1.3 Third International Conference on Construction in the 21st Century (CITC-III)
„Advancing Engineering, Management and Technology"
15-17, September 2005, Athens

Multicriteria Construction Project Scheduling Method Using Evolutionary Algorithm

Piotr Jaskowski
Doctor eng., Institute of Building and Architecture
Lublin University of Technology, Lublin, Poland

Anna Sobotka
Associate Professor, Institute of Building and Architecture
Lublin University of Technology, Lublin, Poland

Abstract
Construction projects are not of repeatable character so their completion scheduling process should consider already existing conditions on its every stage (e.g. application of possible technologically – organisational variants to process completion; potential contractor availability) and constraints (resources and contractors availability limitations, often variable in time). As a result optimal workers and resources schedule should be established in terms of accepted assessment criteria. Most often it is aimed at minimisation of duration and cost project completion influencing its efficiency. The contractor selection process should be realised simultaneously to project schedule and due to that fact the authors describe it as an optimal multicriteria scheduling problem. Bringing down this decision to one criteria analysis is the result of major simplifications and often leads to unsatisfactory results for a decision maker. Due to limitations of possibility precise methods application to solve complex practical issues and heuristic method imperfections, an evolutionary algorithm (using stochastic processes) has been adopted to solve multiple-objective combinatorial optimisation scheduling problems and heuristic algorithm of constrained and variable in time resources and contractors number units allocation. Proposed solutions are generated from achievement scalarizing function based on Tchebycheff utility function.

Keywords
Construction Project Scheduling, Multicriteria Optimisation, Contractor Selection

1. Introduction

When there are many conflicting schedule optimalisation criteria and when completion of one aim is being improved at the expense of the others it cannot be called an optimal solution. The optimal solution for one criterion may turn out to be wrong for the other. For that reason the optimum search must be replaced by solution search which is the best compromise while considering all criteria (Galas et al, 1987).

The best compromise is of subjective notion, therefore to its description preferential information from the decision-maker is necessary. In case of conflicting aims (when improvement of one aim completion is possible at the expense of another one's deterioration) it is difficult to establish global decision-maker's preferences i.e. preferences considering all the aims simultaneously. The decision-maker's preference description is set up on the basis of his information.

The decision maker can express his preferences

1) „a posteriori" not before obtaining particular information about a set of efficient solutions (non-dominated) or a part of it (global and local preferences),
2) „a priori", when:

- the decision-maker wants and is able to price aims completion levels (determine its utility) due to established rule (in form of utility function)
- he shows his preferences in form of aim hierarchy,
- he shows information about aim completion levels which are satisfactory for him,
- he treats all aims equally, agrees to an appropriate compromise, has no experience in using multicriteria model programming, has difficulties in creating tasks of such type.

In the first case, information about decision maker's local preferences can be used in interactive multicriteria programming methods (part of non-dominated solutions set analysis) or the choice of final solution is preceded by the whole non-dominated solutions set analysis (or its approximation), that is after revealing contractor's global preferences.

In the second case, different optimising approaches are used, among others (Galas et al, 1987):

- problem scalarisation making use of utility function or compromise,
- lexicographical programming,
- objective programming.

2. Literature Review

Literature analysis considering multi-optimalisating problems in project scheduling (among others Nagar et al, 1995) allows to distinguish the following types of mostly used procedures:

- heuristic algorithms elaboration (Prystupa, 1996; Ulusoy and Özdamar, 1995),
- bringing down multicriteria problems to one-criterion while making use of utility functions (Wall, 1996; Hegazy, 1999; Leu and Yang, 1999),
- determining efficient solutions (schedules) set and at a later stage the choice from among them the best solution using additional information about decision-maker's preferences for interactive procedures (Hapke et al, 1998; Viana and Sousa, 2000),
- dialogue methods application (Kasprowicz, 2002; Hapke et al, 1998).

