Quality in fives

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CHAPTER 5

RANKING OF SHIFT PATTERNS

The previous chapter described a conceptual model of nursing schedule quality consisting of five independent quality factors. The present chapter describes an experiment designed to answer the second research question (i.e. "How can one operationalize each factor of nursing schedule quality?"). In this experiment, nurse schedulers are asked to rank a number of alternative shift patterns. This experiment is called the 'ranking experiment'.

The ranking experiment is based on a fictitious nursing unit. The first section describes this fictitious nursing unit. The remaining three sections describe the design, the results and the conclusions of the ranking experiment.

5.1 CHARACTERISTICS OF A NURSING UNIT

In order to design a representative nursing unit, a questionnaire was used (see Appendix A). This questionnaire was answered by eighteen nurse schedulers of six health care organizations. As described in the previous chapter, the answers to one of these questions are used to validate the five quality factors of nursing schedules. The remaining questions asked about unit characteristics — such as the number of nurses and levels of nursing expertise — and schedule characteristics — such as length of schedule period and types of shifts. The answers to these questions are used to design a fictitious 'average' nursing unit. This average nursing unit is called 'East-5'.

This section describes some of the remaining results of the questionnaire. These results concern the levels of nursing expertise, length of schedule period, types of working days and quantitative staffing demands. The following sub-sections discus these results and describe the corresponding average values for the East-5 nursing unit.

5.1.1 Levels of nursing expertise

There were two levels of nursing expertise at most nursing units involved in the questionnaire. At the remaining nursing units, there was one. Therefore, two levels of nursing expertise are present at the fictitious East-5 nursing unit. Registered nurses have the highest level of nursing expertise. In this study, nurses working at the second level of nursing expertise are called 'nursing assistants', although others identify this level as "nurses' aids" (see Arthur & Ravindran, 1981, p. 56; Bell, Hay & Liang, 1986, p. 134; Okada & Okada, 1988) or 'nurse assistants' (see Fluharty, 1988). Other levels of nursing expertise, such as 'licensed practical nurses', are not present at the fictitious East-5 nursing unit. In total, the nursing staff of East-5 consists of nine registered nurses and thirteen nursing assistants.

5.1.2 Length of schedule period

The results of the questionnaire showed that the length of the schedule period can vary from fourteen days to eight weeks. Mostly, this period is between four and six weeks. For practical reasons (i.e. it takes less time to arrange), a schedule period length of four weeks will be used at the fictitious East-5 nursing unit.

5.1.3 Types of working days

The results of the questionnaire showed that most nursing units distinguish between three types of working days: normal working days (i.e. Mondays, Tuesdays, Wednesdays, Thursdays and Fridays), weekends (i.e. Saturdays and Sundays), and holidays (e.g. New Year's day, Christmas). Again for practical reasons, two types of working days will be used at the fictitious East-5 nursing unit: normal working days and special working days. These special working days include holidays and weekends.

5.1.4 Quantitative staffing demands

The results of the questionnaire showed a wide variety in types of shifts (e.g. different starting times and different shift lengths) and in the corresponding quantitative staffing demands. Only the standard types of shift are used at the fictitious East-5 nursing unit: day shifts, evening shifts and night shifts. At East-5, the corresponding quantitative staffing demands vary per type of working day. On each normal working day of the schedule period, two night shifts, three evening shifts, and five day shifts need to be scheduled, while on special working days of the schedule period, the quantitative staffing demands are two night shifts, three evening shifts and four day shifts.

5.2 DESIGN OF THE RANKING EXPERIMENT

The previous chapter described the modelling of nursing schedule quality as a concept consisting of five independent quality factors. The research objective of the ranking experiment is to operationalize each of these quality factors. As described in the third chapter, five steps are designed to attain these operationalizations. The first two research steps constitute the preparation part of the ranking experiment. This section discusses the results of these two preparation steps. The next two sections discuss the results of the remaining three research steps.

In the first research step of the ranking experiment, each quality factor was specified by a number of aspects which could be both uniquely identified and unambiguously detected. These aspects are called ‘decision aspects’ (see also figure 3.1). In the second step, each of these decision aspects was translated into alternative shift patterns (i.e. the bottom layer in the hierarchical model of nursing schedule quality).

The following five subsections describe both specifications. Firstly, each quality factor will be specified by means of several decision aspects. The total number of decision aspects per quality factor depends on the theoretical possible variation. For each quality factor, as many decision aspects as possible were formulated. And for each of these decision aspects, all (reasonable) alternative shift patterns were identified.

