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MULTI-SITE CONSTRUCTION PROJECT SCHEDULING CONSIDERING RESOURCE MOVING TIME IN DEVELOPING COUNTRIES

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Summary

Under the booming construction demands in developing countries, particularly in Vietnam situation, construction contractors often perform multiple concurrent projects in different places. In construction project scheduling processes, the existing scheduling methods often assume 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 modelling the real-world constraints. Especially, with respect to developing countries such as the Vietnam which contains transportation systems that are still in backward and low technical standards.

This paper proposes a new algorithm named Multi-Site Construction Project Scheduling - MCOPS. The objective of this algorithm is to solve the problem of minimising multi-site construction project duration under limited available conditions of renewable resources (labour, machines and equipment) combining with the moving time of required resource among activities/projects. Additionally, in order to mitigate the impact of resource moving time into the multi-site project duration, this paper proposed a new priority rule: Minimum Resource Moving Time (MinRMT). The MinRMT is applied to rank the finished activities according to a priority order, to support the released resources to the scheduling activities.

In order to investigate the impact of the resource moving time among activities during the scheduling process, computational experimentation was implemented. The results of the MCOPS-based computational experiments showed that, the resource moving time among projects has significantly impacted the multi-site project durations and this amount of time can not be ignored in the multi-site project scheduling process. Besides, the efficient application of the MinRMT is also demonstrated through the achieved results of the computational experiment in this paper. Though the efforts in this paper are based on the Vietnamese construction conditions, the proposed method can be usefully applied in other developing countries which have similar construction conditions.

1 INTRODUCTION

Under the booming construction demand in developing countries, particularly in Vietnam situation, construction contractors often perform multiple concurrent projects in different places which relate to various owners. Therefore, the scheduling and controlling projects for efficient utilisation of labour, material, equipment and capital are primary tasks of the contractor's managers. One of the most challenges facing construction managers is efficiently scheduling the multiple projects, across a wide geographical area and under the company's limited resources such that subject to overall business strategic direction of the company. This basically leads to the concept of multi-site construction project scheduling. Essentially, this problem can be referred to the well-known problem in the general project management: resource-constrained multi-project scheduling problem [1]. The common objective of resource-constrained multi-project scheduling process can be: minimise multi-project duration, minimise multi-project cost and minimise the multi-project delay.

However, the remarkable different trait between resource constrained multi-site construction project scheduling problem and traditional resource constrained multi-project scheduling problem is that: in a multi-site project environment, projects are often located at various different geographical places, which will be incurred by resource transporting time among projects.

There are two fundamental approaches to the resource-constrained multi-project scheduling process: mathematical programming and heuristics. Mathematical programming approaches seek the best single solution; however, they are far more limited in resolving the large and confusing projects and often require unreasonable computation time [2]. 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 [3]. When multiple projects are deployed in different places and far from each other, this assumption has many shortcomings for properly modelling 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 to the multi-site project durations.

This paper presents a new algorithm named Multi-site COnstruction Project Scheduling - MCOPS that aims to solve the problem of minimizing construction multi-project duration with the moving time and limited available conditions of renewable resources (labour, machines and equipment).

The new MCOPS algorithm is essentially improved from heuristic – priority rules method by three additional features. Firstly, a new priority Minimum Resource Moving Time (MinRMT) is developed, which provide for scheduling activities the power that always receiving the required resources from nearest resource-held points during the scheduling process. Secondly, the parallel schedule generation scheme is revised by considering the resource moving time into the accounting of start and finish time of scheduling activities and creating the resource links to depict the resources transportation from one activity to another activity. Thirdly, in order to describe the resource links among activities in a graphical views as well as detail data views which will be applied for resource management objectives, this paper establishes a Resource Moving Network.

