities: select personnel, rank selected personnel, assign a shift and build a pattern around the shift. The activities are executed by applying inferences on domain knowledge (see KADS). The attention is focused on a specific part of the schedule for each activity. Within the selection and the ranking of selected personnel the focus is on the vertical dimension of the schedule. Whereas within the assignment of a shift and building a pattern around the assigned shift the focus is on the horizontal dimension of the schedule.

The activity *select personnel* aims at sorting out those staff members from the whole set of personnel who can be in principle available for that specific shift under consideration --since they could not be available for several reasons: a labour agreement would be violated, a student nurse has a course or a nurse has a vacation, because of a persons's labour contract, and so on.

The result is a subset containing those staff members who can be scheduled. Herewith the impossible solutions are excluded. Thus, by selecting staff members systematically a scheduler prevents difficulties in generating solutions later. The selection of personnel takes place by applying inference rules. These inferences are represented as production rules. A production rule contains two parts, namely: ‘if ... and then ...’. The first part after IF describes relations among domain entities. After THEN an action is performed. This approach to solving the task is characterized by *‘narrowing the set of possibilities’ rather than ‘searching through the set of possibilities’* (Greeno & Simon, 1988, p. 627). A few examples of inferences that select personnel are given below.

Examples of inferences *select personnel*

IF a labour agreement is not violated for a staff member
THEN select this staff member

IF a night shift was scheduled more than four weeks ago for a staff member
THEN select this staff member

IF none of the other types of shift has been scheduled for a staff member
THEN select this staff member

IF wish pronounced by a staff member
THEN select this staff member

IF a staff member may not be scheduled for a specific shift on the basis of a labour contract
THEN do not select this staff member

IF established data (course, vacation) belongs to a staff member
THEN do not select this staff member

The processing of these inferences results in new data: the created subset of personnel is considered *the availability pool* of staff members for a shift. The advantage of an overview of the availability of staff members is that the scheduler knows whether the number of persons in the availability pool are enough to fulfil the quantitative and qualitative staffing. If the size of this pool is too small, the scheduler has then identified a first possible problem which needs to be solved before starting again with a different task from the scheduling task. For instance, it can be solved by either weakening some inferences if this is allowed, or a practical solution is to ask nurses from a different ward to assist or to hire nurses from an employment agency.

In the next step a decision has to be made about whom is preferred for the assignment of a shift. This is done by the activity *rank selected personnel* which means that a hierarchic structure is imposed on the availability set by applying inferences. The highest staff member in the ranking will get the highest priority to be scheduled. Examples of these kind of inferences are given below.

Examples of inferences *rank selected personnel*

IF wish for a shift pronounced by a staff member
THEN a high position in ranking

IF it was a long time ago that the shift was scheduled for a staff member
THEN a high position in ranking

IF two or more days off before a shift for a staff member
THEN a high position in ranking

IF both wish and history of a staff member are relevant for a shift
THEN a very high position in ranking

IF wish was pronounced for another shift by a staff member
THEN a low position in ranking

Ranking is a complicated factor of the scheduling task because combinations of staff members needed to fulfil the quantity and quality of staffing also need to be taken into account. The point is that a specific combination may lead to a higher priority in the ranking despite a lower priority of an individual. A scheduler therefore has to weigh several combinations within the problem-solving reasoning. Within the activity *ranking selected personnel* the achievement of the scheduling goals directs the final solutions. The scheduling goals are transformed into inferences which are part of the reasoning in scheduling a shift. When a scheduler thus acquires poor knowledge of goals, he/she may not perform the ranking activity very much.

In the next step decisions have to be made about the assignment of personnel to a shift whereby the ranking should be taken into account. This is the activity *assigning a shift*. Within this activity the combination of individual staff members is the leading factor, because the combination of nurses and trainees has to satisfy at least the constraints of quantitative and qualitative staffing of a shift. This implies that some combinations may even be impossible or less desirable according to the scheduler. Finally, those combinations with a high priority are assigned to the shift. A few examples of inferences are given below.

Examples of inferences *assign a shift*

IF a team consists only of trainees in a shift
THEN do not assign a shift to this team

IF a team contains a number of persons which is less then the required minimal quantity
THEN do not assign a shift to this team

The execution of the activity *assign a shift* results in an overview of assigned shifts for a staff member. Assigning implies that the focus is on comparisons among personnel, which differs from the last part to be performed namely, constructing a scheduling pattern for each individual staff member. Hereby the scheduler focuses horizontally on just one nurse. Thus, after assigning a shift to a nurse or trainee, a schedule pattern around the shift will be constructed. This is indicated as the activity *build a pattern*. Examples are given below.

examples of inferences *build a pattern*

IF a shift has been assigned to a staff member
THEN build a pattern around that shift consisting of a block size of two or more for that shift

IF a night shift and weekend off is scheduled for a staff member
THEN build a pattern consisting of a day shift as the next shift

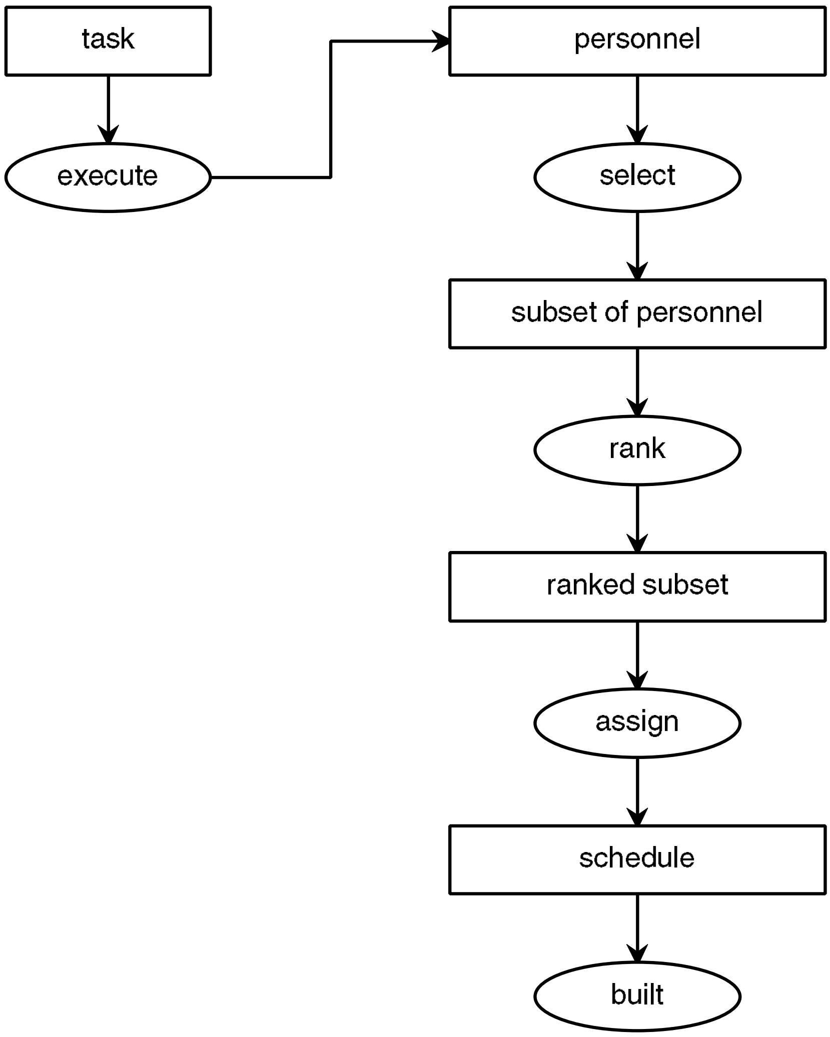
IF a sequence is a day shift followed by a day off for a staff member
THEN build a pattern consisting of an evening shift as the next shift

IF a course is scheduled for a staff member
THEN do not build a pattern of an evening shift as the next shift

IF a weekend has been scheduled for a staff member
THEN build a pattern of same shifts on Saturday and Sunday

The result is *a scheduled pattern for a staff member* and herewith has the scheduling itself attained the end state. The examples of inferences underlying the four subtasks are not meant to be exhaustive but are given as an illustration of knowledge at the inference layer.

Figure 5.11 THE INFERENCE STRUCTURE OF SCHEDULING



In the performance of the different activities the role of domain knowledge is very important. Along with that, counting is also significant in checking the quantity of staffing for a shift. The four activities all together form the inference structure of scheduling that is depicted in figure 5.11.

The sequence in performing respectively selection, ranking, assignment and construction is more or less settled. The execution of them transforms the initial state of making a schedule into several problem states and finally, into the goal state: the nurse schedule. The number of possible solutions is decreased by following this line of reasoning because it operates further on data as the result of a previous action. Each new solution can easily be checked as to whether it is a better solution.

Actually, the scheduler starts with an enormous amount of possibilities and is narrowing his/her view by excluding solutions and focusing on the final solutions. Illustrations of scheduling by experts and novices are presented in the following paragraphs.

Examples of how the empirical data is categorized

The first protocol reveals the problem-solving processes underlying the scheduling of a night shift while the second example reveals the scheduling of the evening shift. The different scheduling activities are denoted.

Protocol of an expert: scheduling the night shift

select	
wish	In week 10 there's nobody who wants to take the night shift. Here I had three people who wanted to do the night shift.
wish	The problem with her is that she wants to have that weekend off.
fixed data	And she has requested vacation then, so she can't be on night duty.
remarks	What I would like is for these two to stay in week 11. For week 10, I have one already. It's a matter of choosing. I'll just pick one. I'll just mark it yellow.
quality	That's an experienced nurse with a student. That's all right.
remarks	Two night shifts for her that week. I'll put her on night shift and just try it since otherwise you could just keep on planning. I'm curious as to what kinds of problems might come up later.
fixed data	That student can't go on night duty, because she has to go to a course.
rank	
wish	You're able to give the people a weekend, but sometimes you can't do anything else. I'll try to find a possibility. I'll look to see when I was on night shift. Or Sonja and then not grant the weekend.
history	I look to see how long in the past she has done a night shift. Sonja hasn't had any night shifts.
quality	She can work with Mies, because she's experienced.

weekends off	I also look at how many weekends off she's had. I do want to take that into account. She has had 8 weekends off, so she should be able to work two weekends in a row and I won't give her the weekend of the 10-11.
assign	
	She's going on night shift. The weekend after that she has off and she's going on a course and can't go
fixed data	on night duty.
remarks	I have three weeks for night duty scheduled. That one's already on it. This one's coming off, because I already have two.
rank	
history	She has worked relatively many night shifts and only works 50% and has already asked for a lot of shifts, it's E. so I'll take her off and then I'll schedule the other ones definitively. So Klaske and Lydia.
quality	It's a bit of a shame to put two experienced people in the night shift. I could also put a student on the night shift. Then I'll move that night shift one week back. You also have to make sure you have properly qualified personnel left over.
history	I look to see when Klaske and Lydia did the night shift. Lydia in week 5 and Klaske in week 8. So it's Lydia's turn first and then Klaske.

Protocol of an expert: scheduling the evening shift

assign	
wish	I'm scheduling Paula for a late shift, she hasn't requested anything
build	
block	and can do them four in a row. So can I.
remark	I'm not scheduling anything definitively yet, because something could come up.
assign	
pattern	After a night shift, I assign Gerrie an evening shift.
build	

wish	Wednesday through Friday, she didn't ask for anything.
select	
weekend off	Hillie has the weekend off, Klaske also has the weekend off and I'm here for evening shifts too.
assign	
quantity	Wednesday, I have two of them. Just Thursday and Friday, I'm giving those to Lydia,
work/day off	her birthday is Saturday. She works 80% and has a bit more time off.

The sequence of the four activities is recognizable in both protocols of the experts. Selecting more than one staff member is a condition for ranking them. If no selection of a person took place then only the activities *assign* and *build* are relevant. The reasoning processes for the activity *select* and *rank* are more complex inferences. In these reasoning processes the expert makes remarks which refer to goals in the nurse scheduling domain. The expert anticipates what will further happen during scheduling. Experts' reasoning is more extensive and more elaborate than that of the novices (Lesgold et al., 1988, p. 317), as can be seen in the novices' protocols below, the novices' reasoning is less extensive and more fragmented.

When a novice focuses on one person, then the activities *select* and *rank* are skipped and the emphasis is on the activities *assign* and *build*. The activity *build* spreads out over more than one week, sometimes the whole planning period. This is in accordance with the fact that novices schedule around the observable schedule. Novices may forget some aspects of the domain: they forget to schedule the head nurse and deputy, they have problems taking all such aspects into account simultaneously, which means that their domain knowledge is less organized compared to that of experts. A poor performance is due to their lack of attention to constraints in the domain (Greeno & Simon, 1988). Novices lack the greater formulations that characterize the expert scheduler with specialized scheduling knowledge. This is illustrated by the following protocols from novices.

Examples of inferences by novices derived from their protocols.

Protocol of a novice-p

select	
personal data	Floor works 100% and the other one 50%.
wish	Isabel would like a couple of evening shifts.
build	
pattern	If she gets a lot of evening shifts she's off the rest of the week. Door 4 evening. First week.
quantity	I just have the problem that 3 get evening shift on March 15.
pattern	60% who get(s) another day off. Thursday evening and then off.
pattern of one person	I take Door 5 evening in 2 weeks. The weekend of March 3-4 she gets late duty. I wanted her to work the weekend and then she has the whole week off and the 4 days working and then 4 again. I have her here Thursday, Friday, weekend and Monday, 5 days working. She still has the rest of the week off. And she works two weekends and is already off two weekends.
select	
counting	Evelien works 50%, 10 days, counting.
pattern	Vacation days and off duty. Floor three evening. Gerrie comes off duty. Renske should here also. Isabel. Hillie first works only 50%. Has regulated
pattern weekend off	eight days' work then she has to do two more. She also has two weekends off.
assign	
counting	Juul works 9 days so she can go off, counting.
evening shift	Isabel evening on the weekend, Floor an evening. 5 evening shifts seems like a lot to me. Is that normal? So that's all the late ones.

Protocol of a novice-p

assign	
wish	Continue with Hillie, she hasn't asked for any night duty.
history	Worked most recently up to February 8. She could work again March 8, if necessary. Hillie, she can't go here. Would she be able to do night duty here this week?
quality	Then too I already have a graduate. Maybe she can go at the end of this, I don't yet have anybody. And there I already have three people in the night shift. I'll start by putting her in for the last week.
history	Isabel that's a graduate, latest night shift on February 8,
fixed data	so she can't go in again until March 8. Then she has one week vacation... Now I'll just see what percentage she works.
remarks	Now I've still got the night shift, I'm not really happy with it. If I can find a solution for that, since I still have to give short time days. No, I really think I have no other... I just don't know how I always get this...
build	
pattern	She has to have three days off, one way or another. Since you come out Thursday, so you should have Friday, Saturday, Sunday free no matter what after the night shift. So I'm going to work on those short time days.
remarks	I'll just continue now with the evening shifts.
quantity	I have two here for every day. I have two here.
assign	
quality	Now on to Saturday, Sunday. What if I put a student in there? Renske, she's dependent, but she is very experienced, so that could work. I've got to put Renske here in the evening shift,
build	
patterns	then she's worked 1,2,3,4,5,6,7 days. I'll give her two evening shifts, that would work. Let's see. Monday, Tuesday nobody's
select	
wish	asked for anything, I can just schedule it myself.

pattern	She didn't work..., she did the night shift, she just had the evening shift.
fixed data	She has vacation. Floor already has a lot of evening shifts,
pattern	Gerrie still doesn't have any evening duty, works 100%,
assign	
	so I can schedule her in. There she's also on vacation,
quality	so I can give her an evening shift here. Gerrie is also experienced, she's not very experienced, so Isabel...,
build	
pattern	then I could give her here 2,3 evening shifts.

Protocol of a novice-np

remarks	Let's see if I get the day shifts to turn out. You have to take so many things into account. I think this week is all done. It's terrible, you really should take a course for it. Christa, she still
assign	
quality	has days left open, so I wanted to give her a day shift, because she's matched with Sonja and that's a first-year student.
quantity	But there are so many day shifts that day, so I'm giving her it off.

The novices will continually check by counting the number of employees whether the quantitative staffing requirement has been complied with. Ranking was not much performed by novices. They concentrate on the building patterns. They possess a less developed procedure in executing the activities of the task scheduling, however, the aggregate sequence is consistent with the inference structure. It can be seen in the task performance that novices skip some parts of the scheduling inference structure.

5.7 CONCLUSION AND DISCUSSION

In this chapter the task performances of expert and novice schedulers are compared in making the schedule. The significant part of dealing with the planning task revealed in the task performance, the task decomposition, the task arrangement and the scheduling itself were investigated. The results concerning the task decomposition reveal only marginal differences between the experts and novices. They decompose the nurse scheduling task in a similar way, in particular the administration and the tasks schedule a shift, schedule the head nurse nurse and the deputy. The novices, however, were not able to perform the tasks resulting from the task decomposition successively and so they decomposed them further into smaller manageable tasks. Moreover, differences were found among the experts in the task decomposition of the task personnel.

More differences were found between the experts and the two novice groups for the arrangement of tasks. The novices revealed an opportunistic task arrangement in contrast with the experts who followed a coherent scheduling strategy. They acquired an adequate script for solving the nurse scheduling task. The result that novices did not perform the scheduling strategy systematically is comparable to the result found in the diagnostic strategy of novices investigated by Schaafstal (1991). The common part of the task decomposition was arranged in a similar way by the experts. Naturally variety in task arrangement among experts was seen in the other tasks as well. The explanation for acquiring the scheduling strategy seems to be a problem-solving reason related to the cognitive limitations, though further experimental research is needed to shed more light on this. The finding that in making schedules not only an expert level can be distinguished from the novice level but also that within the expert group variety in task performance can be discerned is interesting for designing decision support. Obviously, there is not just one way of performing the nurse scheduling task.

