Resource Preference Based Improvement Heuristics for Resource Portfolio Problem[1]

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Abstract

The multi-project problem environment under consideration involves multiple-projects with activities having alternative execution modes, a general resource budget and a resource management policy that does not allow sharing of resources among projects. The multi-project scheduling model for this problem environment is called Resource Portfolio Problem. There are three basic conceptual problems in RPP: (i) determining the general resource capacities from the given general resource budget (general resource capacities determination); (ii) dedication of the general resource capacities to projects (resource dedication) and finally (iii) scheduling of individual projects with the given resource dedications. In this study, different preference based improvement heuristics are proposed for general resource capacities determination and resource dedication conceptual problems. For general resource capacities determination, the current general resource capacity values are changed according to the resource preferences such that the resulting capacity state would be more preferable. Similarly for resource dedication, resource dedication values of projects are changed according to the preferences of projects for resources such that the resulting resource dedication state would be more preferable. These two improvement heuristics separates and couples the conceptual problems. Different preference calculation methods are proposed employing Lagrangian relaxation and linear relaxation of MRCPSP formulation.

Keywords: Multi-project scheduling, resource preference, resource portfolio problem

1. Introduction

Multi-project scheduling is an important way of doing business both in manufacturing and service companies and an important research field in academia. The general approaches for multi-project scheduling problems in literature assume a resource sharing policy which allows a complete access of resources for all projects. This assumption may not hold in certain cases where resources cannot be shared. For example, if projects are distributed geographically and/or characteristics of resources and projects do not allow sharing of resources, resource sharing policy can be infeasible. For these cases a different resource management policy must be defined

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to realistically model the problem environment. The resource management policy where resources cannot be shared among projects is called resource dedication policy in this study. Another general assumption in multi-project scheduling problems in the literature is the given general resource capacities. The general resource capacity values can be another decision level for the multi-project environment such that general resource capacity values are determined from a general resource budget. This integrated multi-project problem environment is called Resource Portfolio Problem (RPP).

The solution methodologies for RPP will need a different approach from multi-project problem solution approaches in literature (see i.e. Kurtulus and Narula (1985); Speranza and Vercellis (1993); Kim and Leachman (1993); Lawrence and Morton (1993); Gonçalves et. al (2008); Mittal and Kanda (2009)). Preference based improvement heuristics are proposed in this study to be used in any solution framework designed for RPP. The basic rationale behind these heuristics is determining resource preferences for the corresponding resource state (general resource capacities or resource dedications) and moving this resource state to a more preferable one.

2. Resource Portfolio Problem

RPP can be summarized as determination of general resource capacities from a general resource budget, dedication of resources to the project according to the determined general resource capacities determined and finally scheduling of individual projects with the resource dedication values. The general problem environment is depicted in Figure 1 below.

