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# Project Portfolio and Contractor Selection Problem Based on Project Scheduling

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## Abstract

In this paper a new formulation of the project portfolio selection problem based on the project schedules have been proposed. The project portfolio selection models usually disregard the project scheduling, whereas is an element of the project selection process. On the other hand, except those cases which only one project is active in each period, the prioritization of the selected projects will not be optimal unless the scheduling of the projects is considered. In this paper, we study a condition, in which between available projects a number of them should be selected and scheduled. The decision-makers must select and schedule a subset of the projects with respect to the constraints associated with contractor selection and the predecessor relationships between activities of the different projects. In other words, we investigate a project portfolio selection problem based on the schedule of the projects, so that the minimum expected profit will be met in the shortest possible time period. Finally, a linear programming model is developed for the problem, where the results indicated the validity of the presented model.

**Keywords:** Contractor selection, Linear programming, Project portfolio selection, Project scheduling.

## Introduction

The managers of the project-based organizations particularly in research organizations, confront the limited financial resources where they always face a project portfolio selection and scheduling problem. Various experimental and analytical mechanisms are developed and presented for project portfolio selection problem. Most of these tools prioritize projects based on the expert opinions about value, importance and available resources of the projects. The project portfolio selection practically determines the strategies and responsibilities of the senior management in organization medium-term future [5, 25]. In the different industries the common approaches and methods of the project selection mainly consists of two steps: First, all of the projects are evaluated separately and then the optimal set of the projects will be selected using a greedy algorithm. These projects are selected and prioritized by the series of predetermined criteria [13, 16, and 19]. Second, the projects are selected one by one according to their priorities until the resources are finished. These methods and approaches are easy and thus are widely used in practical. Nevertheless, it should be noted that the composition of the projects with higher priorities would not necessarily lead to more profitable portfolio [4].The major key in this model is the evaluation of the projects and the assessment of their objective value. One of the project selection policies is the selection process based on the evaluation and ranking of each project. For the ranking of the projects, there are different evaluation methods. The most widely used method is the economic analysis, in which the projects are ranked according to their present net value. On the other hand, in order to overcome the weakness of focusing on the individual criteria in the project ranking, the ranking models are proposed and used based on the several criteria to evaluate the projects [15].

As seen the project portfolio selection models usually disregard the project scheduling, whereas is an element of the project selection process. In this paper we propose a mathematical model to consider the project portfolio selection based on the scheduling of the projects as well as the possibility of contractor selection for each one of the current activities.

The rest of this paper is organized as follows. The literature is reviewed in the next section. In the section “Problem Formulation”, the proposed mathematical model is presented. As an illustration of the model, we present a numerical example in the section “Sample Problem”. The model results analysis is discussed in the section “Problem Results Analysis”. Finally, there is the Conclusions section.

## Literature Review

Many models are suggested to help the organizations to choose and schedule their projects. Santos [8] tries to represent a policy with ranking technique. The ranking method is a structured policy, which simultaneously considers several factors such as economic profit, business goals and so on. However, this method is not appropriate for the issues focused on the access to the resources and relationships between the projects.

Lootsma [17], Lucas and Moore [18] suggested the scoring method for the project selection. The scoring model can afford all of the important factors in the process of project selection and provide the theoretic indicator to select between different projects. Muralidhar et al. [23] presented a project selection approach by the hierarchical decision-making process. These studies argue how the mentioned process mathematically determines the prioritization structure and how it is used in the project selection.

Ghasemzadeh [10] suggests a pre-qualification process in which each project at first must be evaluated separately and if the basic criteria are met, the project can proceed to the next step. The Integrated Project Portfolio Selection Framework presented by Ghasemzadeh [10] was focused on the procedures and relies on how the tools and the techniques are used. This framework is widely used in the relevant academic and operational researches.

In addition, although various mathematical programming models have been introduced for the project portfolio selection problem, most of the conducted studies have left out the impact of the low level of project management and control involved with project scheduling activities.

The mathematical models are the optimization models, which apply the mathematical programming techniques for the optimal selection of projects through the nominee projects. The selection is function of the maximization of the objective and satisfaction of the resource constraints. Schmidt [26] suggests a non-linear programming model to study the dependency of the candidate projects. There are three types of interaction in this model: outcome, output and resource interactions and finally a branch and bound algorithm have been proposed to solve the model. Badri [3] proposed a goal programming model for project portfolio selection in the information system projects.