The execution of the several tasks from the scheduling strategy is actually a scheduling problem. The experts' scheduling procedure consisted of four different activities. In the first two activities they concentrate on the selection and ranking of personnel, then in the last two activities they assign a shift to an individual staff member and finally build a pattern containing more of the same shifts or days off. The novices' scheduling procedure was less thorough, since they may skip one of the four scheduling activities, in particular, the ranking of personnel. Both experts and novices often cite the quantity of staffing of a shift or the number of assigned shifts of a staff member in order to justify their choices. They achieve the aim of the activity by applying inferences to their domain knowledge. The experts revealed more elaborate reasoning than novices by weighing different nurse scheduling goals.

The experts among each other, however, may also differ in the tuning of the goals, though more insight into the hierarchy of goals and the weighing of domain knowledge in the scheduling is needed to clarify the differences among the expert schedulers.

The results discussed in this chapter have implications for designing decision support. When starting the design of decision support from the human perspective, one should rely on the problem solving as revealed by schedulers. Coupled with that, the interesting results regarding the task decomposition and arrangement need to be included in the starting point for the design. The distinction between the invariant and variant parts of the scheduling strategy means that the computerized system should support the different tasks in order to keep the arrangement flexible. Along with that the inference rule underlying the scheduling activities can be easily implemented, which means that less searching is needed to assign personnel to the schedule by the scheduler. Moreover, novice schedulers can also have the expert knowledge at their disposal. By incorporating these aspects into the design, it is then adapted to the scheduler by making the problem less complex, as explained by Timmermans (1991). Decision support aims then at compensating for cognitive limitations.

CHAPTER 6

VARIETY IN OUTCOMES
OF
THE NURSE SCHEDULING TASK

6.1 INTRODUCTION

Chapter 6 discusses the outcomes of the schedule as the result of the performance of the nurse scheduling task. In practice, the scheduler regards the nurse scheduling problem solved when he/she thinks that the outcome of the schedule is feasible on the ward according to the scheduler's ideas. It is thus questionable whether there is one correct solution for the nurse scheduling problem. This can be supported from a theoretical point of view as well. The solution of a complex problem is often not clearly specified since ill-structuredness of a task is associated with ill-defined goals (Keren, 1992, p. 30). In problem-solving terms, the end state of the nurse scheduling task is not clearly defined. This means that, beforehand, the result of this task, namely the schedule, could not be clearly designated. In other words, the end state is not a specific arrangement among domain entities. This implies that a variety of solutions will be considered as allowable solutions. In addition, it is even unlikely that all possible solutions will be computed (Newell & Simon, 1972).

Another reason explaining a variety of solutions is that there will be *'several alternative ways in which they (ill-defined goals) might be satisfied'* (Greeno & Simon, 1988, p. 610). Following a specific solution path depends on the nature of the task decomposition as well as on the task arrangement within the nurse scheduling task by which the solution space changes slightly. Each separate task performed contributes a partial solution to the whole schedule. Thus differences in scheduling strategies also contribute to the variety in outcomes.

A third reason is of a different kind: the variety in outcomes can be attributed to a poor or faulty outcome due to a bad cognitive performance as a consequence of the quality of knowledge and skills used in performing the task. The amount of acquired domain knowledge is reflected in the representation of the begin situation of the problem, on which the next step in solving the problem is based.

When the solution of a problem cannot be straightforwardly attained, which means that a variety of outcomes is possible, the issues at stake are: when the problem is considered to be solved, and what a good solution is (Voss & Post, 1988, p. 281). The solution of a schedule has in general the form of a solution space in problem-solving terms. This is fixed by different constraints and goals significant within the nurse scheduling problem. A feasible schedule needs to satisfy the constraints and fulfil the nurse scheduling goals (as discussed in chapter 4). Some of these are therefore employed in judging the outcomes of the schedule. They concern: the labour percentage, the honouring of wishes, the quantity of staffing, the quality of staffing and the continuity goal. The schedules of the experts and novices are compared on the basis of these criteria in order to gain insight into the variety of solutions.

6.2 OUTCOMES OF THE NURSE SCHEDULE

It is not very surprising that the final outcomes of the schedules should vary within the novice-p and the novice-np group. Interestingly enough, a variety in outcomes was also very definitely found within the expert group. Obviously, the experts developed their own personal notion about the content of the schedule. In order to understand the variety, the schedules are viewed from specific perspectives. In the following, several factors are discussed by which the variety in outcome may be explained between the experts and the novices as well as within a subject group. First, two illustrations for the outcomes of the task administration in which domain knowledge of personnel (explained in chapter 4) is processed are given, and next, the outcomes of the problem-solving part of the nurse scheduling task in which knowledge of goals and constraints and knowledge of shifts (discussed in chapter 4) are processed are illustrated by means of some examples. It should be noted that these criteria need not be the only ones that may explain the variety.

6.2.1 Outcomes of the administration

The outcomes of the personal data: the labour percentage

In the administrative part of the nurse scheduling task the scheduler looks at the personal data in order to recall the specific characteristics of the personnel. One of these concerns the labour percentage which often ranges from 50% to 100% of full time. A nurse who has a labour percentage of 50% must receive ten working days in a planning period of four weeks, whereas a full-time labour percentage means twenty working days. The labour percentage differs among personnel on a ward. The number of working days of personnel in the schedule needs to be in agreement with the corresponding labour percentage. In the problem solving the scheduler must pay extra attention to the number of shifts assigned to each individual staff member; however, in practice, deviations can easily be made in the number of assigned shifts. In order to investigate the demand of scheduling the correct labour percentage, the schedules of the experts and novices were checked by counting the number of shifts assigned for each staff member. The total number of staff members was twenty-one within the experimental nurse scheduling problem. The number of shifts assigned was compared with the expected number of shifts assigned on the basis of the labour percentage. When those two numbers differed then it was considered ‘deviant’. When those two numbers agreed then the correct number of working days had been assigned to that individual staff member. The results are revealed in table 6.1 for the expert group and the two novice groups.

Table 6.1 NUMBER OF ASSIGNED SHIFTS CORRECT FOR EACH GROUP OF SUBJECTS

correct number	experts (n=6)	novices-p (n=6)	novices-np (n=6)
(max=21)	14.83	9.42	4.25

the results have been averaged over the subjects (mean rank)

The Kruskal-Wallis test statistics revealed a significant difference between the three groups (Chi-square = 11.99, df = 2, $p < 0.0025$) implying that they differ in achieving the correct number of assigned shifts related to the labour percentage. The experts perform the best, then the novices-p and lastly, the novices-np. The results of the two novice groups are much worse: the novices-np hardly ever assigned the correct number of shifts for an individual staff member. The three groups differ in the ability to assign the correct number of working days. Despite the fact that the experts perform better on assigning the correct number of shifts for a staff member than the two novice groups, they still reveal ‘too many’ deviations. The experts were expected to perform much better on the basis of their expertise. Even the experts were not the perfect problem solvers. Bad outcomes of the labour percentage may be due to the task performance, in which some pitfalls can be seen. Mistakes can be caused by different aspects of the problem solving: within the counting by miscounting, when the counting is performed in the sequence of performing the several tasks. Mistakes in assigning the correct number of shifts may be due to an overload of the cognitive system, since counting the number of shifts assigned to a staff member is performed along with other tasks from the nurse scheduling task. The scheduler 'forgets' to check the labour percentage. In the protocols it can be seen that the experts often only start counting the number of assigned shifts as the last step, since they had developed heuristics to anticipate deviations by dividing the number of working days over the planning period; for instance, a part-timer who works 50% will get alternately two and three shifts assigned in a week-though, such a heuristic did not guarantee a correct outcome. The novices did not reveal such comparable heuristics in their protocols. Moreover, the results of the novices-np in particular are explained by their lack of domain knowledge of personal data (see chapter 4, table 4.1) under which the knowledge of the labour percentages falls.

In conclusion, although the labour percentage is well-defined in the schedule, there is still a lot of variance. The satisfaction of the labour percentage is thus a source of variety in the outcomes of the schedule, but variety here can mean a bad outcome, since all deviations need to be corrected in the schedule by the scheduler in the aggregate task *evaluation*, and even then mistakes can still be there that then need to be compensated for in the next planning period. Correcting the mistakes would demand much effort from a scheduler. It is therefore better to prevent mistakes in the number of shifts assigned. Preventing mistakes in assigning the correct number of shifts is an important role for decision support.

The outcomes of wishes honoured

Another part of performing the administration consists of processing the wishes stated by personnel. These wishes are placed in the schedule on the corresponding day. A wish can be stated that a shift be scheduled on a specific day or even that a shift would not be preferred on a particular day. A wish positioned in the schedule is thus regarded a special value. Moreover, stating wishes by personnel is an important issue within the nurse scheduling domain. In the problem solving the scheduler decides on the assignment of wishes. Therefore, the nurse scheduling problem offered in the experiment also contains a number of wishes. For the expert group as well as for the two novice groups their schedules are checked to see whether these wishes stated by the personnel from the nurse scheduling problem are honoured or not. The number of wishes honoured are counted. The results are depicted in table 6.2.

Table 6.2 WISHES HONOURED IN ONE PLANNING PERIOD FOR EACH GROUP OF SUBJECTS

	experts (n=6)	novices-p (n=6)	novices-np (n=6)
wishes honoured	5.5	12.67	10.33

the results have been averaged over the subjects (mean rank)

According to the Kruskal-Wallis test statistic, there is a slightly significant difference (Chi-square = 5.63, df = 2, $p < 0.059$) among the three groups in honouring the wishes. The three groups differ with respect to the number of wishes honoured. The novice-p group honoured the most wishes, the experts the least and the novice-np perform in between. In order to get insight into the differences between two groups, a Mann-Whitney U test was carried out. A significant difference was found only between the experts and the novices-p group, $z = -2.56$, $p < 0.01$, indicating that the novices-p honoured significantly more wishes than the experts. Despite the fact that the experts declared that they emphasize the importance of honouring the wishes, they, obviously, did not perform as such. Within the problem solving other reasons may arise that overrule the decision to honour a wish. For instance, the honouring of a wish may conflict with one of the other nurse scheduling goals. In this regard the experts weigh the goals against one another with the result that the scheduler finds what he or she believes to be a better solution than one honouring the wish. The personal influence of the scheduler him/herself on the wishes honoured leads to a variety in outcomes. Moreover, experts made such remarks as that they did not know the staff members within the experiment, which explained why it was easier for them not to honour a wish. Such a remark stresses the delicate aspects of honouring wishes.

The novice-p group performed the honouring of wishes quite consistently. This is typical of novices, to remain fixed on one matter. Their strategy was of a kind in which wishes were to be honoured but in which several goals were not satisfied due to lack of knowledge of goals. This result is in agreement with those from chapter 4: these novices-p are strongly guided by the visual presentation of the wish in the schedule and they lack knowledge on the weighing of goals. The results of the novice-np group clearly show that they acquired less domain knowledge on honouring wishes. The outcomes of the problem-solving are discussed in the following by means of the quantity of staffing, the quality of staffing and lastly, the continuity goal.

6.2.2 Outcomes of the problem solving

The outcomes of the quantity of staffing

The quantity of staffing is one of the objects to focus upon in the problem solving. It consists of a particular number of personnel for the day, evening and night shifts. Moreover, the quantity of staffing must satisfy a minimum number of staffing. However, the scheduler strives for one or two staff members more than is required on the basis of the minimal quantity of staffing especially in the day shift. Because of the restricted number of them available on a ward, it is important that the number of personnel be proportionally divided over the days in the planning period. When too many staff members are scheduled in the first week of the planning period then a shortage of them is expected in the last part of the planning period, implying that the quantity of staffing may not be satisfied. Therefore, the schedules made by the experts and the two novice groups are examined on the minimal quantity of staffing by counting the number of persons assigned in a shift. The number of days which satisfied the minimal quantity of staffing were counted for the day, evening and night shifts for one planning period consisting of twenty-eight days. Table 6.3 reveals the results.

Testing whether the three groups of subjects differ in the performance in satisfying the quantity of staffing revealed a significant result only for the night shift (Kruskal-Wallis Chi-square = 6.04, df = 2, $p < 0.048$), though the novices-np performed worse on all three shifts compared with the experts and the novices-p. A Mann-Whitney U test was carried out to get an indication of differences between two groups of subjects. For the night shift a significant result was found between the experts and the novices-np ($z = -2.28$, $p < 0.02$). For the evening shift each comparison between two groups revealed no significance, while for the quantity of staffing of the day shift, a slightly significant result was

Table 6.3 NUMBER OF DAYS THAT SATISFY THE QUANTITY OF STAFFING FOR EACH SHIFT IN ONE PLANNING PERIOD OF 28 DAYS FOR THE THREE GROUPS OF SUBJECTS

	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
night shift	12.50	9.83	6.17	6.04	< 0.048
evening shift	10.33	11.83	6.33	4.43	< 1.090
day shift	12.50	8.25	7.75	4.07	< 0.130

the results have been averaged over the subjects (mean rank)

found between the experts and the novices-p ($z = -1.891$, $p < 0.058$) as well as between the experts and the novices-np ($z = -1.897$, $p < 0.057$). The novice-np group tended to perform less satisfactorily for all three shifts; the novices-p performed rather well on the quantity of staffing of the evening shift; and a similar result was found for the experts on the quantity of staffing of the night and day shifts.

The quantity of staffing of the day shift is greater than those of the night and evening shifts implying that more counting of the number of assigned staff members to the shift is required. The novices-p were less able to perform the counting adequately only when the quantity of staffing was greater. The novices-np were less able to perform the counting independently of the size of the quantity of staffing, while the experts were able to perform rather well the counting of the quantity of staffing along with their other scheduling activities.

The outcomes of the quality of staffing

One of the other objects to focus upon in the problem solving is the quality of staffing. The quality of staffing consists of a team of differently qualified staff members. The distinct categories for registered nurses are: experienced and inexperienced; and the categories for the trainees are: senior trainee (third and fourth year) junior trainee (first and second years) (see chapters 2 and 4). Depending on the quantity of staffing, several combinations can be created on the basis of these four different qualifications. However, the composition of some teams is regarded as better than others. A team of staff members is ‘advised’ when the different categories are proportionally represented in the quality of staffing. In other words, the quality of staffing may not contain too many or too few of one of the four categories. When this is the case, the team is denoted as ‘allowed’. Lastly, a team is considered as ‘disallowable’ when it contains only trainees. An instance is given for a quality of staffing of the night shift or the evening shift consisting of two staff members:

Advisable teams	one experienced nurse and one senior trainee
	one experienced nurse and one junior trainee
Allowable teams	two experienced nurses
	one experienced nurse and one inexperienced nurse
	two inexperienced nurses
	one inexperienced nurse and one senior trainee
	one inexperienced nurse and one junior trainee
Disallowable teams	two senior trainees
	two junior trainees
	one senior trainee and one junior trainee

The teams as scheduled by the experts and the two novice groups are scored on the basis of these three categories for each day in the planning period. Sometimes a scheduled team does not coincide with one of the three categories; such teams are labelled ‘deviant’. The results are depicted in tables 6.4 to 6.6 for the night, evening and day shifts respectively. None of the groups scheduled a team consisting only of student nurses for all three shifts.

The Kruskal-Wallis test statistic revealed a significant difference among the three groups for the category ‘advised’ (Chi-square = 8.84, df = 2, $p < 0.012$) which implies that the experts more often scheduled an advisable team in the quality of staffing in the night shift than the other two groups. Despite the fact that for the other two categories no significant effect was found (which could be due to the rather small number of subjects), the following tendency can be indicated. The novice-p group seems to prefer to schedule an allowable team for the night shift and the novice-np group scheduled most often teams belonging to the ‘deviant’ category. When comparing two groups, the Mann-Whitney U test revealed significance between the experts and the novice-np group for both ‘advised’ and ‘deviant’ categories (resp. $z=-2.91$, $p < 0.0036$; $z=-1.99$, $p < 0.04$) indicating that for the night shift the experts most often scheduled advisable teams and that the novices-np most often scheduled the so-called deviant teams.

The scheduled quality of staffing for the evening shift is depicted in table 6.5.

Table 6.4 TYPES OF CATEGORIES SCHEDULED IN THE NIGHT SHIFT FOR ONE PLANNING PERIOD OF 28 DAYS FOR EACH GROUP OF SUBJECTS

categories	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
advised	14.00	9.58	4.92	8.84	< 0.012
allowed	7.08	9.92	11.50	2.14	< 0.34
deviant	6.75	8.75	13.00	4.70	< 0.09

the results have been averaged over the subjects (mean rank)

Table 6.5 TYPES OF CATEGORIES SCHEDULED IN THE EVENING SHIFT FOR ONE PLANNING PERIOD OF 28 DAYS FOR EACH GROUP OF SUBJECTS

categories	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
advised	8.92	12.00	7.58	2.18	< 0.33
allowed	12.50	8.42	7.58	2.95	< 0.22
deviant	6.75	8.33	13.42	5.31	< 0.07

the results have been averaged over the subjects (mean rank)

As can be seen in table 6.5 in testing the differences among the three groups a slightly significant result was found only for the category ‘deviant’, indicating that the three groups differ in the amount of scheduled teams indicated as ‘deviant’. The novice-np group scheduled most often such a team. Although for the other two categories a tendency can be indicated that the experts scheduled more often a team qualified as allowable for the evening shift while the novice-p group scheduled more often teams qualified as ‘advisable’. A comparison between the experts and the novices-p revealed a slight significance for the category ‘allowed’ (Mann-Whitney U test, $z = -1.78$, $p < 0.075$). This result supports our finding that the tendency is for experts to schedule more often a team qualified as allowable for the evening shift.