2 FORMULATION OF MULTI-SITE CONSTRUCTION PROJECT SCHEDULING

The *multi-site construction project scheduling problem* is considered as the simultaneous scheduling of two or more projects that are located in different places and demand the resources in a limited resource pool. In general form, the multi-site construction project scheduling problem is defined as follows:

Given:

- A set of construction projects: $\mathbf{p} = \{1, \ldots, P\}$, whereas each project $\mathbf{P} \in \mathbf{p}$ is composed of a set of activities: $\mathbf{a} = \{0, \ldots, A_p\}$ with duration $\mathbf{d}_{ap}$, that must to be executed. The activities 0_p and A_p are dummy activities which just represent for "*project start*" and "*project finish*" of project P, respectively.
- A set of transport time among projects: $\mathbf{t} = \{T_{ij}\}$, whereas $\mathbf{T}_{ij}$ is the transport time from project $\mathbf{P}_i$ to $\mathbf{P}_j$.
- A set of limited amount of **R** resource types: $\mathbf{r} = \{1,\ldots, R\}$, whereas, to be processed each activity $\mathbf{A}_p \in \mathbf{a}$ requires $\mathbf{k}_{a,r}$ units of resource $\mathbf{R} \in \mathbf{r}$ during period of its non pre-emptive duration $\mathbf{d}_{ap}$. With respect to activities $\mathbf{0}_p$ and $\mathbf{A}_p$, the duration $\mathbf{d}_{0r}$ and $\mathbf{d}_{Ar}$ will be zero as well as the resource requirements, $\mathbf{k}_{0,r}$ and $\mathbf{k}_{A,r}$ will be also zero for all $\mathbf{R} \in \mathbf{r}$.
- Let $\mathbf{F}_{ap}$ be the finish time of activity **A** in project **P**, such that feasible schedules can be represented by a vector of finish times $\{F_{0p},\ldots, F_{Ap}\}$. Let **N**(t) be the set of activities in work at time instance **t**. Let IP_{ap} be the set of all immediate predecessors of activity **A** in project **P**.

Objective:

- Optimise: Performance measure ($\forall\, \mathbf{A}_p \in \mathbf{a}, \mathbf{P} \in \mathbf{p}$: find $\{F_{0p},\ldots, F_{Ap}\}$ (1)

Subject to

- $\forall\, \mathbf{A}_p \in \mathbf{a}, \mathbf{P} \in \mathbf{p}, \mathbf{a}^* \in \mathbf{IP}_{ap} : \mathbf{F}_{a^*p} \le \mathbf{F}_{ap} - (\mathbf{d}_{ap} + \mathbf{T}_{a^*,a})$ (2)
- $\forall\, \mathbf{a}, \mathbf{p} \in \mathbf{N}(t)$: $\sum_{a,p \in N(t)} k_{ap,r} \le R_r$ whereas $\mathbf{R} \in \mathbf{r}, \mathbf{t} \ge 0$ (3)
- $\forall\, \mathbf{A}_p \in \mathbf{a}, \mathbf{P} \in \mathbf{p}: \mathbf{F}_{ap} \ge 0$ (4)

The objective function (1) is used to optimise a pre-specified performance measure (such as minimise multi-construction project duration or minimise the multi-site construction project costs). Constraints (2) impose the technical precedence relations between activities. Note that the $\mathbf{T}_{a^*,a}$ is used to denote the minimum resource moving time of resource **R** from resource predecessor- activity **a*** to scheduling activity **a**. Constraints (3) limit the resource demand imposed by the activities being scheduled at scheduling time **t** to the resource available capacity. Finally, constraints (4) enforce the finish time of all activities are determined.

3 A NEW PRIORITY RULE- MinRMT

The basic idea behind the heuristic– priority rules method is that, based on one or more selected priority rules, a prior scheduling order of activities is created and then, a schedule generation scheme - serial or parallel schemes will be applying to schedule and allocate resources to prior activities. In a resource constraint condition, when the resource available pool can not sufficiently supply the required resources to the current scheduling activities, the schedule scheme will take the resources which might be released from the finished activities in different projects, in order to enable the current scheduling activities. Like this, during the scheduling process there are three models of the resource transfers 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].

