Quality in fives

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CHAPTER 2

APPROACHES TO NURSE SCHEDULING SUPPORT

The present chapter compares studies on supporting nurse scheduling. This comparison is based on theoretical quality aspects of nursing schedules. The first section discusses these theoretical quality aspects. The second section discusses the application of these theoretical quality aspects in practice. This is done by comparing seven distinct approaches to developing nurse scheduling support systems. This discussion shows that none of these approaches succeeds in applying all quality aspects. This chapter ends by describing a new approach to supporting nurse scheduling, which aims to apply all theoretical quality aspects.

2.1 THEORETICAL QUALITY ASPECTS OF NURSING SCHEDULES

The previous chapter described several consequences of nursing schedules for the performance of a nursing unit. The present section discusses theoretical guidelines concerning the effect of nursing schedules on the performance of nursing units by evaluating effectiveness, efficiency and job satisfaction (see also Haselhoff, 1987). For each of these three groups of consequences, a theoretical quality aspect is introduced. Furthermore, the previous chapter also indicated that the priorities given to each of these three performance characteristics might differ per health care organization, nursing unit or nurse scheduler. Therefore, a fourth theoretical quality aspect is added which concerns the support of multiple views on nursing schedule quality.

Table 2.1 shows these four theoretical quality aspects and the abbreviations used to identify each of these four. The following four subsections describe these theoretical quality aspects in more detail by discussing a number of studies on the consequences of nursing schedules for the performance of a nursing unit.

Table 2.1 THEORETICAL QUALITY ASPECTS OF NURSING SCHEDULES

care	facilitation of high-quality nursing care
unit	facilitation of efficient nursing care
staff	facilitation of job satisfaction
views	supporting multiple views on nursing schedule quality

2.1.1 Facilitation of high-quality nursing care

The effectiveness of a nursing unit depends on the quality of nursing care. Many studies investigated the effects of nursing schedules on this quality of nursing care (Blau & Sears, 1983; Gallagher, 1987; Fluharty, 1988; Newman, 1991; Morrow, 1994). Most of these studies stress the importance of continuity in the nursing staff for high-quality nursing care. This continuity is defined by the number of different nurses providing care for the same patient during the stay at the nursing unit.

Continuity also depends on the way the providing of nursing care is organized. Marquis and Huston (1994, pp. 139-146) describe five different modes of organizing patient care: case method nursing, functional nursing, team nursing, primary nursing and managed care. In case method nursing (or total patient care), one nurse is assigned to each patient. In functional nursing, several nurses are assigned to the same patient, each completing a different task or function. In team nursing, a team of nurses is assigned to each patient. In primary nursing, each patient has a primary nurse who establishes the care plan and who is responsible for this planning. And finally, in managed care (or case management), a case manager plans and coordinates the patient care, while case associates provide this care. The unit-oriented quality aspects are related to the fit between the characteristics of a particular nursing unit and one of the five modes of organizing patient care. Selecting one of these modes should be based on this fit (Marquis & Huston, 1994).

The influence of a nursing schedule on the quality of nursing care involves the assurance of continuity in the nursing staff. In other words, the quality of nursing care could be improved by increasing the continuity in the scheduled shifts (Bisseling, 1993, p. 65). The relation between a nursing schedule and the quality of nursing care is expressed by a theoretical quality aspect, abbreviated to ‘CARE’.

This facilitation of high-quality nursing care is important because providing nursing care is the primary process of a nursing unit. This theoretical quality aspect is based on the causal relation between the nursing schedule and the consequences of this schedule for providing nursing care as shown in figure 1.3.

2.1.2 Facilitation of efficient nursing care

Salaries paid to nursing personnel constitute the largest chunk of a hospital's budget. Therefore, this human resource must be utilized efficiently (Ozkarahan & Bailey, 1988, p. 306). This means that the total number of a nursing unit's nurses should correspond with the daily staffing demands. The degree of this correspondence strongly determines the efficiency of a nursing unit.

The influence of a nursing schedule on the efficiency of a nursing unit takes into account the daily staff requirements (see Excuro, 1993). For example, whenever the number of daily scheduled nurses exceeds the required number, this decreases the nursing unit's efficiency. This is also true whenever more registered nurses are scheduled during a specific shift than is required. The causal relation between a nursing schedule and the efficiency of a nursing unit (as shown in figure 1.3) is expressed by a theoretical quality aspect, abbreviated to 'UNIT'.