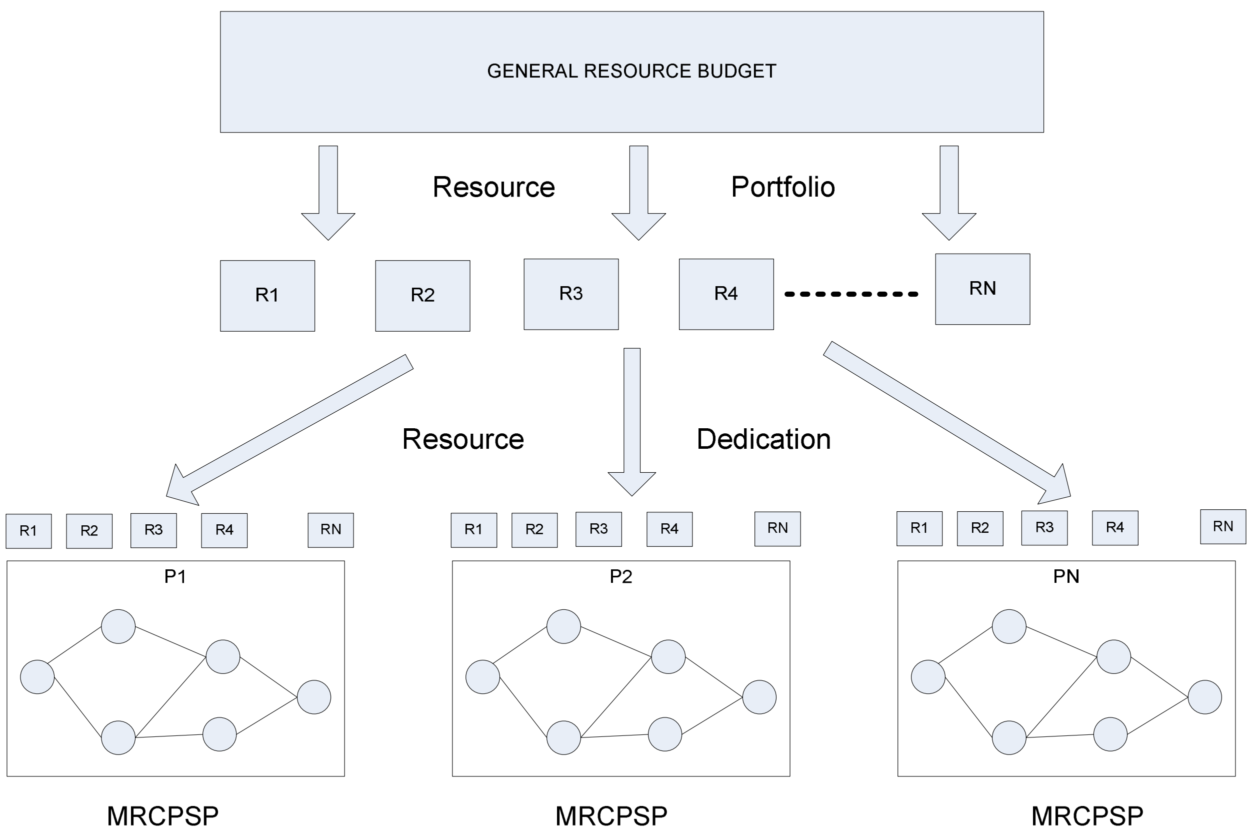

Figure 1. General problem environment for RPP

The proposed mathematical formulation for RPP is given below.

Sets:

V Set of projects, $v= 1, \dots, |V|$
J_v Set of activities, $j = 1, \dots, |N_v|$ of project v
P_v Set of precedence relations of project v
M_{vj} Set of modes of activity j of project v, $m= 1, \dots, |M_{vj}|$
T Set of time periods, $t= 1, \dots, |T|$
K Set of renewable resources, $k= 1, \dots, |K|$
I Set of nonrenewable resources, $i= 1, \dots, |I|$

Parameters:

L_{vj} Latest finish time of activity j of project v
E_{vj} Earliest finish time of activity j of project v
d_{vjm} Duration of activity j of project v, operating on mode m
r_{vjkm} Renewable resource k usage of activity j of project v, operating on mode m
w_{vjim} Nonrenewable resource i usage of activity j of project v, operating on mode m
dd_v Assigned due date for project v
c_v Relative weight of project v
cr_k Unit cost of renewable resource k
cw_i Unit cost of nonrenewable resource i
tb Total resource budget

Decision Variables

x_{vjmt}: Binary decision variable equals to 1, if activity i of project v is finished operating on mode m at time period t; and equals to 0 otherwise.
BR_{vk}: Amount of renewable resource k dedicated to project v
BW_{vi}: Amount of nonrenewable resource i dedicated to project v
TC_v: Weighted tardiness of project v
R_k: Total amount of renewable resource k
W_i: Total amount of nonrenewable resource i

Model RPP

$$min. z_{RDP} = \sum_{v=1}^{V} TC_v \qquad (1)$$

s.t.

