X Anniversary International Scientific Conference
Analysis of International Relations 2018. Methods and Models of Regional Development. Summer Edition
Katowice, Poland 19-20 June 2018

SCHEDULING PROJECTS IN PROGRAMS USING A MULTI-CRITERIA APPROACH

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Abstract: *Scheduling programs, understood as collections of projects related to a common goal, rarely finds a place in the literature. Usually, projects in such a collection share only a common goal. However, there are situations when projects are connected logically, for example by the deliverables obtained. It is difficult to use the critical path method in such a situation, but the problem of choosing the start of the project may occur. Many criteria can affect the selection of the effective start time of the project. Considered criteria may be: the risk of program delay or expected project costs.*
Paper has following objectives: to describe problem of scheduling programs and use multicriteria approach to scheduling projects in it. Using a system approach, after analyzing project scheduling solutions in literature, we applied them appropriately to determine the start time of the project. The approach was verified using an example taken from the literature on the subject.

Key words: *project management, operational research, multicriteria approach*

JEL codes: *C65, O22*

1. Introduction

In the mid-twentieth century, when modern project management was emerged, the terms of project management and program management were used interchangeably. It was only at the turn of the century that these concepts began to be distinguished. Now we understand program management as being aimed at achieving strategic goals, and project goals are mostly product-oriented. As the achievement of strategic goals is related to the achievement of intermediate goals, typically programs consist of many projects related to a common goal. This distinguishes programs from project portfolios, where the linkage between projects is at the level of together used resources.

Project Management Institute defines program as: “related projects, subsidiary programs, and program activities managed in coordinated manner to obtain benefits not available from managing then individually" (PMI, 2017). As program consist of projects, there may be logical relation between them, causing that achieving one goal will depend on the achievement of another. This causes the scheduling problem to occur.

The problem of scheduling programs does not appear in the subject literature. Even in the mentioned PMI standard (PMI, 2017), only the chapter named "Program Schedule Monitoring and Controlling" appears, but there is no chapter devoted to develop schedule. We try to fill this gap, using systemic approach, using methods known from project management. Paper has main objective to describe program scheduling problem. Second is to use multicriteria approach to find best start moment for project in program. We use methods known in project management, adapting them to the specificity of the program.

The remainder of this paper is structured as follows. Section 2 provides a formal concept multicriteria approach to scheduling programs. This section covers also Simple Additive Weighting method explanation, which was used to solve multiple criteria decision making problem. A case study, based on systemic approach to described in literature problem, is presented in Section 3. Finally, Section 4 contain conclusions and direction for further research.

2. Methodology

Using systemic approach we can treat projects in program as activities in project. With this assumption we describe two methods used in project management to develop schedule. The most important is Critical Path Method (CPM).

The Critical Path Method was developed in the late 1950s by Walker and Kelley (1959). Despite the passage of over 50 years, the CPM method is still being mentioned as the main tool for creating schedules. CPM divides activities in each project into two categories: critical and non-critical. Critical activities are those for which the start and finish are strictly defined. They are "critical" in the sense that their delay results in the delay of the whole project. The start time for non-critical activities can, to a certain extent, be freely selected.