The nurse schedulers who participated in the ranking experiment were asked to rank these alternative shift patterns per decision aspect according to each pattern's value for the corresponding quality factor on the basis of their own view

on nursing schedule quality. This means that the best shift pattern according to a nurse scheduler will be ranked first, while the worst shift pattern according to this nurse scheduler's opinion will be ranked as last.

Furthermore, related decision aspects are combined into one (extra) decision aspect. This type of decision aspect will be called a 'combination decision'. These combination decisions contain several decision aspects. The participating nurse schedulers were asked to rank these decision aspects according to their importance for the corresponding quality factor. In other words, the decision aspects are the ranking objects of the combination decisions. These combination decisions are necessary for the determination of the importance of each decision aspect for the corresponding quality factor. On the basis of each decision aspect's importance (i.e. its position in the ranking) the rankings given to these combination decisions can be used to integrate the decision aspects into a single quality factor.

Below, the decision aspects, the corresponding shift patterns and the combination decisions are discussed per quality factor. Appendix B contains a full description of these shift patterns. Below, the decision aspects are identified by a factor code (i.e. 'C', 'O', 'P', 'H' or 'T') and a number (i.e. 1 up to the maximum of 10), while the shift patterns are identified by a factor code, the number of the decision aspect and a letter (i.e. 'a' up to the maximum of 'j').

5.2.1 Decision aspects concerning completeness

The completeness factor represents the degree in which the quantitative demands for occupation per shift are met. Because these quantitative staffing demands differ per type of working day, one decision aspect of the quality factor completeness concerns incompleteness during normal working days (C-1), while another concerns incompleteness during special working days (C-3). Furthermore, the results of the questionnaire also shows that a surplus, which is quantitative overstaffing, does not influence completeness. Therefore, both decision aspects have three alternative shift patterns, which can be described as an incompleteness caused by a daily shortage of one day shift (C-1a and C-2a), one evening shift (C-1b and C-2b) or one night shift (C-1c and C-2c). A third decision aspect related to the completeness factor (C-3) is a combination decision, and has to do with the importance of completeness during normal working days (C-3a) compared to

special working days (C-3b). Table 5.1 mentions the three decision aspects related to the completeness factor. The number of alternative shift patterns are mentioned in parentheses.

Table 5.1 DECISION ASPECTS OF COMPLETENESS

code	decision aspect	sp
C-1	incompleteness on normal working days	3
C-2	incompleteness on special working days	3
C-3	incompleteness per type of working day	2

sp = number of shift patterns

5.2.2 Decision aspects concerning optimality

The optimality factor represents the degree to which nursing expertise is distributed over the different shifts. This nursing expertise per shift can be expressed by the proportion of registered nurses scheduled. This proportion depends on the total number of nurses, and can thus differ per type of shift and per type of working day. Therefore, the optimality factor can be specified in six decision aspects (O-1, O-2, O-3, O-5, O-6 and O-7) and three combination decisions O-4, O-8 and O-9). Each decision aspect has three corresponding shift patterns: one pattern representing about forty percent of registered nurses per shift, one with an extra registered nurse and one with a registered nurse less. The first two combination decisions (O-4 and O-8) combine the importance of the proportion of registered nurses scheduled per type of working day, while the third combination decision (O-9) combines these two combination decisions. Table 5.2 indicates these nine decision aspects related to the optimality factor.

5.2.3 Decision aspects concerning proportionality

The proportionality factor represents the degree to which each nurse has been given about the same number of night shifts, evening shifts and weekends off. This

factor has been specified by three decision aspects and one combination decision. Table 5.3 indicates these four decision aspects related to the proportionality factor.

Table 5.2 DECISION ASPECTS OF OPTIMALITY

code	decision aspect	sp
O-1	day shift optimality on normal working days	3
O-2	evening shift optimality on normal working days	3
O-3	night shift optimality on normal working days	3
O-4	optimality on normal working days per type of shift	3
O-5	day shift optimality on special working days	3
O-6	evening shift optimality on special working days	3
O-7	night shift optimality on special working days	3
O-8	optimality on special working days per type of shift	3
O-9	optimality per type of working day	3

sp = number of shift patterns

The first decision aspect of proportionality (P-1) concerns the proportion of day shifts to evening shifts to night shifts. This decision aspect has been translated into seven shift patterns. Each of these shift patterns represents a total of twenty-four shifts. The first pattern (P-1a) has fourteen day shifts, six evening shifts and four night shifts, while, for example, the last one (P-1g) has ten day shifts, eight evening shifts and six night shifts.