$$\sum_{m=1}^{M_{vj}} \sum_{t=E_{vj}}^{L_{vj}} x_{vjmt} = 1 \quad \forall\, v \in V \quad \forall\, j \in J_v \tag{2}$$

$$\sum_{m=1}^{M_{vb}} \sum_{t=E_{vb}}^{L_{vb}} (t - d_{vbm}) x_{vbmt} \geq \sum_{m=1}^{M_{va}} \sum_{t=E_{va}}^{L_{va}} t x_{vamt} \quad \forall\, v \in V\ (a, b) \in P_v \tag{3}$$

$$\sum_{j=1}^{N_v} \sum_{m=1}^{M_{vj}} \sum_{q=t}^{t+d_{vjm}-1} r_{vjkm} x_{vjmq} \leq BR_{vk} \quad \forall\, v \in V, \quad \forall k \in K \ and \ \forall t \in T \tag{4}$$

$$\sum_{j=1}^{N_v} \sum_{m=1}^{M_{vj}} \sum_{t=E_{vj}}^{L_{vj}} w_{vjim} x_{vjmt} \leq BW_{vi} \quad \forall\, v \in V, \forall\, i \in I \tag{5}$$

$$\sum_{v=1}^{V} BR_{vk} \leq R_k \qquad \forall\, k \in K \tag{6}$$

$$\sum_{v=1}^{V} BW_{vi} \leq W_i \qquad \forall\, i \in I \tag{7}$$

$$\sum_{i=1}^{I} cw_i W_i + \sum_{k=1}^{K} cr_k R_k \leq TB \tag{8}$$

$$TC_v \geq c_v \left(\sum_{t=E_{vN}}^{L_{vN}} \sum_{m=1}^{M_{vN}} t x_{vNmt} - dd_v \right) \quad \forall\, v \in V \tag{9}$$

$$BR_{vk} \ and \ R_k \in Z^+, \quad \forall\, v \in V \ and \ \forall\, k \in K \tag{10}$$

$$BW_{vi} \ and \ W_i \in Z^+, \quad \forall\, v \in V \ and \ \forall\, i \in I \tag{11}$$

$$TC_v \in Z^+, \quad \forall v \in V \tag{12}$$

$$x_{vjmt} \in \{0,1\} \qquad \forall v \in V, \forall\, j \in J_v, \forall\, m \in M_j, \forall\, t \in T \tag{13}$$

Objective function (1) is the minimization of the total weighted tardiness of all projects. Constraint set (2) satisfies activity finish for each project. Constraint set (3) ensures predecessor relationships for all activities of all projects. Constraint set (4) determines the maximum level of renewable resource capacity needed for projects. Constraint set (5) calculates the necessary nonrenewable resources for each project. Constraint sets (6) and (7) determine the required renewable and nonrenewable resource capacity according to the dedicated renewable and nonrenewable resources, respectively. Constraint set (8) is the general resource budget constraint such that general resource capacities cannot exceed the budget. Constraint set (9) calculates weighted tardiness values for each project. Constraint sets (10) - (13) define ranges for decision variables.

3. Preference Based Improvement Heuristics for Resource Portfolio Problem

There are three conceptual problems embedded in the general formulation of RPP: general resource capacities, resource dedication and project scheduling. If the first two conceptual problems can be solved sequentially, then the remaining problems are project scheduling problems for each project with the resulting resource dedications as the resource capacities. This approach can be efficient if one can achieve a means of coupling between the solution approaches of conceptual problems.

In this study improvement heuristics for general resource capacities and resource dedication conceptual problems are proposed. The improvement heuristics are based on general resource preferences and preferences of projects for resources, respectively. Each type of preference in a conceptual problem is calculated from a lower level conceptual problem. This achieves coupling between conceptual problems to a degree. The improvement heuristic for resource dedication values is called Combinatorial Auction for Resource Dedication (CA for RD) and employs results of project scheduling problems for preference calculation. The improvement heuristic for general resource capacities is called Combinatorial Auction for Resource Portfolio (CA for RP) and employs the results of CA for RD. Below these two improvement heuristics are explained in detail.

3.1 Combinatorial Auction for Resource Dedication

CA for RD is an improvement heuristic based on the preferences of the projects for the resources. Basically the procedure takes resource dedication values and project schedules then calculates preferences of projects using project schedules and finally moves the current resource dedication state to a more preferable one. The preference of a project for a resource can be defined as the value of a resource according to the current resource state of a project. In other words, one can define preference of a project for a resource as the expectation for the improvement in objective function when one unit of the corresponding resource is gained by any means. The detailed information related with CA for RD is given in Besikci et. al (2011). There are two different methods proposed for preference calculation for CA for RD; one is based on linear relaxation and the other one is based on Lagrangian relaxation.

