AN INTERACTIVE APPROACH FOR MULTIPLE CRITERIA SCHEDULING IN A CROATIAN HOSPITAL

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Abstract

This paper proposes a decision support system for building and choosing a daily schedule of medical treatments in a hospital according the available resources and following multiple criteria. It uses a Scatter Search metaheuristics empowered by enabling interaction with the decision maker in order to collect his/her preference information and to guide the search to the areas of particular interest. A preference model is built, composed of all general additive monotone non-decreasing value functions compatible with the obtained information using method called Generalized Regression with Intensities of Preference. The set of functions is then applied to a small subset of the set of Pareto optimal solutions, resulting in two rankings: the necessary and the possible one.

Key words: *Decision support systems, Multi-objective scheduling, Heuristics, Hospitals*

1. INTRODUCTION

Increased competition in health care markets coupled with administrative complexity of today's practice is leading to increasing use of sophisticated information systems. Efficient service delivery depends on a successful adaptation of both, the autonomy of the physicians for deciding on patients' treatments, and the managerial control for rational use of resources where the scheduling of medical treatments plays an important role. Consequently, there is a need for a decision support system (DSS) with an ability to construct the schedules and help the decision maker (DM) with choosing the ones that balance between the multiple criteria that need to be taken into account. The case study was provided to us by a Croatian hospital.

The problem we address is to schedule the medical treatments according to the available medical equipment and adequate physicians. The medical treatments consist of a different number of medical procedures among which a precedence relation is defined. The complexity of the problem is furthermore increased when taking into account the multiple criteria that need to be followed.

1.1. A brief review of literature

Due to the large growth of health care industry, the use of management science and operations research in health care has increased. Significant amount of research has been done on scheduling problems, such as nurse rostering (Burke et al., 2004) and operating room scheduling, either with block scheduling (Belien and Demeulemeester, 2007; Blake and Donald, 2002; Patterson, 1996) or open scheduling approach (Marcon et al., 2003). A greedy heuristics for solving a bi-criteria scheduling problem, similar to the problem we describe, is presented by Chern et al. (2008). However, they consider a hierarchical order of criteria, solving the problem in two stages. An interactive procedure for scheduling in hospitals which combines a greedy approach with tabu-search is developed by Oddi and Cesta (2000). From what we understand, their procedure cannot be seen as multi-objective by its very nature, since it minimizes the number of the constraint violations. Also, unlike us, they consider the case where all resources have unary capacity. Apart from the general metaheuristics developed to approximate the Pareto front, researches have proposed different ways of adding interactivity to such procedures (Phelps and Koksalan, 2003; Deb and Kumar, 2007; Luque et al, 2007; Thiele et al, 2007).

1.2. The scope and outline of the paper

This paper aims at developing a DSS for generating and selecting a schedule for the medical treatments which allows the DM to guide the search in different ways. Namely, some interactive procedures require aspiration levels or “weights”, while others expect unacceptable levels for the objectives. Also, many approaches assume the existence of underlying utility/value function and ask for pair wise comparisons of solutions to converge towards the most preferred one. We develop a procedure that integrates all those approaches. However, instead of fitting only one function to explain the preferences as in Phelps and Koksalan (2003), our procedure is based on a method which uses all value functions compatible with the preference information provided by the DM. The Section 2 describes the problem and the associated multiple criteria decision analysis (MCDA) methodology. The Section 3 develops an interactive procedure for generating and selecting the appropriate schedule, built on a Scatter Search (SS) metaheuristics. The Section 4 demonstrates the use of the proposed interactive procedure on an example. The Section 5 provides the conclusions.

2. PROBLEM DESCRIPTION AND THE SELECTED MCDA METHODOLOGY

An important part of the decision aiding process is constructing the representation of the the DM's decision problem. This is accomplished by building “rationality model” from the DM’s answers to the posed preference-related questions. Following the concepts of an MCDA methodology (Bouyssou et al, 2006), we present a so-called evaluation model to organize the available information.