2.1.3 Facilitation of job satisfaction

The job satisfaction of the nursing unit's nurses is strongly based on the effects of the irregular working hours (Hung, 1992). This irregularity of their working hours affects the nurses, not only by restricting their family and social life, but also by disturbing their circadian rhythm.

The circadian system requires a week or more to adjust to a change in routine (Knauth & Rutenfranz, 1982; Schwarzenau et al., 1986). Furthermore, the adjustment of the circadian rhythms to night work always remains incomplete. Possible effects of circadian rhythm disturbances are stomach-ache, indigestion, lack of appetite, headaches, nervousness and dizziness (Dirken, 1966; Hakkinen, 1969). Therefore, the guidelines-based approach tries to minimize the disturbances of circadian rhythms.

Many studies have focused on ergonomic criteria for nurse scheduling

(Knauth & Rutenfranz, 1982; Akerstedt, 1985; Monk, 1986; Bosch & De Lange, 1987; Wilkinson & Allison, 1989). These studies resulted in the following nursing schedule evaluation criteria: just a few night shifts in succession, alternate weekends off, forward rotation of the shifts and no more than seven consecutive working days.

A third theoretical quality aspect is the facilitation of job satisfaction, abbreviated to 'STAFF'. This facilitation of job satisfaction is related to both the flexibility of nurse scheduling and the healthiness of nursing schedules. The flexibility of nurse scheduling depends on the amount of influence the nurses have on their own working schedules by means of personal preferences and specific requests (see Ozkarahan & Bailey, 1988). And the healthiness of nursing schedules is related to which of the ergonomic criteria mentioned above have been considered (see Chen & Yeung, 1992).

2.1.4 Supporting multiple views on nursing schedule quality

The objectives in nursing scheduling are multiple (see Randhawa & Sitompul, 1993). The priorities given to these objectives may differ per health care organization, nursing unit and even per nurse scheduler. This means that nurse scheduling involves multiple views on nursing schedule quality. Therefore, it is important for nurse scheduling support systems to support these multiple views. A high-quality nurse scheduling support system will allow the nurse scheduler to give priority to effectiveness, efficiency or job satisfaction. This supporting of multiple views on nursing schedule quality is a fourth and last theoretical quality aspect and is abbreviated to 'VIEWS'.

2.2 NURSE SCHEDULING SUPPORT SYSTEMS

Research on supporting nurse scheduling has resulted in a large number of nurse scheduling support systems (Smith & Wiggins, 1977; Choi et al., 1986; Chen & Yeung, 1992; Randhawa & Sitompul, 1993; Mietus, 1994, pp. 208-209). Most of these systems are decision support systems. A decision support system is an interactive information system aimed at supporting decision-makers in solving semi-structured problems (Spraque & Carlson, 1982) and consists of three parts: a data

base, a model base and a human-computer interface (Bonczek, Holsapple & Whinston, 1981).

This section compares seven approaches to supporting nurse scheduling. On the basis of the three parts of decision support systems, these eight approaches are divided into three subgroups: model-based, data-based and interface-based approaches. Table 2.2 shows these three subgroups.

Table 2.2 APPROACHES TO SUPPORTING NURSE SCHEDULING

model-based	data-based	interface-based
exhaustive search	data management	interactive scheduling
cyclic scheduling		self scheduling
heuristic search		
knowledge-based search		

The first subgroup of studies on supporting nurse scheduling focuses on the model base of nurse scheduling support system. These approaches to supporting nurse scheduling all provide a formal description of the nurse scheduling problem. This formal model is represented in a model base. There are many different ways to develop the model base of a decision support system. As a result, there are different types of model bases. The differences in type of model base are related to different methods for dealing with the very large number of possible nursing schedules. The collection of all these possible nursing schedules is referred to as the problem space (see Luger & Stubblefield, 1989; Rich & Knight, 1991). The initial state of this nurse scheduling problem is a completely empty schedule. The nurse scheduling problem is solved whenever this initial state has been changed into a goal state, which is a final schedule. The definition of these goal states depends on the type of model used and the intended nursing schedule quality.

