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Multi-criteria evaluation methods in the production scheduling

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Abstract. The paper presents a discussion on the practical application of different methods of multi-criteria evaluation in the process of scheduling in manufacturing systems. Among the methods two main groups are specified: methods based on the distance function (using metacriterion) and methods that create a Pareto set of possible solutions. The basic criteria used for scheduling were also described. The overall procedure of evaluation process in production scheduling was presented. It takes into account the actions in the whole scheduling process and human decision maker (HDM) participation. The specified HDM decisions are related to creating and editing a set of evaluation criteria, selection of multi-criteria evaluation method, interaction in the searching process, using informal criteria and making final changes in the schedule for implementation. According to need, process scheduling may be completely or partially automated. Full automatization is possible in case of metacriterion based objective function and if Pareto set is selected – the final decision has to be done by HDM.

1. Introduction

Optimized organization of work in a production system is a key element of competitive advantage and maintaining of high level of resource utilization [1,2]. Detailed scheduling of each production order, according to current situation of resources allows precise quantitative planning and quick response if there is a risk of failure in meeting due dates [3].

Scheduling in real production systems is very complex. It requires numerous data about the current state of resources and efficient system of operation reporting (without delays). The vast majority of the real scheduling problems are also characterized by the high computational complexity and belongs to the class of NP-hard or strongly NP-hard problems. This means a lot of difficulties in determining the optimal solution in acceptable period of time. In practice, the best from determined set of acceptable (feasible) solutions has to be satisfied.

The fundamental impact on the quality of obtaining solutions has the selection criteria and evaluation method of created schedules. In the optimisation theory, there are many multi-criteria methods for determining solutions that allow selection of compromise solutions, taking into account the identified evaluation criteria representing the preferences of decision makers. Selection of appropriate methods of assessment depends largely on the possibilities of description particular criteria

and relationships between them. General characteristics of multi-criteria optimization methods, presented in e.g. [4,5,6], make the classification by the scope of information that can be given by the decision maker. In this paper the discussion on evaluation process in production scheduling is presented.

2. Evaluation methods

Depending on whether a compromise between criteria is approved or not and whether weights defining the level of significance of individual criteria can be specified, certain class of methods for solving the optimization problem are proposed [7,8,9,10,11,12,13]. Among others, methods based on a convex combination, goal programming, parametric analysis and Minkowski's distance based measures are most frequently distinguished. Irrespective of above division there are two main groups of methods for determining qualitative assessment of schedules:

- methods in which the problem of multi-criteria is transformed to the problem with one criterion, by aggregation of the criteria set to one metacriterion.
- methods of searching for Pareto optimal solutions, which determine a set of effective solutions without aggregating evaluations of selected criteria.

Evaluation of many different types of performance measures, which can be deterministic, probabilistic and also fuzzy, is a quite serious problem. Developed evaluative system is often debatable and strongly dependent on the preferences of expert (experts). Subjective assessment of experts in determining the ratings and aggregation of particular criteria of different nature, as well as the difficulty in interpretation the economic and technical function of the distance are seen as disadvantages of metacriterion-based class of methods. From the set of Pareto optimal solutions one solution is chosen for implementation. This choice, however, requires using some additional criteria.

2.1. Evaluation criteria

The basic performance measures of assessment a production schedule include parameters of tasks depending on the execution times and deadlines, like e.g.: completion time (C_j), flow time (F_j), lateness (L_j), deviation (D_j), tardiness(T_j), earliness(E_j), etc., where j is the number of a task, and parameters of resources, like load of a resource (Rd_i), idle time (I_i), etc. In the set of tasks the maximum (f_{max}), aggregated (f_{sum}), weighted aggregated (f_{sum}^w), average ($\overline{f}$) and weighted average ($\overline{f}^w$) values of these measures can be used. They are calculated as follows (1):

$$f_{\max} = \max_{j=1,\dots,n}(f_j) \quad f_{sum} = \sum_{j=1}^{n} f_j, \quad f_{sum}^{w} = \sum_{j=1}^{n} w_j f_j, \quad \overline{f} = \frac{1}{n}\sum_{j=1}^{n} f_j, \quad \overline{f}^{w} = \frac{\sum_{j=1}^{n} w_j f_j}{\sum_{j=1}^{n} w_j}, \quad (1)$$

Among the criteria consistence, inconsistence or inverse relation may occur. Two criteria K_1 and K_2 at any two different decisions x_1 and x_2:

- are consistent, if

$$\underset{x1,x2\in D}{\forall} K_1(x_1) \le K_1(x_2) \Rightarrow K_2(x_1) \le K_2(x_2), \quad (2)$$

- are inconsistent, if

$$\underset{x1,x2\in D}{\exists} K_1(x_1) \le K_1(x_2) \Rightarrow K_2(x_1) \ge K_2(x_2), \quad (3)$$

- are inverse, if

$$\underset{x1,x2\in D}{\forall} K_1(x_1) \le K_1(x_2) \Rightarrow K_2(x_1) \ge K_2(x_2). \quad (4)$$

If it is possible to determine the relationships between all criteria the objective function can be build. Experts can also give criteria which, due to their nature, may be difficult or impossible to formalize - in order to take them into account the direct participation of human decision maker (HDM) is required.

