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Knowledge-based support for the participatory design and implementation of shift systems

by Andreas Gissel, Dr rer pol,[1] Peter Knauth, Dr-Ing[1]

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Objectives This study developed a knowledge-based software system to support the participatory design and implementation of shift systems as a joint planning process including shift workers, the workers' committee, and management.

Methods The system was developed using a model-based approach. During the 1st phase, group discussions were repeatedly conducted with 2 experts. Thereafter a structure model of the process was generated and subsequently refined by the experts in additional semistructured interviews. Next, a factual knowledge base of 1713 relevant studies was collected on the effects of shift work. Finally, a prototype of the knowledge-based system was tested on 12 case studies.

Results During the first 2 phases of the system, important basic information about the tasks to be carried out is provided for the user. During the 3rd phase this approach uses the problem-solving method of case-based reasoning to determine a shift rota which has already proved successful in other applications. It can then be modified in the 4th phase according to the shift workers' preferences. The last 2 phases support the final testing and evaluation of the system. The application of this system has shown that it is possible to obtain shift rotas suitable to actual problems and representative of good ergonomic solutions.

Conclusions A knowledge-based approach seems to provide valuable support for the complex task of designing and implementing a new shift system. The separation of the task into several phases, the provision of information at all stages, and the integration of all parties concerned seem to be essential factors for the success of the application.

Key terms knowledge-based software system, process model, shift work.

The successful implementation of an effective new shift system is a complex process comprising conflicting interests of the social partners involved (1). To reach a compromise between company goals and the preferences of shift workers, which is very important for the acceptance of a new worktime arrangement, joint planning is recommended (2, 3). Since it has been indicated that a new shift system can be introduced more successfully when operational process support is provided, this support should focus on realistic solutions adapted to local conditions. For this purpose data should be gathered on company operational requirements and the employees' preferences for worktimes, and tools for the participatory development of specific shift systems should be used (4). Training which focuses on the effects of shift work and the development of possible alternative shift systems is also of great importance.

Because of the complexity of arranging shift systems which fulfill constraints on an organizational and ergonomic level, take into account the preferences of workers, and stay within the limits of legal and collective agreements, the use of computer-aided design (CAD) has been proposed for shift schedules (5). Several approaches (6, 7) have successfully demonstrated that computer support can be applied to a variety of tasks within the domain of shiftwork design and implementation. However, problems arise if the whole process has to be covered, as most of the available software tools concentrate on certain subtasks and emphasize the generation of shift rotas.

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On the other hand, numerous concepts aim at supporting the implementation strategy of a new worktime arrangement (8—10). These studies basically cover the complete domain on a descriptive level and are abstract from operability.

To develop a method that both covers the complete process and integrates the expertise of shiftwork research, we carried out a knowledge-based, model-oriented approach that facilitates the required transfer of expert knowledge from research to practical applications (11). The result was a knowledge-based software system that can support available options when a new shift system that has detailed information on the potential advantages and problems of worktime arrangements is introduced.

Methods

As no transferable models have yet been developed that adequately represent the design and implementation of shift systems, we decided to follow a model-oriented approach. The method of model-based and incremental knowledge engineering (12), which subdivides the process of developing knowledge-based systems into knowledge acquisition, design, implementation and evaluation, was used to acquire knowledge, construct a structure model for the domain of shift system design, and realize the first prototype of the system.

The knowledge acquisition was initiated through repeated group discussions with 2 experts, including 1 of the authors, with research experience of 27 and 8 years, respectively, in this field. This discussion resulted in a description of the relevant concepts and subtasks that were integrated into a structured model for the ergonomic design and implementation of shiftwork systems. Subsequently semistructured interviews with one of the experts took place to modify and refine the structured process model.

During the 2nd phase of the knowledge acquisition, an extensive literature search of both printed media and online data bases was carried out. We started with the printed media mentioned by the experts during the interviews and expanded these data by cross-referencing procedures. In addition, the proceedings of former shiftwork symposia were included. Another knowledge source was provided by searching several online data bases for relevant publications. As a prerequisite we constructed a checklist of key words. This checklist was applied to data bases for both books and journals covering the period 1945 through 1996. Altogether 367 relevant studies were identified through the search of printed media and another 1346 publications through an online search, forming a factual knowledge-base of 1713 entities.

