

## MULTICRITERIA SUPPORT OF PROJECT SCHEDULING IN PROGRAMS

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**Abstract:** Programs are collections of projects related to a common goal. Scheduling programs follow other rules than scheduling projects. Even when projects in programs are connected logically, simple methods as the critical path method (CPM) cannot always be used. This paper has the following objectives: to describe the problem of scheduling programs and use the multi-criteria approach to scheduling projects in it. Using a system approach, after analyzing project-scheduling solutions in literature, we applied them appropriately to determine the schedule of the project. The approach was verified using an example taken from the literature on the subject.

**Keywords:** project management, operational research, multi-criteria approach, scheduling.

### 1. Introduction

Contemporary project management distinguishes several structures in which projects can be activated. These are programs and project portfolios. Accordingly, and utilizing the PMBoK standard (PMI, 2017a), “a project is a temporary endeavor designed to produce a unique product, service or result” (PMI, 2017a). In this definition, attention should be paid to the temporality of the undertaking, which means that it has a specified start and end. This fact implies the need for scheduling, which consists in determining the start and end times, not only of the project, but also of the individual activities that make up it. The second important point of the definition is to emphasize the creation of unique deliverables in the form of a product, service or other result.

In today's world, organizations simultaneously embark upon many projects. This raises the need to manage them in a coordinated manner. This creates a project portfolio. The term is defined as: "Projects, programs, subsidiary portfolios, and operations managed as a group to achieve strategic objectives" (PMI, 2017a). The only issue that connects projects in the portfolio is the sharing of organization resources.

As we could see in the previous definition, projects and more complex structures such as programs, can be combined to achieve strategic goals. Programs in this respect are: “[...] a group of related projects managed in a coordinated manner to obtain benefits and control NOT available from managing them individually” (PMI, 2017b). In this case, projects are connected not only by common resources, but also by a strategic goal, and we want to achieve this strategic goal through the implementation of the projects included in the program.

Project scheduling project has long history of applied qualitative methods. The Critical Path Method (CPM) was developed in the late 1950s by Kelley and Walker (1959). Despite the passage of over 60 years, the CPM method is still the main tool for creating schedules.

The problem of scheduling a project portfolio can be seen as the task of scheduling a single project in which there are many activities related to inconsistent graphs. However, they are linked to the need to use common limited resources.

Project scheduling problems are often dealt with via a multi-criteria framework. Herein, most techniques proposed in the literature are dedicated to the Resource Constrained Project Scheduling Problem (RCPSP). Because such a problem is NP-hard, metaheuristic approaches are usually used (Monghasemi, et al., 2015; Tofighian, and Naderi, 2015; Ning, et al., 2017).

A scheduling program is understood as a coordinated collection of projects related to achieving common goal. It rarely finds a place in the literature (Shtub, et al., 1996; Keys, 1991; Keys, 2009). While projects in such a collection share only a common goal, there are situations when projects are connected logically. An example is when the deliverables obtained in one project are necessary in a second. Applying methods like CPM are not appropriate because of different scheduling perspectives. Weaver (2010) addressed this problem by means of consideration from the prospective of diverse knowledge areas. Therein, in the area of risk management, in a project perspective, for example, we try to minimize risk. In the program perspective, however, we expect undefined risks. In the area of communication with stakeholders, a project perspective seeks to align stakeholders with the project goals, but in a program perspective, we try to engage with stakeholders to build on to this relation, long-term value to the organization. Finally, in the schedule management area, Weaver finds that in a project perspective, we want to encompass in the schedule for all of the work, the means for best controlling the work. Thus, in a program perspective, we must incorporate the project schedules at a summary level to manage the gaps and interfaces between projects. Weaver also emphasizes the interdependencies between projects.

By adopting this way of thinking about program management, however, we cannot directly transfer project scheduling methods to program scheduling. There is a need to develop new methods for scheduling programs. Attention must also be paid to linking programs with strategic management (Głodzinski, 2017).

