Resource-Constrained Multi-Project Scheduling with Resource Moving Time for Construction Projects in Vietnam

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Abstract
In the construction project scheduling process, the existing heuristic methods assumed the resource moving time between activities/projects to be negligible. When multiple projects are deployed in different places and far from each other, this assumption has many shortcomings for properly modeling the real-world constraints. Specially with respect to the Vietnam’s situation, with a transportation system still in a backward and low technical standards. Allocating a resource from one project to another is greatly constrained, and it always involves extra costs and time loss. The multi-project duration will be significantly impacted by the resource moving time. This paper proposes a new algorithm named Resource-Constrained Multi-Project Scheduling with Resource Moving Time (RCMPS-RMT) that aims to solve the problem of minimizing construction multi-project duration with the moving time and limited available conditions of renewable resources (labor, machines and equipment). The essence of RCMPS-RMT is based on the improvement of the existing heuristic method–priority rules. In this paper, the computational experiments are also presented to demonstrate that the resource moving time must be included in multi-project scheduling process.

Keywords
Resource Moving Time, Resource Constraints, Multi-Project Scheduling

1. Introduction
Construction contractors usually deploy simultaneously multiple projects under limited resources (e.g. labors and machines) condition. To perform multiple projects, a construction contractor can access two sources of resources: internal resources, which are under the contractor ownership and external resources which can be obtained from the open market. The common objective is to create the most efficient schedule possible to maximize the usage of the contractor’s internal resources and just use the market to balance the contractor’s operation (Shi and Halpin, 2003). Because the project duration is one of the main factors of competitiveness on the difficult construction market, the most important part of a construction project scheduling is the assignment of resources and the harmonization of their work to minimize the project duration. These problems can reputedly be solved as the well-known problem in the operation research: Resource-Constrained Multi-Project Scheduling (RCMPS) (Kurtulus and Davis, 1982).

The scheduling of multiple projects under resource constraints demands extreme difficult computation. In addition to the precedence constraints (technical relationship) between activities within individual projects, there are precedence constraints of the activities among multiple projects due to the sharing of the scarce resources sharing. Therefore, the RCMPS is a hard nonlinear programming problem. There are
two fundamental approaches to the resource-constrained project scheduling process: optimization models and heuristics. Optimization approaches seek the best solutions; however, they are far more limited in resolving the large and confusing projects and often require unreasonable computation time (Sprecher et al. 1998). Hence, heuristics are often applied to generate near-optimal schedules for large and highly constrained projects.

In traditional heuristic methods, most researches have mainly assumed that the resource moving time (RMT) from one activity/project to another is negligible (Hans et al. 2007). When multiple projects are deployed in different places and far from each other, this assumption has many shortcomings for properly modeling the real-world constraints. Specifically in the Vietnam situation with an inconvenient transportation system, the travel speeds are low and there are unforeseen delays due to traffic density and quality limitations. Allocating a resource from one project to another is greatly constrained, and it always involves extra costs and time losses. Hence, the resource moving time noticeably influences the multi-project duration in the multi-project scheduling processes.

The main drawback of existing scheduling methods is the fact that they fail to solve complex practical problems effectively and do not allow for real world conditions and construction constraints. This paper presents a new algorithm named Resource-Constrained Multi-Project Scheduling with Resource Moving Time (RCMPS-RMT) that aims to solve the problem of minimizing construction multi-project duration with the moving time and limited available conditions of renewable resources (labor, machines and equipment). The essence of RCMPS-RMT is based on the improvement of the existing heuristic method—priority rules.

2. Improvement of the Heuristic-Priority Rules method

2.1. Heuristic-priority rules method

Heuristics based on priority rule have been one of the most important solution techniques for resource-constrained multi-project scheduling with renewable resources. Since they are not only easy to understand and to implement but also fast in terms of computational effort, and obtain acceptable results even for large sized projects. Furthermore they are often contained in commercial software packages for project scheduling. The heuristic-priority rules method is made up of two components, a schedule generation scheme and a priority rule. In the scheduling scheme, two different schemes can be distinguished: serial scheme and parallel scheme (Kolisch 1996).