2.1. Stakeholders and the main concerns

Hospital managers have increasingly becoming aware of advantages of an automated solution for daily scheduling of the medical treatments that are to be performed, instead of using manual techniques. Being the stakeholders with an overall view of the problem, the managers are aware that the hospitals' patients and physicians will directly be influenced by the decisions made on the schedules. The schedules are made on a daily basis, and the patients whose treatments do not get scheduled for the given day are left to be scheduled for the day after. By maximizing the number of treatments that are to be performed on a given day, the time of resident patients' stay in the hospital is minimized. On one side, the physicians are concerned about the limited scheduling flexibility, due to the slowness of the manual scheduling, which makes rescheduling during the day almost impossible. On the other side, they fear having tight schedules and feel that having some spare resources might be helpful for unpredicted situations and procedure types they consider to be critical.

2.2. Resources

The medical treatments consist of procedures, which have to be performed in a strictly prescribed sequence, each one on a certain type of medical equipment. There are a certain number of available non-identical pieces of equipment within each equipment type, all having a certain capacity in terms of patients that could be treated at the same type. Each piece of medical equipment needs to be operated by a physician. The schedules are to be made daily, meaning not only that time is limited in terms of difficulties to make such schedules, but also in terms of having to decide on an appropriate schedule on a very short notice, possibly more than once a day. The total number of treatments, as well as the associated procedures and their durations, are known before the beginning of the scheduling process.

2.3. A rough definition of the set of potential schedules (alternatives)

A potential alternative or a solution is a schedule which respects the procedural structure of the medical treatments that are to be performed, the equipment capacities, and physicians’ expertise. There should not be any waiting time between the procedures of a treatment. Finally, a treatment is considered as a unit to be scheduled, meaning that either all of its procedures are scheduled for the day, or none of them are, in which case the whole treatment remains unscheduled.

2.4. An evaluation model

The set of feasible schedules is of a combinatorial nature, which means that the schedules first have to be constructed in order to undergo further analysis. The variables that define a schedule are as follows:

treatment is scheduled for the day or not, starting times of the treatments, equipment assigned to each procedure of each scheduled treatment, physicians assigned to each piece of equipment that is in use. The schedules are evaluated according to the following criteria:

- The more patients fitted into the schedule on a given day, the better.
- The less the maximum waiting time for the physicians', the better.
- The less time periods without an available specialist for the critical procedures, the better
- The less time periods without spare equipment for the critical procedure types, the better.

However, we use additional, auxiliary criteria, in order to ensure efficient use of resources and to assist the metaheuristics in the process of finding the solutions of the problem. These criteria are:

- Minimize the sum of the number of equipment in use over all time slots.
- Minimize the sum of the number of occupied physicians over all time slots.

3. THE INTERACTIVE SCATTER SEARCH PROCEDURE

In this section, a description of the Scatter Search (SS) metaheuristics which is used to approximate the Pareto front is given by explaining how interactivity is added to the SS procedure.

3.1. A metaheuristics for obtaining the approximate Pareto front

The metaheuristics designed for approximating Pareto front follows the usual structure of the SS method (Glover et al, 2000): (1) diversification method used as the initial phase, (2) improvement method, (3) reference set update, (4) subset generation, and (5) solution combination.

Diversification method is used as the initial phase of creating the source set *S* of (potentially) efficient schedules or solutions. The main idea of the method we use is to carry out a series of linked VNS procedures (Hansen and Mladenović, 2001), as presented by Vlah and Figueira (2010). Inspired by the work of Molina et al (2007), it conducts multiple searches, in which the last point of one search becomes the initial point of the next search, during which the solutions are evaluated using the weighted-sum of the normalized objective values, and the objective weights are set randomly for each search. Our VNS procedure tries to obtain better solutions by moving selected patients' treatments to a new starting time and with different allocation of the required resources. It is a modification of the VNS procedure suggested in Vlah et al (2010), which was developed for the single objective case.

In order to restore feasibility and improve the solutions obtained from the combination method a similar VNS procedure as the one used in the diversification method is applied.

The set of reference solutions, *RefSet*, generally consists of a subset of good quality solutions *RefSet1*, and a subset of diverse solutions *RefSet2*. Since dealing with multiple criteria, *RefSet1* will contain the best solutions in *S*, evaluated on each criterion separately, while the *RefSet2* will be updated through a sequential selection of the solutions from *S* that maximize the minimum distance to the *RefSet*.