The second decision aspect of proportionality (P-2) concerns the distribution of days off. This decision aspect has also been translated into seven shift patterns. These patterns differ in length and number of periods of days off. For example, one of these patterns (P-2d) represents four periods of days off, while another (P-2f) contains six periods of days off.

The third decision aspect of proportionality (P-3) concerns the distribution of weekends off. This decision aspects has been translated into four shift patterns. These patterns differ in number of consecutive weekends on. This number is one for the first shift pattern (P-3a), and it increases per pattern to four for the last shift pattern related to this decision aspect of distribution of weekends off (P-3d).

Table 5.3 DECISION ASPECTS OF PROPORTIONALITY

code	decision aspect	sp
P-1	proportionality concerning the numbers per type of shift	7
P-2	proportionality concerning the distribution of days off	7
P-3	proportionality concerning the distribution of weekends off	4
P-4	importance per decision aspect concerning proportionality	3

sp = number of shift patterns

The fourth and last decision aspect of proportionality (P-4) is a combination decision. It concerns the importance per decision aspect concerning proportionality. These decision aspects P-1, P-2 and P-3 are represented as the 'ranking objects' P-4a, P-4b and P-4c, respectively.

5.2.4 Decision aspects concerning healthiness

The healthiness factor represents the degree to which care has been taken of the welfare and health of the nursing staff. This factor has been specified by seven decision aspects and three combination decisions. Table 5.4 mentions these ten decision aspects related to the healthiness factor.

The first decision aspect of healthiness (H-1) concerns the number of consecutive night shifts. This decision aspect has been translated into seven shift patterns. These shift patterns differ from a single night shift for the shortest pattern (H-1a) to seven consecutive night shifts for the longest shift pattern (H-1g).

The second decision aspect of healthiness (H-2) concerns the number of consecutive evening shifts. This decision aspect has been translated into ten shift patterns. These shift patterns differ from a single evening shift for the shortest pattern (H-2a) to ten consecutive evening shifts for the longest shift pattern (H-2j).

The third decision aspect of healthiness (H-3) concerns the number of consecutive day shifts. This decision aspect has also been translated into ten shift patterns. These shift patterns differ from a single day shift for the shortest pattern

(H-3a) to ten consecutive day shifts for the longest shift pattern (H-3j).

The fourth decision aspect of healthiness (H-4) concerns the number of consecutive working days. This decision aspect has been translated into seven shift patterns. These shift patterns differ in the length of the period of consecutive working days. The longest pattern (H-4g) consists of ten consecutive working days, while the shortest pattern (H-4a) consists of four consecutive working days.

Table 5.4 DECISION ASPECTS OF HEALTHINESS

code	decision aspect	sp
H-1	healthiness in relation to the number of consecutive night shifts	7
H-2	healthiness in relation to the number of consecutive evening shifts	10
H-3	healthiness in relation to the number of consecutive day shifts	10
H-4	healthiness in relation to the number of consecutive working days	7
H-5	importance per decision aspect in relation to healthiness of consecutive shifts	4
H-6	healthiness in relation to the amount of resting-time after a night shift period	6
H-7	healthiness in relation to rest during a shift change without days off	4
H-8	healthiness in relation to the amount of rest during a shift change with days off	6
H-9	importance per decision aspect in relation to healthiness of scheduled rest	3
H-10	importance of healthiness of consecutive shifts versus scheduled rest	2

The fifth decision aspect of healthiness (H-5) is a combination decision. This combination decision concerns the importance per decision aspect concerning healthiness of consecutive shifts. It combines the first four decision aspects of healthiness. These decision aspects, H-1, H-2, H-3 and H-4, are represented as H-5a, H-5b, H-5c and H-5d, respectively.

The sixth decision aspect of healthiness (H-6) concerns the amount of rest after a night shift period. This decision aspect has been translated into six shift patterns. These patterns vary from 47.5 hours of rest after a night shift period for the 'shortest' pattern (H-6a) to 103.5 hours of night shift recovery time for the 'longest' shift pattern (H-6f).