Because of restrictions of precise methods application possibility due to complexity of analysed problem and heuristic methods imperfection, optimal schedules of construction project search is executed with metaheuristic methods application which are adapted to the needs of the problem being solved. Non-dominated solutions (from the point of optimalisation aims view) are generated by using scalarising achievements objective function, which enables for determining good representation of the whole non-dominated solutions set and bringing down the problem to one criterion optimalisation task. Optimal solutions by applying such objective function are obtained from the usage of evolutionary algorithms, which are of confirmed utility to solve scheduling problems and little computational complexity. The choice of final solution – a suitable schedule and project contractors – is made by the decision-maker on the basis of the whole non-dominated solutions set representation. The proposed method of solving designing structure executing system does not guarantee the optimal solution achievement (as in Pareto's terms) but assures close to optimal solution achievement (potentially Pareto optimal) in relatively short time. Due to easiness of evolutionary algorithms adaptation to solve different problems, the proposed calculation method is characterised by great freedom of formulating conditions and problem constraints being solved and optimalisation objectives.

3. Proposed Multicriteria Construction Scheduling Method Using Evolutionary Algorithm

3.1 Problem Description

In this paper the problem of construction project scheduling of “complex processes” type in deterministic conditions has been undertaken. These projects include heterogeneous technological processes which are not of cyclic and rhythmical completion character. Construction projects scheduling is based on the use of network methods. Conditions of construction project technology works completion can be described using activity on node convention $= \langle \quad \rangle$ The precedence relations among particular processes constituting the project describes unigraph G, connected, acyclic with one first node and one final node where the nodes represent construction processes being executed and the graph’s curves represent the order dependence of processes’ completion.

T and K functions determined on the nodes’graph set characterise respectively execution time and each process completion cost of particular potential contractors. These contractors can be available only in specific time intervals. The same contractor may execute different processes. In case when the size of works frontage is much smaller than the size of the contractor works frontage there is a possibility of simultaneous work by the same contractor’s organisational (elementary) units on different works frontages.

Completion of particular construction project processes involves the necessity of providing renewable resources different from contractors’, e.g. machines, construction devices. The available resource unit number may be limited and variable (changeable) in time.

Mathematical model has been noted down using binary variable containing information about the completion dates and the process contractor; it takes a general form:
minimalise (together or independently): duration and project completion cost when the following conditions (model constrains) are fulfilled:

- of each process performance,
- of renewable resources availability,
- of contractors availability,
- of executing processes order (precedence relations) maintenance,
- of appropriate level of work quality assurance; this demand is completed by preliminary contractors selection application; as potential contractors are chosen those who are reliable and provide quality demands fulfilment on the required level

Optimalisation criteria, inquired independently, may have solutions which are considerably distant from each other (in criteria span). Project completion time, for example, representing the minimal cost can be much longer than the minimal duration (and even exceed the ordered deadline). Therefore, it is necessary to examine all criteria together.

3.2 Solution Method

Due to the fact that one of optimalisation criteria is the construction project duration minimalisation, this task can be formulated as follows: chose the processes contractors, while satisfying the conditions in order to execute each process and assuring the required work quality for which the cost and project duration are minimal (examined together or independently); processes completion dates (when contractors set is established) has to be calculated in a way that the project completion time of a particular processes contractors set is minimal. The conditions of renewable resources and contractors availability and processes order preservation are to be taken into account. The contractors selection will be executed by using evolutionary algorithm and the limited resources allocation (and the establishment of processes completion dates) will be done by the use of heuristic algorithm to calculate the shortest project completion time in which processes priorities values are also assigned in evolutionary algorithm.

Non-dominated solutions (potentially Pareto optimal) are possible to determine by using an approach taken from objective scheduling theory to create an objective function (scalarising all criteria values) which show losses size resulting from differences between objectives completion in generated solutions and their required (or ideal but possible to achieve) completion levels by the decision-maker (Jaszkiewicz and Slowinski, 1999).

This function (supplementary criterion) takes the following form:

$$= \quad \frac{}{} \left(\quad \right) \frac{}{} + \frac{}{} + \frac{}{} \qquad (1)$$

$$\langle \quad \rangle$$

where:
ρ – sufficiently small number,
– project completion time criterion weight,
TP, CP – project duration and cost respectively,
TP_{min}, CP_{min} – project completion time and cost respectively (one criterion tasks solutions with multicriteria optimalisation task limitations).

This function enables the assignment of none-dominated solutions only. The non-dominated solutions will be found by the use of evolutionary algorithm or heuristic one of calculating the project duration in the limited resources availability conditions.

