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 \textit{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 \textit{‘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:

- \textit{‘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.}

- \textit{The payoff is in extending the range and capability of managers' decision processes to help them improve their effectiveness.}

- \textit{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.
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.
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 informatieverwerkingsysteem 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 cognitive 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

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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, rule1-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 performance, 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

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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 continuous 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.

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

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.

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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.

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


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 criticized 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 (Sprague & 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

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<td>yes</td>
</tr>
<tr>
<td>problem decomposition</td>
<td>three phases</td>
<td>manual</td>
</tr>
<tr>
<td>scheduling pattern</td>
<td>cyclic</td>
<td>flexible</td>
</tr>
<tr>
<td>manual adaptation</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>scheduler</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>software</td>
<td>Basic, Pascal</td>
<td>Prolog</td>
</tr>
</tbody>
</table>
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

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**Table 2.1** OVERVIEW OF NURSE SCHEDULING SYSTEMS (continued)

<table>
<thead>
<tr>
<th>approach</th>
<th>Ozkarahan &amp; Bailey 1988</th>
<th>Courbon &amp; Esaki 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>model</td>
<td>OR</td>
<td>DSS / knowledge-based</td>
</tr>
<tr>
<td>heuristic</td>
<td>goal programming</td>
<td>object-oriented</td>
</tr>
<tr>
<td>problem decomposition</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>scheduling pattern</td>
<td>two phases</td>
<td>none</td>
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<td>manual adaptation</td>
<td>flexible</td>
<td>flexible</td>
</tr>
<tr>
<td>scheduler</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>software</td>
<td>-</td>
<td>Smalltalk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>approach</th>
<th>Diskus 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>model</td>
<td>AI / knowledge-based</td>
</tr>
<tr>
<td>heuristic</td>
<td>object and rules</td>
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<td>problem decomposition</td>
<td>yes</td>
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<td>flexible</td>
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<td>scheduler</td>
<td>yes</td>
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<tr>
<td>software</td>
<td>++++</td>
</tr>
<tr>
<td></td>
<td>Nexpert, C, MS Windows</td>
</tr>
</tbody>
</table>
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.