The problem of scheduling programs does not appear in the subject literature. PMI standard (PMI, 2017b) has only the chapter named "Program Schedule Monitoring and Controlling", but there is no chapter devoted to develop the schedule. We will try to fill this gap, using a multi-

criteria approach. This paper, therefore, has main objective of describing the program-scheduling problem. In the first part, we propose a formal approach. In the next part, we try using this approach to describe exemplary simple program scheduling.

## 2. Methods

We will use an adapted model to describe the scheduling problem. This was proposed by Artigues (2003) for application within a multi-project environment. We will employ the standard notation for scheduling RCPSP problems that was put forward by Brucker (1999), where:

$Q$  – set of projects in program,

$V^q$  – is set of activities of  $q$ -th project  $q \in Q$ ,

$q$  – is project index,

$\mathfrak{R}^p$  – set of renewable resources,

$R_k^p$  – availability renewable  $k$ -th resource –  $k \in \mathfrak{R}^p$ ,

$p_j^q$  – processing time of activity  $j$  in  $q$ -th project.

The RCPSP problem is to find the best schedule for each  $q$ -th project as vector:

$$S^q = (S_0^q, \dots, S_j^q, \dots, S_n^q) \tag{1}$$

where:

$S_j^q$   $j = 0, 1, \dots, n, n+1$  – is the starting point of activity  $j$  in  $q$ -th project. We also add the time when  $q$ -th project starts:

$S_0^q$  – is the moment when  $q$ -th project starts.

Moreover, to simplify the notation, we will introduce the end times for each  $j$ -th activity and each project  $q$ :

$$C^q = (C_1^q, \dots, C_j^q, \dots, C_{n+1}^q) \tag{2}$$

where:

$C_j^q$   $j = 0, 1, \dots, n, n+1$  – is the time of completion of activity  $j$ ,

$C_{n+1}^q$  – is the moment when  $q$ -th project is finished.

We will now define the size of the engaged  $k$ -th resource used within the  $q$ -th project:

$$r_k(S^q, t) = \sum_{j \in A(S^q, t)} r_{jk} \quad (3)$$

where  $r_{jk}$  – is the size of the engaged  $k$ -th resource for the  $j$ -th activity.

The addition of each new project to the program can cause conflicts in the access to resources. We must do this so that these conflicts do not arise. For this purpose, we will create an appropriate schedule of operations. This is a very complex task. To simplify this, we will specify the strategic resources from which scheduling can start.

We can find strategic resources using the approach proposed by Targiel (2012) by solving the problem of goal programming:

$$\min \sum_k y_{kt}^+ \quad (4)$$

s.t.

$$S_{n+1}^q \leq C_{\min} \quad \forall q \in Q \quad (5)$$

$$S_j^q - S_i^q \geq p_i^q \quad \forall i \in V^q - \{n+1\}, \forall j \in V^q - \{0\}, \forall q \cup q+1 \quad (6)$$

$$\sum_q r_k(S^q, t) - y_{kt}^+ + y_{kt}^- = R_k^\rho \quad \forall k \in \mathfrak{R}^\rho \quad \forall t > 0 \quad (7)$$

$$y_{kt}^+, y_{kt}^- \geq 0 \quad \forall k \in \mathfrak{R}^\rho \quad (8)$$

where:

$y_{kt}^+$  – demand over the availability of resource  $k$  at time  $t$ ,

$y_{kt}^-$  – demand below the availability of resource  $k$  at time  $t$ ,

$C_{\min}$  – declared time of completion of the program.

If objective function is equal 0, we have a feasible schedule. Resources for which we have minimum are where:

$$k = \arg \left( \min_k \sum_t y_{kt}^- \right) \quad (9)$$

is the strategic resource.