2.1.1. Schedule generation schemes

*The serial schedule generation* is an activity oriented scheme and consists of J stages, where J is the number of activities to be scheduled. In each stage one activity is selected and scheduled at the earliest precedence and resource feasible completion time. There are two disjoint activity sets associated with each stage: the set of activities already scheduled and the set of activities that are eligible for scheduling, that is, decision activities all of whose predecessors are in the set of activities already scheduled. In each stage, an activity is selected from the set of decision activities in the order established by a priority rule and scheduled as soon as possible, taking into account the precedence relationships of the activities and the availability of the resources. The activity selected is removed from the decision set and added to the scheduled set. Additionally, the decision set is updated with the immediate successors of the activity just scheduled whose predecessors have all been scheduled. The serial scheme finishes when all activities are in the scheduled set.

*The parallel schedule generation scheme* is a time oriented scheme and consists of N stages. In each stage a set of activities (which might be empty) is scheduled. Each stage n is associated with a schedule time $t_n$ where $t_n > t_{n-1}$, and three disjoint sets of activities: decision, complete and active sets. Due to the
schedule time \( t_n \), the set of scheduled activities is divided into subsets: scheduled activities which are completed up to the schedule time are in the complete set and those which are not completed are in the active set. Additionally, the decision set that in contrast with the serial method contains all yet unscheduled activities which are available for scheduling with respect to precedence and resource constraints. The partial schedule associated with iteration is composed of the complete and the in-process sets. The schedule time in a stage is the earliest finish time of the activities scheduled during all earlier stages. Each stage is made up of two steps:

Step 1: The new schedule time is determined and activities with a finish time equal to the new schedule time are removed from the in-process set and put into the complete set. This may place a number of activities into the eligible set.

Step 2: One activity from the eligible set is selected with a priority rule and scheduled to start at the current schedule time taking into account the availability of the resources. Afterwards, this activity is removed from the eligible set and put into the in-process set. Step 2 is repeated until the eligible set is empty, i.e., activities were scheduled or are no longer available for scheduling with respect to resource constraints. The parallel scheme finishes when all activities are in the complete or in-process sets.

Table 1: Most widely used priority rules in heuristic methods

<table>
<thead>
<tr>
<th>Priority Rule (Primary)</th>
<th>Commentary</th>
<th>Formula</th>
<th>Tie-breaker (Secondary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOF</td>
<td>Shortest Operation First</td>
<td>( \text{Mind}<em>{ij} ), where ( d</em>{ij} ) is the duration of the ( i )th activity in ( j )th project</td>
<td>FCFS</td>
</tr>
<tr>
<td>MINSLK</td>
<td>Minimum Slack First</td>
<td>( \text{MinSLK}<em>{ij} ), where ( \text{SLK}</em>{ij} = \text{LST}<em>{ij} - \text{Max(EST}</em>{ij}) ) and terms are defined in standard CPM</td>
<td>FCFS</td>
</tr>
<tr>
<td>SASP</td>
<td>Shortest Activity Shortest Project</td>
<td>( \text{MinF}<em>{ij} ), where ( F</em>{ij} = \text{CP}<em>{i} + d</em>{ij} ) where ( \text{CP}_{i} ) is the duration of the critical path of the project ( j ).</td>
<td>FCFS</td>
</tr>
<tr>
<td>LALP</td>
<td>Longest Activity Longest Project</td>
<td>( \text{MaxF}<em>{ij} ), where ( F</em>{ij} ) is determined in SASP</td>
<td>GRES</td>
</tr>
<tr>
<td>MOF</td>
<td>Maximum Operation First</td>
<td>( \text{Maxd}<em>{ij} ), ( d</em>{ij} ) is defined in SOF</td>
<td>GRES</td>
</tr>
<tr>
<td>MAXSLK</td>
<td>Maximum Slack First</td>
<td>( \text{MaxSLK}<em>{ij} ), ( \text{SLK}</em>{ij} ) is defined in MINSLK</td>
<td>GRES</td>
</tr>
<tr>
<td>MINTWK</td>
<td>Minimum Total Work Content</td>
<td>( \text{MinG}_{ij} )</td>
<td>FCFS</td>
</tr>
<tr>
<td>MAXTWK</td>
<td>Maximum Total Work Content</td>
<td>( \text{MaxG}<em>{ij} ), ( G</em>{ij} ) is defined in MINTWK</td>
<td>FCFS</td>
</tr>
<tr>
<td>FCFS</td>
<td>First Come First Served</td>
<td>( \text{MinES}<em>{ij} ), where ( \text{ES}</em>{ij} ) is early start time of the ( i )th activity from the ( j )th project.</td>
<td>Random</td>
</tr>
</tbody>
</table>

\[
G_{ij} = \sum_{k=1}^{K} d_{ij}r_{ijk} + \sum_{k=1}^{K} r_{ijk} ; K \text{ is the number of renewable resource types } k = 1, \ldots, K; \ d_{ij} \text{ is the duration of the } i \text{th activity in the } j \text{th project}; \ r_{ijk} \text{ is the resource } k \text{ required by activity } i \text{ of project } j; \ AS_i \text{ is the set of the activities already scheduled of project } i.
\]