Stummer and Heidenberger [27] suggested a model and searching approach for Pareto optimal project portfolio in multi-stage decision-making process. The value assessment of the proposed portfolios is widely studied by the multidisciplinary weighting models.

Golabi et al. [12] presented a project portfolio selection model that uniquely maximized the additional values in each project with respect to the resource constraints. Moreover, as a case study he studies the solar energy production problem with regard to the several criteria.

Gabriel et al. [9] have introduced the multi-objective optimization model with regard to the probability distribution of the costs.

Abello et al. [1] examined a special case of the resource constraint project scheduling problem, in which the number of applicable activities changes over time. In other words, unlike the common models of the resource constraint project scheduling problem, in which the number of activities is predetermined, in this case the number of activities is not fixed and varies in the progress of the project. Since the issue of the project portfolio selection and scheduling is categorized in NP-hard (Non-deterministic Polynomial-time) problems [7], in the recent years the meta-heuristic algorithms such as evolutionary algorithms [20] and colony algorithms [7] are used to solve these problems.

Xiao et al. [29] applied an ant colony optimization approach to solve software project scheduling problem. In this proposed approach, with respect to the implementation of the software oriented project activities by some individuals, a mechanism is presented for the distribution of the activities and assigning them to the implementing agents. Ghorbani & Rabani [11] developed a two objective model to maximize the productivity of the projects and minimize the total deviation of the allocated resources in two successive periods and for the problem solving introduced the algorithm based on the genetic algorithm, which is compared with NSGA-2 algorithm. Tasan et al. [28] intended to solve the project portfolio selection and scheduling problems simultaneously in separate networks, which are independently examined for the project portfolio selection and scheduling by the integrated genetic algorithm method. In this presented approach, the multi-stage decision-making approach is used. Minku et al. [22] studied a variety of approaches for the problem of the project scheduling through the efficiency analysis and finally reached an improved approach to solve these types of the problems. This approach is developed based on run-time analysis, in which the efficiency of the proposed approach is improved.

Kazemipour et al. [14] developed the differential evolution algorithm for solving the project portfolio scheduling by the multi-skilled workforce. Such problem is a developed version of the multi-objective as well as multi-mode project portfolio scheduling problem, in which the workforce have different specialties for implementing different activities. In addition to the latter mentioned problem solving approach, a new goal programming model is developed to find the minimum deviation from the average time to complete each project as well as the resources dedication. In addition to the meta-heuristic algorithms, the heuristic approaches are used for the project portfolio selection and scheduling.

Reyck et al. [6] introduced a qualitative three-stage approach to solve the project portfolio selection problem in Information Technology industry, in which there is a strong correlation between the increasing of the portfolio processes and the reducing of the issues related to projects where by regarding to the drawn diagrams the performance is evaluated in each of the three phases of the algorithm. Messelis et al. [21] presented their approach for the automatic selection of the algorithm for solving the project portfolio scheduling problem with multi-mode resource constraint. The proposed approach is based on the concepts of the models, which experimentally include some difficulties. These models have the problem solving features depicted through the algorithm performance. These models are able to predict the performance of the algorithms. Rafiee et al. [24] studied the multi-period project portfolio selection and scheduling problem by using the multi-stage stochastic programming approach.

Artigues et al. [2] have used the robust optimization approach for the resources constraint project scheduling problem with the uncertain duration of the activities. In this regard, a scenario relaxation algorithm and a scenario relaxation-based heuristic is developed to solve the problem.

## Problem Formulation

In most of the problems related to project portfolio selection, the multi-criteria decision-making techniques are used to select the optimal set of projects, while the scheduling of the projects is not considered. Therefore, the project portfolio selection based on the project activities schedule can fairly overcome this gap.