Actually, the experts prefer a rather high quality of staffing, for instance, a team consisting of two experienced nurses. A significant result was also found between the experts and the novices-np for the category 'deviant' ($z = -2.26$, $p < 0.02$) which underlines the reliability of the differences found between the experts and the novices. The novices-np did not possess a well-developed notion of the quality of staffing of a shift.

The quality of staffing of the day shift has a different distribution of qualified staff members since the quantity of staffing is greater compared with the night and evening shifts. An instance is given for the quality of staffing consisting of five staff members for the day shift. The examples given are not exhaustive.

Advisable teams	two experienced nurses, one inexperienced nurse, one senior trainee and one junior trainee
	two experienced nurses, two senior trainees and one junior trainee
Allowable teams	four experienced nurses and one inexperienced nurse
	two experienced nurses and three senior trainees
	five inexperienced nurses
	one experienced nurse, one inexperienced nurse and three junior trainees
Disallowable teams	two senior trainees and three junior trainees
	five junior trainees

Similar teams can be defined consisting of four staff members for the weekend. In the analysis of the quality of staffing for the day shift the difference in the quantity of staffing between the weekdays (five) and the weekend (four) are taken into account in judging to which category a scheduled team belongs. The results for the day shift are depicted in table 6.6.

Table 6.6 TYPES OF CATEGORIES SCHEDULED IN THE DAY SHIFT FOR ONE PLANNING PERIOD OF 28 DAYS FOR EACH GROUP OF SUBJECTS

categories	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
advised	12.50	8.92	7.08	3.29	< 0.19
allowed	9.33	11.33	7.83	1.31	< 0.51
deviant	7.00	9.00	12.50	3.32	< 0.19

the results have been averaged over the subjects (mean rank)

The Kruskal-Wallis test statistic revealed no significance among the three groups, implying that no differences were found for the quality of staffing in the day shift (which may be due to the small number of subjects), although, the results did reveal the tendency that the experts more often scheduled a team belonging to the category ‘advised’, for instance, a team containing two experienced nurses, one inexperienced nurse and two student nurses. The novice-p group more often scheduled the category ‘allowed’ teams, whereas the novice-np group more often scheduled ‘deviant’ teams. Further analysis was done by carrying out the Mann-Whitney U test. The result was a slight significance ($z = -1.77$, $p < 0.07$) between the experts and the novices-np for the category ‘deviant’ implying that the novices-np scheduled teams of this category more often than the experts, which means that they did not have a clear notion of the quality of staffing, while the experts strive for a proportional division of differently qualified personnel which is in agreement with their goals. The novices-p scheduled more highly qualified people than they needed to and in this respect they missed the subtlety that more is not necessarily better.

In conclusion, a comparison among the three groups shows that the experts acquired a richer concept of the quality of staffing: for the night shift they preferred a team qualified as ‘advised’, for the evening shift they tended to prefer a team qualified as ‘allowed’ and lastly, for the day shift a team qualified as ‘advised’. Actually, the experts anticipate the division of the quality of staffing needed for all the three shifts over the planning period. Tentatively speaking, the novice-p group seems to schedule a high degree of quality in a team by scheduling more often a team qualified as ‘allowed’. They realize the importance of the quality of staffing for a shift; moreover, they were able to achieve such a quality of staffing consequently in their task performance. The novice-np groups' quality of staffing is more spread out. They have more variety in teams, which is revealed by the fact that they scheduled more often teams qualified as ‘deviant’. These results support the finding that the novices-np acquired less domain knowledge of the quality of staffing, as well as having more difficulty with the problem solving underlying the task performance.

The outcomes of the goals continuity in personnel over days and continuity in personnel between days for a shift

Along with the quantity and the quality of staffing, the achievement of the continuity goal is also involved in the problem solving. Continuity in personnel means that a patient is looked after by the same team of nurses or nearly the same team as the day before. The achievement of the continuity goal plays a role in the evening and day shifts only, since the night shift is scheduled according to a fixed pattern in which the achievement of this goal is of lesser importance.

The continuity goal appears in two ways. First, it can be realised by scheduling a team for a particular number of days in sequence. Second, part of the team will be replaced by new staff members the day after. The schedules made by the expert group and the two novice groups are examined on realising this continuity goal. The continuity over days was measured by the size of a block. A block contains a particular number of days on which the same team was scheduled. The size of a block refers to a specific amount of continuity. A block size of more than four days denotes much continuity, while a block size of two or three days denotes less continuity, although it is acceptable. A block size of just one day contains no continuity at all. The occurrence of each different block size is counted in the schedules of each subject.

The continuity goal between days was measured by the number of new staff members coming into the team. When less than half of the staff members are ‘new’, it is considered a continuous transition between the days. It is denoted as having less continuity when half of the staff members or even more are ‘new’. No continuity between days is the case when a completely new team of staff members is scheduled. The question is whether the experts achieve full continuity in the outcomes of the schedules more often than the novices. Table 6.7 depicts the results of the continuity goal over days for the day and evening shifts. The Kruskal-Wallis test statistic did not reveal any significant effect, implying that the three groups hardly differ in realizing the continuity goal as measured by the block sizes. This means that the subjects did not differ in scheduling a specific block size for either the day or the evening shift; however, this may be due to the small number of subjects. We can, however, tentatively

Table 6.7 TYPE OF CATEGORIES OF THE CONTINUITY GOAL OVER DAYS SCHEDULED IN THE DAY- AND EVENING SHIFT FOR THE THREE GROUPS OF SUBJECTS

day shift block size	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
full continuity	7.00	9.83	11.67	3.79	< 0.15
less continuity	7.58	11.17	9.75	1.41	< 0.49
no continuity	12.50	9.00	7.00	3.27	< 0.19

evening shift block size	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
full continuity	9.17	9.33	10.00	0.08	< 0.95
less continuity	9.92	11.67	6.92	2.47	< 0.29
no continuity	9.83	6.83	11.83	2.69	< 0.26

the results have been averaged over the subjects (mean rank)

indicate a tendency for the experts to schedule most often a block size of just one day, i.e. no continuity, in particular the day shift, which may mean that the experts also consider other goals at the same time. The novices-p most often scheduled a block size of two or three days for the day and evening shifts, indicating that they may consider this continuity goal only. The novices-np most often scheduled a block size of four days or more in the day shift. For the evening shift no tendency can be found, which may be an indication that they indeed lack domain knowledge of the continuity goal.

The results of the continuity goal between days are revealed in table 6.8.

For this goal also, testing revealed no significance, implying that no differences among the three groups for the achievement of the continuity goal between days were found in the outcomes of the schedules for the day and evening shifts. Tentatively speaking, the experts more often revealed full continuity in the day shift than the two novice groups. Moreover, the novices-np more often revealed no continuity in personnel for the day shift, whereas the novices-p attempted to take this goal into account. Though the experts considered the continuity in personnel between days an important nurse scheduling goal, more elaborate research is needed to investigate the achievement of the goal in the schedule.

Table 6.8 TYPE OF CATEGORIES OF THE CONTINUITY GOAL BETWEEN DAYS FOR A SHIFT SCHEDULED IN THE DAY- AND EVENING SHIFT FOR THE THREE GROUPS OF SUBJECTS

day shift	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
full continuity	10.17	10.08	8.25	0.52	< 0.76
less continuity	9.50	9.08	9.92	0.08	< 0.96
no continuity	7.75	9.67	11.08	1.68	< 0.43
evening shift	experts (n=6)	novices-p (n=6)	novices-np (n=6)	χ^2	p
full continuity	8.42	11.75	8.33	1.61	< 0.44
less continuity	11.25	9.50	7.75	1.30	< 0.51
no continuity	10.58	5.92	12.00	4.36	< 0.11

the results have been averaged over the subjects (mean rank)

6.3 CONCLUSION AND DISCUSSION

Despite all having the same starting point for the making of a schedule, the resulting variety of outcomes of the schedule was obvious between the experts and the novices, however, less obvious among the experts. Variety in outcomes of the schedule was investigated for a number of aspects related to the administration part as well as the problem-solving part of the nurse scheduling task. The outcomes of the labour percentage in the schedules revealed that the novices and even the experts made mistakes in the assignment of the correct number of shifts. Such a ‘variety’ in outcomes in the administration is due to a bad task performance caused by a cognitive overload, since controlling the correct number of assigned shifts per staff member needs to be done, along with all other problem-solving activities, by counting.

The outcomes of honouring wishes could not be evaluated as a faulty outcome. The variety in these outcomes among schedulers is influenced especially by the amount of domain knowledge acquired. The experts' domain knowledge contains more goals which are all considered in the problem solving; the honouring of a wish may then be overruled. In the weighing of several goals the personal notion of a scheduler can be decisive for the final choice. When only one goal is considered, such as was seen with the novices-p, the variety in outcomes is less. It would be interesting to get more insight into the problem-solving processes underlying the weighing of goals between schedulers.

Maintaining the quantity of staffing for the three shifts did not cause many difficulties in the task performance. The experts and the novices-p performed rather well in achieving the minimal staffing of a shift, whereas the novices-np had a few more problems. These findings can be attributed to the problem solving rather than to the acquisition of domain knowledge.

The quality of staffing revealed a different picture. Variety in outcomes of the schedule among the schedulers was found for the quality of staffing. The quality of staffing depends more on the domain knowledge acquired for a specific shift. The novices consistently scheduled greater quality in the staffing of one shift, whereas the experts distributed the available quality of staff members over the night, evening and day shifts. Moreover, the notion of the quality of staffing differs between the three shifts among the experts. In the night shift they often scheduled teams consisting of an experienced nurse and a trainee, while for the evening shift they preferred a team containing more quality. It seems that the experts had acquired a greater concept of the quality of staffing. A next step in understanding the problem solving would be to see how they distribute the quality of staff members available on a ward over the shifts within one planning period.

The outcomes of the continuity goal revealed that the experts prefer continuity in personnel between days (by which there will always be a staff member who is well known to the patients on the ward) to the continuity goal referring to block sizes for the same team of staff members (by which it can happen that there is a full team of new staff members and thereby no continuity in patient care). More elaborate research is surely needed to investigate the tendencies indicated for the continuity goal for the experts and the two novice groups.

Thus, a variety in outcomes in nurse scheduling can be explained by the richness of domain knowledge acquired, by whether the task performance is well done, and by the schedulers' personal style. It is therefore better to speak of less or more satisfactory outcomes of a schedule rather than right or wrong outcomes.

Variety in outcomes has implications for decision support. Bad outcomes as seen for the labour percentage can be easily remedied by a computerized system that performs the counting automatically. However, it is not always possible to evaluate the outcome of a schedule straightforwardly, such as is the case for the weighing of the nurse scheduling goals. In that case, decision support needs to fulfil a different role by being able to adapt to more subjective notions on the outcomes of the schedule. One way to fulfil this requirement is by offering several solutions to the user. In computing the solutions, the system needs to take into account the differences in the quality of staffing among the three shifts. Moreover, it should be possible for the user to manipulate the offered solutions.

CHAPTER 7

PLANNING SKILLS UNDER DECISION SUPPORT: COMPUTER-AIDED NURSE SCHEDULING

7.1 INTRODUCTION

The present chapter is about the influence of computer-aided nurse scheduling on the task performance. Roth and Woods (1989) had also investigated the effects of decision support based on a cognitive task analysis. They found that decision support improved the task performance, and second, that the variety of possible solutions for a specific problem increased.

A task presented in a computer-aided situation differs from that in the manual situation (Waern, 1989). The scheduler thus has to perform a ‘new’ nurse scheduling task. It is divided between the scheduler and the computerized system whereas in the manual situation the task performance was completely done by the scheduler. The fact that the computer-aided nurse scheduling can be regarded a new problem-solving situation, implies that the demand on domain knowledge along with the problem-solving processes may change. The main purpose of this study is to explore to what extent the problem-solving processes underlying the task performance change under the influence of decision support. In the manual situation it was found that the task decomposition, the task arrangement, and the use of domain knowledge comprise the greatest part of the problem-solving for making a schedule. The role of these aspects underlying the task performance will be investigated along with whether decision support also places specific demands on the scheduler. Therefore an experiment with the ZKR system that was based on the results of the cognitive task analysis discussed in chapters 4, 5 and 6, was designed to investigate the task performance by experts and novices in a decision-aided situation.

7.2 COMPUTER-AIDED NURSE SCHEDULING: THE ZKR SYSTEM

The task performance under decision support was investigated by using the ZKR nurse scheduling system developed within the project DISKUS. In the framework of this thesis the ZKR system is therefore considered as a tool for doing research. This needs to be distinguished from the original aim within the project DISKUS, namely, the development of a computerized system that aims at supporting the scheduler in making schedules. ZKR is an abbreviation of 'ZieKenhuisRoostering' (nurse scheduling). The design of the ZKR system was grounded on the results of the cognitive task analysis (see chapter 4, 5 and 6) from which the results are discussed in this thesis since this sets up a background for the development of knowledge-based systems (Waern, 1989). After the phases of knowledge acquisition and knowledge structuring, by which a thorough understanding of the nurse scheduling task was acquired, and which are part of the cognitive task analysis, the next phase in building the ZKR system was the knowledge representation. This phase comprises the representation and the implementation of the structured knowledge resulting from the preceding phases, according to a particular formulation that consists of production rules (IF... THEN...) and structured objects (frames). They are both used in the expert shell Nexpert which comprises objects and classes along with rules. It results in a computerized system that needs to be tested and evaluated in the next phase. Although the performance of the ZKR system depends for a large part on the nature of the knowledge representation and the implementation, the usability of the system is also fixed by the nature of the interaction between the user and the system. This is shaped for the ZKR system by associating it closely with the manual way of working by a scheduler. In this way, the semantical distance between the scheduler and the system becomes smaller. Moreover, this is in line with a design principle for decision support from cognitive psychology. Another characteristic is the modular set-up of the system by which the different tasks of the nurse scheduling task can be performed in each random sequence. In addition, the ZKR system offers the user different types of support. It is possible to work interactively in cooperation with the system, as well as to adapt generated schedules manually. Moreover, it is the responsibility of the scheduler to decide on the final schedule (Mietus & Oldenkamp, 1992). The ZKR system was further elaborately described in several reports concerning design considerations, the modelling, technical and software aspects (see Jorna, 1992; Mietus & Oldenkamp, 1992; Oldenkamp, 1991, 1992). In the meantime it is being further developed for practical use in hospitals. In the present paragraph the functions of this system are discussed from the human problem-solving perspective.

The functions offered by the ZKR system

The functions of the ZKR nurse scheduling system resemble for the most part the several tasks found in the cognitive task analysis and discussed in chapter 5 which concern administration, problem solving and evaluation at the aggregate level. Below, they are discussed in detail.

Administration

The administrative function of the ZKR system aims at the specification of the nurse scheduling problem for the planning period scheduled by preparing data needed to be processed in the problem solving. It concerns introducing and updating if necessary the administrative data, such as personal data, wishes, courses, vacations, etc. After choosing a specific planning period, the relevant administrative data is automatically placed on the schedule within the user interface. For instance, the wishes, courses, and vacations are recognizably represented in the schedule by colouring those cells related to a specific combination of a day and a staff member (see figure 7.1). For instance, a vacation of a nurse is represented by the colour red. By means of clicking on a staff member, all available personal data of that staff member is shown in a window. The system also automatically computes the historical data. An overview of the updated historical data can optionally be obtained. After finishing the computer-aided making of the schedule, the administrative data can again be updated in order to deliver a complete overview of the scheduled planning period.