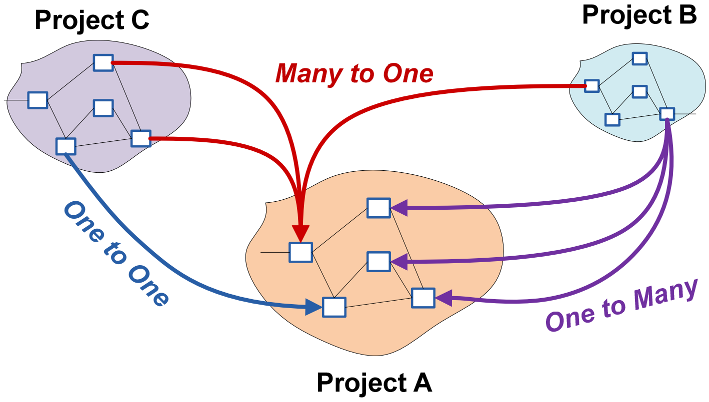


FIG. 1: Resource Transfer Models

Based on these resource transfer models, in the multi-site construction project scheduling process, at a point of scheduling time there will be numerous resources which will be released from different finished activities in different places. Thus, there is a normal logicality that the current scheduling activities will first take the resources from the nearest activities in order to minimise the resource moving time and eventually minimise the multi-site project duration. In the case the nearest activity can not support enough the required resources; scheduling process will consider the resources from further activities. To automatically take this logical analysis into the scheduling process, a new priority rule: Minimum Resource Moving Time (MinRMT) is proposed in order to rank the finished activities follows a prior supplying order of the released resources for the scheduling activity such that the resources will be transferred with a minimal moving time.

As shown in [Figure 2], the new priority rule – Minimum Resource Moving Time - MinRMT is processed as follows: At each scheduling step during the multi-site projects scheduling process, there is a set **A**[v] of ***v*** finished activities which contain the resources that might be transferred to the required activity **RA**. The central resource pool is also considered as a finished activity. Corresponding with each finished activity set **A**[v] is the set of resource transfer time **T**[v], which represents for transport times from each activity in **A**[v] to required activity **RA**. MinRMT firstly finds an activity that owns the minimal transport time **T**[v] and moves this activity - **A**[v] to a ranked set **P**[v]. Thereafter, a computational loop is processed until all of the remained finished activities in the set **A**[v] to be ranked and moved to ranked set **P**[v]. As a result, at each scheduling step, the start time of required activity **RA**, if it is supplied enough required resources to schedule, will be equal the finish time of finished activity **A**[v] adding with the transport time **T**[v].

```
Input
Integer    v        (v is the number of finished activities. Note that the
                    resource pool is also considered as activity).
Array      A[v]     (a set of finished activities).
Array      T[v]     (a set of transport time t from each activity v to RA).
Output
Activity List P[v], which is ranked according to a prior order to provide resources to RA.
START MinRMT
    WHILE array A[v] is not empty DO
    {
        SELECT    the activity v with minimal T[v];
        MOVE      activity v from A[v];
        UPDATE    P[v] := v;
    }
    RETURN P[v];
    END WHILE
END MinRMT
```

FIG. 2: Pseudo-code of new priority rule – Minimum Resource Moving Time - MinRMT

4 MCOPS – SCHEDULE GENERATION PROCEDURE

Once the initial construction project data is defined such as individual activity durations, resource requirements and technical precedence, the next main task in the project management process is to schedule the project activities by the temporal arrangement and resources allocation in order to ensure the successful execution of the determined activities. In a multi-site projects environment, the projects can not be considered separately because they are linked with each other by common resource constraints. Corresponding with resource links, the resource moving time among projects significantly increase the project durations when projects are interspersedly distributed in different places. In order to consider the affect of the resource moving time among activity/projects to the start and finish time of scheduling activities as well as the multi-site project duration, this paper improves the parallel schedule generation scheme by two following features:

- Creating resource links among activities/projects due to the resource constraints during the multi-site construction project scheduling process.
- Calculating resource moving time among activities/projects and considering it into the activity's start times during the multi-site construction project scheduling process.