Solutions that will combined are chosen as 2-element subsets of *RefSet*, where the first element is taken from *RefSet1* and the second element is taken from *RefSet2*. The solutions that are used are then deleted from *S* in order to encourage finding the solutions different from those already considered. In order to get new solutions from the two solutions that are chosen to be combined, we use a path re-linking procedure (Glover et al, 2000). The solutions along the path are generated by iteratively detecting the treatments which are to be removed from the initiating solution and the treatments which are to be inserted in it from the guiding solution.

3.2. The interactive approach

The SS procedure focuses on finding a good approximation of Pareto front. However, given a rather large set of alternatives, the DM is faced with a problem of choosing the “best” schedule. Therefore, an interactive procedure is designed to assist the DM in making the decision on an appropriate schedule, as well to allow him/her to guide the search procedure according to his/her preferences.

In real-world decision making, it is highly unlikely that the DM will be able to state his preferences directly, e.g. by providing exact “weights” of the objectives. Thus, we elicit indirect preference from the DM. Eliciting indirect preference information is used in the ordinal regression paradigm, originally applied in UTA method (Jacquet-Lagreze and Siskos, 1982) where a single compatible value function is used. An extension of UTA-like methods is implemented in UTAGMS method (Greco et al, 2008). The method establishes a necessary and a possible weak preference relation in the whole set of considered actions. The necessary ranking (partial preorder) identifies preference statements being true for all compatible value functions, while the possible ranking (complete binary relation) identifies preference statements being true for at least one compatible value function. The preference information has the form of a partial preorder in a subset of training actions, instead of having a complete preorder like in AHP (Saaty, 2005) and MACBETH (Bana e Costa et al, 2005) methods, where preference information is composed from comparisons of all pairs of actions. The method which generalizes UTA and UTAGMS methods, called Generalized Regression with Intensities of Preference (GRIP), has recently been presented by Figueira et al (2009). The GRIP method takes into account additional preference information in the form of comparisons of preference intensities.

3.3. The general scheme of the method

We propose an interactive approach based on the idea by Gomes da Silva et al (2006), which consists of two phases: the learning oriented phase and the search-oriented phase.

The learning oriented phase aims to familiarize the DM with the schedules from the approximated Pareto front, which was obtained by the SS procedure described in the previous section. Moreover, the goal is to obtain a set of solutions called the generator set that will be subjected to the search-oriented phase. The DM can provide the reference points and observe the closest solutions, evaluate the weights on each objective function, or reduce the feasible area by adding constraints on objective values. Upon obtaining any solution, the DM can decide which solutions to keep. This phase continues until the DM feels that there is sufficient information for building his/her preference structure.

In the search-oriented phase, the DM undertakes a complete evaluation of the generator set. The DM should provide more information about the actions from the current generator set, while at the same time, his/her understanding of the trade-offs between the criteria should be increasing. In addition, adding solutions from the approximated Pareto front to the generator set, the DM can obtain new Pareto optimal solutions using the elements of the generator set and interacting with the components of SS procedure. In this phase, the DM can choose from the following possible interactive options:

- *Removing solutions*: the DM decides to directly eliminate a solution from the generator set.
- *Neighborhood search*: The DM selects a solution, which is used as initial solution for the improvement method. The searches are done in different “directions” in the neighbourhood of the selected solution, since the weights for guiding the search are not specified. Thereby, the system may obtain and offer new Pareto optimal solutions, as candidates for the generator set.
- *Try to improve a solution*: The DM selects a solution to improve and specifies a set of weights. The system then runs improvement procedure of the SS method on the selected solution, guided by the specified set of weights. If the search results with newly obtained solutions, it is up to the DM to decide which of them to keep i.e. to add to the generator set.
- *Try to combine solutions*: The DM selects at least two solutions from the generator set that he/she wishes to combine with expectancy of obtaining new Pareto optimal solutions and zooming the investigation in this area. The system then runs SS procedure using the set of solutions specified by the DM as the SS reference set.
- *Evaluate a subset of the generator set*: The DM selects at least two solutions to compare and specifies their partial preorder. The preference information given by the DM on such a training set is then used to build compatible additive value functions.
- *Returning to the learning-oriented phase*: If the DM eliminates all the solutions from the generator set or wants to improve the knowledge about the possible solutions, he/she can return to the learning-oriented phase. Also, the DM can return to revise the generator set if there is not even a single function compatible with the given preference information.