Problem solving

The problem-solving function of the ZKR system aims at the generation of (partial) schedules. It contains the scheduling of the day, evening and night shift that is separately performed by the system. These three tasks are sufficient to generate a complete schedule for one planning period of four weeks. An important difference between these tasks is the division of the planning period into smaller parts that are separately scheduled. The night shift is entirely scheduled for four weeks at once whereas the scheduling of the day and evening shifts are performed per week. The user is free to choose the sequence in scheduling these three shifts. The system does not impose a specific task arrangement in the scheduling of shifts. The ZKR system computes solutions for the chosen shift on the basis of scheduling knowledge and rules captured in the system by using techniques from the field of Artificial Intelligence supplemented with Operational Research techniques. From the computed solutions of each shift the five best solutions are presented to the user. They are all acceptable solutions for the schedule, but the first solution is the ‘best’ and the fifth is the ‘poorest’ solution. This so-called ‘best solution’ is the first one presented in the schedule but the other four solutions can be examined separately. For example, the user

Figure 7.1

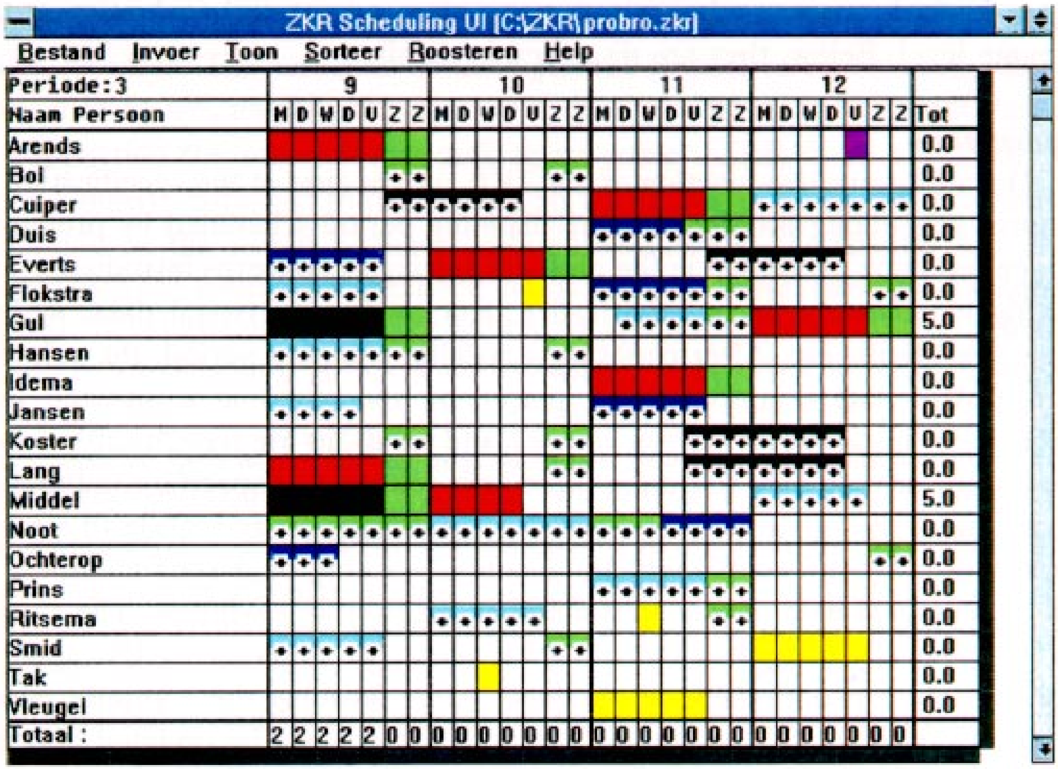
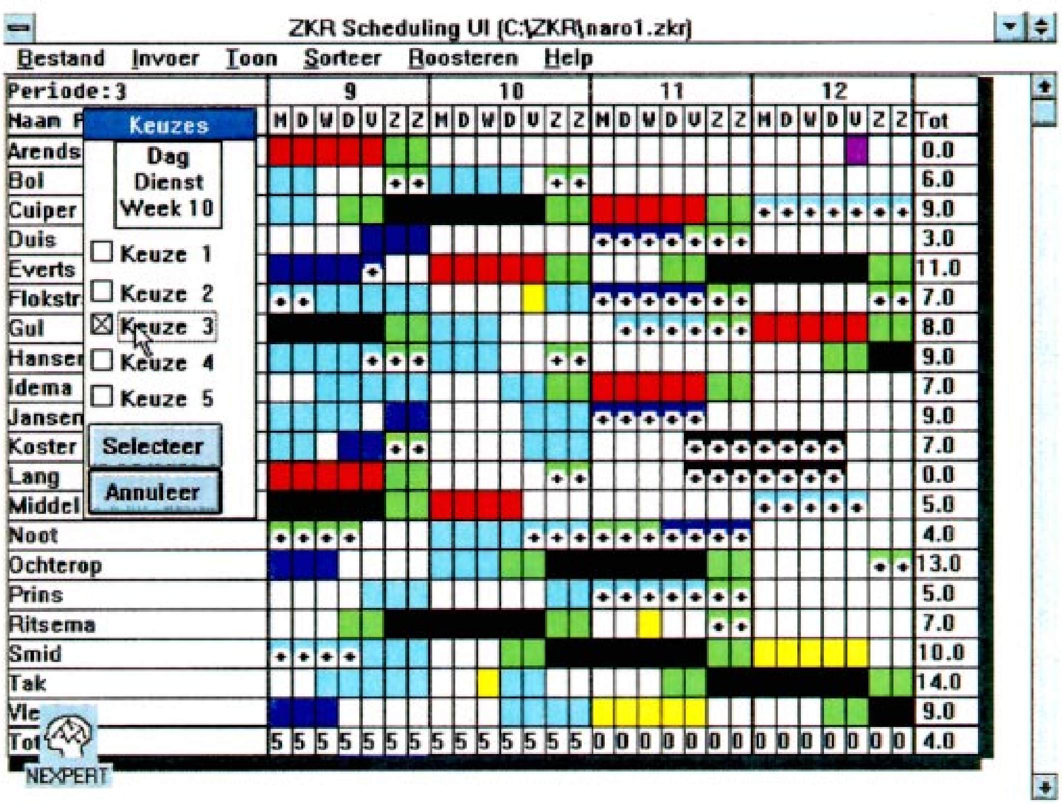


Figure 7.2



could jump from the fifth to the third solution and then decide that the second one was the most suitable solution for the specific shift being handled. The user may run through all five solutions as often as needed according to his/her personal view. After making a final choice, the scheduled shift is presented in the schedule as depicted in figure 7.2.

Within the problem solving the counting of the number of scheduled shifts per staff member as well as counting the quantity of staffing in a shift is automatically done by the ZKR system. The results of this counting are presented in the schedule and are immediately available to the scheduler. By performing the counting the system relieves the scheduler of this time-consuming task.

Moreover, it is always possible for the user to adapt the solutions manually if for any reason the user prefers to overrule the computed solution. Lastly, the days off and short-time days need to be manually scheduled.

Evaluation

The evaluation of the generated schedule needs to be performed manually by the user. It is always possible to make slight changes in the schedule by manually resolving parts of the schedule. The possibility of manual adaptations is important because the scheduler may consider that some changes lead to a better schedule despite the captured knowledge and rules in the ZKR system, the so-called emergence of ad hoc goal functions.

Below, an overview of the functions and the related tasks are given.

administration	introducing personal data
	introducing wishes
	introducing courses and vacation etc.
	looking after historical data
problem solving	scheduling the night shift
	scheduling the evening shift
	scheduling the day shift
counting	the quantity of staffing
	the number of work days of a staff member
manual	adapting the days off and short time days
evaluation (manual)	evaluating and resolving, if needed, specific parts of schedule

The functions such as presented by the ZKR system resemble the three aggregate tasks along with their subtasks distinguished in the task performance when performing the task manually. The user or scheduler is free to choose which task is going to be executed by the system. In this way the schedule is created little by little instead of wholly by the cooperation between the user and the system.

7.3 A CHANGING ROLE FOR THE SCHEDULER IN A DECISION-AIDED SITUATION

The ZKR system takes over a part of the task performance that normally would be done by the scheduler him/herself in the manual situation. The cooperation between the ZKR system and the scheduler is discussed from the task performance perspective. The scheduler still has to perform a part of the administration by updating the wishes, courses, vacation etc. However, historical data are now computed by the ZKR system and processed in computing solutions of the schedule.

The task decomposition as part of the problem solving is represented by making a choice from among the day, evening and night shift. In this regard the scheduler should be content with this task decomposition, although the scheduler has to arrange the sequence of executing them since the ZKR system does not impose a fixed order. This implies that the scheduler gets the opportunity to perform his/her preferred scheduling strategy, (for instance, a scheduler may prefer to schedule the evening shift after a day shift) and not be hampered by difficulties of a problem-solving nature. In the manual situation the scheduler often scheduled the day shifts as the last one. In this sense the ZKR system offers more flexibility in arranging the tasks.

The scheduling procedure, when executed, leading to a solution of the schedule, is completely performed by the system. This means that the counting, searching for personnel available for a shift, ranking the availability pool, composing teams satisfying the quantity and quality of staffing does not need to be done any more by the scheduler. In addition, it implies that all the burdensome extra control activities can be omitted in the making of a schedule. Moreover, automated counting would not bring about as many mistakes as occurred in the manual situation. However, the scheduler does have to judge the five presented solutions and choose one of them in the end. This is a new aspect of the nurse scheduling task under the decision-aided situation. Of paramount importance is that the scheduler is able to judge the solutions by the different aspects significant for nurse scheduling, such as the different goals. In this regard the effort of the scheduler may shift to the judgment of the nurse scheduling goals away from performing complex problem-solving processes. When the scheduler does not agree with one of the offered solutions as a whole, he/she may overrule them partly or entirely by making changes manually. In this way, the responsibility lies with the scheduler: the judgment of the scheduler remains essential in the making of the schedule when using the ZKR system. It may be obvious that the role of the scheduler changes with decision support and along with that it is expected that the nature of the problem solving underlying the task performance will differ as well. Below an overview of the division of labour between the scheduler and the ZKR system is presented.

	division of labour
administration	
introducing personal data	scheduler
introducing wishes	scheduler
introducing courses and vacation etc.	scheduler
looking after historical data	automated
problem solving	
scheduling the night shift	automated and scheduler
scheduling the evening shift	automated and scheduler
scheduling the day shift	automated and scheduler
evaluation	scheduler
counting	automated
manual	
scheduling the days off and short-time days	scheduler

The changing role for the scheduler will become significant in the problem solving. In order to understand the nature of the changes a closer investigation on the task performance by experts and novices is needed. An experiment is designed therefore with the ZKR system, though it deviates slightly from the methodological aspects related to the manual situation discussed in chapter 3. Some methodological issues are discussed first in the paragraph following.

7.4 METHODOLOGICAL ASPECTS OF THE EXPERIMENT UNDER DECISION SUPPORT

7.4.1 Subjects

The same persons participated in the experiment under decision support as in the experiment in the manual situation. There was a long time (one year) between these two sessions, so that they would not remember that the scheduling problem offered in both situations was the same problem. This implies that there is not a learning effect in the subjects. However, the distinction between the two novice groups expired because the subjects from the novice-np group had in the meanwhile become second-year student nurses, which means that they had acquired two years of practical nursing experience when the experiment took place. In this sense they were now comparable with the novice-p group.

7.4.2 Procedure

The experiment was run either in the private offices of the head nurses or, for the novices, in a quiet classroom at school. All subjects were asked not to exchange any information about the ZKR system and the presented schedule problem during the period the experiments took place.

Every experiment started by running a tutorial which instructed the subjects how to interact with the ZKR system by the use of a mouse. After reading the user manual carefully, all subjects were adequately prepared to perform the scheduling task on the computer. This took about twenty minutes. Then, a written schedule problem (the same as within the manual condition) was presented and all participants were asked to make a conclusive schedule by using the system.

The information concerning the scheduling history of each employee such as the recent weekend and night shifts worked, courses and personal wishes, were already included in the nurse scheduling system. This differs from the other session in which these data were presented on small cards and the subject had to write it down on the schedule by him/herself. The automatically generated schedule for each consecutive shift, which had to be judged, presented the names of the scheduled nurses on screen, as well as the results of the counting of the quantity of staffing for the actual shift. This also differs from the manual session in which the scheduler had to perform this by him/herself. It was possible to make manual corrections in the schedule.

Each subject had as much time as was needed for making his or her definitive schedule. During the task performance the subjects were asked to think out loud and this was recorded on tape at each session. The experiment ended with a short interview on their experience with the nurse scheduling system. The results obtained were regarded as confidential. Below an overview of the different aspects forthcoming within the making of a schedule is presented.

manual	**decision support**
data needed for the administration presented on small cards	data needed for the administration already implemented in the ZKR system
counting by scheduler	counting by system
quantity of staffing to be computed by the scheduler	quantity of staffing presented automatically on the user interface
scheduling by scheduler	scheduling by system

7.4.3 Measures

A log file implemented in the ZKR system registered a chronological record of the different tasks and investigated solutions of a scheduled shift undertaken by each subject while working on the scheduling problem. Each shift under consideration was registered as well as each solution that was evaluated. This results in a precise overview of different steps performed by the scheduler. along with the time needed for each separate activity that was also recorded in the log file.

Also, a protocol analysis was performed on the tape-recorded data in order to reveal the cognitive processes while working with the system.

The effects of decision support on task performance were measured by the following variables which included the sequence in shifts (scheduling strategy), the judgment of the five solutions and the choice made from one of the five solutions proposed by the nurse scheduling system, and the required time for the task performance to schedule the day, evening or night shift. Only the sequence of shift referring to the task arrangement was also measured in the manual situation. The others are new under decision support.

7.5 PROBLEM SOLVING UNDER DECISION SUPPORT

Problem solving under a decision-aided situation, in particular the ZKR system, is discussed by examining the task performance as shown when making a schedule. As far as it is possible the same aspects put forward in the problem solving in the manual situation are considered in the decision-aided situation as well (see 7.3.3). However, the form of the nurse scheduling task has been changed under decision support compared with the manual situation, implying that the task environment differs between the two situations and accordingly the demand on the problem solving can differ as well. This means that the aspects to be examined have a slightly different meaning depending on the task environment under consideration. For instance, the task decomposition in the ZKR system is based on the manual task decomposition of the administration, problem solving and evaluation, but is fixed for the scheduler, unlike in the manual situation, and is therefore not examined here.

The arrangement of the tasks

Along with the task decomposition, the other problem-solving principle in dealing with a planning task is the task arrangement. This means that tasks are ordered to be executed sequentially, thereby making the task performance manageable for the scheduler. Making a schedule supported by the ZKR system the user is still challenged by choosing the order in which tasks are going to be executed, with the difference that the type and the number of tasks can no longer be freely chosen any more since they are now part of the functionality of the ZKR system. The task arrangement as performed by the ZKR system but imposed by the subjects is investigated since it may change compared to the manual way of scheduling. Each single task is now offered by the ZKR system: the scheduler becomes less dependent on the problem-solving processes related to the task decomposition, and the scheduling strategy can now be performed more flexibly. This means that the scheduler gets more freedom of choice to fix the scheduling strategy. It is therefore expected that the schedulers will reveal more variety in their task arrangement by tuning the arrangement of the tasks more to the schedule's present state; we expect in particular that the fixed order of scheduling the night shift first, then the evening shift and then the day shift, will not be obeyed strictly. The task arrangement under decision support is investigated in this respect by looking at the sequence of shifts. Each choice of a shift can be considered a single task to be executed by the ZKR system. When all these choices are placed in sequence, each subject exposed a specific scheduling strategy, for instance, a scheduling strategy consisting of the sequence evening shift, night shift, day shift.

The results of the task arrangement are depicted table 7.1. The ‘standard’ sequence of night-evening-day is set off against all the other possible sequences which are: day-evening-night; day-night-evening; evening-day-night; evening-night-day; night-day-evening.

Table 7.1 THE TASK ARRANGEMENT PERFORMED UNDER DECISION SUPPORT BY THE SUBJECTS

	night evening day	not (night, evening, day) all others
experts (n=6)	4	2
novices (n=8)	2	6

The Fisher-exact test revealed a significant difference (c = 0.16, df = 1, alfa = 0.025) between the experts and novices, implying that they differ in the task arrangement; that is, the experts chose the sequence night-evening-day while the novices performed another sequence deviating from the experts', for instance, the sequence day-evening-night. The experts' scheduling strategy was still the same as had been revealed in the manual situation, while for the novices the finding that they reveal hardly any sequence is similar to the manual situation as well. However, two experts attempted to experiment with their sequence in shifts in order to attune it with their view that the day shift is the most important one. From the previous investigations on the domain knowledge of nurse schedulers it was known that the day shift was denoted as the most important shift in a nurse schedule because most of the workload of patient care is focused in the daytime. Therefore, all experts designated their preference for the day shift as the shift to start with when a schedule had to be produced. An expert scheduler gave the reason for this by saying:

> I should actually say it the other way round, the day shift has priority. Only because there are so many problems with the evening and night shifts do I tackle them first. But that is scheduling technically; as regards quality, you really should schedule the other way round, you should begin with the day shift and what's left over [schedule] for the evening and night shift.

This result suggests that some of the expert schedulers did indeed adapt their scheduling strategy to their preference. They tried out whether it was possible to make a schedule on the basis of domain knowledge only. Tentatively speaking, the effect of decision support on the task performance may be a change towards the shift considered the most important one to be scheduled first. In this respect it seems that under decision support the use of domain knowledge dominates a more general problem-solving skill such as the task arrangement. This means that the scheduler called less upon their procedural experience of how to perform the nurse scheduling task. The other experts said that they prefer to schedule the day shift first but that they did not take the opportunity to do so with the ZKR system. In fact, they commenced with the night shift. Moreover, this was in contrast to the novices, most of whom also started with the day shift. Although this difference can be explained by differences in knowledge and skills between experts and novices, the rigid manner in which the experts started with the night shift and handled the sequence of shifts, as they were commonly used to, was not necessary under the present conditions of decision support. This was illustrated by the finding that the novices, who started with an alternative shift and consequently handled a different sequence of shifts than the experts, also succeeded in the accomplishment of their task. The novices took decisions which were not based on already acquired procedural experience in the domain of nurse scheduling, but they succeeded in the application of interactive scheduling with the system. The novices had not yet learned scheduling, whereas the experts had a disadvantage when working with the ZKR system since they first needed to ignore the scheduling strategy they were used to. Further practice with the system is needed to observe possible changes in the scheduling strategy in experts.

Choosing a solution

The next aspect to be dealt with in cooperating with the ZKR system, after the choice of a task, is the five solutions presented. The ZKR system displayed five alternative solutions in which personnel are assigned to the chosen shift. They are all acceptable solutions for the schedule, but the first solution is the ‘best’ and the fifth is the ‘poorest’ solution. This so-called ‘best solution’ is the first one presented in the schedule though the other four solutions can be examined separately. The possibility of choosing from these potential solutions introduces a new aspect of the nurse scheduling task under decision support, in comparison with the manual situation, in which the scheduler concentrates on finding just one solution. The task performance demanded by the system requires, ideally speaking, that the scheduler needs to judge each single solution, then compare them with each other, before a final decision can be taken. The first issue is whether the scheduler makes use of the number of solutions offered, the second question is on which criteria are the solutions judged, and lastly, which solution is finally chosen by the scheduler. Each question is further discussed below.

The way the schedulers dealt with the facility of several solutions is investigated by means of the following categories. The first one is that a scheduler considers all five solutions, the second one is that two to four solutions are considered, for instance, solutions one, three, and four were considered. The scheduler does not need to follow the fixed sequence from one to five. It is also possible to go back to a solution already considered. The third category is that the scheduler considers just one solution (the first presented solution); that can only be solution one. All solutions considered for a shift by the subject were registered in the log file which is scored by means of the three categories for each subject. The results are given in table 7.2.