2.2. Methods based on the distance function

These methods involve the search for solutions to the nearest approved referenced evaluation. The evaluation of solutions in Euclidean space could be expressed by a point. This reference point has not been associated with any existing, acceptable solution. Generally, the distance between the reference point and the point representing a given solution is calculated using the Minkowski's measure expressed by the formula:

$$L_\delta(z^{ref}, z^r) = \left(\sum_{o=1}^{nk} \left| z_o^{ref} - z_o^r \right|^\delta \right)^{\frac{1}{\delta}}. \quad (5)$$

where:
$z^{ref}=\{z_o^{ref}, o=1,...,nk\}$ – reference point,
$z^r=\{z_o^r, o=1,...,nk\}$, $z_o^r=K_o(H_r)$ – point representing evaluation of a given solution H_r,
nk – size of criteria set,
δ – parameter of distance function.

Minkowski's distance as a generalized measure, depending on the value of the parameter δ is known as: Hamming distance (L1) with δ = 1, the Euclidean distance (L2) at δ = 2 or Chebyshev distance (L∞) at $\delta \to \infty$.
The reference point for evaluation can be an ideal or utopian. The ideal point z^{id} represents a solution that takes the optimal values by all accepted criteria:

$$\underset{o=1,...,nk}{\forall} z_o^{id} = \min_{H_r \in Ha} (K_o(H_r)). \quad (6)$$

where:
$K_o(H_r)$ – partial evaluation of H_r schedule by o-th criterion.

Utopian point z^{ut} is a solution that dominates the ideal solution, where relation $z^{ut} \le z^{id}$ applies to all criteria with at least one strict inequality. Ideal or utopian ideal solution may not be achievable. Minimization of the distance to the reference point is frequently used in cases where there are no preferences for any criterion. In case of different criteria weights, the scaling process in each dimension (criterion) should be performed.

2.3. Creating a Pareto set

Methods of this class enable determination of a set of non-dominated solutions (Pareto efficient) in the multi-criteria problems. The solution x representing a schedule H_r is dominated by the other solution x' $(x \neq x')$, where x' is the same or more preferable than x for all criteria and more preferable than x for at least one criterion. Depending on the requirements, different types of effective solutions from the Pareto set may be distinguished: weak, proper, strict, non-strict, extreme weak, extreme strict [4].

3. The HDM participation

Although scheduling process in many cases can be fully automated, under certain conditions the participation of HDM may be desired or forced. In figure 1 the scheduling procedure in the context of evaluation process and participation of HDM is shown. At the beginning of the scheduling process the model of scheduling task should be completed. The model, usually described symbolically by $\alpha|\beta|\gamma$, consists of three groups of information: the configuration of production resources (α), assumed hard constraints (β) and the form of objective function (γ) which determines the schedule evaluation method. This is the first stage (D1), where HDM can make changes according to given situation. From schedule evaluation point of view the set of criteria and relation between them – if possible – are established. The expert or group of experts can formulate various criteria, but not all can be possible to formalize. Formalized criteria enable the determination of partial assessments in generating solutions - this step is the most common computer-aided, using specialized software. The next decision (D2) is related to the selection of multi-criteria evaluation method. It reflects the preferences of expert and also feasibility of a given production system. If the set of criteria has defined relationships between the criteria then one of the metacriterion-based methods can be used. In other case a method that creates a Pareto set of solution is recommended to use. Decisions group D3 is related to the supervision of the process of creating solutions – stopping, redirecting and changing selected parameters of the model, constraints and resources as well as evaluation criteria and their weights. These decisions are made based on the observation of the searching process and the set of results. Decisions D4 are associated with the use of informal criteria in the schedules evaluation process. They allow making the final choice of solution from the Pareto set, as well as a changing in the ranking list of best scored schedules sequenced by metacriterion. Using informal criteria is also applied in the group of decision D3 and may have impact on the searching for solutions and also in D5, where HDM makes the final correction of a schedule (if necessary).

In the literature usually three groups of methods of HDM participation in the scheduling process are distinguished: ‘a priori’, interactive and ‘a posteriori’ [4,14]. Accordingly, HDM can act at the beginning, when the scheduling problem is formulated, during the process of searching solutions and after that, when choosing the final solution. In relation to them, decisions specified in presented solution can be classified as follows: D1 and D2 - ‘a priori’, D3 – interactive, D4 and D5 - ‘a posteriori’.

4. Which method is the most appropriate?

The choice of evaluation method depends on many factors, and it should be preceded by detailed analysis of enterprise behaviour at the production planning and control stage [15], and also analysis of the environment impact on its operation.

The great importance for the development of the scheduling assessment scheme in particular implementation is estimating of the required frequency of scheduling repetition and specifying the time window for obtaining a solution. It is closely related to the frequency of different types of disturbances that lead to the need for repetition of scheduling process. The most common reasons are: resources breakdowns (machines, tools, absence of workers), new orders and/or changes in their priorities, changes in organizational parameters like release times or due dates, delays in orders realization and also results of small disturbances accumulation. Determination of the minimal time interval available for creating / repairing a schedule in this case is also important - this is crucial if in the process of evaluation HDM participation is expected.