The schedules obtained by this procedure cannot be appropriate by way of the program point of view. For that reason, we propose a new method to better tailor plans to stakeholder requirements. Herein, the considered moments of the start times of each projects in the program form a set of alternatives A:

$$A = \{a_1, a_2, \dots, a_m\} \tag{10}$$

where

$$a_k = (S_0^1, C_{n+1}^1, S_0^2, C_{n+1}^2, \dots, S_0^q, C_{n+1}^q, \dots, S_0^{|Q|}, C_{n+1}^{|Q|}) \tag{11}$$

This time we will consider only discrete, finite number of alternatives. Each alternative is a vector, containing the start times and finish times of each project in the program.

We also define the criteria. Then:

$$F = \{f_1, f_2, \dots, f_n\} \tag{12}$$

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 for scheduling the start times of activities in the project was considered in the papers (Targiel, and Nowak, 2018; Targiel, et al., 2018) and solved by means of a sophisticated interactive procedure, taking into account the preferences of decision-makers. In these papers, the cost of the project, the risk of delay and the risk related to the quality of results were considered as criteria.

Now we can define the multicriteria decision-making problem as:

$$Min\{f_1, f_2, \dots, f_n\} \tag{13}$$

s.t.

$$C_{n+1}^{q_1} \leq S_0^{q_2} \quad \forall q_1 \in Q^* \tag{14}$$

where  $Q^*$  – a subset of the project set  $Q$  for which logical dependencies occur, for example the results of project  $q_1$  are required for project  $q_2$ .

Such a problem can be solved by means of sophisticated interactive procedures, taking into account the preferences of decision-makers. We can also use also Simple Additive Weighting (SAW) method (Zionts and Wallenius, 1983). Depending on the preferences of the stakeholders, expressed by criteria weights, different decision options can be selected using the utility function:

$$p_i = \sum_{k=1}^n w_k r_{ik} \tag{15}$$

where:

$$r_{ik} = \frac{\max_l f_k(a_l) - f_k(a_i)}{\max_l f_k(a_l) - \min_l f_k(a_l)} \tag{16}$$

is a normalized evaluation of alternative  $a_i$  with respect to criterion  $f_j$  and by  $w_k$ , we have marked the weights assigned to each  $k$  criterion, meeting the conditions:

$$\sum_{k=1}^n w_k = 1 \quad (17)$$

$$w_k \geq 0 \quad (18)$$

The best alternative is one with highest value  $p_i$ . The method for cost criteria has been presented.

### 3. Results

In order to illustrate the proposed method, we must considered a portfolio of projects discussed in the literature (Hanh Quang, 2008). We will look at this portfolio as the program shown in Figure 1. A summary of incorporated actions is shown in Table 1.

**Table 1.**  
*Activities of the projects in program*

Activity $j$	$D_j$	Predecessors( $j$ )	Resources
Project P1			
P1-1	3,33		2A, C
P1-2	4		2A, B, C
P1-3	5	P1-1, P1-1	A, C
Project P2			
P2-1	5		A,B,C
P2-2	4	P2-1	2A,
P2-3	5	P2-1	A,2B,C
P2-4	4	P2-2, P2-3	2A,C
Project P3			
P3-1	5		2A, C
P3-2	4		2A, B, C
P3-3	5	P2-1, P2-1	A, C

Note. Adapted from: "Scheduling resource constrained project portfolios with the principles theory of constraints" by K. Targiel. Copyright 2013.