The Mann-Whitney U test revealed a significant difference between the experts and the novices for the category ‘one solution considered’ for the day and evening shift: the experts considered one solution only more often than the novices, who passed through several of the five solutions. Moreover, a similar tendency can be seen within each subject group for all three shifts. Both groups, however, make use of the five solutions presented to a great extent, though the experts prefer to consider one solution only later on and the novices keep considering all five solutions. By regarding several potential solutions of a shift more information is processed in order to take a decision. Judging one solution did not cause much difficulty, though performing a comparison among the different solutions was rather demanding, because it was sometimes hard to remember a solution since just one solution was presented in the user interface. An example of a part of an expert's log file is given, revealing the task performance for the evening shift in a particular week of the planning period:

Table 7.2 NUMBER OF SOLUTIONS CONSIDERED FOR THE DAY-, EVENING-, AND NIGHT SHIFT FOR THE TWO GROUPS OF SUBJECTS

	day shift			evening shift			night shift		
	5 s	2-4 s	1 s	5 s	2-4 s	1 s	5 s	2-4 s	1 s
experts (n=6)	7.67	8.42	10.17	6.83	9.17	9.83	7.17	7.67	8.17
novices (n=8)	7.38	6.81	5.50	8.00	6.25	5.75	7.75	7.38	7.00
z	-0.13	-0.79	-2.59	-0.52	-0.52	-2.01	-0.32	-0.21	-1.15
p	0.89	0.42	0.01	0.59	0.15	0.04	0.74	0.83	0.24

legend: 5 s = five solutions
2-4 s = two - four solutions
1 s = one solution

the results have been averaged over the subjects (mean rank)

considers all five solutions first	considering solution one
	considering solution two
	considering solution three
	considering solution four
	considering solution five
starts with solution one again,	considering solution one
weighs solution one and two	considering solution two
	considering solution one
	considering solution two
decides to consider another	
solution	considering solution three
	considering solution four
	considering solution five
decides not to choose solution five,	considering solution three
weighs solution three and four	considering solution four
	considering solution three
	accept solution three

Although at a first glance it appears to be a rather complicated process, it took less then ten minutes to accept solution three finally. The scheduler jumps quickly from one to the other after controlling the presented solution on nurse scheduling goals considered particularly important for nurse scheduling. The judging process of the solutions is discussed below.

Judging the solutions presented by the ZKR system

For computing solutions different aspects of the nurse scheduling problem are taken into account by the ZKR system. These aspects, abstracted from the results of the cognitive task analysis performed within this study, were designated as important in the making of a schedule manually. The question is whether the scheduler still processes such criteria in the interpretation of the solutions. Therefore the tape-recorded data of each subject, with the verbally justified decisions while working on the schedule problem, were written down on paper. A protocol analysis was performed on these texts in order to understand the major criteria used to make the final decision for each shift by the experts and the novices.

Generally speaking, both the experts and the novices applied their domain knowledge in the judgment of the solutions. Both experts and novices were especially focused on checking the achievement of goals, for instance, they checked the quality of staffing of a shift. They hardly make any comments on the constraints and the quantity of staffing of the three shifts. This is explained by the fact that the experts and novices easily recognize that those aspects of nurse scheduling were taken into account by the ZKR system. This is also illustrated by their protocols. An expert states why she checks the quality of staffing:

> I look at their experience. It's not a problem, it's just curiosity.

The expert again:

> I find the evening shifts and the night shifts the hardest ones to schedule. So I'll do that first. Then you could say that you should have the most continuity in the day shift. I am going to do that first, that means a lot of fuss for me. I'm going to do the day shift first, how much continuity ...

An expert judged the solutions on the continuity goal:

> What I like about this. Every time there is an overlap, a shift. So if I start those two that there is still one from the evening before, I think that's a really good system.

The advantage for the experts is that they only have to check the goals which can be done separately for each goal. Moreover, this is done per week. In the manual situation, on the other hand, the bottleneck was first to realize such a solution in which all goals were attained. The scheduler then checks the achievement of the nurse scheduling goals until the evaluation of the whole schedule, thus, after finishing the problem solving.

The goal under consideration in the novice group largely depended on the observable features of that part of the schedule which agrees with the manual situation, despite the fact that the ZKR system contains more goals. This was illustrated in the protocol analysis where the novices often pointed to the schedule pattern which successively determined their decisions.

> Vleugel has planned evening shift, then a day off and then work again. Gul does have the evening shift, is supposed to then rotate early, has got off. I don't like this choice one so much. This one is a bit better since Gul can now have those days off. And then she could rotate to day shifts. Duis also gets off and begin on Monday with the evening shift and the weekend after that off again too. She really should be off then. It works out well for Noot, has off, could also get off then again, has 6 days off. And the evening shift after that. Sonja has 2 days working, 3 off and 4 working. So does Water. The drawback is then Juul. Otherwise choice 3 is really quite good.

The novice paid a lot of attention to the schedule pattern, especially to the tuning of shifts and the total number of working days, although some of the novices mentioned continuity in the day and evening shift. This suggests that novices can acquire knowledge of goals on the basis of the solutions. In the protocols it can be seen that both the experts and the novices considered the honouring of the wishes and the quality of staffing in the night shift important compared with the day and evening shifts. Domain knowledge acquired is thus applied in the judgment of the solutions of the ZKR system for the day, evening and night shift. In this sense domain knowledge remains important in the making of the schedule despite computer-aided nurse scheduling. Moreover, it underlines the fact that the scheduler needs to be supported instead of replaced by a computerized system.

The chosen solution

The key point is which one of the five solutions is finally chosen for the definitive schedule by a scheduler. From the view of the ZKR system the first solution is the best solution whereas the fifth solution is the worst solution. An expert should be able to recognize the nature of the differences among the solutions since they are based on the experts' scheduling knowledge. The first solution agrees more with an optimal processing of the experts' knowledge than the others. It is therefore expected that the expert group would choose the first solution more often than the novice group. Since it is here the definitive solution chosen, the related part of the task performance is only considered in the log file. This means that those solutions resulting in the final schedule of four weeks are under consideration. The chosen solutions by the subjects are categorised on the basis of the ‘first solution chosen’ and ‘the second to fifth solution chosen’. However, a solution could not be computed by the ZKR system for every week because of technical problems in the software. At the time of this study the ZKR system used was not a fully operational system. The results somewhat may be flattering since not every subject could finish the making of the schedule. The results are depicted in table 7.3.

Table 7.3 THE SOLUTION CHOSEN FOR THE DAY-, EVENING-, AND NIGHT SHIFT FOR THE TWO GROUPS OF SUBJECTS

	day shift		evening shift		night shift	
	f	s-f	f	s-f	f	s-f
experts (n=6)	10.58	5.83	9.67	6.83	9.17	6.33
novices (n=8)	5.19	8.75	5.88	8.00	6.25	8.38

legend: f = first solution
s-f = second-fifth solution

the results have been averaged over the subjects (mean rank)

The Mann-Whitney test revealed a significant difference between the experts and the novices for the day and evening shift (resp. $z = -2.66$, $p = 0.007$; $z = -1.79$, $p = 0.07$) implying that the experts chose the first solution more often than the novices. The experts were thus able to distinguish the first solution from the second to fifth solutions, whereas the novices did not make such a distinction. No such significant result was found for the night shift. The experts recognized their criteria in the first solution which they had denoted as important in making a schedule manually. A within-group comparison reveals the same pattern for all three shifts: experts chose more often the first solution and the novices chose more often one from the second to fifth solutions. If the experts had only chosen the first solution then obviously, an ‘optimal’ solution could be defined; however, they sometimes preferred one of the other solutions. A choice for one of these refers to the possibility that factors other than the criteria elicited from the experts may play a role. Such factors may be prompted by a personal motivation or they may come into perspective during the problem solving itself. Offering several solutions by a computerized system meets the needs of and is beneficial to a scheduler in the making of a schedule.

Although the results discussed are encouraging from a cognitive point of view for computer-aided nurse scheduling, they need to be tentatively interpreted. By being supported the scheduler is relieved of a lot of problem solving, thereby reducing the memory load and freeing more of the scheduler's attention for judging the solutions. Moreover, the ZKR system stimulates a more structured way of working compared with the manual situation. Both the experts and the novices were aided by the system. They were able to perform a task arrangement according to their personal preference. In this sense the ZKR system enabled a flexible scheduling strategy. The experts, and the novices as well, examined a considerable number of solutions each time a decision needed to be made for a specific shift. Moreover, in judging the solutions the schedulers made greater use of their domain knowledge. According to Roth and Woods (1989) by providing a broader range of variation in attaining possible solutions, the overall task performance may improve, which may lead to a better decision making in the end.

***Time investment*.**

Nurse scheduling is considered a time-consuming task in practice. One of the requirements a computerized system is desired to fulfil is saving time. The time needed to schedule a shift by the scheduler or user consists of judging the solution, jumping between solutions and finally choosing one of the solutions. This was recorded in the log file. Each measurement started immediately after the appearance of the first offered solution on the screen and ended when a definitive choice was made. The time required by the experts and the novices to decide which solution fit best for the actual shift handled, before proceeding to the next one, was obtained from the log file. All attempts were taken into account independent of whether all solutions were considered, and in which sequence the solutions were considered, along with whether it led to the final schedule. Thus each shift scheduled by the system and judged by the user is regarded as a serious attempt. The time needed by the ZKR system to compute solutions for the scheduling of a shift was excluded. Table 7.4 reveals the results.

Table 7.4 NUMBER OF TIME (IN MINUTES AND SECONDS) SPENT ON SCHEDULING THE DAY-, EVENING-, AND NIGHT SHIFT BY THE SCHEDULER

	experts (n=6)	novices (n=8)
time spent on the day shift per week	2.41	3.59
time spent on the evening shift per week	2.14	3.57
time spent on the night shift for four weeks	6.43	4.38

the results have been averaged over the subjects

Testing revealed a significant difference (F-value = 4.96, df = 11, $p < 0.077$) between the experts and novices for the night shift only, implying that the novices needed less time for scheduling the night shift than the experts. The amount of time needed for scheduling the day and evening shift is more or less equal between the two groups. It should be noted that judging the solutions for scheduling the night shift could take more time because of the four weeks scheduled for the night shift than the day and evening shifts, which were scheduled per week by the system. These findings need to be tentatively interpreted since within both groups the subjects revealed rather dispersed time scores for all three shifts. Tentatively speaking, the results reveal that scheduling the day, evening and night shift can be finished in a restricted amount of time, within one hour, with support from the ZKR system. However, the scheduling of the these three shifts does not deliver a complete schedule. In this sense the time needed is a little bit flattered since the processing of the administrative data was not taken into account and the scheduling of days off has to be done manually in this prototype. Also the time needed to evaluate the final schedule was not considered here. These aspects of decision-supported scheduling need to be added in order to get a more complete view on the time investment. Moreover, in practice, negotiation with personnel on a ward about assigning a shift still has to be done by the scheduler and unexpected things could always happen that need to be processed into the schedule. However, in comparison with the manual situation all these aspects may not need more time. The performance of the administration is shortened for the scheduler since many data are immediately available, and historical data is automatically computed. Moreover, no counting needs to be performed any more by the scheduler. In a computer-aided situation this decreases the time needed for making a schedule.

7.6 CONCLUSION

The role of decision support in the task performance of the experts and novices was investigated in the present chapter. Some experts and most of the novices made use of the function of the system to impose a sequence in performing the tasks *scheduling a shift* tuned to their personal preference. It is concluded that the task arrangement as part of the scheduling strategy is, to for the most part, directed by domain knowledge. This implies that the role of procedural experience, significant in managing the task performance manually, is changing. It will become less important since a part of the procedural experience has been taken over by the ZKR system by offering a number of tasks in a structured way. The manual task performance has been analyzed in order to be implemented in a computerized system. Moreover, the expertise related to the task decomposition is embedded in the system. The use of decision support on the task performance, in particular the scheduling strategy, is considered fruitful. The performance of the three aggregate tasks still consists of the sequence administration, problem solving and evaluation. However, the updating of the administrative data, in particular the historical data, is more quickly available. The evaluation, however, still needs to be performed explicitly. The other problem-solving aspect when using the ZKR system are the five solutions presented. This is a rather new aspect of the problem solving. In the manual situation, the scheduler routinely converges to one solution and rarely compares possible alternatives at the same time. This is because many repetitive tasks such as counting and checking are such a major component of the cognitive demand that examining separate solutions simultaneously exceeds the working memory capacity (Newell & Simon, 1972; Anderson 1983; Newell 1990). The experts only considered one solution more often than the novices, especially for the day and evening shifts. When judging the solutions both groups appealed to their domain knowledge. This may explain the fact that the experts immediately chose the first solution after some experience with judging the other four solutions, since it is more similar to the experts' knowledge. Moreover, the results did indeed reveal that they chose the first solution more often than the novices, although the experts also preferred one of the other solutions sometimes. Deciding on the five solutions revealed that it is important that a computerized system leave the responsibility to the user in making a schedule. An advantage revealed by the results was that making a schedule in cooperation with the system will lead to a time-saving. Although this is very important, other advantages can be tentatively indicated as well. The counting performed automatically by the system gives a reduction in miscalculations, improving the problem solving along with saving time. The ZKR system aims at the support of the manual task performance since parts of the schedules referring to a specific shift instead of an entire schedule are offered. By this means, the scheduler can focus on a specific part of the scheduling problem so that more solutions can thoroughly be weighed, which results in better decisions. In the final chapter a comparison between the scheduling task with and without decision support is discussed.

CHAPTER 8

CONCLUSIONS

8.1 INTRODUCTION

The principal notion underlying this thesis is the application of the skills, knowledge and rules acquired by the scheduler in the design of a computerized planning system for more effective decision support. This was investigated by answering the research questions:

1. Which skills, knowledge and rules underly the task performance of a planning task in nurse scheduling?

2. What role do skills, knowledge and rules play in the task performance of nurse scheduling with and without decision support?

3. What is the operational relevance of the skills, knowledge and rules for designing decision support for this planning task?

In the following a summary is given of the results and conclusions related to the research questions.

8.2 CONCLUSIONS

8.2.1 Understanding planning

Let us now turn to the first research question concerning the skills, knowledge and rules underlying the making of a schedule. The making of a schedule is organized into three aggregate tasks, viz. administration, problem solving, and evaluation. The performance of the administrative part is evident, whereas the problem-solving part is more demanding from a cognitive point of view; therefore, the problem-solving results need to be controlled, which is the main activity within the evaluation. In this study the emphasis was on the problem-solving aspects.

The first aspect of problem solving-based behaviour notable in the task performance is the acquisition of domain knowledge. Various types of domain knowledge are distinguished in nurse scheduling and discussed in chapter four, namely: knowledge of the schedule, knowledge of shifts, knowledge of personnel, knowledge of constraints and knowledge of goals. The acquisition of domain knowledge partially took place in the making of a schedule. The results revealed differences between the experts and the novices in the amount and the content of domain knowledge. In contrast with the experts, the novices lack the knowledge pertaining to the effective making of the schedule, such as knowledge of goals and knowledge of constraints. The novices possess knowledge of the schedule and some knowledge of the personnel such as can directly be acquired either from the framework of the schedule itself or from the personnel. Their knowledge is oriented to surface features within the nurse scheduling. The experts thus possess greater domain knowledge content than the novices.

The second aspect of problem solving-based behaviour emerging in the task performance is the scheduling strategy, discussed in chapter five. Performing the scheduling strategy consists of determining different tasks combined with the ordering of the tasks. The three groups of subjects revealed the same decomposition of the nurse scheduling task into the three aggregate tasks, namely, the administration, the problem solving and the evaluation. However, the task decomposition of the problem solving revealed a less homogeneous picture. Differences as well as similarities showed up in the problem-solving part between the experts and novices and even within the experts' group and the novices' groups. Similarities in the task decompositions among the experts are the task schedule a shift, the task schedule the head nurse and the assistant head nurse and the task schedule the deputizing. Within the expert group they differ in decomposing the task schedule personnel and the task schedule the planning period. Thus, even schedulers who perform at the expert level revealed a variety among themselves in decomposing the problem-solving part of the nurse scheduling task. The two novice groups revealed a comparable task decomposition within the problem solving that is even similar to that of the experts. The results for the experts and the novices agree with regard to the tasks schedule a shift and schedule the head nurse and assistant head nurse. However, only the novices performed the task schedule one staff member and schedule one day, implying that the novices decompose the tasks more than the experts with regard to the tasks schedule personnel and schedule the planning period. Experience with the nurse scheduling task is important for acquiring an efficient task decomposition.

Table 8.1 OVERVIEW OF TASKS PERFORMED MANUALLY BY THE EXPERTS AND THE NOVICES

	manual		
	experts	novices-p	novices-np
administration			
process personal data	+	+	+
determine fixed data	+	+	+
determine historical data	+	+/-	+/-
determine wishes	+	+	+
problem solving			
schedule the night shift	+	+	+
schedule the evening shift	+	+	+
schedule the day shift	+	+	+
schedule the off-duty shifts	+	+/-	+/-
schedule the head and ass. head nurse	+	+/-	+/-
schedule the deputizing	+	-	-
schedule the responsible qualified nurse	+/-	+/-	-
schedule the trainees	+/-	-	+/-
schedule the part-timers	+/-	-	-
schedule one staff member	-	+/-	+/-
schedule a weekend	+/-	+/-	+/-
schedule a week	+/-	+/-	+/-
schedule one day	-	+/-	+/-

legend: + = performed by the schedulers
- = not performed by the schedulers
+/- = performed by some of the schedulers within a group (= variety within one level of expertise)

An overview of the tasks resulting from the task decomposition is given in table 8.1

Another aspect of the scheduling strategy is the arrangement of the tasks in order to perform all the several tasks effectively. Performing tasks in a controlled sequence was rather demanding for the novices, especially for the novices-np (no practical training experience in hospitals) compared with the experts. Even the two novice groups differ with regard to arranging the administrative tasks. The novices-np were not able to execute these tasks before they started with the problem solving, while the novices-p (practical training experience in hospitals) and the experts both performed very well on this part. A comparable result was found for the scheduling of a shift. While the experts and the novices-p schedule a strict sequence, namely, night-evening-day, the novices-np followed an opportunistic sequence. Thus, along with the task decomposition, the novices-p resemble the experts concerning the arrangement of the tasks belonging to the task schedule a shift. These similarities refer to the invariable part of a scheduling strategy. However, the novices-p have more problems executing each of these tasks all the way through. They skip to the next task before finishing it, while the experts perform these tasks consistently. Moreover, in scheduling the personnel or the planning period the novices soon fall back into the tasks schedule one person or one day, as the case may be. Even within the expert group variety was seen in arranging the tasks related to scheduling personnel or planning period with the exception of the scheduling of the head nurse and the assistant head nurse and the deputizing.