In a 3rd step we formalized the structure model and constructed a model of expertise which formed the core of the knowledge-based system. The model of expertise was then tested for performance on 12 case studies which had been collected from both the literature and practical change projects that had been carried out by our institute. As the overall results of the application of the model of expertise have been very positive, we have implemented the prototype of the knowledge-based system on a standard windows platform, attention being paid to conventional user and software interfaces.

Results

The structure model

The structure model provides a semiformal representation of the domain of shift-system design and implementation using different types of modeling primitives. In the structure context, which serves as a view of the data flow of the process, activity nodes containing the description of one step of an expert in his or her problem-solving are given, whereas concept nodes constitute an object which can act as an input to or output from an activity. Inference links are used to connect these 2 types of nodes.

The whole process has been divided into 6 different phases. During the preparation phase the modification of an existing shift system or the implementation of a completely new worktime arrangement is initiated. This step provides information on the aims of the new shift system, the proposed organization of the changeover, and the process support that is available for all parties possibly affected on a company level. In this way communication between the management, the superiors of the departments concerned, the workers' committee, and the shift workers is supported. The central output of this activity is structured information for the system user, and it is also linked to the input of the following orientation phase (figure 1).

In the 2nd phase the most important constraints on the shift system under development are defined. It focuses on determining the workers' preferences concerning worktime and the quantitative description of the company goals. In this context information on the intended operational time and the reasons for the necessary change are acquired. Other important information is provided by the input of the branch of industry that the company belongs to, as it determines the range of legal and union constraints (eg, minimum rest periods between 2 shifts or agreed weekly worktime). In addition, during the orientation phase, decisions on different types of shifts and the planning of the number of crews manning each have to be made. As these decisions may have initial consequences on the possible negative effects of the new shift system from an ergonomic point of view, detailed ergonomic information has to be provided as support. This support comes from the factual knowledge base of 1713 studies in the field of shiftwork research on entities relevant to the characteristics of the shift system under development. Specific features of the new shift system that may induce increased risk for the workers are analyzed. As minor alterations of company goals may have positive effects on the ergonomic quality of shift systems, it is possible to define new projects at this stage. This action corresponds to the creation of a new project file in the software system.

In contrast to other approaches, the set of requirements is not converted to a generating procedure for shift rotas, as it may lead to problems concerning the acceptance of the generated results by the shift workers. During the expert interviews we found that one alternative is to search for a shift system which has already proved to be successful in other companies and which shows a reasonable similarity to the defined requirements, and thus acts as a basis for discussions and improvements. For this basic solution easy adaptation to the new application and consideration of ergonomic recommendations have to be ensured to the greatest possible extent. Therefore a clear area of application is created for the well-known problem-solving method of case-based reasoning. During the following design phase, the negative aspects of the basic solution have to be reduced by incrementally improving the shift system according to the preferences of the workers and ergonomic guidelines. This reduction is achieved through a participative approach supported by adequate software tools for shift system design. As again the decisions taken during this step affect the ergonomic quality of the system, an explanation module is used which is analogous to that of the orientation phase (ie, possible problem areas caused by the features of the system are linked to studies in the field of shiftwork research). In this way constant support is realized concerning a priority list