2.1.2. Priority rules

Priority rule sorts the set of decision activities in the scheduling process. The sort of activities obtained with priority rules depends on the approach used and often obtains different schedules. Priority rules can be based on the basis of the information: activity-based, project-based, and resource-based. Activity-based rules assign high priority to an activity based on a parameter or characteristic of the activity itself, for instance activity’s duration or float. Project-based rules assign priorities to activities based on the project they belong to, or characteristics of that project, such as the shortest activity from the shortest
project (SASP) rule. Resource-based rules assign priority in terms of resource demands in each project or activity. The priority is usually assigned to activity’s resource demand which lead to potential bottleneck activities. Table 1 present the most widely used multi-project heuristic rules available in the literature. The primary priority sort (priority rule) pertains to all activities; the secondary priority (tie-breaker) sort pertains to activities where two activities have the same primary sort.

2.2. Improvement of the heuristic-priority rules method

2.2.1 Resource moving time
In the resource-constrained project scheduling process, if there are enough required resources to schedule an activity, the activity is scheduled at its earliest possible time according to its technical relations with precedence activities. However, if there are not enough required resources for scheduling, this activity should be delayed until it acquires enough available resources. After it is delayed day by day, all or some amount of resources that caused the delay of the activity should have been released from some other activities’ completion. At this time, the required resources are available throughout its whole duration. Like this, one or more resource links are created between scheduling activity and completed activities and the commenced date of the scheduling activity will be the delay time plus the transfer time to move the resource from the finished activity to the scheduling activity. Generally, there are three models of the resource transfer among activities: a) the resources are transferred from many activities to one activity; b) the resources are transferred from one activity to many activities; c) the resources are transferred from one activity to one activity as presented in Figure 1. The improvement of the heuristic-priority rules method to take the resource moving time into the scheduling process is presented in Figure 2 (the rectangle box with dot line).

Figure 1: Resource Transfer Models

In the multi-project scheduling process, at a point of time there may be many resource types which will be released from different finished activities. Thus, there is a normal logicality that the scheduling activities will first take the resources from the nearest activities. Then, there are not enough required resources; it will continuously consider the resources from further activities. To take this logical analysis to the scheduling process, this paper proposes a new priority rule: Minimum Resource Moving Time (MinRMT), which ranks the finished activities follow an order to support the released resources to the scheduling activity. This priority rule is referred to the well-known algorithm Dijkstra’s algorithm (Dijkstra 1959).

2.2.2. Resource flow network
In the contractor’s construction operation, the resource allocation plan (resource flow network) is one of the basements of the internal management system. To achieve effective performance and consistent working cooperation in the project execution, the resource flow network (RFN) will be announced to every responsible agent such as site managers, workers department managers and machinery pool managers etc. Therefore a RFN is necessary to identify and to depict the amount of resources that are transported from the end of one activity to the beginning of another activity, from this project to the other projects.
The resource flow network is generated based on the resource links that are created among activities in the multi-project scheduling process (see Fig.2 and Fig. 5). This network therefore will be consistently associated with the multi-project scheduling and the managers can easily assess the effects of the resource contention on various projects and see the interdependencies among projects and the causal relationships influencing various projects. Additionally, this network is also extremely useful in the case that some special activities in emergency situations need to immediately concentrate the resources to accomplish before the required date. Based on the resource information from the resource flow network, the project managers can make the resolving decisions more quickly. Besides, in practice the construction contractor has also to face with a continuing demand to execute new bided projects. Therefore, several times during the course of a typical business day, the central manager may need to re-control the resource availability to bid new projects. This problem also needs the information from the resource flow network.

a) The Improved Serial heuristic algorithm

b) The Improved Parallel heuristic algorithm

Figure 2: Improvement of the Generation Scheduling Scheme

2.3. Numerical illustration

To demonstrate the proposed scheduling procedure, an example network consisting of two small projects with a total of seven actual activities (activity that contains duration and required resources) is used to depict the RCMPS-RMT processes. Figure 3 presents the detailed data of the example through an activity on node network. The time to move the resources from project 1 to project 2 are assumed to be one day. The maximum available resource amount is presented in Table 2. The available resource amounts are enough to schedule individual projects according to the unconstrained resource conditions. The resource conflicts among projects occur when the individual projects are scheduled simultaneously as depicted
in Figure 4. As we can see in the Figure 4(a) the overload of resources RA, RB and RC concentrate on the beginning phase of the two-project network. To solve these problems, RCMPS-RMT is applied to minimize project make-spans under the resource constrained and resource transfer time.