Four different approaches to developing a model base for a nurse scheduling support system are discussed below. These approaches differ in the technique for 'navigating and pruning' the state space search (i.e. investigating and narrowing this search). The first model-based approach uses 'brute force' by evaluating all possible nursing schedules. This means that the state space search covers the entire problem space. In this way, the optimal nurse schedule will be found. This approach is called 'exhaustive search'. The second model-based approach to supporting

nurse scheduling is called 'cyclic scheduling'. This approach only allows cyclical schedules to be arranged. Therefore, cyclic scheduling adds an extra restriction to the search for optimal schedules. The third model-based approach to supporting nurse scheduling uses heuristics. These heuristics are used to reduce the state space search to the most promising part of the problem space. This approach is called 'heuristic search'. The fourth and last model-based approach to supporting nurse scheduling is called 'knowledge-based search'. The knowledge-based search approach uses domain-specific knowledge to reduce the large problem space of the nurse scheduling problem.

The second subgroup of studies on supporting nurse scheduling focuses on the data base of nurse scheduling support system. This subgroup contains one approach, which is called 'data management'. This data management approach aims to reduce the complexity of the nurse scheduling data structure.

The third and last subgroup of studies on supporting nurse scheduling focuses on the human-computer interface of the nurse scheduling support system. This subgroup contains two approaches: 'interactive scheduling' and 'self-scheduling'. Interactive scheduling aims to combine the strengths of both the human scheduler and the computer-based support system in order to solve the nurse scheduling problem, while self-scheduling tries to solve this problem by allowing nurses to arrange their own working schedules.

Each of the following seven subsections discusses one of these approaches to supporting nurse scheduling. The approaches will be scored on a qualitative scale, consisting of the values 'positive' (+), 'mediate' (±) and 'negative' (-). For an approach to supporting nurse scheduling, 'CARE' has a positive value when following this approach results in nursing schedules that facilitate high-quality nursing care. In the opposite case, when the arranged nursing schedules result in low-quality nursing care, this criterion has a negative value. The mediate value will be used for the remaining cases. In the same way, 'UNIT' has a positive value when following this approach increases the efficiency of the nursing unit. In the case of a decrease in efficiency, this criterion has a negative value. The mediate value will be used for the cases in which the approach followed did not affect the efficiency of the nursing unit. Thirdly, 'STAFF' has a positive value when following this approach results in increasing the job satisfaction among the nurses. In the opposite case, this criterion has a negative value. The mediate value will be used for the remaining cases. Finally, 'VIEWS' has a positive value when this approach is able to deal with different views on the quality of nursing schedules. If only one view is supported, this criterion has a negative value. The mediate value will be used for the remaining cases.

2.2.1 Exhaustive search for optimal schedules

The first approach to supporting nurse scheduling applies an exhaustive search of the problem space. The objective of this exhaustive search approach is to obtain the optimal nursing schedule (see Warner & Prawda, 1972). This approach makes use of mathematical models to search for this optimal schedule. The exhaustive search approach is dominant within the field of Operations Research (see Miller, Pierskalla & Rath, 1976; Warner, 1976). However, this approach can also be found in other fields (see Fitzpatrick et al., 1987, p. 10).

The standard method for obtaining an optimal nursing schedule is to convert the nurse scheduling problem into a two-stage assignment problem (Arthur & Ravindran, 1981, p. 56). This two-stage assignment problem is also referred to as the combination of the day-of-the-week problem and the time-of-day problem (Ozkarahan & Bailey, 1988, p. 308).

The objective in the first assignment stage — the day-of-the-week problem — is to find the optimal set of work patterns. For each day of the schedule period, these work patterns determine whether a nurse has a day on or a day off. The optimal work pattern is mostly found by using goal programming (see Arthur & Ravindran, 1981, p. 56) or linear integer programming (see Rosenbloom & Goertzen, 1987, pp. 19-22). The objective in the second stage — the time-of-day problem — is to find the optimal shift assignment for each working day in these work patterns.