The interactive procedures stops when the DM feels that there is enough information for making the final decision. The complete scheme of the interactive procedure described here is shown in Figure 1.

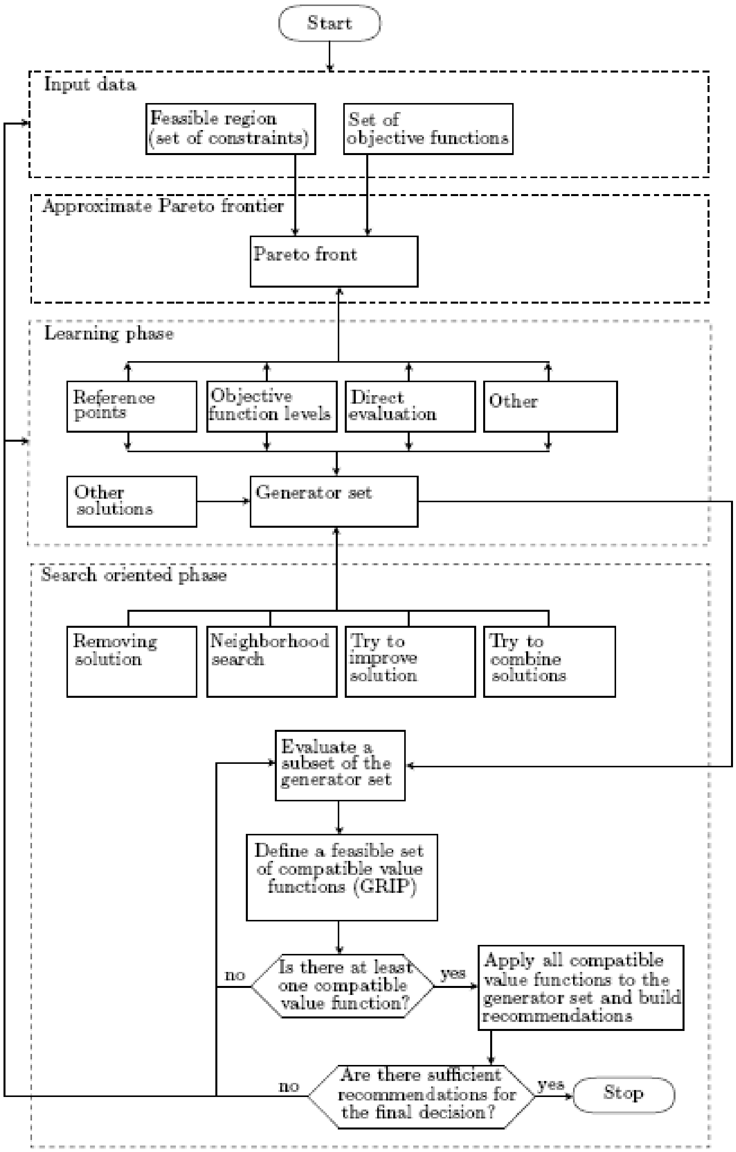

Figure 1: The general scheme of the interactive method.

4. INTERACTIVE METHOD ON AN EXAMPLE

To evaluate the potentialities behind the proposed method, the procedure was implemented in Delphi, with AMPL using CPLEX. The procedure is illustrated on an example based on the data description given by the Croatian hospital. There are 50 treatments to be scheduled in 48 time units. Running the SS procedure for two minutes resulted with an approximated Pareto front containing 139 solutions.

4.1. Solutions retained for a further study

Through the learning phase and using different forms of interaction with the software, eight solutions are chosen to form the generator set, as shown in Table 1.

Obviously, solutions in the generator set are not comparable unless preference information is expressed by the DM.

Table 1: The solutions in the generator set.