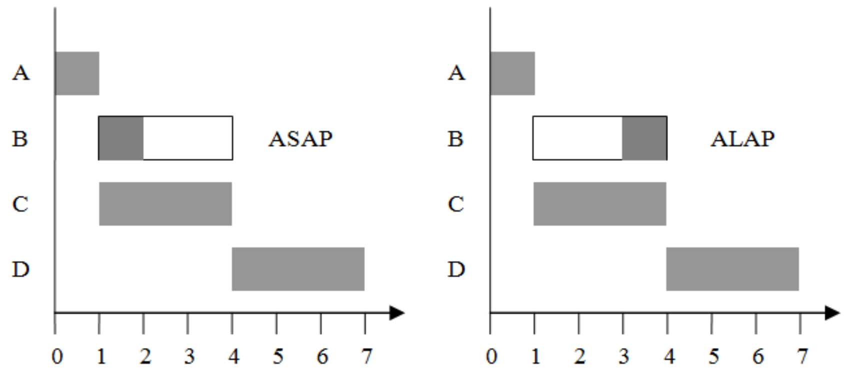
In the literature, little attention is paid to non-critical activities. Castro et al. (2008) consider this problem while analyzing the slack allocation in Program Evaluation and Review Technique (PERT). PERT is another method used for scheduling, based on CPM, in which are considered random activity durations. They propose an allocation rule that assigns extra time to the activities proportionally to their durations in such a way that no path duration exceeds the completion time of the whole project. Similar problem, extended to a stochastic framework, is also considered in (Castro et al., 2014). Although defining a critical path is extremely important for project management, in the literature little attention is paid to the identification of such a path in the PERT model. This problem is considered by Monhor (2011), who proposes a new probabilistic approach for comparing path durations and defines the concept of probabilistically critical path as a stochastic counterpart of the deterministic critical path.

In practical applications, deterministic estimation is usually used for activity duration. However, even in this situation, the project manager faces the problem of determining when a non-critical activity should start. Two approaches are usually proposed to solve this problem:

- As Soon As Possible (ASAP),
- As Late As Possible (ALAP).

Fig. 1 describes these approaches, assuming that B is a non-critical activity, while the others are critical.

Fig. 1 Approaches to the choice start a non-critical activity



Source: Own work.

The ASAP approach is more appropriate when it is very important to meet the project deadline. This method minimizes the risk of exceeding this date. On the other hand, ALAP, the more risky approach, can be selected to meet resource constraints. There is also a third option: to start a non-critical activity between these extremes. The aim of this paper is to propose a new method for solving problem when to start project in program if we have some freedom in this choice.

In some cases the result of an project depends on its finish time. This is the case, for example, of construction projects where the cost depends on the cost of building materials which varies seasonally. In this situation, choosing the right moment to start project is of major importance. This is an interesting research problem which raises the question of whether it is possible to determine the optimal start time using the history of changes in the factors that determine the result of the activity. Targiel (2015) has solved this problem using real option approach. This approach leads to the determination of the expected cost as a function of the start of the project. Using systemic approach we can use this method to programs. This method was used to calculate expected cost in case study.

Other important factor in scheduling is risk. Shi et al. (2014) considered schedule risk in the delivery risk structure of the 2010 Guangzhou Asian Games Construction program. Nowak and Targiel (2018) measured this risk as a probability of delay. A non-critical activity must be finished before a specific point in time. Its delay causes a delay of the entire project. This probability can be derived from the expected duration estimated using the PERT method (Program Evaluation and Review Technique) (Stauber et al., 1959), but it is more appropriate to confront this calculation with expert knowledge and intuition. For each alternative we ask an expert to define the probability of delay. This approach allows to take into account the risk associated with weather which is very important for construction projects.

Another important criterion in scheduling is the risk of poor quality, measured as the probability of such quality. It was also considered in (Nowak and Targiel, 2018). In some situations, the value of this probability is influenced by the start time of an activity. For example, in a construction project, the risk of poor quality depends on the weather, which changes during the year. Similarly to the risk of delay, we assume that the risk of poor quality is estimated by an expert.

Taking into account these three factors when determining the start time of the project leads to a multi-criteria model. The considered moments of the start of the project form a set of alternatives A:

$$\mathrm{A} = \{a_1, a_2, ..., a_m\}. \tag{1}$$

The aforementioned factors affecting the determination of the project start moment will be, after their quantification, to be treated as criteria. Then:

$$\mathrm{F} = \{f_1, f_2, ..., f_n\} \tag{2}$$

is the set of objective functions for each criterion. By $f_j(a_i)$ we denote the evaluation of alternative a_i with respect to criterion f_j.

A similar problem was considered for scheduling activities in the project in papers (Nowak and Targiel, 2018; Targiel et al., 2018) and solved with sophisticated interactive procedure taking into account the preferences of decision-makers. In this case we use Simple Additive Weighting (SAW) method (Churchman and Ackoff, 1954).