The fundamental difficulty in choosing final solutions designed to be completed lies in determining weight factors which represent decision-maker's preferences. In the paper in order to choose final solutions (to determine criteria significance) the following approaches are proposed:

1. When the decision-maker is able to determine his preferences considering particular criteria weights, an optimal task solution with objective function is generated (1).
2. Graphic (approximated) dependence representation between duration criterion weight and TP, KP criteria values for potentially non-dominated solutions (on the basis of generated value for finite number of duration criterion weghts). The analysis of the non-dominated solutions set will allow the decision-maker to determine the criterion importance which represents a final solution.

The diagram of problem solving algorithm constituting the basis to establish computer system which will support construction project scheduling is shown in Figure 1.

The minimal project completion cost is calculated as a sum of the minimal all processes completion costs. The minimal process completion cost represents the lowest particular process execution cost among its all potential contractors.

The shortest project completion time with limited and changeable in time renewable resource availability is calculated by the use of evolutionary algorithm (Jaskowski and Sobotka, 2004) and heuristic algorithm of estimating the shortest project completion time (Jaskowski and Sobotka, 2004).

The solutions of two onecriterion optimalisation tasks (duration and project completion cost minimalisation) are necessary to objective function creation (1) scalarising these criteria values in the bicriteria optimalisation task. This function is used to estimate chromosomes adaptation (fittnes) in evolutionary algorithm which represent bicriteria optimalisation scheduling solutions. Practical Application of the method is presented in a separate paper.