The objective of improved method is to make the relation among activities/projects more clearly and to minimise the increase of multi-site projects duration and due to the resource moving time and resource constraints. This is depicted as follows [Figure 45]:

```
Input
Integer   TA; // TA is total number of activities in a multi-site construction project.
Array     RML[ap]; //RMT is a set that contains all of resource links among activities.
Array     MF[ap]; //MF is the set that stores scheduled results of all activities in multi-site
          construction project.
Array     $D_T$ ; // Decision Set contains eligible activities to be scheduled at each
          scheduling time step T.
Array     $A_T$ ; //Active Set contains on going activities which have the finish time bigger
          than current scheduling time step T.
Array     $C_T$ ; //Complete Set contains all finished activities at each scheduling step.
Array     $K_{r(T)}$ ; //Resource Set contains all available resources which used to schedule
          activities.
Output
Multi-Site Construction Project Schedules, Resource Moving Links;

START MCOPS-Algorithm
    Initialisation : $T := 0$ ; $A_0 = \{0\}$; $C_0 = \{0\}$; $K^*_{r(0)} = R_r$ ; $MF := \{0\}$;
    WHILE $|A_T \cup C_T| \le TA$ DO
    {
        $T := \min \{F_{ap*}\}$; whereas ap* $\in A_{T*}$; // T* is the immediate previous
        scheduling time step.
        CALCULATE Active Set $A_T$ , Complete Set $C_T$, Decision Set $D_T$,
        Remains Resources $K^*_{r(T)}$; MF[ap];
        FOREACH activity ap in Decision Set $D_T$
        {
            //Check the resource requirements with remains capacity.
            IF $k_{ap,r} \le K^*_{r(T)}$ THEN
                //Implement priority rule Minimum Resource Moving Time.
                PROCESS MinRMT;
                //Calculate the start and finish time of activity ap.
                CALCULATE  $S_{ap} := T + T[v]$ ; $F_{ap} := S_{ap} + d_{ap}$;
                MOVE       ap to Active Set $A_T$ ;
                SAVE       Resource Moving Links to RML[ap];
                CALCULATE  Remains Resources $K^*_{r(T)}$;
                UPDATE     Remains Resources $K^*_{r(T)}$;
            ELSE
            Go to next activities;
        }
        Go to next scheduling time step T;
    RETURN MF[ap];
    }
    END WHILE
END MCOPS-Algorithm
```

FIG. 3: Pseudo-code of Multi-Site Construction Project Scheduling – Algorithm

5 RESOURCE MOVING NETWORK

Resource moving network is defined as a network that depicts the amount of resources transported from one activity to another activity, from this project to the other projects.

In the contractor's construction operations, the resource moving network or resource allocation plan is one of the crucial parts. This is used to handle interdependencies among projects, such as to know where interdependencies exist and to manage possible conflicts between construction sites. Or in the case that a special activity is in emergency situation and it needs to immediately engage the resources from other activities to accomplish before the required date. The project managers can make the decision more quickly base on the data from the resource moving network. Besides, for the effective and consistent working cooperation in the project execution phase, the resource moving network must be announced to every responsible participant such as site managers, personnel department managers and machinery pool managers etc. Additionally, in practice the construction contractors often want to execute new bided projects. Like this, 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 moving network.

In this paper, the resource moving network is constructed based on the resource links that to be created during multi-site project scheduling process, so that the managers can visibly assess the effects of the resource contention on various projects and see the interdependencies among projects and the causal relationships influencing various projects. The Graphical User Interface - GUI of resource moving network will be presented through an illustrative example in the next section.

6 ILLUSTRATIVE EXAMPLE

In order to illustrate the proposed multi-site construction project scheduling (MCOPS) – algorithm, an example of multi-site project, which consists of two small simple projects named Building repair 1 and Building repair 2, with a total of seven actual activities (activity that contains duration and required resources) is implemented.