In this paper, we investigate a project portfolio selection problem based on the schedule of the projects, so that the minimum expected profit will be met in the shortest possible time period for the completion of the projects in the portfolio. Moreover, it is assumed that various activities in different projects are performed by different contractors, so that there is a set of authorized contractors for every activity, whereas every activity is utmost carried out by one of them. In other words, in order to determine a contractor for any activity with respect to the diversity of the contractors to carry out, different scenarios can be depicted, which by modeling represented in this paper the best scenario would be selected with respect to the authorized contractors for each activity and their scheduling, so that all of them are satisfied and the minimum expected profit is met in the shortest possible time period.

The set of indices, parameters and decision variables of the problem are as follow:

**Sets and Indices:**

$I$: The set of the projects

$i, i'$: Project index

$J$: The set of the activities

$j, j'$: Activity index

$K$: The set of the contractors

$k, k'$ : Contractor index

$J_i$: Project i set of the activities

$n_i$: Project i last activity

$k_j$: The set of the contractors who can perform activity j

$P_j$: Activity j set of the predecessors

**Parameters:**

$t_{ijk}$: The required time for performing activity j of project i by contractor k.

$C_i$: Project i profit

$S$: Minimum project portfolio expected profit

$M$: Large number

**Variables:**

$x_{ijk}$ : Start time of the activity j of the project i performed by the contractor k

$Z_{ijk}$: Binary variable indicating that activity j of project i is performed by the contractor k or not
$y_i$: Binary variable indicating that project i is selected or not
$y_l$: Binary variable associated with $l^{th}$ constraints
T: Latest completion time of the projects

**Objective function and problem constraints:**

$$Min\,T \tag{1}$$
$$T \geq x_{ijk} + t_{ijk}Z_{ijk} \qquad \forall i \in I; j = n_i\,;\, k \in k_j \tag{2}$$
$$\sum_{k \in k_j} x_{ijk} \geq \sum_{k' \in k_{j'}} \left(x_{ij'k'} + t_{ij'k'}Z_{ij'k'}\right)\ \forall\, i \in I; j, j' \in J_i\,; k \in k_j; k' \in k_{j'}\,; j' \in P_j \tag{3}$$
$$x_{ijk} \leq MZ_{ijk} \quad \forall\, i \in I; j \in J_i\,;\, k \in k_j \tag{4}$$
$$x_{ijk} \geq x_{i'j'k} + t_{i'j'k} - M\left(2 - Z_{ijk} - Z_{i'j'k} + y_l\right)$$
$$\forall i, i' \in I; j \in J_i\,;\, j' \in J_{i'}\,; j \neq j';\, k \in k_j \cap k_{j'} \tag{5}$$
$$x_{i'j'k} \geq x_{ijk} + t_{ijk} - M\left(2 - Z_{ijk} - Z_{i'j'k} + 1 - y_l\right)$$
$$\forall i, i' \in I; j \in J_i\,;\, j' \in J_{i'}\,; j \neq j';\, k \in k_j \cap k_{j'} \tag{6}$$
$$y_l \leq \frac{1}{2}\left(Z_{ijk} + Z_{i'j'k}\right) \qquad \forall i, i' \in I; j \in J_i\,;\, j' \in J_{i'}\,; j \neq j';\, k \in k_j \cap k_{j'} \tag{7}$$
$$y_l \leq \frac{1}{2}\left(M(2 - Z_{ijk} - Z_{i'j'k}) + 2\right)$$
$$\forall i, i' \in I; i = i'; j \in J_i\,;\, j' \in J_{i'}\,; j \neq j';\, k \in k_j \cap k_{j'}\,; j \in P_{j'} \tag{8}$$
$$y_l \geq \frac{1}{2}\left(M(Z_{ijk} + Z_{i'j'k} - 2) + 2\right)$$
$$\forall i, i' \in I; i = i'; j \in J_i\,;\, j' \in J_{i'}\,; j \neq j';\, k \in k_j \cap k_{j'}\,; j \in P_{j'} \tag{9}$$
$$\sum_{k \in k_j} Z_{ijk} \leq 1 \quad \forall i \in I\,;\, j \in J_i \tag{10}$$
$$\sum_{i \in I} C_i\, y_i \geq S \tag{11}$$
$$y_i = \sum_{k \in k_j} Z_{ijk} \qquad \forall i \in I\,;\, j \in J_i \tag{12}$$
$$T, x_{ijk} \geq 0 \quad,\quad y_i, Z_{ijk} = Binary \tag{13}$$