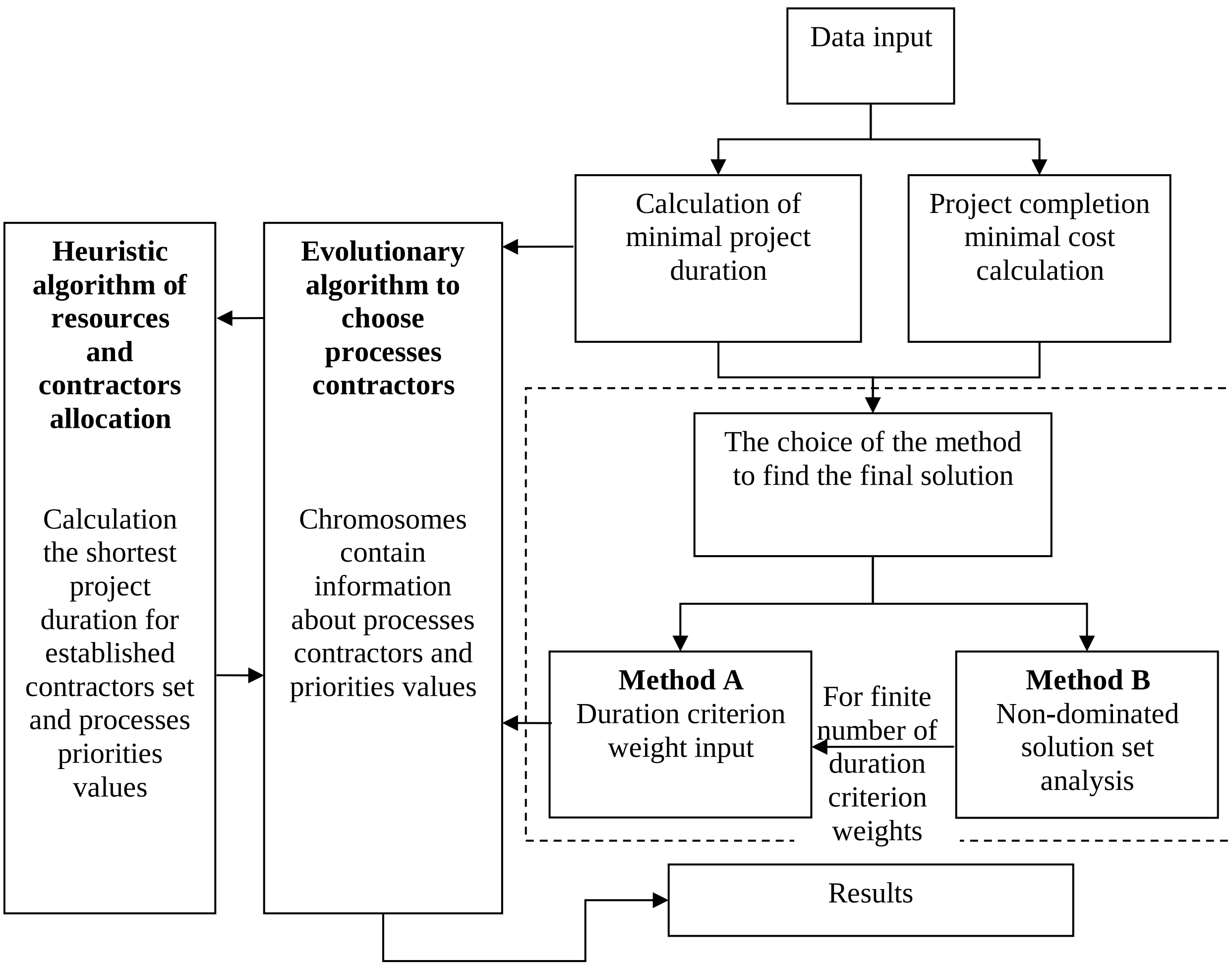

Figure 1: Idea of the proposed multicriteria construction project scheduling method

4. Conclusions

Multicriteria project scheduling problems are solved using several methods. Because of great computation complexity of precise methods, they are only used for scheduling test problems with a small number of processes and require simplified assumptions. Practical problems require making allowances for many different situations, conditions and limitations in the planning process. In practical uses metaheuristic algorithms are more appropriate methods. Proposed method does not guarantee the optimal solution in terms of Pareto but enables a good approximation of the set of non-dominated solutions achievement in a relatively short time and characterises with freedom of formulating conditions and constraints.

5. References

Galas, Z., Nykowski, I. and Zolkiewski, Z.(1987). *Multicriteria programming*, PWE, Warszawa (in Polish).

Hapke, M., Jaszkiewicz, A. and Slowinski, R. (1998). „Interactive analysis of multiple-criteria project scheduling problems". *European Journal of Operational Research*, No. 107, pp. 315-324.

Hegazy T. (1999). „Optimization of Resource Allocation and Leveling Using Genetic Algorithms". *Journal of Construction Engineering and Management*, Vol. 125, No. 3, pp.167-175.

Jaskowski, P., Sobotka, A. (2004). 'Scheduling construction projects with resources accessibility limited and changeable in time". *Journal of Civil Engineering and Management. Vilnius: Technika, 2004, t. X, Nr. 4, p. 267–276.*

Jaszkiewicz, A., Slowinski, R. (1999). „The 'Light Beam Search' approach – an overview of methogology and applications". *European Journal of Operational Research*, No. 113, pp. 300-314.

Kasprowicz T. (2002). *Construction project engineering*, Wydawnictwo i Zakład Poligrafii Instytutu Technologii Eksploatacji, Radom–Warszawa (in Polish).

Leu, S.-S., Yang, Ch.-H. (1999). „GA-Based Multicriteria Optimal Model for Construction Scheduling". *Journal of Construction Engineering and Management*, Vol. 125, No. 6, pp. 420-427.

Nagar, A., Haddock, J. and Heragu, S. (1995). „Multiple and bicriteria scheduling. A literature survey. *European Journal of Operational Research*, No. 81, pp. 88-104.

Prystupa, M. (1996). *Decision making proplems in construction investments projects*, Polska Federacja Stowarzyszeń Rzeczoznawców Majątkowych, Warszawa.

Ulusoy, G. and Özdamar, L. (1995). „A heuristic scheduling algorithm for improving the duration and net present value of a project". *International Journal of Operations & Produkcion Management*, Vol. 15, No. 1, pp. 89-98.

Viana, A. and Sousa, J.P. (2000). „Using metaheuristics in multiobjective resource constrained project scheduling". *European Journal of Operational Research*, No. 120, pp. 359-374.

Wall, M.B. (1996). „A Genetic Algorithm for Resource-Constrained Scheduling". Massachusetts Institute of Technology (ftp://lancet.mit.edu/pub/mbwall/phd/thesis.ps.gz).