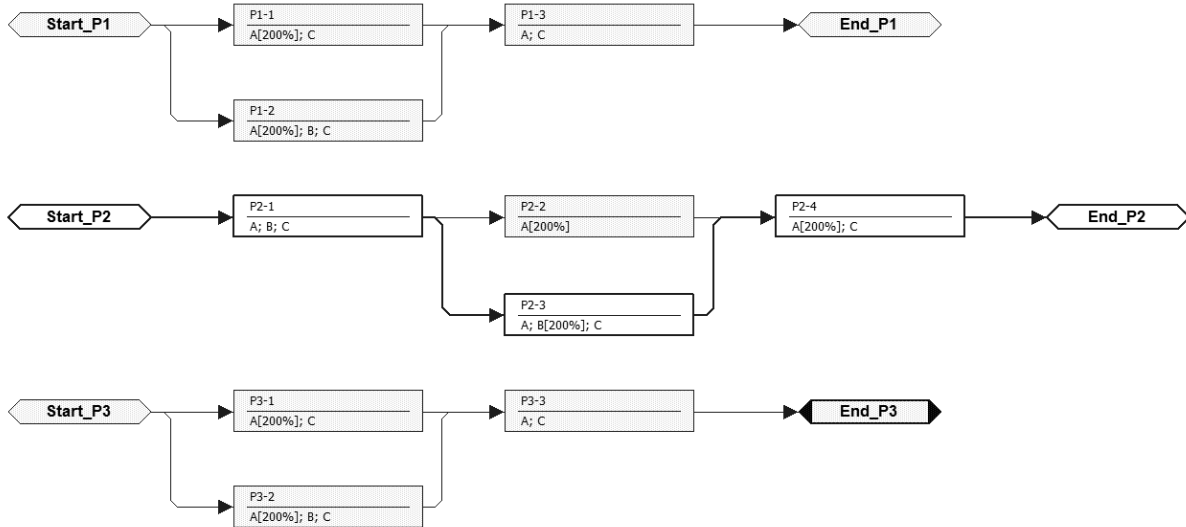
The availability of resources used (A, B, C) is shown in Table 2.

**Table 2.**  
*Resources*

Resource	A	B	C
Availability	4	2	2

Note. Adapted from: "Resource-Constrained Multi-Project Scheduling with Resource Moving Time for Construction Projects in Vietnam" p. 103 by L. Hanh Quang.

The graph of activities of the project portfolio is shown in Figure 1.



**Figure 1.** Graph of activities in the program. Adapted from: “Scheduling resource constrained project portfolios with the principles theory of constraints” by K. Targiel. Copyright 2013.

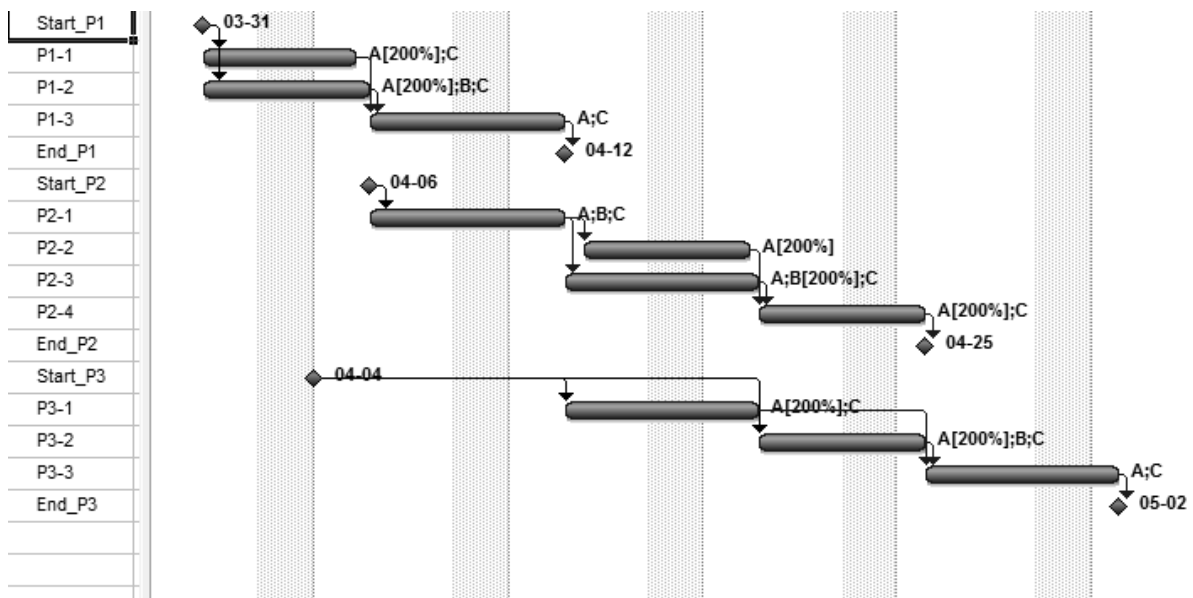
Using the procedure described in (Targiel, 2013), we obtain feasible schedules for each project:

$$S^1 = (1, 1, 5),$$

$$S^2 = (5, 10, 10, 15),$$

$$S^3 = (14, 19, 23)$$

which are presented in Figure 2.



**Figure 2.** Gantt chart for whole program. Adapted from: “Scheduling resource constrained project portfolios with the principles theory of constraints” by K. Targiel. Copyright 2013.

However, this feasible schedules cannot be appropriate from a program point of view, so we will use the method proposed in this paper to better tailor plans to stakeholder requirements.

Let's assume that it is important for stakeholders to not only to finish the program in the shortest time, but, first of all, to obtain the right quality results. This is associated with extending the deadlines for project implementation. We will define two criteria:

$$f_1 = \underset{q}{\text{Max}} C_{n+1}^q \quad (19)$$

$$f_2 = |S_0^3 - C_{n+1}^1 - 10| \quad (20)$$

The first equation (19), describes the minimization of time necessary to complete the entire program. The second (20) describes the minimization risk of bad quality. The results of project 1 are necessary for project 3, but for better quality there should be a 10 days delay between these projects.

We will consider two alternatives:

$$a_1 = (1, 9, 5, 19, 14, 28) \quad (21)$$

$$a_2 = (1, 9, 5, 19, 19, 33) \quad (22)$$

The first alternative  $a_1$  represents the acceptable timetable received, the second alternative  $a_2$  represents the schedule in which the last project was delayed by five time units to achieve better quality. Because quality is more important than competition time, we assume weights  $w_1 = 0,1$  and  $w_2 = 0,9$ . The normalized evaluation  $r_{11}$  of alternative  $a_1$  with respect to criterion  $f_1$  is equal to 1. In the same way, normalized evaluation of alternative  $a_2$  with respect to criterion  $f_1$  is  $r_{21} = 0$  and  $r_{12} = 0$ ,  $r_{22} = 1$ . Using the weights, this gives us the following values of the utility function for the first alternative  $p_1 = 0,1$  and the second alternative  $p_2 = 0,9$ . This means that the second alternative is more favorable. A second program schedule should be selected.

## 4. Discussion

The problem of program scheduling using quantitative methods is discussed in the paper. A different perspective in program management means that methods known from project management such as the CPM method cannot be used directly. The multifaceted nature of this problem makes multi-criteria methods seem useful.



The example under consideration is very simple, but demonstrates the possibility of using a multi-criteria approach. In real problems, the number of criteria can be much larger. A quantitative record of stakeholder requirements can be another problem. These are problems that must be solved individually in each case.

Difficulties in modeling such decision-making situations do not reduce the potential benefits of using the proposed approach. These benefits boil down to building better relations with stakeholders, which is the most important for the organization from a strategic point of view.

## 5. Summary

In the paper, a new approach to scheduling programs was considered. This new procedure is based on the multi-criteria approach. The proposed approach is illustrated by a simple example showing the feasibility of implementing this approach. The procedure can be applied in many organizations that want to build strategic relations with key stakeholders.

In future research, we would like to apply our approach to real programs. Modeling various stakeholder requirements by quantitative methods will be the key to these studies. It will also be interesting to examine the usefulness of the proposed approach.

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