Lets

$$r_{ik} = \frac{\min_l f_k(a_l)}{f_k(a_i)} \tag{3}$$

be normalized evaluation of alternative a_i with respect to criterion f_j, and

$$r_{ik} = \frac{f_k(a_i) - \max_l f_k(a_l)}{\min_l f_k(a_l) - \max_l f_k(a_l)} \tag{4}$$

is second method normalized evaluation of alternative a_i with respect to criterion f_j. Then we can calculate:

$$p_i = \sum_{k=1}^{n} w_k r_{ik} \tag{5}$$

for each alternative $i = 1,...,m$.
Through w_k we have marked the weights assigned to each k criterion, meeting the conditions:

$$\sum_{k=1}^{n} w_k = 1, \tag{6}$$

$$w_k \geq 0 \tag{7}$$

for each criterion $k = 1,...,n$.
The best alternative is one with highest value p_i. The calculation of normalized values has been presented for cost criteria.

SAW method is a simple and intuitive method that can be used with the assumption of independence of preferences. The only difficulty of this method is the need to directly provide weights reflecting the preferences of the decision maker.

3. Results and Discussion

As an example, we consider project that should be completed by no later than December 31st. The nominal completion time is 3 months. Obviously, the sooner the project is started, the lower the risk that the project will be delayed. Table 1 presents the expected costs for various starting times and the values of the two other objective functions for each alternative. The second is probability of delay and the last one is probability of poor quality. Evaluation of both criteria determined by experts.

Tab. 1 The set of alternatives with evaluations

Alternative	Starting time (month)	Expected cost (M PLN)	Probability of delay	Probability of poor quality
a_1	January	206.635	0.01	0.80
a_2	February	205.913	0.02	0.50
a_3	March	205.194	0.04	0.40
a_4	April	204.476	0.10	0.20
a_5	May	203.762	0.11	0.05
a_6	June	203.050	0.15	0.05
a_7	July	202.340	0.16	0.05
a_8	August	201.633	0.18	0.15
a_9	September	200.928	0.19	0.20
a_{10}	October	200.226	0.20	0.30

Source: Nowak and Targiel (2018).

For presented in table 1 data we used SAW method to find best alternative, which is in this case best moment to start project. The most important was cost, we use weight $w_1 = 0.4$. For second most important criterion we assume probability of delay with weight $w_2 = 0.3$. The same important was probability of bad quality which has weight $w_3 = 0.3$. For normalization we use first method. Results are presented in table 2.

Tab. 2 Normalized evaluations calculated with first method

Alternative	Starting time (month)	Normalized expected cost	Normalized probability of delay	Normalized probability of poor quality	p_i
a_1	January	0.97	1.00	0.06	0.71
a_2	February	0.97	0.50	0.10	0.57
a_3	March	0.98	0.25	0.13	0.50
a_4	April	0.98	0.10	0.25	0.50
a_5	May	0.98	0.09	1.00	0.72
a_6	June	0.99	0.07	1.00	0.71
a_7	July	0.99	0.06	1.00	0.71
a_8	August	0.99	0.06	0.33	0.51
a_9	September	1.00	0.05	0.25	0.49
a_{10}	October	1.00	0.05	0.17	0.47

Source: Own calculations.

As we can see in table 2 best moment to start project is May. This solution is unique and unambiguous. We noticed that the result is very sensitive to the choice of weights. In table 3 we present winning alternatives for some combinations of weights.

Tab. 3 Winning alternatives for different weights

Normalized expected cost weight w_1	Normalized probability of delay weight w_2	Normalized probability of poor quality weight w_3	Winning alternatives	p_i
0.4	0.3	0.3	a_5	0.72
0.3	0.4	0.3	a_1	0.71
0.3	0.3	0.4	a_5, a_6, a_7	0.72
0.5	0.3	0.2	a_1	0.80
0.5	0.2	0.3	a_5, a_6, a_7	0.81
0.5	0.25	0.25	a_5, a_6, a_7	0.76
0.8	0.1	0.1	a_5, a_6, a_7	0.90
0.3(3)	0.3(3)	0.3(3)	a_5	0.69

Source: Own calculations.