The objective function is calculated in Eq. (1), whereas the variable T is given for the Constraint (2), which means that the project portfolio is implemented in the completion time of the last activity of the last ongoing project. The Constraint (3) represents a predecessor relationship between the project activities, which means that the start time of the successor activities should be posited after the completion time of their predecessor activities. The Constraint (4) indicates that in the case of not allocating an activity to a particular contractor (non-selection of the activity), the start time would not be set for that specific activity. When two activities are performed in one project or two different projects by the same contractor, the Constraints (5) to (9) should be satisfied, thereby it means that the both activities due to having same contractor could not overlap with each other.

These constraints are activated in the case of assigning a contractor to carry out two separate activities, the start time of an activity take place after finishing another. In condition that two activities belong to a project, the sequence of their implementation time would be based on predecessor network of the project. The Constraints (8) and (9) state such condition.

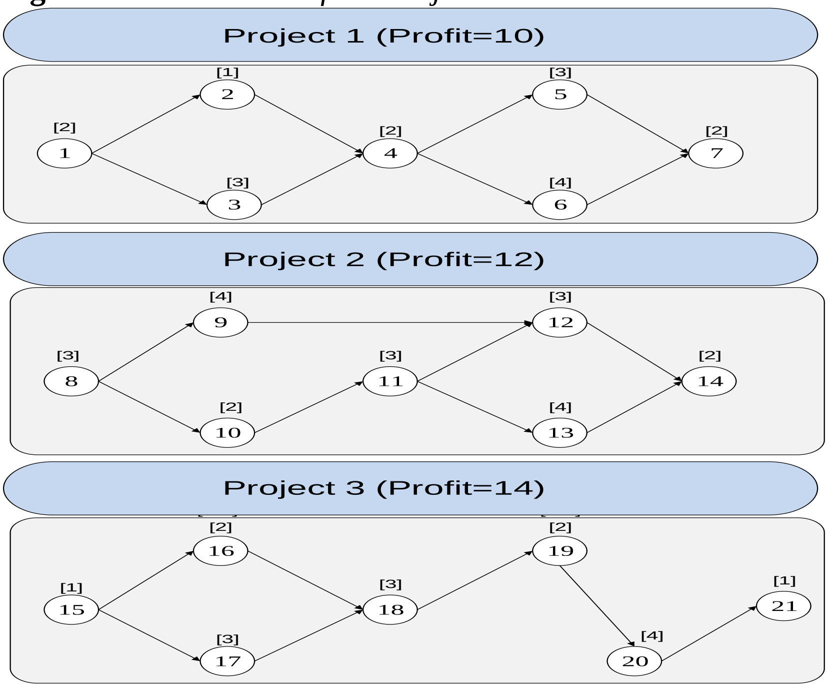
The Constraint (10) states that each activity is utmost allocated to one contractor. In other words, the implementation of an activity cannot rely on two different contractors. The Constraint (11) is used to satisfy the minimum expected profit of the project portfolio.

When a project is selected for inclusion in the project portfolio, all of the project activities must be performed by their authorized contractors, in other words, each activity must be carried out by a particular contractor. When a project is not selected, no contractor will be assigned to its activities. The above conditions are stated in the Constraint (12). Finally the sign constraint correspond to decision variables is mentioned in the Constraint (13).

## Sample Problem

In the sample problem, as shown in Figure 1, a network consists of three projects, as each one has seven activities, in which the activities of the projects can also be performed by six different contractors is considered. The network of these projects and the duration of the activities are shown in the following figure.

**Figure 1.** *The Network of the Projects*



Regarding to the above figure, predecessor relationships between the activities and the list of authorized contractors for each activity is presented in Table 1:

**Table 1.** *Predecessor Relationships and Authorized Contractors of the Activities*

| **Activity** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| **Predecessor/s** | - | 1 | 1 | 2<br>3 | 4 | 4 | 5<br>6 |
| **Authorized Contractor/s** | 1 | 1 | 2<br>3 | 1<br>2 | 3 | 4 | 5<br>6 |
| **Activity** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| **Predecessor/s** | - | 8 | 8 | 10 | 9<br>11 | 11 | 12<br>13 |
| **Authorized Contractor/s** | 5 | 6 | 3<br>4 | 2 | 1<br>6 | 6 | 3 |
| **Activity** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
| **Predecessor/s** | - | 15 | 15 | 16<br>17 | 18 | 19 | 20 |
| **Authorized Contractor/s** | 2<br>3 | 4<br>5 | 1<br>3<br>6 | 1<br>2<br>3 | 4 | 5 | 6 |

For example, in order to perform activity 3, either contractor 2 or 3 can be used. In addition, when its predecessor activity (Activity 1) is performed, this activity can be initiated.