	Criteria			
	1	**2**	**3**	**4**
s_1	50	14	20	29
s_2	50	14	23	27
s_3	49	0	20	29
s_4	49	0	28	28
s_5	45	19	6	15
s_6	45	19	7	12
s_7	44	0	6	14
s_8	44	0	10	12

4.2. Evaluations of the solutions

If the DM specifies his first comparison as $s_1 < s_2$ i.e. s_1 is preferred to s_2, the GRIP method provides the necessary ranking shown in Figure 2(a). It can be observed that the computed partial preorder contains the preference information provided by the DM (dashed arrow), but also additional comparisons that are obtained from the initial information (continuous arrows), in this case when $s_3 < s_4$. If the DM in the second step adds a new comparison as s4 < s7, the method results in the partial preorder shown in Figure 2(b). It should be noticed that in some cases initial information does not produce any new comparisons, as it was in this step. The DM can find that this necessary ranking is still too poor for making a decision. Providing new information as $s_5 < s_6$ results with the necessary ranking shown in Figure 2(c). In this step, an additional piece of information is obtained from the stated initial comparison, so $s_7 < s_8$. If the DM finishes the evaluation by stating that $s_4 < s_5$, by observing the graph in Figure 2(d), he/she can decide that the necessary ranking is now rich enough to make the final choice; for example, that solution s_3 is the “best choice”, or to provide further preference information to enrich the necessary ranking. Also, the DM may want to return to any of the steps of the interactive procedure and try improving some of the solutions or combining them to obtain new solutions to be evaluated.

4.3. Providing robust conclusions according to the concepts of possible and necessary

We use presentation of the necessary ranking, resulting from preference information provided by the DM, as a support for generating further reactions. In general, the necessary ranking is not complete, so it can represent incomparability between solutions. However, it has another appealing property: it can be considered robust with respect to the preference information. Namely, any pair of solutions compares in the same way whatever the additive value function compatible with the preference information is used. It arises from the fact that the resulting preference relations are based on all compatible value functions rather than on only one or few among the many possible functions. Moreover, in addition to providing necessary ranking, the system can also give the possible ranking of the solutions identifying preference statements being true for at least one compatible value function.

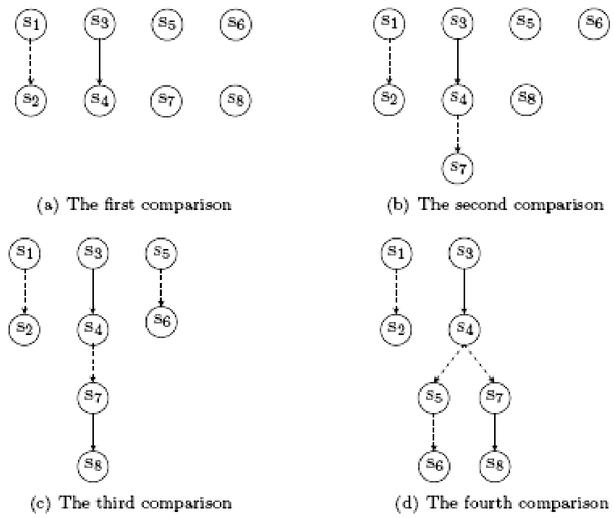

Figure 2. Solution evaluations.

5. CONCLUDING REMARKS AND FUTURE RESEARCH

This study has been motivated by the issues arising from scheduling the medical treatments in a Croatian hospital. We propose an interactive SS procedure capable of dealing with the high complexity of the problem and multiple criteria that need to be followed. In addition to constructing the feasible schedules, the procedure enables the DM directing the search to the areas of particular interest by providing different forms of interaction with the system. The possibility to choose any form of interaction gives the DM more flexibility with using the system than constraining him/her to provide only one type of information. Moreover, the system provides the DM with the rankings of the solutions under his/her consideration resulting from the preference model built by eliciting indirect preference information. Distinguishing necessary and possible rankings, the GRIP method includes a form of robust analysis instead of using a single “best-fit” value function. Notice that the system is quite general and can easily be adapted for dealing with different problems. As for future research, we propose improving the implementation of the DSS and applying it to other types of problems.

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