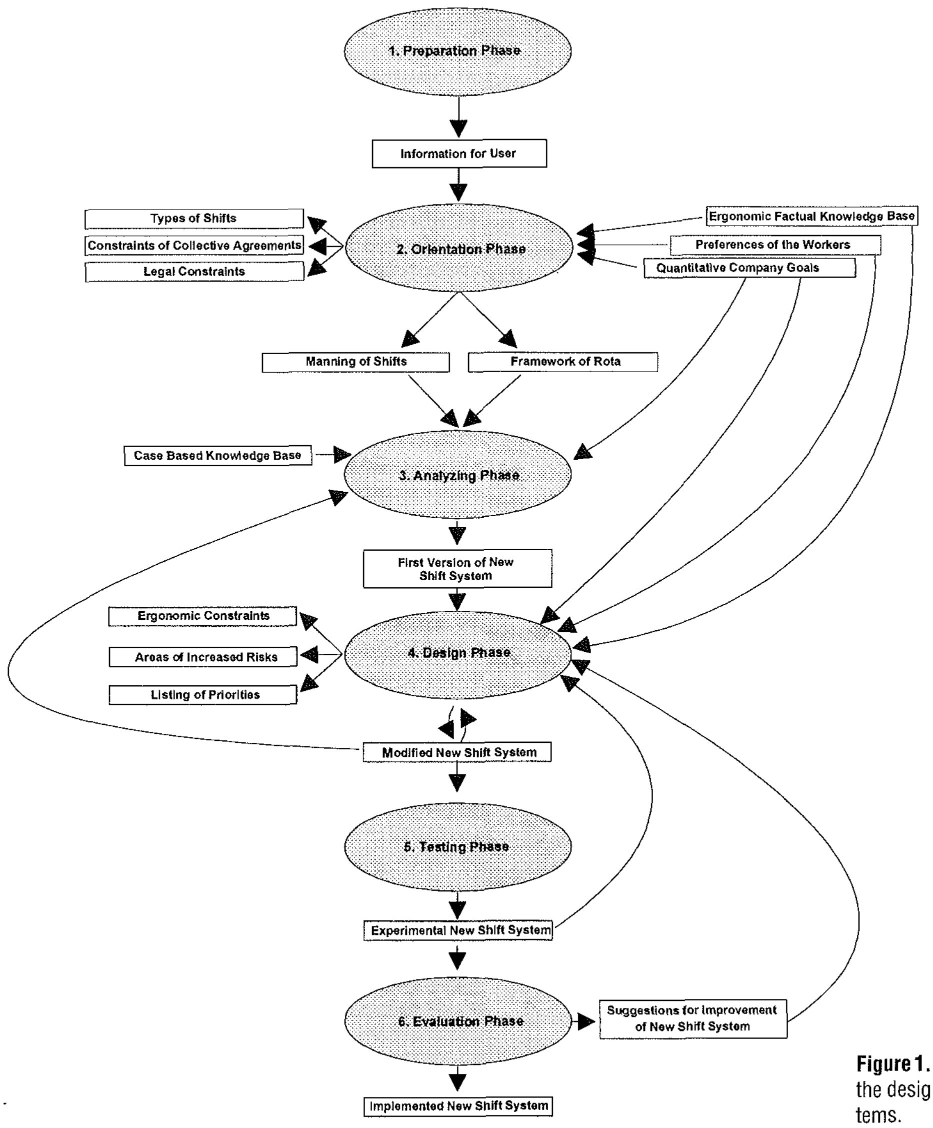

Figure 1. Top layer of the structure model for the design and implementation of shift systems.

of improvements based on the findings of shiftwork research; therefore it is possible to make sound decisions rather than to depend on an automated decision process.

The organizational context of these tasks consists of workshops, which can lead to several alternatives for the new shift system. After being extensively informed, all the workers affected by the new systems are asked to vote on the alternatives. The most favored shift rota is then tested for a predefined period. At the end of the testing phase the employees vote again, and the new system is either implemented with no time limit or the design phase continues with renewed modifications or the tested system is completely canceled. In this case a new design and implementation process can be initiated.

Operationalization and testing of the problem-solving method

During the interviewing phase we discovered that, to avoid the problems inherent in the generation of shift rotas (ie, the possibility of very limited acceptance of the generated results by the shift workers), the 1st version of a new shift system should focus on a search for a worktime model which has already been implemented in other applications and which has been positively evaluated from an ergonomic point of view. The 1st version of the new shift rota can then be modified and adapted to the actual situation, and thus it acts as the basis for a solution.

This is a clear indication for applying the problem-solving method of case-based reasoning, which works as a 3-stage procedure for shift system design and implementation. In the 1st step a preselection has to be made using a data base of existing shift systems to exclude cases irrelevant for the given problem. During the 2nd step the similarity of the shift systems in the data base and the worktime arrangement being designed has to be calculated; the data are then interpreted in the 3rd step. If there is an indication that the data base contains a shift system that is both sufficiently similar and ergonomically well designed, the knowledge-based system suggests this shift rota as a reference case.

The performance of this problem-solving procedure depends to a great extent on the data base from which comparable cases are selected and on the operationalization of the measurement of similarity. In our system the actual case data base contains 409 shifts collected from examples of projects in our institute and information provided by companies and publications. This collection represents a variety of shift systems relevant to practical applications, the focus being on continuous systems. The measurement of similarity is constructed around the 5 dimensions of agreed weekly worktime, operational time, length of the rota, number of crews working on different shifts on each day of the week, and the classification of the shift system (eg, rotating shift systems including night work or permanent morning shift systems). The length of a rota is integrated to identify similar shift systems because it is a characteristic that is important to many shift workers and thus affects the acceptance of a new system. In addition, the personnel required for manning a system may change.

