Different Resource Management Policies in Multi-Mode Resource Constrained Multi-Project Scheduling

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***Abstract*—This study investigates different resource management policies in resource constrained multi-project problem environments. The problem environment under investigation has alternative modes for activities, a set of renewable and nonrenewable resources used by activities and further considerations such as general resource budget. The characterization of the way resources are used by individual projects in the multi-project environment is called resource management policy in this study. The solution approaches in the literature for multi-project problems generally defines the resources as a pool that can be shared by all the projects which in fact creates a general assumption for the resource usage characteristics. This resource management policy is referred as resource sharing policy in this study. Resource sharing policy can be invalid in some certain cases where sharing assumption is not feasible because of some characteristics of resources and/or projects which require different resource management policies for the multi-project environment. According to the characteristics of resources and projects, resource management policies such as resource dedication, relaxed resource dedication and generalized resource management policies can be defined. In this paper, these resource management policies will be defined and their mathematical formulations will be presented and discussed.**

***Index Terms*—Multi-project scheduling, resource management policies, resource portfolio problem.**

I. Introduction

Multi-project management constitutes an important part in of the business in both manufacturing and services and with its complex nature it is an important research topic in the literature. Multi-project scheduling problems consist of several projects that involve finish to start zero time lag and non-preemptive activities with multiple modes. There are both renewable and nonrenewable resources in the environment constraint with a general resource budget. Uncertainty in the multi-project environment is not considered in this paper.

The general approach for multi-project scheduling problems is considering the available resources as a shared pool which is open to all projects. With this approach, the individual projects in the multi-project problem can be combined by adding dummy start and finish activities and the overall multi-project problem can be solved over this big combined network. Solution approaches based on this methodology in fact assumes a specific resource usage characterization or a specific relation between projects and resources in the multi-project environment. This resource related characterization of the multi-project environment is named as resource management policy in this study. The resource management policy for the aforementioned multi-project environment is called resource sharing policy and this type of renewable resources is named as shared resources.

Different multi-project environments can require different resource management policies according to the certain characteristics of the projects and/or resources. For example, the projects that are geographically distributed such that sharing of resources is too costly or infeasible, require another resource management policy to model the multi-project problem environment realistically. This resource management policy is named as resource dedication policy. The renewable resource that cannot be shared among different projects is called dedicated resources. Under this resource management policy, resources cannot be shared among projects and must be dedicated among different projects such that the dedicated resources cannot be shared. Resource dedication policy is discussed in detail in [1].

Another resource management policy can be relaxed resource dedication policy where the resource dedication concept is relaxed in the following way: the renewable resources that are dedicated to a project can be transferred to other projects which have a starting time later than the finish time of the aforementioned project. This relaxed resource dedication policy can be feasible when resource sharing is not allowed during the course of projects but transferring of renewable resources to another project is possible when one of the projects starts after the other one finishes. This type of renewable resources is called relaxed dedicated resources.

The final resource management policy discussed in this study is characterizing resources in the multi-project environment by the most general approach. Three types of renewable resources are defined in this resource management policy, namely shared resources, dedicated resources and relaxed dedicated resources with the corresponding characteristics as described above.

Another assumption of the general approaches for multi-project scheduling is a predetermined or given general resource capacities set. These general resource capacities values can be included as another decision for the multi-project scheduling problem. With this approach, the multi-project environment would have a conceptually higher decision level which can be defined as deciding the general resource capacities according to the project requirements in the multi-project environment. The resource management policies discussed above can be integrated with this general resource capacities decision. This problem is defined as Resource Portfolio Problem (RPP) which can take different forms with different resource management policies.

The remainder of this paper continues with the discussions of shared resources, resource dedication, relaxed resource dedication and generalized resource management policies in RPP.

II. Resource Management Policies

A. Shared Resources Policy

Resource sharing policy considers the general resource capacities as a shared resource pool where all the individual projects have unlimited access. This point of view for the resource management brings specific advantages for the solution of the multi-project problem. The projects in the multi-project environment can be integrated by adding a general start node that all nodes of the projects that do not have a predecessor are assigned as successors of this start node, and a general end node that all nodes that do not have a successor are assigned as predecessors of this end node. Then this combined project network can be solved using different approaches for project scheduling (see i.e [5], [2], [6], [3]). A mathematical formulation for shared resource policy can be obtained from the mathematical model proposed by [7].