Another example of exhaustive search uses constraint programming for solving the nurse scheduling problem. Constraint programming combines logic programming — an artificial intelligence technique — with operations research techniques (Weil et al., 1995). Constraint programming enables the problem modelling to be dissociated from the algorithms used for the solution, which provides flexibility in adjusting the formal model of the nurse scheduling problem. Weil and others (1995) showed the efficiency of constraint programming in solving a nurse scheduling problem with thirty nurses in a single-skill class, which they modelled as a problem with 1470 constraints.

The main drawback of the exhaustive search approach is its rigidity concerning the priority structure of the optimization algorithm. Although both goal programming and constraint programming offer more flexibility in choosing priorities, it still requires a fully specified hierarchy of priorities. Mostly, it is not possible to provide this specification because the relative significance of various requirements may change depending on the situation during the period concerned (Okada & Okada, 1988, p. 54).

In general, the exhaustive search approach cannot cope with individual differences among nurse schedulers concerning their view on nursing schedule quality, mainly because user interaction is almost impossible (see Ozkarahan & Bailey, 1988, p. 306). This drawback is mostly combined with rigidity in dealing with personal requests and preferences by the nursing staff, although the studies described by Warner (1976) and Arthur and Ravindran (1981, p. 56) were able to take nurses' preferences and nurses' special requests into account. However, most researchers following the exhaustive search approach conclude that their system should not be considered as a rigid tool for schedule generation, but more as a decision-makers' aid in negotiations and decisions (see Weil et al., 1995). The generated optimal schedule should be thought of as the first step in constructing the final schedule (Arthur & Ravindran, 1981).

2.2.2 Search for cyclic schedules

The second approach to supporting nurse scheduling only searches for cyclic schedules. Many studies have described procedures for developing cyclic scheduling patterns for the nursing staff (Howell, 1966; Frances, 1966; Smith, 1975; Rosenbloom & Goertzen, 1987). A cyclic schedule is a schedule which recurs after a fixed cycle. Cyclic schedules have the advantage that they can be rotated among employees so that a new schedule (theoretically) only need be produced for a nursing unit when changes occur in its average daily staff requirements. Predictable work patterns result which facilitate a staff member's planning of personal activities around a shift schedule, and unpopular work stretches are shared equally by the rotating staff.

However, there are a number of disadvantages of cyclic scheduling (see Smith & Wiggings, 1977, p. 196; Fluharty, 1988, p. 24). For example, individual preferences for particular shifts are not taken into account. And also vacations, holidays and staff resignations create complications. Okada (1992, p. 417) concludes that, despite the merits of cyclic scheduling, its applicability is very limited. Mietus (1994, p. 37) comments that since nurse scheduling is mostly characterized by a flexible alternating scheduling pattern which contrasts with the features of a cyclic schedule, cyclic scheduling does not seem to be very useful in the daily practice of nurse scheduling.

When comparing this second approach with the first approach, the main advantage of the cyclic scheduling is the resulting recurrence of the nursing

schedules. This recurrence enables the prediction of the type of shift in the future, which should have a positive effect on job satisfaction. However, cyclic scheduling does not allow changes in the work schedules, which partly reduces this positive effect.

2.2.3 Heuristic search for feasible schedules

Perhaps the most significant feature of the nurse scheduling exercise is a tendency to start with an excessively tight set of specifications, and to relax certain constraints when it becomes apparent that all specifications cannot be achieved. Furthermore, it seems almost impossible to define a simple hierarchy or set of priorities to enable a completely mechanical relaxation of the constraints. This caused some researchers to adopt the heuristic search approach (see Smith & Wiggins, 1977, pp. 197-198).

Heuristic search uses heuristic models to find feasible schedules. A heuristic model is a set of rules that is constructed on the basis of some sources of expertise. A heuristic model does not guarantee an optimal solution. This heuristic search can be found within the fields of both Operations Research and Artificial Intelligence. Its most important advantage compared with the exhaustive search approaches is the increased efficiency in finding feasible schedules.

Smith and colleagues (1977; 1979) followed the heuristic search approach by using list processing. Others also adopted this approach (see Okada & Okada, 1988; Okada, 1992). These studies aimed to solve the nurse scheduling problem by applying a state space search procedure similar to the manual method of the human scheduler.