3.1.1 Linear Relaxation Based Preference Calculation

The linear relaxation based preference calculation employs the linear relaxation MRCPSP formulation (Talbot, 1982). Note that with a current resource dedication state the resource capacities of the projects are given. When the linear relaxation of MRCPSP formulation with these resource capacities is solved, it can give important results related with the current resource state of the project such as the allowable upper bounds (AUB) for the resource constraints. AUB of a constraint show the upper bound value that the current basis will still be optimal; in other words, when the right hand side of the constraint is increased to AUB value or beyond, the current basis will not be optimal anymore. This information can be used for preference calculation such that the preference of a project for a resource can be calculated as the normalized closeness of the resource capacity to the AUB. The preference calculation using linear relaxation of MRCPSP formulation is given below.

For project *v* and renewable resource *k*

$$a_{kv} = \frac{1}{\max_t\{AUB_{vkt} - DR_{kv}\}} \tag{14}$$

$$p_{kv} = \frac{a_{kv}}{\sum_{v=1}^{V} a_{kv}} \tag{15}$$

For project *v* and renewable resource *i*

$$a_{iv} = \frac{1}{AUB_{vi} - DW_{iv}} \tag{16}$$

$$p_{iv} = \frac{a_{iv}}{\sum_{v=1}^{V} a_{iv}} \tag{17}$$

Where for project *v* and renewable resource *k* (nonrenewable resource *i*) DR_{kv} (DW_{iv}) is resource dedication value, a_{kv} (a_{iv}) is closeness of the resource capacity to the AUB and p_{kv} (p_{iv}) is the preference.

3.1.2 Lagrangian Relaxation Based Preference Calculation

Lagrangian relaxation based preference calculation employs the Lagrangian relaxation of the mathematical model of MRCPSP proposed by Talbot (1982) where renewable and nonrenewable resource constraints are relaxed. An additional constraint is added to the formulation which sets the makespan of the schedule as the possible least makespan for the project network. The preferences of the projects for the resources are calculated from the corresponding Lagrangian coefficients after a couple of subgradient optimization steps. The Lagrangian coefficients for the renewable and nonrenewable resource constraints show the infeasibility that is accepted to reach the least possible makespan for the project. These coefficients can be used as the preferences of the projects for the resources. Below preference calculation is given.

$p_{kv} = max_t\{\alpha_{vkt}\}$ Preference calculation for renewable resource i (18)

$p_{iv} = \beta_{vi}$ Preference calculation for renewable resource k (19)

3.1.3 Moving to a More Preferable Solution

With the calculation of preferences (either with linear relaxation based or Lagrangian relaxation based) the remaining task is moving the current resource dedication state to a more preferable resource dedication state. This task is executed by calculating the slack resources of each resource for each project and distributing these slack resources according to the preferences of projects for the resources. The slack resource amount can be easily calculated from the schedules of the projects by subtracting the resource usage from current resource capacity. Then a knapsack model is used to distribute the slack resources according to the preferences where preferences are used as values gained from a resource transfer to a project and objective is maximizing the total value gained under the constraints of slack resource amounts. The new resource dedication state is generated by allocating the slack resources. The overall procedure is depicted in Figure 2 below.