The dynamics of the system and environment may cause changes in the set of criteria in subsequent iterations of scheduling. Production systems where such changes do not happen too often and next steps of determining the solutions have the same set of criteria and system weights are easier to automate of scheduling process.

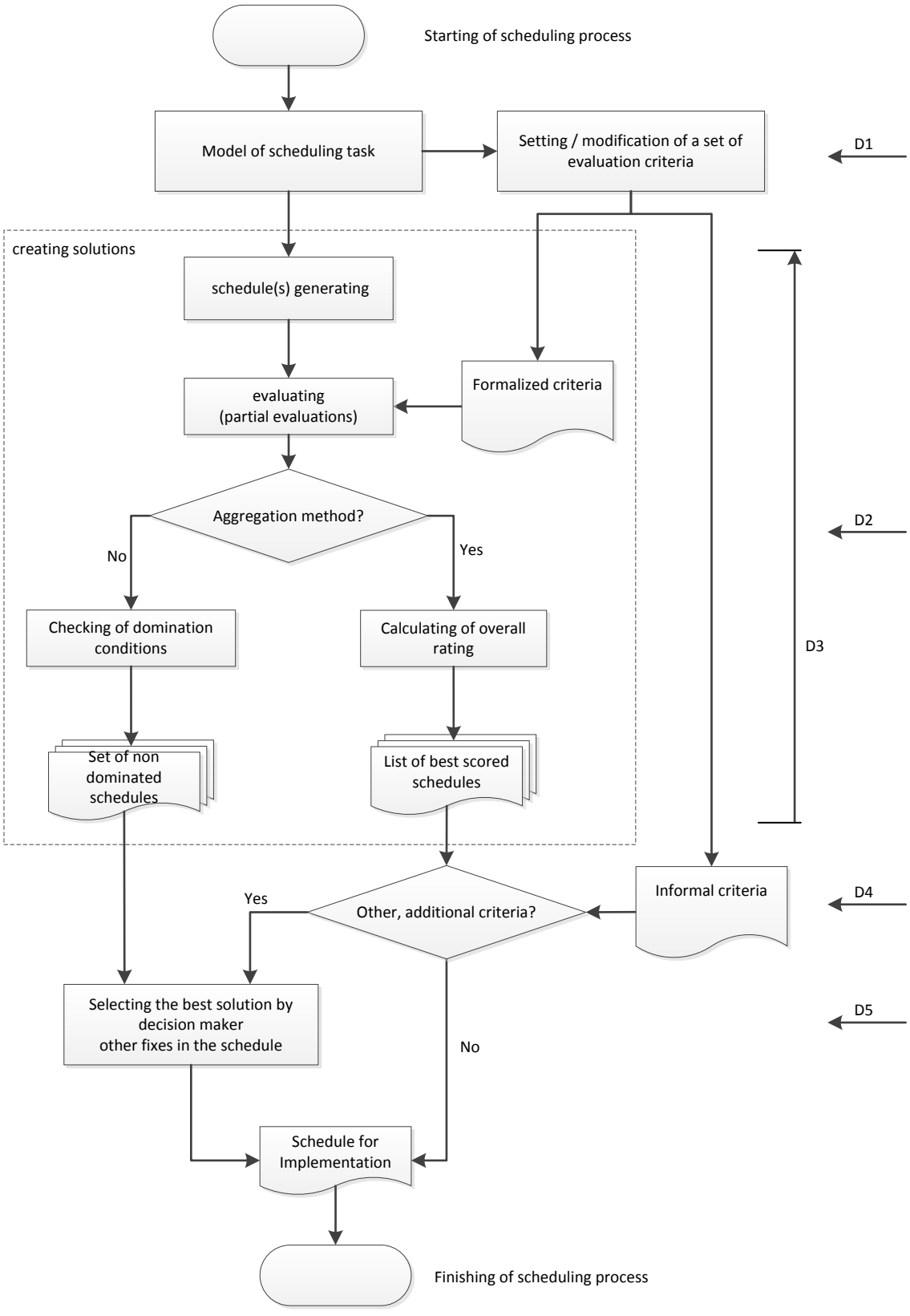

Figure 1. The overall procedure of evaluation process in production scheduling

5. Conclusions

The decision on the method of schedules evaluation is very important for the effectiveness of the production planning and control system. According to presented general procedure there are several ways for executing the evaluation process in scheduling. The basic division involves metacriterion and Pareto set classes of methods. In the case of automated systems, fully autonomous decision-making is possible only with the use of metacriterion methods but selection of the appropriate method in a given implementation depends on answer to many various questions. It should be decided how often scheduling process should be executed, and how much time is to determine solutions. The frequency of executing of scheduling process depends on the type of production and the frequency of disruptions that makes realized schedule out of date. The selected method has also great influence on the expected functionality of the supporting software. Is HDM able to take part in it? Formalized criteria, their fixed set and a small number of disruptions can greatly relieve HDM in the process of scheduling.

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