As there is no increase in the required personnel for multiple lengths of shorter rotas, the explanation module indicates to the user that more alternative solutions can be achieved by modifying the requirements of the length of the rota accordingly. To avoid a similarity measure of 0, the default value is set at 1. The checking of the cases in the data base for applicability to a new shift system starts with the calculation of relative differences from the requirements. If predefined tolerances are violated, a shift system is excluded from further checking, which corresponds to the preselection of the problem-solving method (figure 2).

If a shift system successfully passes these criteria, the results for the agreed weekly worktime and operational time are combined and integrated into the calculation of the total difference together with the other 3 dimensions (ie, the length of the rota, the number of crews working different shifts each day of the week, and the classification of the shift system). The decision to suggest a certain shift system as a possible first version for the new system not only depends on similarity, it also considers ergonomic quality. Our approach uses the Besiak procedure (13) to check the compliance of shift systems with ergonomic recommendations on the basis of 14 weighted criteria. The final decision is then based upon the multiplicative combination of the results of the Besiak procedure with the results of the total difference. This procedure takes into consideration the fact that a minor deviation from company goals can be compensated by a better Besiak score, which can be illustrated by the results of case study 8 (table 1).

For this shift system a rota length of 6 weeks, an operational time of 168 hours per week, and an agreed weekly worktime of 40 hours were required. Further requirements comprised 1 night shift crew every day of the workweek, 1 evening shift crew every day except Sunday, 2 crews on morning shifts on Monday, Tuesday, Saturday and Sunday, and 3 crews on morning shifts on Wednesday through Friday. The application of the problem-solving strategy resulted in a shift system which exactly met all dimensions of similarity except for the number of crews working on different shifts on each day of the workweek. The proposed solution had 1 crew on each of the evening and night shifts on every day of the week and 2 crews on the morning shift on all days from Monday to Sunday. Thus a similarity measure of 20.05 resulted. A difference concerning the class of the shift system would have resulted in an increase in this result by a default value of 30 (table 2).

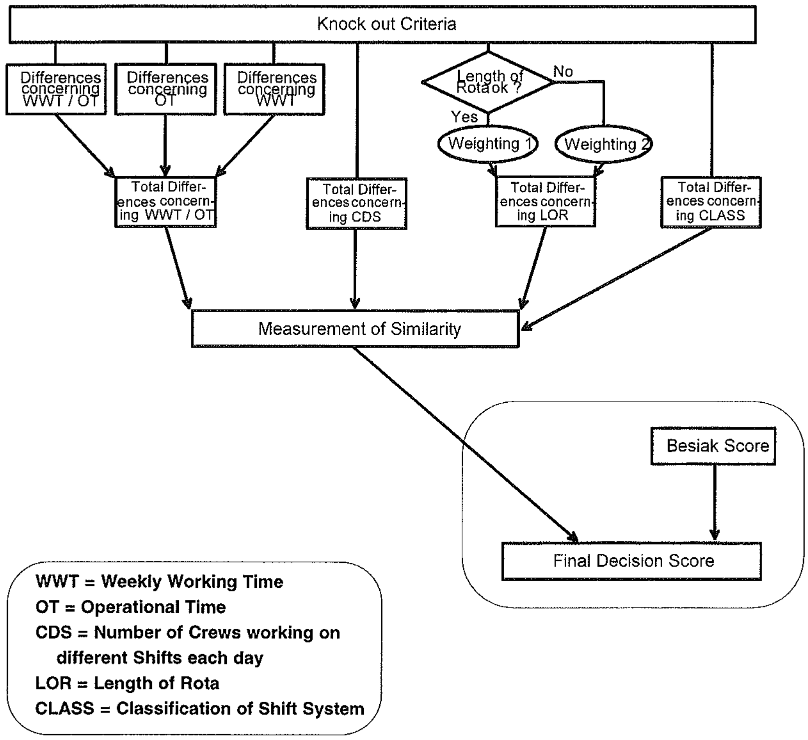

Figure 2. Structure of the problem-solving method of case-based reasoning.