The seventh decision aspect of healthiness (H-7) concerns the amount of rest during a shift change without days off. It has been translated into four shift patterns. These patterns vary from eight hours of rest for the 'shortest' pattern (H-7c) to thirty-two hours for the 'longest' shift pattern (H-7b).
The eighth decision aspect of healthiness (H-8) concerns the amount of rest during a shift change with days off. It has been translated into six shift patterns. These patterns vary from thirty-two hours of rest for the 'shortest' pattern (H-8d) to fifty-six hours for the 'longest' shift pattern (H-8c).

The ninth decision aspect of healthiness (H-9) is a combination decision. This combination decision concerns the importance per decision aspect concerning healthiness of scheduled rest. It combines the three decision aspects H-6, H-7 and H-8. These decision aspects are represented as H-9a, H-9b and H-9c, respectively.

The tenth decision aspect of healthiness (H-10) is again a combination decision. It concerns the importance of healthiness of consecutive shifts (H-10a) versus healthiness of scheduled rest (H-10b). It thus combines the two combination decisions H-5 and H-9.

Table 5.5 DECISION ASPECTS OF CONTINUITY

code	decision aspect	sp
T-1	continuity during night shifts	4
T-2	continuity during evening shifts	4
T-3	continuity during day shifts	4
T-4	continuity per type of shift	3

sp = number of shift patterns

5.2.5 Decision aspects concerning continuity

And finally, the continuity factor represents the degree to which there is continuity in the nursing staff during the different shifts. This factor has been specified by three decision aspects and one combination decision. Table 5.5 mentions these four decision aspects related to the continuity factor.

The first decision aspect of continuity (T-1) concerns the continuity during night shifts. This decision aspect has been translated into four shift patterns. These patterns differ in the distribution of the fourteen night shifts a week over the nursing staff. As a consequence of this distribution, the pattern with the highest continuity (T-1d) involves the scheduling of two nurses a week, while the pattern with the lowest continuity (T-1c) involves the scheduling of six nurses a week.

The second decision aspect of continuity (T-2) concerns the continuity during evening shifts. This decision aspect has also been translated into four shift patterns. These patterns differ in the distribution of the twenty-one evening shifts a week over the nursing staff. As a consequence of this distribution, the pattern with the highest continuity (T-2d) involves the scheduling of seven nurses a week, while the pattern with the lowest continuity (T-2e) involves the scheduling of nine nurses a week.

The third decision aspect of continuity (T-3) concerns the continuity during day shifts. This decision aspect has alos been translated into four shift patterns. These patterns differ in the distribution of the thirty-three day shifts a week over the nursing staff. As a consequence of this distribution, the pattern with the highest continuity (T-3a) involves the scheduling of ten nurses a week, while the pattern with the lowest continuity (T-3e) involves the scheduling of fourteen nurses a week.

The fourth decision aspect of continuity (T-4) is a combination decision. This combination decision concerns the continuity per type of shift. It combines the first three decision aspects of continuity. These decision aspects T-1, T-2 and T-3 are represented as the ranking objects T-4a, T-4b and T-4c, respectively.

5.3 RESULTS OF THE RANKING EXPERIMENT

Ten nurse schedulers from five different health care organizations ranked the discussed alternative shift patterns per decision aspect on the basis of the corresponding quality factor. As described in the third chapter, the agreement among the nurse schedulers with respect to these rankings can be computed on the basis of Kendall's coefficient of concordance (Kendall, 1979, pp. 94-106). These coefficients of concordance determine whether nurse schedulers agree on the relative ‘quality’ of each shift pattern. Table 5.6 shows these resulting coefficients of concordance per quality factor and per decision aspect. Appendix A shows the corresponding rankings per decision aspect.

In this table, the coefficients of concordance marked with an asterisk (*) are significant when using an error tolerance of one percent. For these marked coefficients of concordance, the probability that the rankings of the ten nurse schedulers are similar is ninety-nine percent certain. Below, these coefficients of concordance are discussed per quality factor.

Table 5.6 COEFFICIENTS OF CONCORDANCE PER QUALITY FACTOR PER DECISION ASPECT

number	C	O	P	H	T
1	0.52 *	0.23	0.16	0.64 *	0.57 *
2	0.57 *	0.77 *	0.36 *	0.87 *	0.01
3	0.11	0.86 *	1.00 *	0.83 *	0.68 *
4		0.53	0.08	0.46 *	0.49 *
5		0.48 *		0.49 *	
6		0.70 *		0.29 *	
7		0.73 *		0.54 *	
8		0.05		0.23 *	
9		0.35		0.36 *	
10				0.04	

* $p < 0.01$

5.3.1 Rankings of shift patterns concerning completeness

The ten nurse schedulers agreed about the relative importance of incompleteness for each type of shift. According to this agreement, a shortage of a night shift is worse than a shortage of an evening shift or a day shift, and a shortage of an evening shift is worse than a shortage of a day shift. On the other hand, the results did not show that shortages during special working days are worse than shortages during normal working days.