TABLE. 1: The available resource amount

Resource Name	Mason (R1)	Plumber (R2)	Painter (R3)
Availability	3	2	2

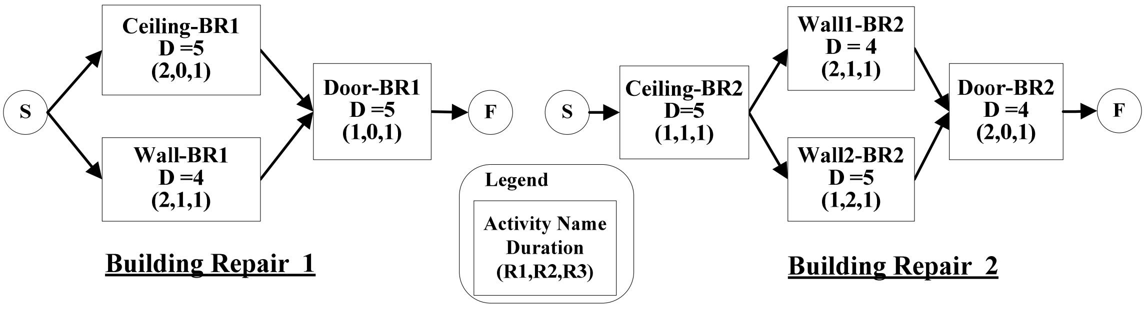


FIG. 4: Example of two-project network (Activity-On-Node)

As shown in [Figure 4], the initial multi-site project data is depicted through an activity – on – node network. The resource moving time is assumed to be one day from Building repair 1 to Building repair 2. The available resource amount that used to process these two projects is presented in [Table 1]. These available resource amounts are not enough to concurrently schedule both projects at the same time therefore, the proposed multi-site construction project scheduling (MCOPS) algorithm is applied to minimise project make-spans under the resource constrained condition and resource moving time.

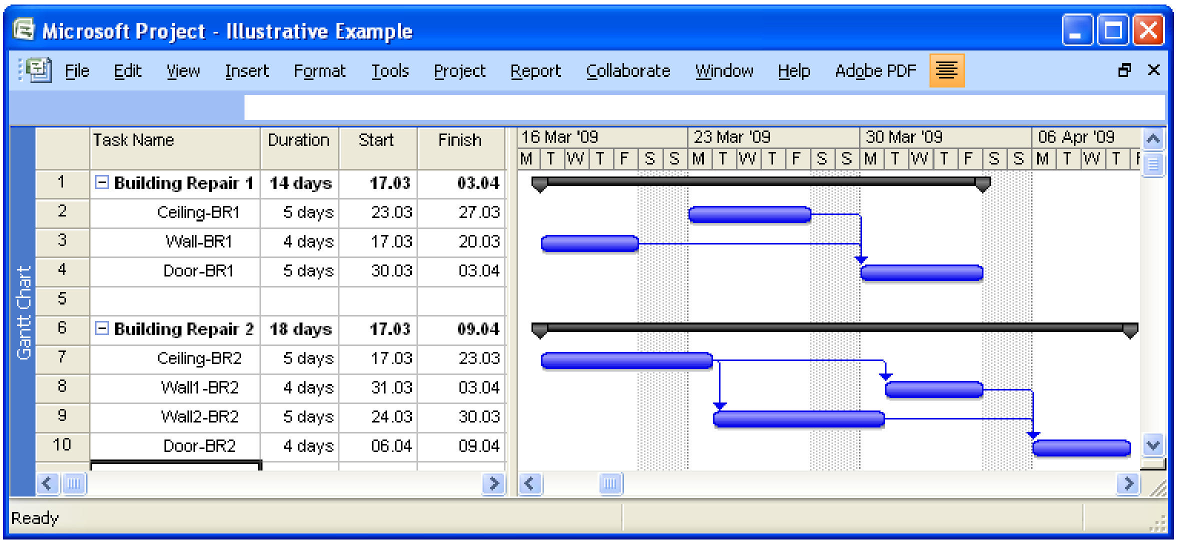
Practically, in order to find feasible multi-site project schedules, all types of common priority rules will be sequentially applied by Multi-Site Construction Project Scheduling - MCOPS algorithm, to produce interim feasible schedules. Then, construction managers will choice the most feasible schedule in order to deploy and to implement the multi-site construction project.