## Problem Results Analysis

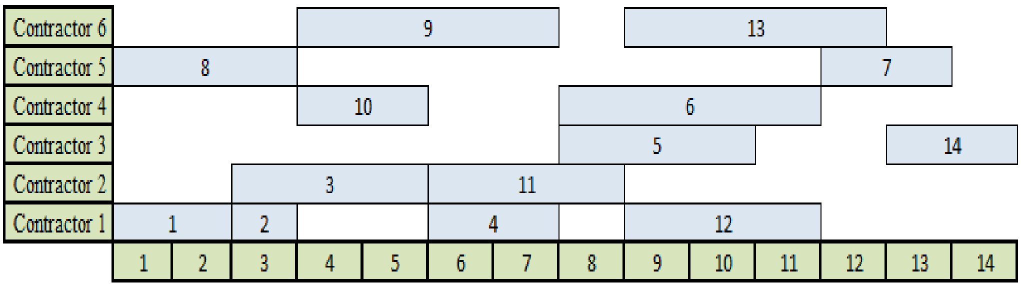
After the modeling and solving of the mentioned problem by Lingo Software, the scheduling of the activities and the selected contractor to perform every activity are presented in Table 2.

**Table 2.** *Optimal Solution of the Problem*

| Activity | Project | Start Time | Respective Contractor |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | | 3 | 1 |
| 3 | | 3 | 2 |
| 4 | | 6 | 1 |
| 5 | | 8 | 3 |
| 6 | | 8 | 4 |
| 7 | | 12 | 5 |
| 8 | 2 | 1 | 5 |
| 9 | | 4 | 6 |
| 10 | | 4 | 4 |
| 11 | | 6 | 2 |
| 12 | | 9 | 1 |
| 13 | | 9 | 6 |
| 14 | | 13 | 3 |

According to the above table, among the three nominee projects, Projects 1 and 2 are selected for the project portfolio, as these projects provide the least expected profit which is equal to 22 cost units. In addition, the contractor is specified to perform each activity. For example, Activity 3 is done by contractor 2. Also the scheduling of the activities are given in the above table, which represents the beginning time of each activity. The graphical diagram of the activities carried out by the contractors is shown in Figure 2.

**Figure 2.** The *Graphical Diagram of the Problem*




According to the above figure, non-overlapping constraint of the activities carried out by a contractor is evident. In addition, according to this figure, the scheduling of the activities is done based on the mentioned modeling, where the predecessor relationships between the activities are fulfilled. Both above cases, confirmed the validity of the model designed for the problem. Also, according to the software output and the scheduling, the minimum required time to complete the project portfolio is equal to 14 time units.

## Conclusions

In this paper, the modeling and proposed solution are studied and evaluated to help the top level management in the organization to consider the project portfolio selection process in their organization through the real impact of the projects and the related processes for the selected contractor. In the project selection process, neglecting the issue of the conflict and competition between activities of the projects, which may affect the duration of the activities and then affect the completion time of the project portfolio, leads to unrealistic scheduling. This issue points to the significance of the project portfolio selection process based on the scheduling of the each project. In other words, unlike the other techniques for the project portfolio selection, which generally use the multi-criteria decision-making approaches and the decision making criteria are disregarded in the schedule of the projects, the project portfolio selection based on the scheduling of the nominee projects and their interference effects, will be close to the real conditions and more practical.

In this paper, according to the presented assumptions, a linear programming model was presented to consider the project portfolio selection based on the scheduling of the projects as well as the contractor selection possibility for each one of the current activities. Afterward, a sample problem was designed, while the obtained results confirmed the validity of the model.

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