5.3.2 Rankings of shift patterns concerning optimality

The rankings of shift patterns related to optimality showed a significant communality on five of the six decision aspects. These results show that qualitative understaffing is worse than qualitative overstaffing. Furthermore, the nurse schedulers agreed that qualitative understaffing during evening shifts or night shifts is worse than qualitative understaffing during day shifts, and that qualitative understaffing during day shifts on special working days is worse than on normal working days. On the other hand, the results did not show that qualitative understaffing (or qualitative overstaffing) during special working days is worse than qualitative understaffing (or qualitative overstaffing) during normal working days.

In order to interpret the coefficient of concordance for the final combination decision (O-9), a coefficient of concordance was computed with a virtual third decision aspect. This gave a coefficient of concordance of 0.07, which was not significant using an error tolerance of one percent.

5.3.3 Rankings of shift patterns concerning proportionality

The results of the rankings on the first decision aspect of proportionality (P-1) showed that the ten nurse schedulers did not agree about the best proportion of day shifts to evening shifts to night shifts. On the other hand, the ten nurse schedulers agreed about the best distribution of both days off and weekends on. The significant coefficient of concordance in the shift patterns concerning the distribution of days off (decision aspect P-2) can be explained on the basis of the numbers of single days off. This type of single day off is a sequence of shifts with one day off between two days on. The significant coefficient of concordance in the shift patterns concerning the distribution of weekends off (decision aspect P-3) can be explained on the basis of the number of consecutive weekends on. Finally, the insignificant coefficient of concordance for the combination decision of healthiness (P-4) was caused by the disagreement on this first decision aspect of proportionality. Analyzing the relative rankings on this combination decision of the other two decision aspects showed that the occurrence of a shift pattern consisting of one day off between two days on was significantly worse than the occurrence of two consecutive weekends on.

5.3.4 Rankings of shift patterns concerning healthiness

The rankings of shift patterns related to healthiness showed a significant communality on all decision aspects and on two of the three combination decisions. Below, these results are discussed per decision aspect or combination decision.

Blocks of consecutive night shifts with a length of three or four are the healthiest (decision aspect H-1). Both shorter and longer night shifts periods were significantly unhealthier.

Blocks of consecutive evening shifts with a length of two, three or four are the healthiest (decision aspect H-2). These resulting rankings showed that the nurse schedulers mostly agreed about the three most unhealthy shift patterns, which consisted of eight, nine and ten consecutive evening shifts. Even when these three shift patterns were replaced by a single shift pattern, the coefficient of concordance for this decision aspect slightly decreased to 0.76*, but still remained significant, using an error tolerance of one percent.

Blocks of consecutive day shifts with a length of two, three, four, or five are the healthiest (decision aspect H-3). These resulting rankings showed that the nurse schedulers mostly agreed about the three most unhealthy shift patterns, which consisted of eight, nine and ten consecutive day shifts. Even when these three shift patterns were replaced by a single shift pattern, the coefficient of concordance for this decision aspect slightly decreased to 0.57*, but still remained significant, using an error tolerance of one percent.

Analyzing the rankings given by the ten nurse schedulers for decision aspect H-4 showed a significant concordance, which means that these rankings were statistically similar. The 'average' ranking expressed in consecutive working days was 7, 6, 5, 4, 8, 9 and 10. This can be summarized by stating that blocks of consecutive days on with a length of more then seven are unhealthy.

The ten nurse schedulers agreed about the first combination decision of healthiness (H-5). This agreement concerns the fact that the occurrence of a block of consecutive days on, with a length of more than seven, is worse than an unhealthy block of consecutive shifts.

The nurse schedulers also agreed about the decision aspect of healthiness that concerns the amount of rest after a night shift period (H-6). This agreement concerns the fact that, after a block of consecutive night shifts, at least three days must follow.

Furthermore, the results also show communality in the rankings concerning the decision aspects H-7 and H-8, and concerning the combination aspect H-9. This communality can be summarized by stating that the occurrence of an evening shift

followed by a day shift is unhealthy.