In this illustrative example, because of the objective is just to illustrate step by step of the proposed multi-site construction project scheduling algorithm, therefore the priority rule SOF (Shortest Operation First) is randomly applied for presentation. The scheduling steps based on MCOPS algorithm are presented in [Figure 5].

Scheduling time step T	Decision Set D_T	Active Set A_T	Remains Resource Set $K^*_{r(T)}$	Completed Set C_T	Resource Links Set RML
0	{Ceiling-BR1, Wall-BR1, Ceiling-BR2}	{Ceiling-BR2, Wall-BR1}	{0,0,0}	{0}	
4	{Ceiling-BR1}	{Ceiling-BR2, Ceiling-BR1}	{0,1,0}	{Wall-BR1}	{Wall-BR1, Ceiling-BR1}
5	{Wall1-BR2, Wall2-BR2}	{Ceiling-BR1, Wall2-BR2}	{0,0,0}	{Wall-BR1, Ceiling-BR2}	{Wall-BR1, Wall2-BR2}, {Ceiling-BR2, Wall2-BR2}
9	{Door-BR1, Wall1-BR2}	{Wall2-BR2, Door-BR1}	{1,0,0}	{Wall-BR1, Ceiling-BR2, Ceiling-BR1}	{Ceiling-BR1, Door-BR1}
10	{Wall1-BR2}	{Wall1-BR2, Door-BR1}	{0,1,0}	{Wall-BR1, Ceiling-BR2, Ceiling-BR1, Wall2-BR2}	{Wall2-BR2 Wall1-BR2}, {Ceiling-BR1, Wall1-BR2},
14	{Door-BR2}	{Door-BR2}	{1,2,1}	{Wall-BR1, Ceiling-BR2, Ceiling-BR1, Wall2-BR2, Wall1-BR2}	{ Wall1-BR2, Door-BR2}

FIG. 5: Step by step of scheduling process based on MCOPS algorithm

In order to solve more large problems in real construction situations, which may contain many construction projects, an automatic computational program of the proposed MCOPS algorithm will be programmed based on Microsoft Visual Studio C# 2005, and Microsoft SQL Server 2005. [Figure 6] presents the Gantt chart of Building Repair 1 and 2 in MS Project software, which subject to resource constraints and resource moving time. Figure 7 typically displays the resource moving network in graphic and resource moving data in detail correspond with resource Mason.



	Task Name	Duration	Start	Finish
1	**Building Repair 1**	**14 days**	**17.03**	**03.04**
2	Ceiling-BR1	5 days	23.03	27.03
3	Wall-BR1	4 days	17.03	20.03
4	Door-BR1	5 days	30.03	03.04
5				
6	**Building Repair 2**	**18 days**	**17.03**	**09.04**
7	Ceiling-BR2	5 days	17.03	23.03
8	Wall1-BR2	4 days	31.03	03.04
9	Wall2-BR2	5 days	24.03	30.03
10	Door-BR2	4 days	06.04	09.04