The experts' scheduling strategy can be characterized as script-based planning. When scheduling they make use of a mental scheme each time guiding the cognitive processes required in making a schedule. By consulting such a script a reduction on the working memory load is achieved, since it is easy to see where one is in the problem solving and which tasks are already done and which one is to be performed next. The experts performed the nurse scheduling task in a structured way. The novices' scheduling strategy is regarded as opportunistic planning. This means that the task performance depends on decisions which just come about -- they performed the nurse scheduling task in an unstructured way. The novices could not consult a comparable script as the experts had done.

In conclusion, the scheduling strategy attributed to the task decomposition and task arrangement plays a significant role in the nurse scheduling task. As well as having knowledge about the domain, it is also beneficial to perform a particular strategy for solving a complex task. Comparable findings that the performance of a complex task involves not only specific domain knowledge but also knowledge on strategies were also found by Schraagen (1994) who investigated an experimental design task for setting up research by comparing experts and novices. In addition one of his findings was that the use of strategies will lead to higher quality outcomes. In general, the quality of problem solving and decision making can thus be improved by making the performance of a task explicit, implying that the focus should be not only on the quality of the final results of the problem-solving process, but also on the way the task was dealt with.

The scheduling strategy consists thus of manageable tasks. In the execution of these tasks the assignment of the personnel to a shift takes place. This refers to the third aspect of problem solving-based behaviour notable in the task performance and is discussed in chapter five. Four activities were distinguished in the scheduling in which personnel are assigned to shifts: selecting personnel, ranking personnel, assigning personnel, and lastly, building a pattern. Each of these activities is executed by the processing of rules that are inferences applied to domain knowledge. The experts performed the four activities successively, though it is possible to jump to one of the foregoing activities. By performing the selection and ranking of personnel first, the scheduler focuses on the vertical dimension of the schedule. The horizontal dimension, i.e., the course of time within the planning period of the schedule, emerges, then, when a pattern is built around the assigned shift. The novices performed a less elaborate scheduling procedure compared with the experts. They often skipped the activities rank and assign and strongly focused on building a pattern. The novices immediately jumped from select a person to building a pattern.

A major aspect of scheduling is maintaining the goals. The weighing of the nurse scheduling goals addressing personnel is done within selecting and ranking personnel, whereas the weighing of the nurse scheduling goals aimed at guaranteeing a high standard of care for the patients is done within the assignment of a shift and the building of a pattern. The novices did not perform the elaborate scheduling procedure, implying that they had acquired relatively simple rules and consequently, no attention was paid to the weighing of the several nurse scheduling goals. Characteristic of expert scheduling is the interaction between domain knowledge and the activities within the scheduling procedure.

Counting the quantity of staffing and the number of assigned shifts per staff member is needed to justify decisions made during scheduling, which must be performed according to labour regulations. In table 8.2 the different scheduling activities are summarized for the experts and the novices.

In conclusion, problem solving-based behaviour with respect to the manual performance of the nurse scheduling task is thus characterized by a well-acquired declarative domain-knowledge base processed in the execution of the tasks by inference rules, together with scheduling strategies consisting of a number of ordered tasks in order to deal with the ill-structured nurse scheduling task.

Table 8.2 OVERVIEW OF THE SCHEDULING ACTIVITIES BY THE EXPERTS AND THE NOVICES

scheduling	experts	novices
select personnel	+	-
rank selected personnel	+	-
assign shift	+	+
build a pattern around shift	+	+
maintaining the goals	+	+
counting	+	+

legend: + = performed by the schedulers
- = not performed by the schedulers

Another interesting aspect related to knowledge, rules and skills underlying the task performance was the result of the task performance, that is, the outcomes of the nurse schedule. This is discussed in chapter six. Not surprisingly, differences in outcomes were found between the experts and the two novice groups. Such differences are due to differences in the acquisition of domain knowledge. Domain knowledge of the quality of staffing for the night, evening and day shifts was less developed among the novices. The same was found for the nurse scheduling goals. Differences in outcomes can be attributed to a badly performed task, such as counting, in which a mistake can easily be made. This was revealed in the outcomes of the quantity of staffing, especially for the day shift. A more interesting finding is that the subjects within a group differ among one another in their outcomes. Even experts differ in their final solution of the outcome. Such a variety in schedule outcomes can be attributed to differences in the weighing of the several nurse scheduling goals. Another aspect that may explain the variety is the order in which tasks are performed. It is thus hardly possible to specify one generally accepted outcome for the (nurse) schedule. Accordingly, the issue of optimizing can be questioned for nurse scheduling. Moreover, the knowledge and experience that a scheduler has with making schedules play a prominent role in deciding which outcomes are acceptable for the schedule. Use of declarative domain knowledge, script-based planning and goal maintenance results in 'better' schedules. An objective criterion for 'good' schedules has not been established.

8.2.2 Comparison of the nurse scheduling task with and without decision support

The second research question invites a comparison between the nurse scheduling task performed with and without decision support. This is discussed in this paragraph in order to understand the altered demand of the task performance as the consequence of a computerized system. An overview of tasks and the role of the scheduler and of the ZKR system in the performance of the nurse scheduling task is depicted in table 8.3 under the manual and the decision-supported situation. Below an explanation of the table results is given.

Administration

The scheduler still performs the tasks related to the administration except for determining the historical data; that is now automatically done by the system. In practice, the scheduler needs to insert data that may change among planning periods, such as the wishes and courses. In this regard the demand of the performance of the administrative tasks would not change very much. The benefits of decision support lie in the fact that the system enables the scheduler to process the administrative data in a more structured way and moreover, these data are more accessible if asked for, since they can be accessed conveniently via the user interface. The availability of the historical data on the worked shifts in particular can be more closely examined in the problem solving by the scheduler compared with the manual situation. Decision support improves the performance of the administrative tasks by offering structure.

Problem solving

The differences between working with and without decision support are more remarkable within the problem-solving part. A scheduler has at his or her disposal the tasks provided by decision support, which in the case of the ZKR system are the three tasks belonging to the scheduling of a shift. When activating these tasks the ZKR system fulfils the role of a knowledge-based system. Moreover, these three tasks are sufficient to make a complete schedule. In addition, a number of tasks that are performed in the manual situation are now performed implicitly by the ZKR system, namely, the tasks *schedule the responsible qualified*

Table 8.3 THE COMPARISON BETWEEN THE NURSE SCHEDULING TASK PERFORMED MANUALLY AND THE NURSE SCHEDULING TASK AIDED BY DECISION SUPPORT FOR THE EXPERTS AND THE NOVICES

	manual				decision support	
	scheduler expert	scheduler novice	scheduler novice-np		scheduler epb	ZKR system
administration						
process personal data	+	+	+		+	-
determine fixed data	+	+	+		+	-
determine historical data	+	+/-	+/-		-	+
determine wishes	+	+	+		+	-
problem solving						
schedule the night shift	+	+	+		+	+
schedule the evening shift	+	+	+		+	+
schedule the day shift	+	+	+		+	+
schedule the off-duty shifts	+	+/-	+/-		+	-
schedule the head and assistant head nurse	+	+/-	+/-		+	-
schedule the deputizing	+	-	-		+	-
schedule the trainees	+/-	-	-		+	-
schedule the responsible qualified nurse	+/-	-	+/-		+	+
schedule the part-timers	+/-	-	-		+	+
schedule one staff member	-	+/-	+/-		+	-
schedule a weekend	+/-	+/-	+/-		+	-
schedule a week	+/-	+/-	+/-		+	+
schedule one day	-	+/-	+/-		+	-

legend: + = performed by actor
- = not performed by actor

epb = electronic plan board

nurse and *schedule the part-timers*. The results of the task *schedule a shift* enhanced these two aspects. When the scheduler wants to schedule as in the manual situation, then these tasks can still be performed manually. The ZKR system fulfils than the role of an electronic planning-board. Most of the tasks need not be performed any more by the scheduler when cooperating with the computerized system. The several tasks performed in the manual situation are in fact reduced to a limited number of tasks under decision support. This means that the schedulers are no longer burdened with the demand of decomposing the nurse scheduling task into smaller tasks. Moreover, the ZKR system supports a part of the manual task decomposition referring to the invariant part, implying that the scheduling task becomes clearly recognizable. However, the arrangement of the tasks is still required. The scheduler imposes the sequence of the tasks to be performed by the ZKR system. The planning aspect of the nurse scheduling task with regard to determining the tasks becomes of lesser importance in the task performance, since the scheduler has to deal with a restricted number of the same tasks in contrast to the manual situation. In conclusion: decision support reduces the number of tasks, fills in gaps and omissions of the scheduler and maintains flexibility for task distribution between scheduler and system.

Scheduling

If under decision support a number of tasks are taken over by a computerized system then it is obvious that this will also include consequences for the scheduling itself. In table 8.4 the tasks referring to the scheduling itself are compared for the two situations.

The greatest transformation from the manual task to decision support is revealed for the scheduling itself. Performance of the complicated scheduling procedure and searching for solutions are no longer necessary, while the use of domain knowledge, in particular maintaining the goals, is demanded in both situations. The experts and the novices did carry out these tasks in their task performance. In this sense it can be said that there is an active cooperation between the scheduler and the system. This can also be observed in a new aspect of the scheduling task under decision support, namely, judging and choosing among alternative solutions. The scheduler still has to use his or her domain knowledge, namely, in the judgment of the solutions; this is a new aspect of the nurse scheduling task. While the scheduler converges to one solution in the manual task performance, he/she judges alternative solutions when aided by the system. The scheduler has now thus a variety of solutions at his or her disposal.

The last task to be mentioned is counting, which is performed so many times in the manual task performance. The experts and the novices did not need

Table 8.4 OVERVIEW OF THE SCHEDULING ACTIVITIES PERFORMED BY THE SCHEDULER AND THE ZKR SYSTEM

scheduling	manual		decision support		
	scheduler expert	scheduler novice-p/np	scheduler expert epb	scheduler novice epb	ZKR system
select personnel	+	-	-	-	+
rank selected personnel	+	-	-	-	+
assign shift	+	+	-	-	+
build a pattern around shift	+	+	-	-	+
maintaining the goals	+	+	+	+	+
judging alternative solutions	-	-	+	+	-
counting	+	+	-	-	+

legend: + = performed by actor
- = not performed by actor

epb = electronic plan board

to perform the counting themselves. Moreover, the scheduler has at his/her disposal more precise and 'up to date' data under decision support.

In conclusion: some aspects of the manual task are partly incorporated in the computerized system --enhancing a restricted number of tasks offered, the scheduling process itself, the counting-- whereas other aspects which are still important, such as maintaining the goals, remain the responsibility of the scheduler. New aspects also emerged under decision support: the number of solutions offered and consequently, the judgment of solutions, by which the application of knowledge is broadened. The manual task differs thus from the decision-supported task; this would be reflected in some way or other in the role of skills, knowledge and rules underlying the task performance, which leads us to the other part of the second research question.

8.2.3 The task performance under decision support

Making a schedule aided by decision support, discussed in chapter seven, puts a particular demand on the nurse scheduler. The task performance of the scheduler is partly moulded by the computerized system. The first change is the role of domain knowledge. The scheduler shifted to emphasizing the knowledge of goals in the judgment of the solutions since searching for a solution is taken over by the system. This means that performing the rules/inferences is becoming less intensive for the scheduler. The problem-solving capabilities are improved by decision support since the solutions can be considered more thoroughly.

There is also a shift in using strategic knowledge. The scheduling strategy depends on the tasks offered by the system. This implies that the task decomposition is already determined. The scheduler's role is then to arrange the tasks, which they can freely choose. Some of the experts did not stick to the normal scheduling strategy they use in the manual situation. They experiment with it by tuning the task arrangement to their preference for a specific sequence, which is possible because of the flexibility in task arrangement provided for by the ZKR system. For instance, one of the experts performed the sequence day, evening and night shift instead of their usual strategy of the night, evening and day shift. They are guided by domain knowledge of the shifts in knowing that the day shift, in fact, needs to be scheduled first. The novices were able to deal adequately with the tasks offered despite lacking in-depth domain knowledge of the shifts, though they were not bound by a particular strategy. Moreover, it was possible to have the system perform each arrangement in tasks. The scheduler is more able to adapt the scheduling strategy to personal preference, resulting in a greater measure of flexibility. Tentatively speaking, the

ZKR system increases the variety in performing the scheduling strategy, among the experts in particular, since they were less restricted by their problem-solving capabilities. The schedulers are thus less hindered by cognitive limitations, which also results in performing the nurse scheduling task in a structured way. Related to this, the quality of the making of a schedule or, as the case may be, the problem solving, is improved.

The change in the scheduling itself is due to its partly being taken over by the system. Each task scheduling the day, evening and night shift was separately executed. Consequently, the scheduling by the scheduler enhances the judgment of the (five) solutions presented by the system. Each solution referring to a scheduled shift represents then a part of the schedule's outcome. The scheduler applies domain knowledge in judging the different solutions. The experts developed a preference while working with the ZKR system for considering one solution, while the novices checked all five solutions. The experts might have learned more quickly than the novices that the first solution offered was the best solution. They checked whether their domain knowledge, especially their knowledge of the nurse scheduling goals, was displayed in the presented solution and soon came to the conclusion that the first solution came closest. The novices did not make a clear distinction in hierarchy among the solutions. In conclusion: the most significant change between making a schedule with and without decision support is that attention is shifted to other activities in the task performance. In scheduling with the system some of the types of domain knowledge such as the knowledge of the nurse scheduling goals are more explicitly used, while, for instance, knowledge of shifts becomes less important since the quantity of staffing is automatically performed and counted as well. The processing of domain knowledge in the judging of solutions becomes a core activity. Besides, the scheduler is manually busy dealing with the several tasks, while under decision support this becomes less demanding. The task performance under decision support enhances for the most part the task arrangement with regard to the scheduling strategy, and regarding the scheduling, the judgment and choice of solutions.

When comparing the experts and the novices in table 8.3 and 8.4, the differences between them are greater for the manual situation than for the decision-supported situation. The nurse scheduling task is accessible to them in a structured way, which benefits the novices especially. This means that decision support makes not only the experts more competent in making a schedule, since they did make greater use of their strategic knowledge in the task arrangement and of their domain knowledge in judging the solutions, but also the novices. If in the manual situation the scheduler is dependent on his or her scheduling knowledge, in the decision-support situation the experts and the novices both have access to the same scheduling knowledge processed in the scheduling. In this regard, the novice may have greater domain knowledge at his or her disposal compared with the manual situation.

The changes in the task performance lead to a different demand on the scheduler, or to put it in other words, a different allocation of the cognitive resources. So the demand on the working memory capacity decreases because of the fact that the scheduling itself is supported. The scheduler will therefore pay more attention to other aspects in the making of a schedule. The cognitive limitations play a less influential role since the number of tasks is reduced and the tasks are more efficiently performed. In this sense decision support leads to an improvement of the nurse scheduling task for the scheduler. The cognitive effort required is limited and less time is needed for making a schedule.

In conclusion: decision support still requires an elaborate use of domain knowledge. The role of task and strategic knowledge, however, becomes less demanding from a cognitive point of view under decision support. The same is also true for the rules applied in the scheduling; the stereotyped rules especially can be incorporated under decision support. Thus attention on understanding the knowledge and skills of the scheduler will lead to more effective decision support.

8.2.4 Effective decision support

From the comparison between the nurse scheduling task with and without decision support and the related task performance the operational relevance of insight in knowledge, rules and skills evolves for designing decision support. This sets up the answer to the third research question.

In the making of the schedule the scheduling strategy performed and the domain knowledge acquired characterize the task performance (chapter 4 and 5). Both aspects reveal the ill-structuredness of the task, and related to this, the complexity of the nurse scheduling task along with the role of the cognitive limitations. Decision support should help to deal with the complexity of problems and, related to this, the cognitive effort needed for solving such problems (Timmermans, 1991). This means for the design of decision support that: *decision support should be adapted to characteristics of the human task performance.* This guideline implies that the manual scheduling should be taken seriously. When the support is based on the manual task decomposition, the computerized system is then compatible with the actual task performance (Visser, 1992). Supporting the strategic aspects of the nurse scheduling task comprehends the organization of the tasks, which refers to the division into the administration, the problem solving and the evaluation (chapter 5). De Jong (1992) made a comparable conclusion for the trip planning domain that a DSS should offer integrated support, though typical of DSSs is the support of tasks at a more generic level, implying that the planning task is supported to a lesser degree. Therefore *decision support should support the tasks up to the more detailed level of the scheduling (problem-solving) strategy.* However, schedulers differ from one to another in their scheduling strategy, implying that there is not just one way of making a schedule. *Decision support then needs to offer the possibility of adapting to different scheduling strategies.* Hoc (1988) also pointed out that a planning aid should take the individual differences into account.