Another example of the heuristic search approach to supporting nurse scheduling is given by a nurse scheduling system developed by Randhawa and Sitompul (1993). In order to generate work patterns, the model base of this system consists of a best-first search algorithm, which is a heuristic search technique.

Compared to the previously-discussed exhaustive search approaches, the heuristic search approach increases the efficiency of the state space search. However, this heuristic search approach does not do very well with regard to job satisfaction, because personal requests will only be granted whenever these requests do not conflict with other priorities. Furthermore, a heuristic approach is implicitly based on a certain view on nursing schedule quality, which makes it less useful whenever another view is applied.

2.2.4 Knowledge-based search for good schedules

The fourth approach to supporting nurse scheduling applies knowledge to search the problem space. This knowledge-based search approach tries to find good schedules by using a knowledge base, a model base in which knowledge is represented. A knowledge base contains expertise formalized into so-called 'production rules' (see Newell & Simon, 1972; Newell, 1990). A production rule consists of a condition part (the IF part) and an action part (the THEN part). An example of a production rule in the domain of nurse scheduling is given by Chen and Yeung (1992, p. 323) and is as follows:

IF previous shift is evening
THEN assign day shift [cf = 70 percent]
AND assign evening shift [cf = 90 percent]
AND assign night shift [cf = 20 percent]

The shift assignment of the previous shift is tested. If it is true, all the three 'conclusion clauses' will be considered. The 'cf' is the certainty factor which expresses how certain the conclusion is. In the nurse scheduling problem, it will be more appropriate to interpret 'cf' as the preference for a particular shift (Chen & Yeung, 1992, p. 323).

The knowledge bases are developed by using knowledge acquisition techniques to elicit the domain knowledge of human experts and to formalize this knowledge into production rules (e.g. Boose & Gaines, 1988; Roth & Woods, 1989). These production rules guide the state space search. This approach is dominant within the field of Artificial Intelligence (e.g. Smith, 1976).

An example of the knowledge-based search approach is given by Chen and Yeung (1992). They combined knowledge-based search with optimization algorithms. This resulted in a nurse scheduling system which uses linear zero-one goal programming to obtain an optimal work pattern and a knowledge base to assign the particular shifts to these work patterns.

Compared to both the exhaustive search approaches and the heuristic search approach, the knowledge-based search approach produces the best result in terms of job satisfaction of the nursing staff. This is because all kinds of different rules concerning the granting of special requests can be incorporated into the knowledge base. However, this method of dealing with requests and preferences of the nursing staff is based on the view of the expert nurse scheduler who provides the

scheduling knowledge. Therefore, this knowledge-based search approach does not do very well with regard to the support of multiple views on nursing schedule quality.

2.2.5 Data management for nurse scheduling

The search-based approaches discussed above uses a formal model to deal with the complexity of the nurse scheduling problem. The fifth approach to supporting nurse scheduling focuses on managing the complex data structure involved in nurse scheduling. This data management approach to supporting nurse scheduling uses data base management techniques to deal with the complexity of the nurse scheduling data domain.

The data management approach has been (partially) followed by Smith and Wiggins (1977) and Courbon and Esaki (1992). Difficulties in adapting purely mathematical structures to incorporate the complicated constraints involved in nurse scheduling caused Smith and Wiggins (1977) to adopt problem-oriented data structures, and Courbon and Esaki (1992) encountered this data management as the first problem to be tackled in order to develop a nurse scheduling support system. This problem is about taking care of a complex data structure containing employee information — such as seniority, part-time or full-time, type of shifts, history of previous schedules and requests for the coming four weeks schedule — and schedule data — concerning past and present allocation of nurses to day shifts, evening shifts, night shifts or days off.

The advantage of the data management approach lies in the reduction of the human data management. This enables the nurse scheduler to spend more time on the scheduling problem itself. This approach scores positively on the theoretical quality aspect of supporting multiple views on nursing schedule quality because it does not restrict the nurse scheduler to applying one or a small set of views on nursing schedule quality. However, this approach has a mediate score on the remaining three theoretical quality aspects because it does not necessarily contribute to a higher performance of the nursing unit.