Table 1. Similarity of shift systems obtained by testing case-based reasoning on 12 case studies.

Case	Length of rota (weeks)			Operational time (h/week)			Weekly worktime (h)			Crews on different shifts
	Required	Found	Difference (%)	Required	Found	Difference (%)	Required	Found	Difference (%)	Difference (%)
1	3	3	0	110	108	1.8	36.66	36.00	1.8	4.8
2	4	4	0	168	168	0	38.00	42.00	10.5	0
3	4	4	0	144	144	0	36.00	36.00	0	0
4	4	4	0	144	144	0	36.00	36.00	0	4.8
5	5	5	0	168	168	0	36.50	35.20	3.6	9.5
6	5	5	0	168	168	0	33.60	33.60	0	0
7	6	6	0	168	168	0	38.00	40.00	5.3	19.0
8	6	6	0	168	168	0	40.00	40.00	0	19.0
9	11	10	9.1	168	168	0	38.23	38.40	0.4	19.0
10	10	10	0	168	168	0	33.60	33.60	0	0
11	12	12	0	168	168	0	40.66	37.30	8.2	33.3
12	15	15	0	168	168	0	33.60	33.60	0	0

The Besiak score for this solution was 325.9, and the final decision score was 6534.3. Although the knowledge base detected another possible solution with a better Besiak score of 319.1, this alternative solution was ignored due to its lower similarity of 29.57, which resulted in a final decision score of 9435.79.

For flexibility, both the weightings of the Besiak procedure and those used to determine the results for differences can be modified according to the preferences of the users. The performance of the case-based reasoning module of the knowledge-based system has been tested on 12 case studies as shown in table 1. Nine of these case studies concerned continuous shift systems with an operational time of 168 hours per week, while 3 other studies were in the field of discontinuous shift systems including work at night but excluding work on weekends with an operational time of 110 to 144 hours per week. The required length of the rotas varied between 3 and 15 weeks and the agreed weekly worktime was between 33.6 and 40 hours. The results show that, for the majority of the case studies, the shift systems proposed as a basis for further refinement by the knowledge-based system suited the actual problem well. This was especially the case for the length of the shift rotas, the operational time, and the agreed weekly worktime. The deviation from the requirements for the shift system that was deducted in the knowledge base was 6% or less in at least 8 of the 12 case studies. No deviation at all occurred for the classes of the shift systems, where any differences would have resulted in a fixed increase in the value of the measurement of similarity. Although the comparability concerning the number of crews working on each shift was more restricted, the overall similarity indicated that valuable support is provided. In addition, these basic versions of the new shift systems have already shown to be a good compromise from an ergonomic point of view, even if some improvements could still be implemented during the design phase of the changeover process.

Realization of the prototype

The structure model provides the base for implementing the prototype of the knowledge-based system. Thus the software supports all phases of designing and implementing a new system. With the exception of the 3rd phase of the structure model (eg, the selection of a comparable shift system that can act as a solution for the rota under development) all the steps require extensive user interaction. Therefore the visualization of important data seems to be of great importance. This is especially the case when complicated rotas have to be constructed, which typically include a long shift rota, many different types of shifts, and a complicated structure of the manning of each shift. In this case the system provides an overview concerning the number of crews working on different shifts over a 24 hour period for each day of the week (figure 3).

Support for ergonomic decisions has been realized through the explanation module of the knowledge-based system. By mapping features of the shift system being designed according to the findings of studies in the field of shift work research, possible problems associated with

Table 2. Calculation of the similarity measure for case study 8.[a] (WWT = weekly worktime, OT = operational time, CDS = number of crews working on different shifts each day, LOR = length of rota, CLASS = classification of shift system)

	Crews on morning shift		Crews on evening shift		Crews on night shift	
	Required	Found	Required	Found	Required	Found
Monday	2	2	1	1	1	1
Tuesday	2	2	1	1	1	1
Wednesday	2	$\boxed{3}$	1	1	1	1
Thursday	2	$\boxed{3}$	1	1	1	1
Friday	2	$\boxed{3}$	1	1	1	1
Saturday	2	2	1	1	1	1
Sunday	2	2	0	$\boxed{1}$	1	1