When following the structure of the task, the requirement for a computerized system that can be deduced is the modularity of the system. In the ZKR system it was realised by not only supporting the administration separately from the problem solving, but also offering the scheduling of the shifts separately (chapter 7). The modularity of the ZKR system means that the nurse scheduling task is more structured and that a solution of the schedule is not computed in one step, but rather per task, whereby a partial solution of the schedule is offered. The scheduler will judge these separate solutions implying that domain knowledge can be added per partial outcome of the schedule. This results in the guideline: *decision support should offer an elaborate and thorough use of domain knowledge.* Insofar as it is hardly possible to capture all aspects of domain knowledge acquired by an expert, part of the knowledge will be kept implicit. Therefore, the ZKR system emphasized the judgment of the scheduler in the cooperation. Falzon and Visser (1989) referred to a comparable implication for decision support that the problem solver him/herself will be the best judge, especially when there is no one right solution. This leads to the following guideline for designing decision support: *decision support should facilitate manipulation of the proposed solutions*. The ZKR system did not offer ready-made solutions of the schedule but offered the possibility of manipulating the solutions by manual adaptations. The scheduler may adapt his/her goal functions during the judgment of the solutions (chapter 7). A computerized system should therefore support the user by being highly interactive and offer a sufficient degree of freedom (Hofstede, 1992).

The division of tasks between the user and the system supports the generic view that a computerized system should not replace but support. It is therefore useful that *an interactive system ought to be based on considerations about human and computer strengths and weaknesses* (Wickens, 1984). Waern (1989), among others, mentioned that people are good at creative tasks, intuitive problem solving (heuristics), and tasks with a low need for precision; on the other hand computers are good at repetitive tasks, algorithmic problem-solving, tasks with a high need for precision and can perform a routine check (p. 128). An example is the counting within scheduling. Counting is a repetitive task that burdens the working memory leading to errors in the outcomes of the schedule. However, it is not the main task in scheduling and it ought not to cause errors. Decision support can take over such a task, resulting in a minimal load on the working memory (Hoc, 1988). On the one hand much computing work can more quickly and easily be performed by the computerized system. On the other hand the computer can function as an extension of the short-term memory by keeping partial solutions or by offering several solutions. By searching for solutions the scheduler is relieved of complex reasoning which took up a great part of the working-memory capacity. *The responsibility for the final schedule which is operational on a ward, however, remains with the scheduler.*

When these guidelines are taken into account into the design of a computerized system, then, effective decision support will be achieved. Effective decision support stimulates a structured way of performance and improves the problem-solving capabilities. It should include procedures that compensate for the shortcomings of a problem solver. Then it is better adapted to the scheduler, and the system and the scheduler cooperate in solving complex tasks. However, these guidelines can only meaningfully be incorporated into the design when the problem is elaborately analyzed by a cognitive task analysis, because then decisions can be made based on the right grounds. It would be useless to design decision support when one does not know what needs to be supported. Therefore an important guideline is that *a cognitive task analysis should be the basis for designing effective decision support*. Moreover, if *the knowledge and skills are not taken into account then the design lacks cognitive validity.* This is important since then the user understands the performance of the system because it is comparable to the daily practice of making a schedule. Besides, one also knows what the system needs to do. The system is better grounded in the daily practice of solving the complex task. Then it is expected that decision support will improve the quality of decision making. The improvements resulting from the use of the ZKR system compared with the manual nurse scheduling task performance are that the scheduler considers more solutions, more attention can be given to the maintenance of the goals, difficult tasks are performed by the system and the scheduling strategy can be performed flexibly. Moreover, the making of a schedule is less time-consuming. It should, however, be noted that the nurse scheduling task under decision support differs in a qualitative nature from that of the manual situation. This means that unforeseen situations may happen. In the following section the question whether the findings and conclu-sions can be generalized is discussed.

8.3 GENERALITY OF THE RESULTS

The question to be considered when ending any research study is the generality of the results. What can others learn from this research? Results related to the domain of nurse scheduling can be used in other (manpower) planning domains in which comparable issues play a role. One such issue is that schedulers used vaguely defined goals in the making of a schedule making it hard to indicate what is understood by an optimal solution.

Findings related to the task performance as a consequence of the ill-structuredness of the nurse scheduling task can be generalized to other complex domains such as a diagnostic domain or a design domain. Dealing with complex tasks consists of the acquisition of domain knowledge along with the acquisition of a specific strategy. It is expected that performing a specific sequence of tasks, such as schedule the night shift and so on, will also be seen in the task performance in other manpower planning domains. Although, one needs to be prepared for the fact that even experts can differ one another in solving problems.

The guidelines for effective decision support can be generalized to designing more advanced computerized systems; since they are generic in nature and found in other research as well, they can therefore be considered as more general guidelines.

8.4 FUTURE RESEARCH

It would be interesting to investigate further the hypotheses that are tentatively tested in this research in an experimental setting in order to understand planning and scheduling knowledge better. Hypotheses referring to differences between schedulers at the same level of expertise need to be further investigated. A more thorough testing of hypotheses concerning a comparison between the experts and the novice schedulers will offer insight into the learning of the nurse scheduling task. The planning skills, especially insight into activities performed automatically, need to be paid further attention in nurse scheduling. It would also be interesting to perform comparable research in other manpower planning domains in order to further generalize the results.

Other interesting research would be a further investigation of the influence of decision support on problem solving and decision making, since solving a problem under decision support is quite a new task that may bring along unexpected changes in the organization. Schedulers might use the system to back up their argument why a person is assigned to a specific shift. Experiences with the ZKR system can shed light on this. It is expected that the nurse scheduling policy may also be influenced by decision support: ‘new’ data is accessible to which the policy is tuned and adapted (chapter 2).

Also future research that aims at understanding ill-structured problems should standardize a cognitive task analysis. It is a useful method of investigating in a systematic way the knowledge and skills underlying the task performance without and with decision support (chapter 3). Although it is time-intensive, a cognitive task analysis stimulates the schedulers to make a schedule as they are used to in their practical setting by which it is made clear what kind of difficulties can be met in practice. Hereby an understanding of the problem in context overrules the problem moulded into some theoretical model. A cognitive task analysis attempts first to understand the richness of the real world which is benefiting since complex organization problems do not have a strictly technical nature. Moreover, the role of the problem solver is more prominent in such problems. The knowledge acquisition lays open the knowledge and experience gained in dealing with the organization's problem. When a better understanding of the problem is gained then the organization is more able to decide what kind of solution to a problem is appropriate. In addition, the insights from the cognitive task analysis can then be processed in shaping the solution. This was, in fact, the course taken for the development of the ZKR system.

Cognitive task analysis' importance is enhanced when organizations are viewed as knowledge-intensive entities. The organization is becoming more and more dependent on the knowledge carriers whether they are humans or machines. An important catalyst to such organizational change is knowledge technology (Simons, 1992). A cognitive task analysis helps then by offering insight into the knowledge aspects embedded in the organization. Understanding the knowledge, rules and skills will then lead to improvements in not only computerized systems by which effective decision support is achieved, but also to improvements in the business processes itself.

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APPENDIX A

Het aangeboden roosterprobleem

Algemeen probleem: het maken van een verpleegdienstrooster.
Er bestaat de volgende situatie: een verpleegafdeling heeft te maken met 21 ver pleegkundigen (16 gediplomeerden en 5 leerlingen) verdeeld over twee sub afdelingen (units) A en B (aantal bedden respectievelijk 13 en 11). Er moet een rooster worden gemaakt voor de periode 26 februari tot en met 25 maart 1990.

Beginsituatie van de periode:
|week 9|week 10|week 11|week 12|
februari maart
m d w d v z z m d w d v z z m d w d v z z m d w d v z z

De verpleegkundigen (met dienstverband, subafdeling, functie en kwaliteit) zijn:

Anna Arends	90%		hoofd	zeer ervaren
Boukje Bol	90%		waarnemend hoofd	zeer ervaren
Christa Cuiper	100%	A	gediplomeerd	ervaren
Door Duis	50%	A (avonddienst)	gediplomeerd	zeer ervaren
Evelien Everts	50%		gediplomeerd	zeer ervaren
Floor Flokstra	100%	A	gediplomeerd	weinig ervaren
Gerrie Gul	100%	A	gediplomeerd	ervaren
Hillie Hansen	50%	A	gediplomeerd	ervaren
Isabel Idema	100%	A	gediplomeerd	weinig ervaren
Juul Jansen	50%	A	gediplomeerd	ervaren
Klaske Koster	80%	B	gediplomeerd	zeer ervaren
Lydia Lang	80%	B	gediplomeerd	zeer ervaren
Mies middel	90%	B	gediplomeerd	ervaren
Nardie Noot	60%	B	gediplomeerd	ervaren
Olga Ochterop	100%	B	gediplomeerd	ervaren
Paula Prins	100%	B	gediplomeerd	weinig ervaren
Renske Ritsema	90%	A	leerling (2e jaar)	afhankelijk

Sonja Smid	90%	A	leerling (1e jaar)	afhankelijk
Tanja Tak	90%	B	leerling (4e jaar)	zelfstandig
Vera Vleugel	90%	B	leerling (2e jaar)	afhankelijk
Wilma Water	90%	B	leerling (1e jaar)	zeer afhankelijk

1 Het hoofd en het waarnemend hoofd coördineren de beide subafdelingen (units).

2 Voor de hele afdeling zijn de minimale bezettingen bepaald:
a. minimale bezetting nachtdiensten: 2
b. minimale bezetting weekeind dagdiensten: 4
c. minimale bezetting weekeind avonddiensten: 2
d. minimale bezetting vroege en late dagdiensten: 5
e. minimale bezetting avonddienst: 2

3 Wilt u met behulp van de bovenstaande gegevens proberen een zo goed mogelijk rooster voor de verpleegafdeling samen te stellen? Wilt u bij het maken van het rooster zo veel mogelijk hardop denken?

APPENDIX B

Dutch examples of protocols by experts and novices from chapters 5 and 7.

Voorbeeld protocollen uit hoofdstuk 5

Protocol van een expert

Strategische overgangen tussen de verschillende taken

Alle wensen zijn ingevuld. Ik ga nu kijken wie de nachtdienst heeft gedraaid ...
De wachten zijn nu definitief gepland. Nog even de uitslaapdagen en de vrije week enden. Ik ga nu net als anders de avond diensten plannen.

Protocol van een expert

Strategische overgangen tussen de verschillende taken

Ik ga nu naar de tweede week. Ga eerst even naar het weekend ..... Twee avond diensten heb ik rond. De rest is dagdienst. Wie heb ik allemaal? .... Dit is het dus voor deze week.
De volgende week. We gaan eerst maar weer eens kijken hoe we het met de avond dienst doen.....

Protocol van een beginneling

Het roosteren van een persoon

Isabel komt in de avonddienst. Nee, dat doe ik anders, ik doe een leerling in de avonddienst. Die komt in de avonddienst en dan Isabel een late. En Juul krijgt een dag vrij. Dit blijft vroege dagdienst, dit blijft avonddienst, en dat ook. Floor komt in late dienst en Sonja komt in late, Isabel een dag vrij, Juul komt in vroege dagdienst. Hillie een dag vrij. Boukje van vroege dagdienst naar .... Door, voor hoeveel procent werkt die ook al weer? 50%. Wordt ook roostervrij voor Door. Floor gaat naar de nachtdienst, nee naar de avonddienst. Zo! Hillie krijgt een vroege dagdienst of nee, die de .... En dan blijft die hetzelfde, wordt dit een roostervrij. Renske weer in de avonddienst en dit blijft ook avonddienst. Anna heeft ADV en Baukje? Dagdienst? Christa en Floor, Door ... dit blijft gelijk. Isabel blijft in vroege dagdienst. Juul komt in de nachtdienst, Renske blijft in de avonddienst. En Sonja in de vroege dagdienst. Dan zaterdag op zondag. Sonja: twee dagdiensten. Even kijken wie zit in de nachtdienst? Juul blijft in de nacht dienst in het weekend. Dan komt Door weer in de avonddienst. Dan heb ik genoeg voor de vroege dagdienst en avonddienst en nachtdienst. Dan doe ik de rest roostervrij. En dan doe ik zondag ook precies hetzelfde rooster.

Protocol van een beginneling

Het roosteren per dag

Dan heb ik maandag klaar! Die heeft vrij, die ook. Dinsdag, ik begin met de dag dienst. We hebben er vijf van:12345. Er moet ook een late dagdienst zijn. Die heb ik gisteren gehad, dus geef ik haar vandaag een.... Even kijken, avond dienst, code 5. een, twee, dat heb ik dus. en twee nachtdiensten: een, twee. Dat heb ik dus ook, de rest krijgt vrij.....
Nu donderdag: 1 2 3 4 5. Avonddiensten, hier een 5, daar een 5. Nacht diensten, een twee. Dat heb ik ook, dus ben ik snel klaar. Vrijdag ......

Protocol van een expert

Het roosteren van de nachtdienst

In week 10 is er niemand die in de wacht wil. Ik had hier drie mensen die in de wacht willen. Het probleem is met haar dat ze vrij wil zijn in dat weekend.
En zij heeft vakantie aangevraagd dus dan kan ze niet in de wacht.
Ik kies er in principe voor om die twee te laten staan in week 11. Voor week 10, ik heb er al een

voor. Het is een beetje uitzoeken. Ik doe maar wat. Ik zet eerst een gele. Dat is een ervaren verpleegkundige met een leerling. Dat kan.
Twee wachten voor die week. Ik doe haar in de wacht en probeer het maar want anders blijf je bezig met plannen. Ik ben benieuwd wat voor problemen er straks kunnen komen. Die leerling kan niet in de wacht want ze moet naar cursus. Je hebt wel een weekend gehonoreerd aan de mensen maar soms kan het niet anders. Ik probeer wel te zoeken naar een mogelijkheid. Ik kijk wanneer Tanja in de wacht heeft gezeten. Of Sonja en dan niet het weekend vrij honoreer. Ik kijk hoelang het geleden is dat ze een wacht heeft gedraaid. Sonja heeft geen w acht gehad Sonja kan met Mies die is ervaren. Ik kijk ook hoeveel weekenden ze heeft vrij gehad, daar wil ik best rekening meehouden. Ze heeft 8 weekenden vrij gehad, ze kan nu best twee weekenden achter elkaar werken en ik honoreer het weekend van 10-11 niet. Ze gaat de wacht in. Het weekend daarna is ze vrij en dan gaat ze naar cursus en kan ze ook niet de wacht in. Ik heb drie weken gepland voor de wacht. Die wacht staat er ook al op. Deze wacht gaat er af omdat ik al twee wachten heb.
Die heeft relatief veel wachten gedraaid en maar 50% werkt en al aardig wat diensten heeft aangevraagd, het is Evelien dus die haal ik eraf en dan plan ik de anderen definitief. Klaske en Lydia dus. Misschien is het wel zonde om twee ervaren mensen in de nachtdienst te doen. Ik kan ook kiezen voor een leerling in de wacht. Dan schuif ik die ene wacht een week op. je moet ook zorgen dat je voldoende gekwalificeerd personeel overhoudt. Ik kijk wanneer Klaske en Lydia in de wacht hebben gezeten. Lydia in week 5 en Klaske in week 8. Dus Lydia is eerst aan de beurt en daarna Klaske

Protocol van een expert

Het roosteren van de avonddienst

Ik plan bij Paula een late dienst, ze heeft niets aangevraagd en kan ze vier achter elkaar. Isabel kan het ook wel. Ik plan nog niets definitiefs omdat er iets kan tussen komen. Na een wacht geef ik Gerrie op woensdag tot en met vrijdag een late dienst, ze heeft niets aangevraagd. Hillie heeft het weekend vrij, Klaske heeft het weekend ook vrij en ik plan voor haar ook late diensten. Woensdag heb ik er twee. Donderdag en vrijdag nog, die geef ik aan Lydia ze is wel zaterdag jarig. Ze werkt 80% en heeft iets meer vrij.

Protocol van een beginneling

Voorbeelden van gemaakte inferenties

Floor werkt 100% en de andere 50%.
Juul wil graag een paar late diensten.
Als ze veel late diensten krijgt is ze de rest van de week vrij. Door 4 late. Eerste week. Ik zit alleen met probleem dat krijgt 3 late op 15 maart.
60% die krijgt nog een vrije dag erbij. Donderdag late en dan vrij. Ik neem Door 5 late in 2 weken. Weekend van 3-4 maart krijgt ze late dienst. Ik wou dat ze het weekend werkt en dan heeft ze de hele week vrij. en dan 4 dagen werken en dan nog een keer vier. Ik laat haar hier donderdag, vrijdag, weekend en maandag, 5 dagen werken. De rest van de week heeft ze nog vrij. En ze werkt twee weekenden en is al twee weekenden vrij. Evelien werkt 50%, 10 dagen, tellen. Vakantiedagen en roostervrij.
Floor drie late. Gerrie komt uit de wacht. Renske moet hier ook. Isabel. Hillie eerst werkt ook maar 50%. Heeft aangevraagd. acht dagen werk dan moet ze nog twee. Zij heeft ook twee weekenden vrij.
Juul werkt 9 dagen dus die kan vrij, tellen.
Isabel late in het weekend, Floor late. 5 late diensten vind ik veel. Is dat normaal? Zo dat zijn alle late.