B. Resource Dedication Policy

Resource dedication policy in a multi-project environment becomes a requirement when resource cannot be shared among projects because of the characteristics of projects and/or resources. This resource management approach did not take much attention in the project scheduling literature. [4] identifies different multi-project scheduling environments and specifies resource dedication problem as a tactical level problem in the case where projects are characterized as independent from each other. [1] investigates resource dedication policy with given general resource capacities and propose solution approaches for the problem.

The mathematical model for RPP with resource dedication policy is given below.

Sets:

V	set of projects, $v \in V$
J_v	set of activities of project v, $j \in J_v$
P_v	set of all precedence relationships of project *v*
M_{vj}	set of modes for activity *j* of project *v*, $m \in M_{vj}$
K	set of renewable resources, $k \in K$
I	set of nonrenewable resources, $i \in I$
T	set of time periods, $t \in T$

Parameters:

E_{vj}	Earliest finish time of activity *j* of project *v*
L_{vj}	Latest finish time of activity *j* of project *v*
d_{vjm}	Duration of activity *j*, 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:

$$x_{vjmt} = \begin{cases} 1 & \text{if activity } j\text{, operating on mode } m\text{,} \\ & \text{in project } v \text{ is finished at period } t \\ 0 & \text{otherwise} \end{cases}$$

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 cost of project *v*
R_k	=	Total amount of required renewable resource *k*
W_i	=	Total amount of required nonrenewable resource *i*

Mathematical Model RPP-RD

$$min.\ z = \sum_{v \in V} TC_v \tag{1}$$

Subject to

$$\sum_{m \in M_{vj}} \sum_{t=E_{vj}}^{L_{jv}} x_{vjmt} = 1 \ \forall\ j \in N_v \text{ and } \forall\ v \in V \tag{2}$$

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

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

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

$$\sum_{v \in V} BR_{vk} \leq R_k\ \forall\ k \in K \quad (6)$$

$$\sum_{v \in V} BW_{vi} \leq W_i\ \forall\ i \in I \quad (7)$$

$$\sum_{i \in I} cw_i W_i + \sum_{v \in V} cr_k R_k \leq TB \quad (8)$$

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

$$x_{vjmt} \in \{0,1\}\ \forall\ j \in J,\ \forall\ t \in T,\ \forall\ m \in M$$
$$\text{and } \forall\ v \in V \quad (10)$$

$$BR_{vk} \in Z^{+}\ \forall\ v \in V \text{ and } \forall\ k \in K \quad (11)$$

$$BW_{vi} \in Z^{+}\ \forall\ v \in V \text{ and } \forall\ i \in I \quad (12)$$

$$R_k \in Z^{+}\ \forall\ k \in K \quad (13)$$

$$W_i \in Z^{+}\ \forall\ i \in I \quad (14)$$

$$TC_v \in Z^{+}\ \forall\ v \in V \quad (15)$$

The objective function (1) is determined as minimization of the total weighted tardiness cost for all projects. Constraint (2) forces all the activities of all the projects to finish once and only once. Constraint set (3) satisfies the precedence relations between activities. Constraint set (4) and (5) set the renewable and nonrenewable resource dedication values for each project respectively. Constraint (6) and (7) calculates the total renewable and nonrenewable resource requirements respectively. Constraint set (8) limits the total renewable and nonrenewable resource costs with the general resource budget. And finally constraint (9) calculated the weighted tardiness values for each project.

The resource dedication concept is achieved by constraint sets (4) and (6). Constraint set (4) sets BR_{vk} for the corresponding resource and project as the maximum resource usage over all time periods which is the required amount of resources that must be dedicated to the project. Constraint set (6) ensures that the resource dedication values for all projects cannot exceed the general renewable resource capacity. With this approach renewable resources cannot be shared among different projects.

C. Relaxed Resource Dedication Policy

The complete resource dedication policy is not a very general case even though it has its own merits of usage. In some cases, the renewable resources that are dedicated to an already finished project can be used by the projects that are subject to start. This approach would have certain benefits when renewable resources can be transferred in the aforementioned way and the resource budget is limited.