[a] Similarity = (total differences concerning WWT/OT)
+ (total differences concerning LOR)
+ (total differences concerning CLASS)
+ (total differences concerning CDS)
+ (default value)

$$= (0) + (0) + (0) + \left(\frac{4}{21} \cdot 100\right) + (1)$$

$$= 20.05$$

$\boxed{}$ Difference to company requirements

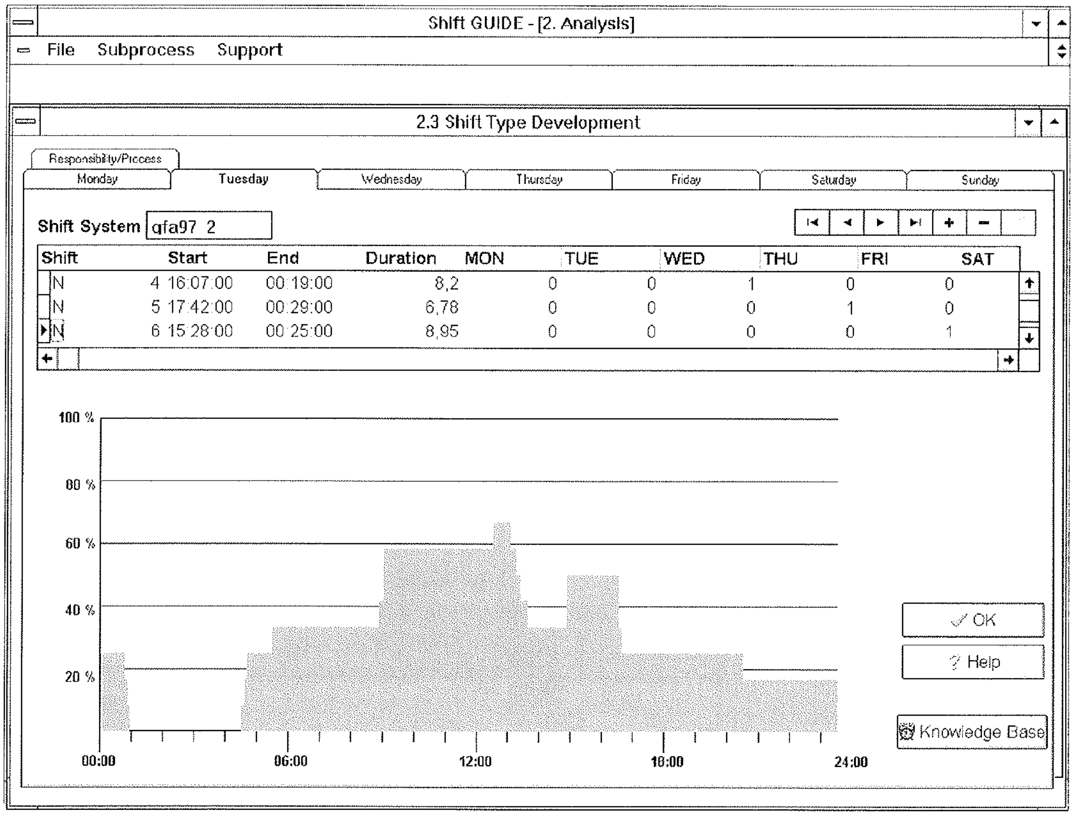

Figure 3. Visualization of different shifts and percentage of work crews present for complex shift systems in the knowledge-based system.

certain features can be detected during the design process. The explanation module shows the features observed in published studies, together with the negative effects on shift workers (figure 4).

This support focuses on covering the definition of different types of shifts during the orientation phase and the final design of the new shift system in the 4th phase. This design step is performed by participative modification of the solution basis acquired by case-based reasoning.

Concluding remarks

The design of shift systems is a complex task that should be carried out as a participatory process involving all parties of a company that might be affected by a change in worktime arrangements. In order to provide support, the use of computer-aided time scheduling is proposed. We used a knowledge-based approach, which subdivides the whole process into 6 phases. Through application of the software tool, the constraints of the new system are defined, a basic version of the new system derived from good examples of shift systems already in use is developed, and the final design is supported.

Our results indicate that, by using case-based reasoning taking into account the main parameters of a shift system (ie, the agreed worktime, operational time, the length of rota, the number of crews working on different shifts on each day of the week and the classification concerning types of shift systems), transferable models can be acquired. The application to 12 case studies showed that, with this procedure, solutions that can act as a basis for further participative discussions and modifications are derived without shift systems being automatically generated. This ability for adjustment can be crucial to the acceptance of a new shift system by the workers.