The only insignificant coefficient of concordance concerning the healthiness factor concerns the importance of healthiness of consecutive shifts compared to healthiness scheduled rest. On the basis on the ten rankings on this combination decision, it cannot be concluded that the former aspect is more (or less) important than the latter.

5.3.5 Rankings of shift patterns concerning continuity

The rankings of shift patterns related to continuity showed a significant communality on two of the three decision aspects (T-1 and T-3) and on the only combination decision (T-4). The first two significant coefficients of concordance can be explained on the basis of the number of corresponding nurses scheduled for the same shift the day before. Furthermore, the communality in the rankings on the combination decision showed that continuity is most important during the day shifts.

5.4 CONCLUSIONS OF THE RANKING EXPERIMENT

The objective of the ranking experiment was to provide specifications for the operationalization of each quality factor. The previous section described the results of the ranking experiment. Concluding from these results, this final section describes the specifications for the operationalization of each quality factor.

The completeness factor can be specified as a function which decreases according to the relative number of shortages. This relative quantitative shortage depends on the ratio between the number of 'missing' nurses and the required number of nurses.

The optimality factor can be specified as a function which decreases according to the relative deviation from the qualitative staffing demands. This relative qualitative deviation depends on the ratio between the number of 'missing' registered nurses and the required number of registered nurses.

The proportionality factor can be specified as a function which decreases with each occurrence of either a single day off or a sequence of two weekends on. It should be noted that this means that the occurrence of a sequence of three

weekends on decreases proportionality twice as much as the occurrence of a sequence of two weekends on.
The healthiness factor can be specified as a function which decreases with each occurrence of an unhealthy shift pattern. These unhealthy shift patterns concern sequences of too many days on or too few days off.

And finally, the continuity factor can be specified as a function which decreases with each absence of continuity. This discontinuity occurs whenever the number of nurses scheduled for a day shift, who are also scheduled for a day shift on the previous day, is less then the required number.

These specifications of the five quality factors provide guidelines for an answer to the second research question described in the third chapter: “How can one operationalize each quality factor?”. The following section describes how these specifications are used to develop nursing schedule quality metrics. These metrics are represented as formulas. These formulas provide the required answer to the second research question (i.e. they describe how to operationalize each quality factor).

5.5 OPERATIONALIZATION OF NURSING SCHEDULE QUALITY

This section describes the operationalization of the quality factors based on the specifications described above. In this description, the term quality indicator will be used for an operationalized quality factor. These quality indicators will indicate the value of the corresponding quality factors on a scale from zero to one.

The following five subsections discuss the formulas used to compute the value of these indicators. These computations should, one way or another, integrate over the length of the schedule period (N), the number of types of shift (D), and the staff size (M). Furthermore, a calibration factor α will be used to make sure that precisely sufficient quality will reflect a value of 0.55.

5.5.1 Indication of completeness

The results of the ranking experiment showed that the completeness factor can be specified as a function which decreases according to the relative amount of shortages. This relative quantitative shortage depends on the ratio between the

number of 'missing' nurses and the required number of nurses. On the basis of this specification, the completeness factor is operationalized into a completeness indicator. The value of this completeness indicator is represented as C.

$$C = 1 - \left[\frac{\sum_{i=1}^{N} \sum_{j=1}^{D} \frac{\max (0, (n_{i,j} - n'_{i,j}))}{n_{i,j} + n'_{i,j}}}{N \times D} \right]^{\alpha}$$

Formula 5.1: Indication of the value of the completeness factor (C)

The value of the completeness indicator depends on the planned number of staff members per type of shift, represented as $nN_{i,j}$, in relation to the required number of staff members per type of shift, represented as $n_{i,j}$. The value of the latter variable varies per number of the day of each week (i) and type of shift (j). Table 5.7 shows these values. In this table, i=1 represents a Monday and i=7 a Sunday. Furthermore, j=1 stands for day shifts, j=2 for evening shifts, and j=3 represents night shifts.