2.2.6 Interactive scheduling

The sixth approach to supporting nurse scheduling focuses on the human-computer interface of the nurse scheduling support system. The interactive scheduling approach stresses the human-computer interaction between the human scheduler and the nurse scheduling support system (see Ahuja & Sheppard, 1975). According to this approach of interactive scheduling, 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 (Bell, Hay & Liang, 1986).

Support for the interactive scheduling approach is given by a survey of manpower planning models. Edwards (1983) reviewed several mathematical and statistical models and concluded that good representation of results and ease of use are more important to users than theoretical sophistication.

Others followed the interactive scheduling approach in combination with another approach (see also Hofstede, 1992, pp. 55-57). For example, Bell, Hay and Liang (1986) applied interactive scheduling in combination with combined search to develop a nurse scheduling support system. They described the developed system's interface as a user-friendly interactive component which allows the user to run their model — which is a combination of an algorithm and a heuristic — and display the results. Mietus (1994) described a research project that combined the interactive scheduling approach with the knowledge-based search approach.

The main advantage of the interactive scheduling approach lies in the combination of the scheduling expertise of the nurse scheduler and the representational facilities of the decision support system. This allows nurse schedulers to apply their own views on nursing schedule quality (i.e. this provides a positive score on the support of multiple views on nursing schedule quality). However, interactive scheduling has a mediate score on the remaining theoretical quality aspects.

2.2.7 Self-scheduling

The most important feature of the seventh and last approach to supporting nurse scheduling is that it enables the nursing unit's nurses to schedule their own working hours. This approach is called self-scheduling (Miller, 1984; Hung, 1992, p. 6). The essence of this scheduling method lies in the shared responsibility of all members of the nursing staff to arrange good nursing schedules.

Several studies (see Hinshaw et al., 1987; Marquis, 1988) described the

negative consequences of nurses perceiving a lack of control over their working hours, such as increased attrition rates and burnout among nurses. On the basis of these studies, Marquis and Huston (1994) concluded that scheduling has become a major factor in either fostering job satisfaction or in promoting job satisfaction and subsequent nurse retention. Therefore, managers who strive to develop a perception among staff that they do possess some control over scheduling can improve job satisfaction (Marquis & Huston, 1994, p. 215).

The main advantage of self-scheduling is the resulting job satisfaction. Unfortunately, following this approach could result in a shift of the nursing unit's priorities from patient-centred to staff-centred, which negatively affects the quality of nursing care. Furthermore, this approach mostly supports the nurses' view on nursing schedule quality.

Table 2.3 COMPARISON OF APPROACHES TO SUPPORTING NURSE SCHEDULING

	care	unit	staff	views	+	±	-
exhaustive search	+	+	-	-	2	0	2
cyclic scheduling	+	+	±	-	2	1	1
heuristic search	+	+	±	-	2	1	1
knowledge-based search	+	+	+	-	3	0	1
data management	±	±	±	+	1	3	0
interactive scheduling	±	±	±	+	1	3	0
self-scheduling	-	±	+	±	1	2	1

2.2.8 Conclusions of the comparison

Table 2.3 summarizes the comparison of the eight approaches to supporting nurse scheduling discussed above. It shows the scores of these approaches on the five quality aspects. It also shows the totals of positive, mediate and negative scores.

With regard to the facilitation of high-quality and efficient nursing care, only the four model-based approaches score positively. With regard to the facilitation of job satisfaction of the nursing staff, only self-scheduling and the knowledge-based search approach score positively. And with regard to the support of multiple

views on nursing schedule quality, only data management and interactive scheduling score positively. Therefore, the main conclusion of the comparisons of the seven approaches to supporting nurse scheduling is that none of the discussed approaches scores positively on all comparison criteria.

2.3 THE APPROACH OF QUALITY INDICATION SCHEDULING

All theoretical quality aspects discussed in the second section are important for an effective approach to supporting nurse scheduling in practice. As none of the approaches discussed in previous section has a positive score on all the theoretical quality aspects, a new approach with positive scores on all four theoretical quality aspects was researched. This new approach is called 'Quality Indication Scheduling'.

The Quality Indication Scheduling approach is based on three basic assumptions. The first basic assumption is that nurse schedulers will have identical notions about the nursing unit's effectiveness, efficiency and job satisfaction. It is assumed that this can be expressed in a formal way. This assumption is called the assumption of formalization. The formal expressions of these three notions will be called quality factors of nursing schedules.