To facilitate reliable decisions when shift systems are adapted to the preferences of workers (eg, during workshops), an explanation module of the knowledge-based system enables the users to monitor the consequences of the modifications continuously. This explanation module integrates and structures the findings of 1713 studies in the field of shiftwork research and provides information on possible negative effects associated with certain characteristics of a shift system. However, the information contained in the listing of possible negative effects provided by the explanation module might be redundant to a certain degree, especially when specific restrictions are given and all solutions share a high number of problematic features. A possible solution to overcome this problem could be to distinguish between negative effects that can be found in all the solutions and specific negative effects of all the solutions.

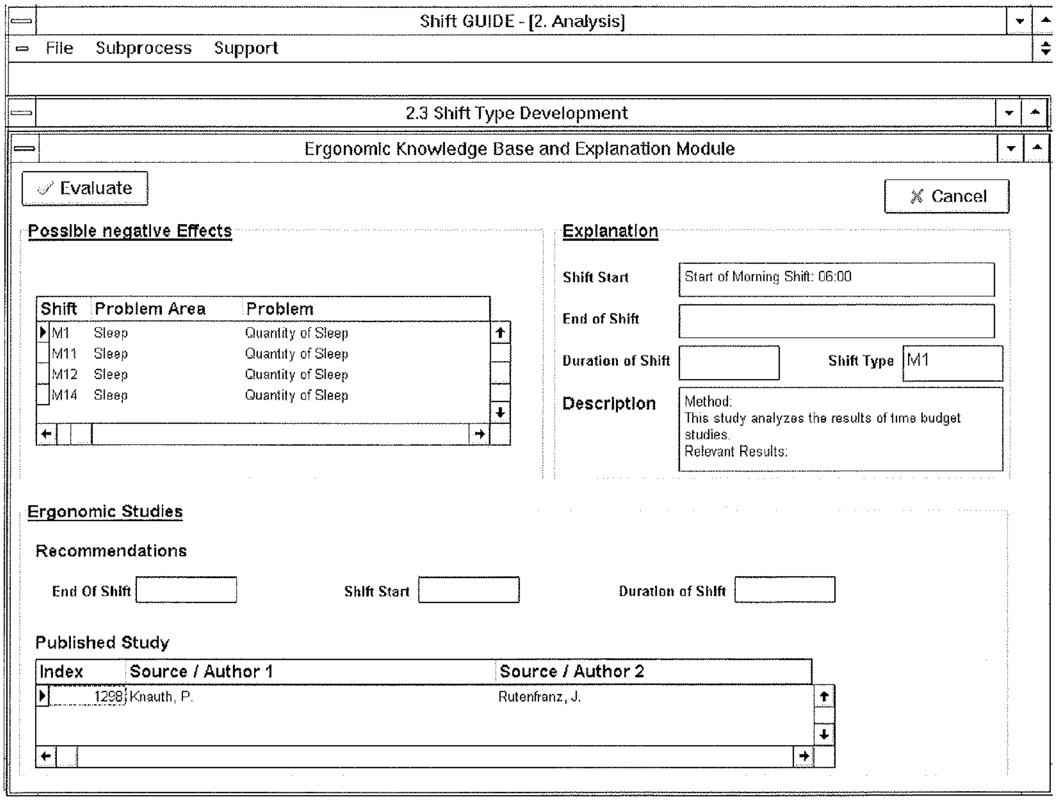

Figure 4. Implementation of the explanation module. [M1 = morning shift (start: 0413, end: 1234); M11 = morning shift (start: 0459, end 1336); M12 = morning shift (start: 0520, end: 1707); M14 = morning shift (start 0430, end: 1300]

As so far the testing of the knowledge-based system has focused on rather traditional problems, such as continuous shift systems with a maximum length of rota of 15 weeks, it would be desirable to extend the knowledge base to cover even more complex situations, such as service sector applications or public transport. Moreover, the evaluation of the knowledge-based system should be expanded to cover more discontinuous applications. It is indicated, however, that the limitations of the system are to be expected more because of the structure of the factual knowledge base (ie, a concentration on continuous shift systems), which can act as a possible first version of a new rota, than because of the realized problem-solving method. In addition, further field applications of the system are planned.

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