Protocol van een beginneling

Voorbeelden van gemaakte inferenties

Ga ik verder met Hillie, die heeft geen nachtdienst aangevraagd. Laatste gedraaid tot en met 8 februari. Ze zou er 8 maart weer in kunnen, eventueel. Hillie, hier kan ze niet. Zou die deze week de nachtdienst kunnen doen hier? Dan heb ik ook al een gediplomeerde. Kan ze misschien op het eind hiervan. heb ik nog niemand. En daar heb ik ook al drie mensen in de nachtdienst. Zet ik haar eerst voor de laatste week op. Isabel dat is een gediplomeerde, laatste nacht dienst op 8 februari, dus die kan er pas 8 maart weer in.
Dan heeft ze een week vakantie..... Nu nog kijken hoeveel % ze werken.
....
Nou ik zit nog even met de nachtdienst, het zit toch niet helemaal lekker. Of ik daar een oplossing voor kan vinden, want om steeds ATV te geven... Nee ik denk dat ik toch geen andere... Ik weet

gewoon niet meer hoe ik dat altijd krijg... Ze moeten in ieder geval toch wel drie dagen vrij zijn, want je komt er donderdag uit, dus je moet vrijdag, zaterdag, zondag sowieso vrijzijn na de nachtdienst. Dus dan werk ik toch maar met die ATV's.
Ik ga gewoon nog maar even verder met de avonddiensten. Ik heb hier voor elke dag twee. Daar heb ik er twee. Moet ik verder met zaterdag, zondag. Als ik daar nu eens een leerling bij in zou doen? Renske die is afhankelijk, maar zij is zeer ervaren, dus dat zou wel kunnen. Moet ik hier Renske erbij in de avond dienst doen, dan heeft zij 1,2,3,4,5,6,7 dagen gewerkt. Geef ik haar hier twee avonddiensten, dat zou wel kunnen. Verder kijken. Maandag, dinsdag dan heeft niemand wat aangevraagd, kan ik gewoon zelf plannen. Zij draaide niet..., zij heeft in de nachtdienst gezeten, zij heeft net avonddienst gehad. Zij heeft vakantie. Floor heeft al een hele hoop avonddienst, Gerrie heeft nog geen avonddienst, werkt 100%, dus die kan ik op mijn rooster inplannen. Heeft daar ook nog vakantie, dus dan kan ik haar hier wel een avonddienst geven. Gerrie is ook ervaren, die is weinig ervaren, dus Isabel.., dan zou ik haar hier 2, avonddiensten kunnen geven.

Protocol van een beginneling

Voorbeelden van gemaakte inferenties

Even kijken of ik met wel met de dagdiensten uitkom. je moet met zoveel dingen rekening houden. Ik denk dat ik deze week afgehandeld heb. Vreselijk, je zou er eigenlijk een cursus voor moeten volgen. Christa, die heeft nog dagen open staan, die wou ik dus een dagdienst geven, omdat ze gekoppeld is aan
Sonja en dat is een eerste jaars leerling. Maar er zijn zoveel dagdiensten die dag, dus ik geef haar vrij.

Voorbeeld protocollen uit hoofdstuk 7

Protocol van een expert

Ik moet het eigenlijk andersom zeggen, de dagdienst in haar prioriteit ligt. Alleen dat de avond en nachtdienst de meeste problemen oplevert, ga ik die het eerst te lijf. Maar dat is rooster technisch, kwalitatief gezien behoor je net anders om te roosteren, moet je beginnen met de dagdienst en dan wat overblijft voor de avond en de nachtdienst.

Protocol van een expert

Beoordelen van de aangeboden oplossingen van het rooster

Ik zit te kijken naar ervarenheid. Dat is geen probleem. Dit is pure nieuws gierigheid.

Dezelfde expert opnieuw:

Ik vind de avonddiensten en de nachtdiensten de vervelendste diensten om te roosteren. Dus dat doe ik eerst. Dan zou je kunnen zeggen in de dagdienst moet je de meeste continuï teit hebben. Dat ga ik eerst doen, dat vereist een hele omslag bij mij. Ik ga eerst de dagdienst doen, hoeveel continuï teit...

Protocol van een expert

Beoordelen van de aangeboden oplossingen van het rooster

Wat ik hier goed aanvind. Er is iedere keer een overlapping, een verspringing. Dus als die twee beginnen dat er ook nog een van de vorige avond er is, dat vind ik zelf een heel goed systeem.

Protocol van een beginneling

Beoordelen van de aangeboden oplossingen van het rooster

Vleugel heeft ingepland avonddienst dan een dag vrij en daarna weer werken. Gul heeft wel de avonddienst, zou dan vroege moeten draaien, heeft vrij ge kregen. Ik vind deze keuze 1 niet zo. Deze is iets beter want Gul kan nu die dagen vrij krijgen. En dan zou ze dagdiensten kunnen draaien. Duis krijgt ook vrij en kan dan maandag beginnen met de avonddienst en het weekend erna ook weer vrij. Dan moet ze eigenlijk vrij hebben. Op zich komt het voor Noot mooi uit, heeft vrij, zou dan ook weer vrij kunnen krijgen, heeft 6 dagen vrij. en de avonddienst erachter aan. Sonja heeft 2 dagen gewerkt, 3 vrij en 4 werken. Dat is met Water ook zo. Het nadeel is dan Juul. Verder is keuze 3 wel heel mooi.

APPENDIX C

The ZKR system further developed

The prototype used in this thesis is being further developed into a fully operational planning system that is forthcoming for nurse scheduling in hospitals. In general, the ZKR system provides for several functions needed to perform nurse scheduling efficiently and effectively, comprising an entire task and decision support, along with administration and processing of the nurse schedules. The graphical user interface is easy to deal with for the scheduler, who still decides the task and sequence to be performed. In addition, the ZKR system can flexibly be adapted to specific characteristics on a ward. Some aspects are new in comparison with the proto type. These are summarized below:

- The scheduler can let the ZKR system control the labour contract rules and the specific hospital rules while having the final decision on the outcomes of the schedule.
- It is possible to adapt the schedule in any given planning period and check the outco mes and administer it again.
- Different weights can be assigned to goal functions such as the qualitative staffing, continuity of staffing, honouring wishes and distributing the shifts among personnel.
- Constraints can be separately selected for each war d.
- The ZKR system supports the printing of the schedules and the making of notes about the shifts scheduled for the personnel, along with the use of management information in the framework of nurse scheduling policies.

Technical aspects of the ZKR system

The ZKR nurse scheduling system consists of three different subsystems, namely, a user interface, knowledge bases and algorithms. The user interface is built in Microsoft Windows (Version 3.1, Microsoft Inc. 1992). The knowledge base is built in an expert shell (Nexpert Object, version 2.0. Neuron Data Inc. 1990) and the algorithms in programme language C (Version 5.1, Microsoft Inc. 1991). All software was run under MSDOS (Version 6.0, Microsoft Inc. 1991). The hardware needed is an IBM-compatible personal computer (IBM com patible, 386 SX, 8Mb internal memory, 80 Mb hard disk) provided with a colour graphics VGA card.

SUMMARY IN DUTCH

Samenvatting

Bij het ontwerpen van beslissingsondersteuning wordt slechts zijdelings aandacht besteed aan de menselijke factor in het geheel. Met name technische en modelmatige overwegingen zijn van doorslaggevende betekenis bij de ontwik keling van beslissingsonderste unende systemen. Terwijl kritische kanttekeningen met betrekking tot het succes en falen van beslissingsondersteuning veelal ver wijzen naar de rol van de taakuitvoerder. In het taakdomein waarop de be treffende beslissings ondersteuning zich richt, zijn de verworven kennis en ervaring van de taakuitvoerder essentieel in de taakuitvoering. Met name omdat hier veelal sprake zal zijn van complexe, slecht gestructureerde taakdomeinen het geen betekent dat het probleem niet op routine matige wijze opgelost kan worden maar dat er een beroep gedaan wordt op de creativiteit van de taaku itvoerder. Het opstellen van dienstroosters voor verpleegkundigen is zo'n probleem oplossingstaak. Echter, een taakuitvoerder is beperkt in zijn/haar cog nitieve vaardigheden hetgeen mede de wijze van probleem oplossen bepaald. De theoretische achtergrond in deze studie voor het begrijpen van het probleem oplossende karakter van deze taak is de 'human problem solving theory' van Newell en Simon (1972). Daarnaast wordt er uitgelegd wat verstaan wordt onder de taakuitvoerder als informatieverwerkend systeem.

De centrale hypothese in deze studie is dat inzicht in kennis en vaardig heden en vervolgens, op grond van deze inzichten het ontwerp van een beslis singsondersteunend systeem b aseren zal leiden tot effectieve beslissings ondersteuning. Dit onderzoek houdt zich bezig met het vinden van een antwoord op de volgende onderzoeksvragen:

1 Welke regels, kennis en vaardigheden liggen ten grondslag aan de taak uitvoering van de planningstaak bij verpleegdienstroostering?

2 Welke rol spelen regels, kennis en vaardigheden in de taakuitvoering met en zonder beslissingsondersteuning?

3 Wat is de relevantie van de regels, kennis en vaardigheden voor het ontwerpen van beslisssingsondersteuning voor deze planningstaak?

In hoofdstuk 2 wordt er eerst dieper ingegaan op algemene aspecten met betrekking tot het taakdomein van verpleegdienstroostering in ziekenhuizen. Verpleegdienstroostering is het toewijzen van verplegend personeel aan dag-, avond- en nachtdiensten in een bepaalde roosterperiode, hierbij ondermeer rekening houdend met CAO afspraken, de eisen gesteld aan de kwantitatieve en kwalitatieve bezetting van een dienst en de verschillende roosterdoelen. Vervolgens eindigt hoofdstuk twee met een beschrijving van een aantal reeds gedane onderzoeken naar beslissingsondersteuning van verpleegdienstroostering. Deze onderzoeken illustreren steeds een van de volgende benaderingen: de Operation Research/Managment Science benadering, de DSS benadering en de Knowledge-Based benadering. Het ZieKenhuisRooster systeem (ZKR) dat gebruikt is in het kader van deze studie valt onder de laatste benadering.

In hoofdstuk 3 is de methodologische verantwoording en in het bij zonder de cognitieve taakanalyse waarvan de kennisacquisitie fase is uitgevoerd, uitgebreid besproken. De planningstaak 'het opstellen van dienstroosters' die onder de verantwoordelijkheid van een hoofdverpleegkundige van een ziekenhuisafdeling valt, is experimenteel onderzocht in een tweetal ziekenhuizen. Hiertoe zijn de gegevens van een bestaande verpleegafdeling genomen hetgeen betekent dat in er in feite sprake is van een reëel dienstroosterprobleem zoals dat voorkomt in de dagelijkse praktijk. De roostermakers uit de ziekenhuizen kun nen als experts beschouwd worden, terwijl de leerlingverpleegkundigen die deelnamen aan het onderzoek als beginnelingen aangeduid zijn. De planningstaak is eerst onderzocht in de handmatige situatie en vervolgens in de beslis sings-ondersteunde situatie.

In het algemeen zijn voor het uitvoeren van een taak twee soorten kennis van belang. Naast declaratieve kennis die betrekking heeft op het 'weten wat' er zich afspeelt in het taakdomein, speelt procedurele kennis met betrekking tot het 'weten hoe' de taak uitgevoerd zal gaan worden, een rol in de taakuitvoering. Hoofdstuk 4 gaat in op domeinkennis die een roostermaker heeft verworven voor het opstellen van een dienstrooster. In het taakdomein van ziekenhuis roostering zijn vijf typen domeinkennis onderscheiden: kennis over het rooster, kennis over de diensten, kennis over het personeel, kennis over de randvoorwaarden en kennis over de doelen. Experts en beginnelingen verschillen van elkaar in gebruik van domeinkennis. De experts maken allerlei afwegingen gebaseerd op de verschillende typen kennis terwijl de beginnelingen zich richten op de waarneembare aspecten in het rooster en hierop hun beslissingen baseren. Beginnelingen streven veelal een bepaald doel na terwijl experts gelijkertijd meerdere doelen tegen elkaar afwegen.

Kenmerkend voor het uitvoeren van een planningstaak is het opdelen van de hoofdtaak in allerlei subtaken. De wijze van opdelen en het roosteren zelf zijn besproken in hoofdstuk 5. Het opstellen van een rooster bestaat uit drie algemene taken. Het eerste deel is de administratie, vergelijkbaar met de voorbereiding op het volgende deel namelijk het probleem oplossen waarin ondermeer de administratieve gegevens een rol spelen en de taak wordt afgerond met een evaluatie van het resultaat van het probleem oplossen. Elke van deze taken worden nog verder opgedeeld. Onder het probleem oplossen vallen de taken het roosteren van de diensten, het roosteren van het personeel en het opdelen van de planningperiode. Ook deze taken worden verder gesplitst. De taakuitvoering omvat naast het decomponeren van de planningstaak, het plaatsen van de verschillende taken in een bepaalde volgorde. Deze twee aspecten van de taakuitvoering verwijzen naar de roosterstrategie. Niet alleen experts en beginne lingen verschillen van elkaar in roosterstrategie maar ook experts onderling lieten verschillende roosterstrategieën zien. De roosterstrategie van beginne lingen is aangeduid als opportunistisch plannen. De experts daarentegen voeren op systematische wijze hun roosterstrategie uit, beschouwd als 'script-based' planning. De overeenkomst tussen de experts betreft met name het roosteren van de nachtdienst, de avonddienst en de dagdienst, terwijl zij van elkaar ver schillen in het decomponeren van het roosteren van personeel of in de opdeling van de planning periode. Kennelijk is er niet een manier om de taak uit te voeren. De taakuitvoering van planning omvat voor een groot deel het uit voeren van een strategie.

Het roosteren zelf waarin personeel wordt toegewezen aan een dienst in het rooster vindt plaats binnen de uitvoering van de verschillende taken uit de roosterstrategie. Het roosteren is opgedeeld in een viertal activiteiten: het selecteren van personeel, het rangordenen van geselecteerd personeel, het toewijzen van personeel en het aangeven van een roosterpatroon rondom de toegewezen dienst. De experts voeren deze roosterprocedure consequent uit terwijl de beginnelingen veelal de middelste twee stappen achterwege laten. Twee belangrijke aspecten die naar voren kwamen in het roosteren, zijn het handhaven van de roosterdoelen en het tellen van de kwantitatieve bezetting en het reeds aantal toegewezen diensten aan een personeelslid. Het tellen dient met name ter controle op en rechtvaardiging van de genomen beslissingen.

Hoofdstuk 6 gaat dieper in op de uitkomsten van het rooster. Het licht voor de hand dat experts en beginnelingen van elkaar verschillen in rooster uitkomsten. Minder voor de hand liggend is, dat ook experts onderling van elkaar verschillen. Met name in het afwegen van de roosterdoelen kan de subjec tieve invloed van de roostermaker een rol spelen. De volgorde in de uit tevoeren taken zal bovendien ook leiden tot een variëteit in roosteruitkomsten. Dit betekent dat het moeilijk aan te geven is wat onder de beste roosteruitkomst moeten worden verstaan. Het is dan ook verstandiger om dit aan de beoordeling van de roostermaker over te laten wat een acceptabel rooster is.

In hoofdstuk 7 wordt de uitvoering van de planningstaak 'het maken van een rooster' met behulp van beslissingsondersteuning besproken. Hiervoor is gebruik gemaakt van het ontwikkelde planningssysstem, het ZKR systeem, in het kader van het projekt DISKUS. Het ontwerp van het ZKR systeem is gebaseerd op de resultaten van de cognitieve taakanalyse uitgevoerd in het kader van deze studie. Het ZKR systeem is opgezet volgens de handmatige taakuitvoering. De administratieve taken zijn min of meer hetzelfde gebleven. Alhoewel de admini stratieve gegevens beter en sneller beschikbaar zijn voor de roostermaker. Het probleem oplossingsaspect levert de grootste veranderingen op. De opdeling van de taak in kleinere taken is nu vastgelegd in het systeem middels een beperkt aantal taken. De keuze van de volgorde in de uit te voeren taken door het systeem is volkomen vrij voor de gebruiker. Een aantal experts probeerden inder daad een roosterstrategie uit op grond van hun domeinkennis, dat wil zeggen zij hielden zich niet langer vast aan de volgorde nacht-, avond- en dan de dagdienst roosteren. Het vele tellen uit de handmatige taak wordt nu automatisch bijgehouden en gepresenteerd in de user-interface. Ook het roosteren zelf wordt gedaan door het ZKR systeem. Een interessant verschil met de handmatige taak is dat de experts nu een vijftal oplossingen door het systeem gegenereerd, tot hun beschikking hadden. Hieruit moesten ze een kiezen. In de beoordeling van de oplossingen controleerden de experts en ook de novices trouwens met name de roosterdoelen. Bovendien een oplossing kon, zonodig naar de inzichten van de gebruiker, aangepast worden. De planningstaak is nu niet alleen veel gestructureerder in de beslissingsondersteunde situatie vergeleken met de handmatige situatie, maar ook zal de roostermaker efficiënter van domeinkennis gebruik gaan maken.

In hoofdstuk 8 zijn er een aantal aanbevelingen voor effectieve beslissings ondersteuning gedaan die afgeleid zijn uit de vergelijking tussen het roosteren met en het roosteren zonder een systeem. In het algemeen zou beslissingsonder steuning zich moeten richten op het verbeteren van de probleem oplossings vaardigheden van de taakuitvoerder. Dit betekent dat er rekening gehouden moet worden met aspecten van de handmatige taakuitvoering in het ontwerp van beslissingsondersteuning waarbij ook rekening gehouden is met individuele ver schillen tussen roostermakers. Dit kan gerealiseerd worden ondermeer door de strategie uitgevoerd voor het oplossen van de taak te onder steunen en door het stimuleren van een grondig gebruik van domeinkennis. Een eis gesteld aan het beslissingsondersteunend systeem is dat het voorziet in de mogelijkheid tot mani pulatie van de aangeboden oplossingen. Effectieve beslis singsondersteuning zal dan leiden tot kwaliteitsverbetering in het probleemoplossingsproces en in de besluit vorming, in die zin dat alternatieve oplossingen gestructureerd kunnen worden vergeleken.