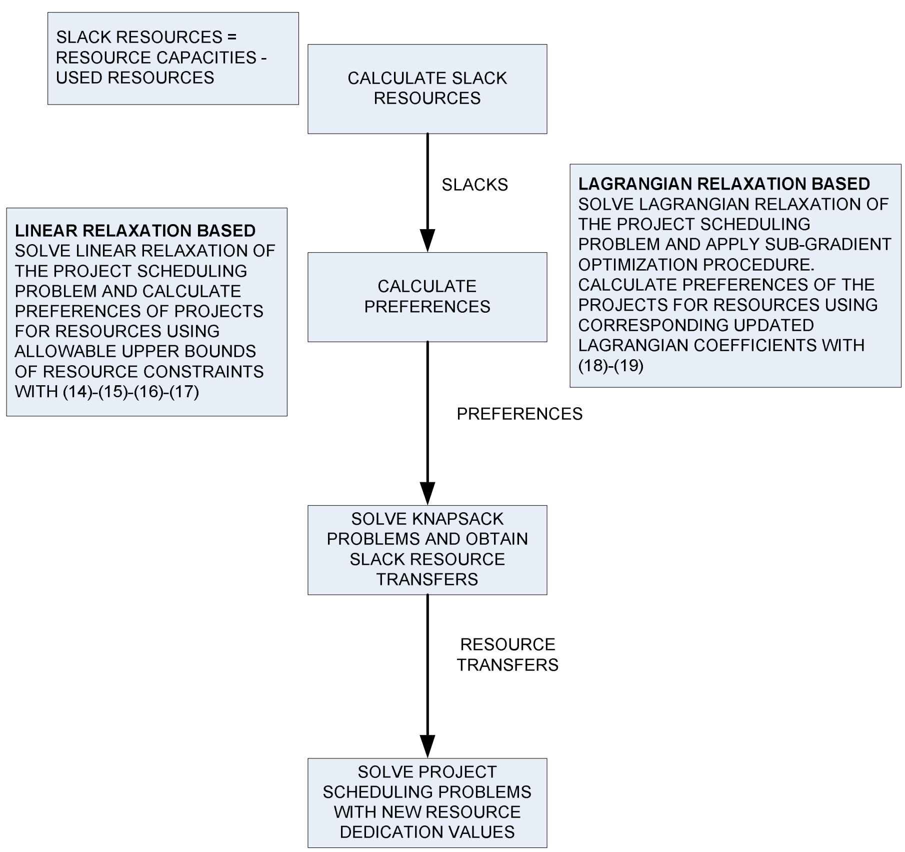

Figure 2. The general procedure for combinatorial auction for resource dedication

3.2 Combinatorial Auction for Resource Portfolio

Similar to CA for RD, CA for RP is an improvement heuristic that is based on preferences for general resource capacities. This procedure basically relies on preferences for general resources, which is used to distribute the slack budget among resources. The budget distribution is determined employing a knapsack model similar to the knapsack model described above. To calculate the preferences of general resources the preference calculation from CA for RD is employed such that the preference of a general resource is the sum of preferences of individual projects for that resource.

$g_k = \sum_{v=1}^{V} p_{vk}$ preference of general renewable resource k (20)

$g_i = \sum_{v=1}^{V} p_{vi}$ preference of general nonrenewable resource i (21)

With this approach the improvement heuristic for resource dedication is coupled with the improvement heuristic for general resource capacities.

3.3 Generating a New Solution with Preference Based Improvement Heuristics

The CA for RD and CA for RPP can be used to generate a new solution for RPP. When a solution of RPP is given the project schedules, resource dedications and general resource capacities will be present with the solution. The CA for RD procedure moves the resource dedication state of a solution to a more preferable one. Similarly CA for RP moves the general resource capacities to a more preferable general resource state. Then resource dedication values are updated according to this new general resource capacity state using preferences of projects for the resources and schedules for individual projects can be generated by solving MRCPSP for each project with the given resource dedication values as resource capacities.

4. Conclusions and Further Research Topics

In this study, RPP under resource dedication resource management policy is presented. RPP is a special case of multi-project scheduling problem which will be very hard to solve since the single project case is proven to be NP Hard. Thus, solution approaches for RPP will include heuristic approaches to be efficient. The contribution of this study is the improvement heuristics that can both separate and couple at the same time the problem into conceptual problems. The proposed heuristics are based on preference concept. For resource dedication, preferences of projects for resources are used to move the current resource dedication state to a more preferable one. Similarly for general resource capacities, preferences of general resources are used to move the general resource capacities to a more preferable state. The coupling of these two different heuristics is achieved by means of integrated preference calculations.

A further research direction is using these improvement heuristics in a solution infrastructure like genetic algorithm and test the efficiency of the proposed improvement heuristics.

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