Table 2. The available resource amount

<table>
<thead>
<tr>
<th>Resource Name</th>
<th>RA</th>
<th>RB</th>
<th>RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

![Figure 3: Example of two-project network (Activity-On-Node)](image)

Table 3: Resource-Constrained Multi-Project scheduling process

<table>
<thead>
<tr>
<th>Scheduling time step</th>
<th>Activity</th>
<th>R-P</th>
<th>D</th>
<th>Start</th>
<th>Finish</th>
<th>RA</th>
<th>RB</th>
<th>RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = 0</td>
<td>P1-2</td>
<td>-</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>P2-1</td>
<td>-</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>T = 4</td>
<td>P1-1</td>
<td>P1-2</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>T = 5</td>
<td>P2-3</td>
<td>P1-2; P2-1</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>T = 9</td>
<td>P1-3</td>
<td>P1-1</td>
<td>5</td>
<td>9</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>T = 11</td>
<td>P2-2</td>
<td>P1-1; P2-3</td>
<td>4</td>
<td>12</td>
<td>16</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>T = 14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T = 16</td>
<td>P2-4</td>
<td>P2-2</td>
<td>4</td>
<td>16</td>
<td>20</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: The scheduling result according to RCMPS-RMT

<table>
<thead>
<tr>
<th>P</th>
<th>Activity</th>
<th>D</th>
<th>S</th>
<th>F</th>
<th>A-P</th>
<th>R-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>1-1</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>-</td>
<td>P1-2</td>
</tr>
<tr>
<td></td>
<td>1-2</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>4</td>
<td>P1-1; P1-2</td>
</tr>
<tr>
<td>P2</td>
<td>2-1</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>-</td>
<td>P1-1; P2-1</td>
</tr>
<tr>
<td></td>
<td>2-2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>P2-1</td>
<td>P1-1; P2-1</td>
</tr>
</tbody>
</table>
Whereas: A-P: Activity Predecessor; R-P: Resource Predecessor; D: Activity Duration.

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2-4</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-1; P2-2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>P2-2; P2-3</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

a) The required resources confliction

b) The resources utilization profiles after scheduling

Figure 4: Resource conflict when scheduling simultaneously

Figure 5: Resource Flow Network

4. Computational Experiments

The main purposes of this section are to evaluate the impact of resource moving time when it is included into the multi-project scheduling process and the effect of the new secondary priority rule Minimum Resources Moving Time (MinRMT). Besides, the improved heuristic-priority rules method is also verified. This paper considers three cases as follows: (1) considering the multi-project scheduling without
the resource moving time (RMT). (2) Considering the multi-project scheduling with the RMT, but not applying the priority rules-MinRMT. (3) Considering the multi-project scheduling with the RMT and applying the MinRMT.

4.1. Multi-project sample

In the literature, the author could not find any standard example for the resource-constrained multi-project scheduling problem. Hence, this paper refers to single project examples in PSPLIB (Kolish and Sprecher 1996), and then generating the multi-project examples based on the following rules:
* This paper constructs four multi-project scheduling examples corresponding with four types: J30 set, J60 set, J90 set and J120 set in PSPLIB. Each multi-project example contains 5 projects that are chosen at random of different single-project in each set type.

* Activities are subject to finish-start precedence constraints with zero minimum time lags. Each activity has a single execution mode with fixed integer duration as the examples in the PSPLIB. Activities are only scheduled when all required resource types are available.

* Resource capacity is calculated by adding the resource capacities of each single-project in the PSPLIB.

4.2. Resource Moving Time

In order to obtain resource moving time among projects that closely cements with real construction projects in Vietnam. A survey was designed that carried out in one of the largest State Owned Construction Enterprise (ThangLong Construction Corp.) of Vietnam. The investigation papers were sent to the project managers as well as the schedulers of all companies in this corporation who have from 5 to over 20 experience years in construction industry. 40 investigation papers were sent out with 40 papers returned the response rate is 100%. According to the investigated results, the resource moving time among projects often falls into a range between one day and five days. Therefore, this paper applies the resource moving time among projects which are determined as random in a range of 1 day to 5 days.