Mathematical model for RPP under relaxed resource dedication policy is given below.

Additional Parameters:

Ω A big number

Additional Decision Variables:

f_v = Release time of project *v*

$S_{vv'k}$ = Amount of renewable resource *k* given to project *v*‘ from project *v*

$$y_{vv'} = \begin{cases} 1 & \text{if project } v' \text{ is released after project } v \text{ is finished} \\ 0 & \text{otherwise} \end{cases}$$

Model RPP-RRD

$$\textit{min. } z = \sum_{v \in V} TC_v \quad (1)$$

Subject to

$$\sum_{j \in N_v} \sum_{m \in M_{vj}} \sum_{q=t}^{t+d_{vjm}-1} r_{vjkm} x_{vjmq} \leq BR_{vk} + \sum_{v' \in V} SR_{v'vk}$$
$$\forall\ k \in K\ \forall\ t \in T\ \forall\ v \in V \quad (14)$$

$$BR_{vk} + \sum_{v' \in V} SR_{v'vk} \geq \sum_{v' \in V} SR_{vv'k}$$
$$\forall\ k \in K \text{ and } \forall\ v \in V \quad (15)$$

$$f_{v'} - f_v - \sum_{t=E_{vN}}^{L_{vN}} \sum_{m \in M_{vN}} t x_{vNmt} \leq \Omega(y_{vv'})$$
$$\forall\ v, v' \in V \quad (16)$$

$$f_v + \sum_{t=E_{vN}}^{L_{vN}} \sum_{m \in M_{vN}} t x_{vNmt} - f_{v'} \leq \Omega(1 - y_{vv'})$$
$$\forall\ v, v' \in V \quad (17)$$

$$SR_{vv'k} \leq \Omega(y_{vv'})$$
$$\forall\ v, v' \in V \text{ and } \forall\ k \in K \quad (18)$$

$$TC_v \geq C_v\left(f_v + \sum_{t=E_{vN}}^{L_{vN}} \sum_{m \in M_{vN}} x_{vNmt} - dd_v\right)$$
$$\forall\ v \in V \quad (19)$$

$$y_{vv'} \in \{0,1\}\ \forall\ v \in V \quad (20)$$

$$f_v \in Z^{+}\ \forall\ v, v' \in V \quad (21)$$

$$SR_{vv'k} \in Z^{+}\ \forall\ v, v' \in V \quad (22)$$

(2), (3), (5), (6), (7), (8), (10), (11), (12), (13)

The resource sharing policy that allows resource transfer between projects added the following changes to the mathematical model. First of all, renewable resource usage constraints for each project (14) have a resource usage capacity as the sum of dedicated resource value and the total transferred resource to the project from the other projects. In constraint (15) the total resource that can be transferred by a project is limited with the total resources dedicated to this project and the total resource it gained from transfers. Constraint (16) and (17) sets decision variable $y_{vv'}$ to 1 if project *v* is finished before project *v'* is released and 0 otherwise. Thus the $SR_{vv'k}$ values will only have positive values if project *v* is finished before project *v'* is released with constraint (18), it will be set to 0 otherwise. The weighted tardiness for each project is calculated according to the release times of project in constraint (19).

D. Generalized Resource Management Policy

The generalized resource management policy incorporates all the characteristics of the aforementioned resource management policies by identifying three different types of renewable resources: shared, dedicated and relaxed dedicated. The mathematical formulation for this resource management policy will have three different types of renewable resource usage constraints for different renewable resource types. For the corresponding renewable resource types different renewable resource usage and general renewable resource capacity constraints can be used for the mathematical formulation of the generalized resource management policy.

III. Conclusion

To realistically model different multi-project environments different resource management policies should be taken into account. In this study, different resource management policies are tried to be identified, namely shared resources policy, resource dedication policy, relaxed resource dedication policy and the generalization of these three resource management policies. With these different resource management policies, multi-project scheduling problem environments can cover very important project and resource characteristics that must be taken into account. In addition to this, mathematical formulations for resource dedication and relaxed resource dedication policies are given and discussed in a multi-project scheduling environment with a general resource budget. Solution methodologies for these different resource management policies will have different approaches because of the characteristics that resource management policies incorporated to the problem environment.

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