The winning solution varies between: start the project in January (if the higher weight has a limitation of the delay risk) and the start of the project in the summer months (if the quality risk weight is higher). Only if the weights are similar, we get unique solution, to start the project in the first month of the summer period, namely in May. The small variability of the evaluation in the first criterion, which was the result of the normalization method adopted, resulted in a greater impact of w_2 and w_3 weights on the final solution.

We use for normalization also second method, given by equation (4). Results are presented in table 4.

Tab. 4 Normalized evaluations calculated with second method

Alternative	Starting time (month)	Normalized expected cost	Normalized probability of delay	Normalized probability of poor quality	p_i
a_1	January	0.00	1.00	0.00	0.30
a_2	February	0.11	0.95	0.40	0.45
a_3	March	0.22	0.84	0.53	0.50
a_4	April	0.34	0.53	0.80	0.53
a_5	May	0.45	0.47	1.00	0.62
a_6	June	0.56	0.26	1.00	0.60
a_7	July	0.67	0.21	1.00	0.63
a_8	August	0.78	0.11	0.87	0.60
a_9	September	0.89	0.05	0.80	0.61
a_{10}	October	1.00	0.00	0.67	0.60

Source: Own calculations.

This time, as we can see in table 4, best moment to start project is July. Second method gives a greater variation in the value of the first criterion, therefore the lower the cost achieved in July, gives better position in ranking, compared to May obtained with first method.

This time we also checked the sensitivity of the obtained solutions for the selection of criteria weights. We do it for the same set of weights. In Table 5 we present winning alternatives for some combinations of weights.

This time winning solution varies between: start the project in May and the start of the project as late as possible in October. Similar weights results in solution to start project in May. The bigger variability of the evaluation in the first criterion, which was the result of the normalization method adopted (second), resulted in a greater impact of w1 weight on the final solution. Then solution is to start project as late as possible, namely in October.

Tab. 5 Winning alternatives for different weights (second method of normalization)

Normalized expected cost weight w_1	Normalized probability of delay weight w_2	Normalized probability of poor quality weight w_3	Winning alternatives	p_i
0.4	0.3	0.3	a_7	0.63
0.3	0.4	0.3	a_5	0.62
0.3	0.3	0.4	a_5	0.68
0.5	0.3	0.2	a_{10}	0.63
0.5	0.2	0.3	a_9, a_{10}	0.70
0.5	0.25	0.25	a_{10}	0.67
0.8	0.1	0.1	a_{10}	0.87
0.3(3)	0.3(3)	0.3(3)	a_5	0.64

Source: Own calculations.

As the result is very sensitive to the choice of weights, there is the necessity of their precise selection. The SAW method used does not give the possibility of precise estimation of weights to the decision-maker's preferences. Interactive methods allow it. This problem was discussed for two criteria in (Targiel et al., 2018), and for three criteria in (Nowak and Targiel, 2018). In these papers, the project scheduling was considered, but accepting the systemic approach presented in this paper, treating projects in the program as activities in the project, we can easily transfer these solutions to the scheduling programs.

In scheduling programs, a multi-criteria approach seems more appropriate, as many factors affect the selection of the right moment for the start of the project being part of the program. Simple approaches using only the adapted CPM method seem to be insufficient.

4. Conclusions

In presented paper, was undertaken important but rare in the literature problem of scheduling programs, understood as collections of projects connected by a common goal. Using the systemic approach, methods known from project management were adopted. The results obtained seem promising. However as the weight of projects in relation to project activities is higher, hence the necessity of taking into account many factors during scheduling. This results in the usefulness of using a multicriteria approach.

In the paper multi-criteria problem was defined and solved with SAW method. This method turned out to be highly sensitive to the choice of parameters in the form of criteria weights. This necessitates further research on the use of multi-criteria methods in the presented problem.

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