Table 5.7 REQUIRED NUMBER OF STAFF MEMBERS PER TYPE OF SHIFT (n_{ij})

j \ i	1	2	3	4	5	6	7
1	5	5	5	5	5	4	4
2	3	3	3	3	3	3	3
3	2	2	2	2	2	2	2

An acceptable shift pattern for the completeness factor turned out to be a shortage of one nurse on a day shift. A shortage of one nurse on an evening shift was still acceptable. The least acceptable shift pattern for the completeness factor was a shortage of two nurses on a day shift. Further more, a shortage on the night shift was unacceptable. Therefore, an α of 0.1373 is used. For example, this operationalization results in a value for C of 0.60 for a shortage of one nurse during the day shift on a normal working day, a value of 0.56 for a shortage of one nurse during the evening shift, and a value of 0.53 for a shortage of one nurse during the night shift.

5.5.2 Indication of optimality

The results of the ranking experiment showed the optimality factor can be specified as a function which decreases according to the relative deviation from the qualitative staffing demands. This relative qualitative deviation depends on the ratio per type of shift between the number of 'missing' registered nurses and the required number of registered nurses. On the basis of this specification, the optimality factor is operationalized into an optimality indicator. The value of this optimality indicator is represented as O.

$$O = 1 - \left[\frac{\sum_{i=1}^{N} \sum_{j=1}^{D} \frac{| l_{i,j} - l'_{i,j} |}{l_{i,j} + l'_{i,j}}}{N \times D} \right]^{\alpha}$$

Formula 5.2: Indication of the value of the optimality factor (O)

The value of the optimality indicator depends on the planned number of registered nurses per type of shift, represented as $lN_{i,j}$, in relation to the required number of registered nurses per type of shift, represented as $l_{i,j}$. The value of the latter variable varies per number of the day of the week (i) and type of shift (j). Table 5.8 shows these values.

Acceptable shift patterns for the optimality factor turned out to be a surplus of one registered nurse on a day shift, an evening shift or a night shift. A shortage of one registered nurse on a day shift on a normal working day was still acceptable. The least acceptable combination of shift patterns for the optimality factor was twice a surplus of registered nurses on a day shift on a special working day. Furthermore, shortages of registered nurses on the evening shift or the night shift were unacceptable. Therefore, an α of 0.1651 is used. For example, this operationalization results in a value for O of 0.63 for a surplus of one registered nurse on a normal working day during the day shift, and a value of 0.60 for a shortage of one registered nurse in the same situation. Furthermore, this operationalization results in a value for O of 0.60 for a surplus of one registered nurse during an evening or a night shift, and a value of 0.53 for a shortage of one registered nurse during both types of shift.

Table 5.8 REQUIRED NUMBER OF REGISTERED NURSES PER TYPE OF SHIFT (i_j)

j \ i	1	2	3	4	5	6	7
1	2	2	2	2	2	1	1
2	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1

5.5.3 Indication of proportionality

The results of the ranking experiment showed that the proportionality factor can be specified as a function which decreases for each occurrence of either a single day off or a sequence of two weekends on. On the basis of this specification, the proportionality factor is operationalized into a proportionality indicator. The value of this proportionality indicator is represented as P. Formula 6.3 represents the way in which this value is computed.

$$P = 1 - \left[\frac{\sum_{j=1}^{M} \left(v_j + \frac{w_j}{2} \right)}{M \times \left(\frac{N}{2} + 1 \right)} \right]^{\alpha}$$

Formula 5.3: Indication of the value of the proportionality factor (P)

The value of this quality indicator depends on the number of occurrences of single days off, represented as v_j, and the number of occurrences of sequences of two weekends on, represented as w_j.

An acceptable shift pattern for the proportionality factor turned out to be the occurrence of one sequence of two weekends on. The occurrence of one single day off was still acceptable. The least acceptable combination of shift patterns for the proportionality factor was the occurrence of one single day off combined with a sequence of two weekends on. Therefore, an α of 0.1468 is used. For example, this operationalization results in a value for P of 0.62 for one occurrence of a sequence of two weekends on in the four-week nursing schedule, and a value of 0.58 for the occurrence of a single day off for one nurse in the arranged schedule.

5.5.4 Indication of healthiness

The results of the ranking experiment showed the healthiness factor can be specified as a function which decreases with each occurrence of an unhealthy shift pattern. These unhealthy shift patterns concern sequences of too many days on or too few days off. On the basis of this specification, the healthiness factor is operationalized into a healthiness indicator. The value of this healthiness indicator is represented as H.

$$H = 1 - \left[\frac{\sum_{i=1}^{N} \sum_{j=1}^{M} o_{i,j}}{N \times M} \right]^{\alpha}$$

Formula 5.4: Indication of the value of the healthiness factor (H)

The value of this quality indicator depends on the independent variable $o_{i,j}$ The default value for this variable is 0. The value of 1 is used for unhealthy shift patterns. Table 5.9 shows these unhealthy patterns.