4.3. Implementation method

According to the researches of Lova and Tormos (2001) and Kolish (1996), the parallel schedule generation scheme (P-SGS) often outperforms compared to the serial schedule generation scheme. Therefore, to safe the calculation time, this paper only applies the P-SGS to generate the feasible multi-project scheduling. Besides, to clarify the role of resource moving time in the scheduling process that is based on the priority rules-heuristic methods; this paper has investigated all nine most widely used priority rules as presented in Table 1. In order to verify the achieved results, this paper will use two criteria measurements corresponding to the single project approach and multi-project approach as presented in Lova and Tormos (2001):

The Mean-Project-Delay (Eq. 2) will be applied to estimate the increase of individual project durations caused by the resource moving time:

\[
\text{Mean-Project-Delay} = \frac{\sum_{i=1}^{M} D_{i}}{M}
\]

Whereas: M is the number of projects in the multi-project system. \(D_{i}\) is the different time between the resource-constrained project duration with and without resource moving time.
The Multi-Project-Delay (Eq. 3) will be applied to measure the increase of total multi-project duration results by the resource moving time:

\[
\text{Multi-Project-Delay} = \frac{\max (\text{DI}_i) - \max (\text{DR}_i)}{\max (\text{DR}_i)}
\]  

(3)

Whereas: \( \text{DR}_i \) is the individual project duration under resource constraint condition as traditional calculation.

For simple calculation, this paper only focuses on the time that is used to move resources from a project to other projects. The time that is used to transfer the resources from the global resource pool (head office) to individual projects and within a project are assumed to take no time. The proposed heuristic-priority rules method has been coded using the Microsoft C# programming language and Microsoft SQL Server 2005.

4.4. Results of the computational experience

In order to confirm the correct performance of the proposed RCMPS-RMT process, the authors first applied it to schedule all four multi-project samples with unconstrained resource conditions. The achieved results are identical with the original project due dates that are supported in the PSPLIB. That is to say the proposed RCMPS-RMT is confident to scheduling the projects including resources moving time.

With Mean-Project-Delay criterion, the average project delays caused by the resource moving time (RMT) correspond to four multi-project samples (J120, J90, J60 and J30) are presented in Figure 12. All the heuristic-priority rules generated significant different results between the multi-project scheduling with and without RMT. The resource moving time has contributed to 29.3\% average delay increase of individual projects.

![Figure 12. Resource moving time in Mean-project delays](image-url)
With *Multi-Project-Delay criterion*, the achieved results are similar. The multi-project duration significantly increased to 26.60% average when the RMT is included into the multi-project scheduling process. The additional average multi-project delays when considering the RMT are presented in Figure 13. These initial achieved results prove that the resource moving time among projects can not be ignored when multiple projects are deployed far from each others.

Figure 14 presents the comparison of the multi-project scheduling between the cases which apply and do not apply the proposed secondary priority rule MinRMT. In the case that the MinRMT is applied, the total project delays are reduced to 7.34% average compared with the cases without MinRMT. This result shows the effective performance of MinRMT in the project scheduling process.

5. Conclusion and Further Research

This paper incorporated the resource moving time among projects to the resource-constrained multi-project scheduling, which has not been considered in previous research. Due to the intractability of the RCMPS, heuristic rules are the only viable solution procedures for scheduling large scale construction projects. This paper has proposed a new algorithm - RCMPS-RMT - which based on the improvement of the heuristic-priority rules method to optimize multi-project duration under resource constraints and resource moving time conditions. A computational experiment showed that the resource moving time among projects can not be ignored in the multi-project scheduling process. Though the characteristics of the multi-project environments in this research are mainly applied in the construction industry in Vietnam, the developed approach is applicable to other countries, especially to the developing countries which have a backward transport infrastructure.

Nevertheless, the assumption of heuristic methods is based on a static determined execution environment. Construction projects are often deployed in an open execution environment, during the execution phase of construction projects, the initial scheduling always has to be adapted to the reality state due to the dynamic and incomplete data. Hence, project activities must be subject to considerable uncertainty, which may lead to numerous schedule disruptions. Further research should focus on finding the solution that to make the stability for the multi-project scheduling as well as the resource flow network against the uncertainty.

6. References