The second assumption is the assumption of robustness. This assumption states that nurse schedulers might differ in priorities given to the nursing unit's effectiveness, efficiency and job satisfaction, respectively. For example, some nurse schedulers might give the highest priority to providing efficient nursing care, while others give the highest priority to maintaining job satisfaction.

The third assumption is the assumption of effectiveness. This assumption states that nurse scheduling can be effectively supported by informing nurse schedulers about the quality factors of nursing schedules. This assumption fits well with the interactive scheduling approach.

The present chapter ends by discussing these three assumptions in more detail. The following three subsections also discuss the resulting positive scores on the four theoretical quality aspects.

2.3.1 Assumption of formalization

The first assumption of the Quality Indication Scheduling approach is the assumption of formalization. This assumption states that a formal representation of the quality of the nursing schedule can be constructed. Furthermore, it is assumed that this formal representation consists of several independent aspects of nursing schedules. These aspects will be called quality factors.

On the basis of the consequences of nursing schedules for the performance of nursing units (see also figure 1.3), three possible quality factors have already been identified. The first one concerns the effectiveness of the nursing unit. This factor refers to continuity in the daily staffing. The second quality factor of nursing schedules concerns the efficiency of the nursing unit. This factor refers to the daily staffing demands. And the third quality factor of nursing schedules concerns the job satisfaction of the nursing staff. This factor refers both to applying ergonomics criteria and to allowing nurses to specify preferences and requests.

The approach of Quality Indication Scheduling aims to represent the overall quality of a nursing schedule as a combination of the quality factors of nursing schedules. If successfully implemented, this approach will score positively on the facilitation of both high-quality and efficient nursing units and job satisfaction.

2.3.2 Assumption of robustness

The second assumption of the Quality Indication Scheduling approach is the assumption of robustness. As stated above, priorities given to each of the three performance characteristics may differ according to the health care organization, nursing unit or nurse scheduler. Therefore, it is expected that each nurse scheduler might give a different quality value to the same nursing schedule. This means that the Quality Indication Scheduling approach claims that the perfect or optimal nursing schedule does not exist. What is best depends on the view on nursing schedule quality (i.e. the priorities given to each of the three performance characteristics).

The assumption of robustness states that the quality of a particular nursing schedule according to a nurse scheduler can be computed as a weighted sum of the values of the quality factors. The quality factors are assumed to be generic and therefore valid for all nurse schedulers, while the weights are expected to be specific and therefore to vary according to the nurse scheduler. By introducing weights, the Quality Indication Scheduling approach scores positively on the comparison criterion of supporting multiple views on nursing schedule quality.

2.3.3 Assumption of effectiveness

The third assumption of the Quality Indication Scheduling approach is the assumption of effectiveness. This assumption states that informing nurse schedulers about the current values of the quality factors will reduce the task complexity. Without this additional information, the nurse schedulers 'compute' these values themselves, which means that they have to do a lot of counting and checking. By informing them about these factor values, nurse schedulers will be able to put more cognitive effort into increasing the quality of nursing schedules.

The approach of Quality Indication Scheduling can be summarized as follows. Firstly, independent quality factors of nursing schedule quality are conceptually modelled. Then, these quality factors are operationalized in order to measure the values of these factors. Finally, the effectiveness of informing nurse schedulers about the values of these quality factors will be investigated. These three steps will be called the analysis, operationalization and application of nursing schedule quality.

The Quality Indication Scheduling approach combines aspects of the three distinct approaches to supporting nurse scheduling discussed in the last section. This approach applies a formal way of modelling the performance characteristics of the nursing unit, which is also done in the exhaustive search approach. Furthermore, knowledge acquisition techniques will be used to attain these formal representations, which is also done in the knowledge-based search approach. A third approach of which certain aspects are also present in the Quality Indication Scheduling approach is interactive scheduling. The Quality Indication Scheduling approach combines the computation powers of the nurse scheduling support system with the scheduling expertise of the nurse scheduler, which is also done in this interactive scheduling approach.

The next chapter will discuss the methodological foundation of this research approach. Then, chapters four to seven will describe the research results. The eighth chapter will describe the conclusions based on these results.