These unhealthy shift patterns are represented as sequences of codes. Table 5.10 explains these codes.

The unhealthy shift patterns presented above are consistent with the ergonomics criteria for nurse scheduling discussed in the second chapter. For example, three of these criteria are no more than seven consecutive working days, just a few night shifts in succession and forward rotation of the shifts. These criteria correspond to the first, fourth and last unhealthy shift pattern presented in table 5.9, respectively.

The least acceptable combination of shift patterns for the healthiness factor was the occurrence of two unhealthy shift patterns. Three or more unhealthy shift patterns per nursing schedule turned out to be unacceptable. Therefore, an α of 0.1383 is used. For example, this operationalization results in a value for H of 0.59 for the occurrence of one unhealthy shift pattern in the arranged four-week nursing schedule, and three of these patterns result in a value of 0.52.

Table 5.9 UNHEALTHY SHIFT PATTERNS

shift pattern	description
S S S S S S S S	8 consecutive days on
D D D D D D	6 consecutive day shifts
E E E E E	5 consecutive evening shifts
N N N N N	5 consecutive night shifts
N N O O S	only 2 days off after a series of night shifts
O S O	only 1 consecutive day on
E D	a day shift directly following an evening shift

Table 5.10 MEANING OF SHIFT CODES

code	description
D	day shift
E	evening shift
N	night shift
S	day on
O	day off

5.5.5 Indication of continuity

The results of the ranking experiment showed the continuity factor can be specified as a function which decreases with each absence of daily continuity. This daily continuity depends on the number of nurses scheduled for a day shift, who are also scheduled for a day shift on the previous day. An absence of daily continuity occurs whenever this number of 'overlapping' nurses is less than the required number. On the basis of this specification, the continuity factor is operationalized into a continuity indicator. The value of this continuity indicator is represented as

T (the C already represents completeness).

$$T = 1 - \left[\frac{\sum_{i=1}^{N} \frac{\max (0, (t_{i,j} - t'_{i,j}))}{t_{i,j} + t'_{i,j}}}{N} \right]^{\alpha}$$

Formula 5.5: Indication of the value of the continuity factor (T)

The value of this indicator depends on the planned continuity per day, represented as t'_i, in relation to the required continuity per day, represented as t_i. On the basis of the results of the ranking experiment, the value of the latter variable is set at two. This means that, each day, two overlapping nurses need to be scheduled.

Three absences of continuity in a schedule turned out to be the least acceptable combination of shift patterns for the continuity factor. More absences of continuity were unacceptable. Therefore, an α of 0.2397 is used. For example, this operationalization results in a value for T of 0.66 for one absence of continuity, a value of 0.60 for two such absences, and a value of 0.52 for four absences of continuity in the arranged four-week nursing schedule.

5.5.6 Discussion of the operationalizations

The described quality indicators differ in orientation to the schedule. These orientations will be called vertical, horizontal and diagonal.

Both the completeness and the optimality indicator are vertically oriented. This means that they 'scan' a nursing schedule per daily column (top-down). They integrate over the vertical dimension and are scaled with the length of the schedule period (N) and the number of types of shift (D). These indicators are independent of the staff size (M).

The proportionality and the healthiness indicators are horizontally oriented. This means that they 'scan' a nursing schedule per row (left-right). They integrate over the horizontal dimension and are scaled with the staff size (M) and the length of the schedule period (N). These indicators are independent of the number of types of shift (D).

Finally, the continuity factor is both vertically and horizontally oriented. It will therefore be called 'diagonally' oriented (down-left-right). It integrates over both the vertical and the horizontal dimension and is related to a vertical requirement (i.e. $t_i = 2$) and scaled with the (horizontal) length of the schedule period (N).

This indicator is independent of both the number of types of shift (D) and the staff size (M).

The described operationalizations of the five quality factors all ground on the specifications concluded from results of the ranking experiment. One plausible interpretation of these specifications resulted in the five quality indicators described above. Other interpretations of these specifications are also possible. However, this is of little importance for the auditing experiment described below. The main purpose of these operationalizations is to provide an indication of the 'goodness' of a nursing schedule for each quality factor. Furthermore, these indications must be in the same order of magnitude, which is the case for the described quality indicators.