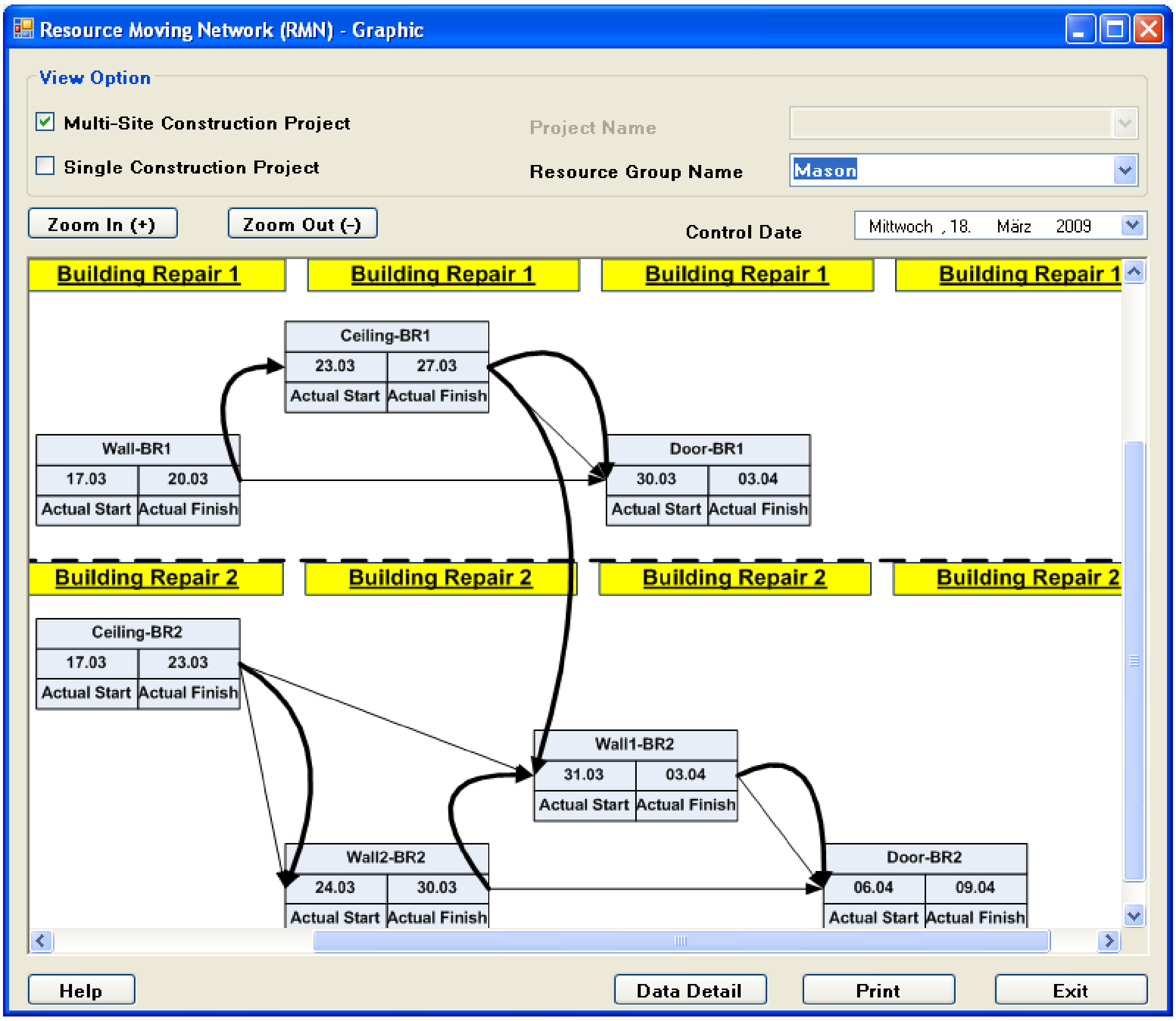
FIG. 6: Gantt chart of Building Repair 1 and 2 after applying MCOPS-algorithm

7 EVALUATION AND VERIFICATION

7.1 Introduction

The main purposes of this section are that; firstly verify the application of MCOPS algorithm in large problems when many projects are combined into multi-site project samples. Secondly, evaluate the impacts of resource moving time in the multi-site project duration. Thirdly, specify the positive effect of the new secondary priority rule Minimum Resource Moving Time (MinRMT). As a result, the computational experiments in this section will be considered according to three cases as follows:

- Considering the multi-project scheduling duration without the resource moving time.
- Considering the multi-project scheduling duration with the resource moving time, but not applying the priority rules-Minimum Resource Moving Time - MinRMT.
- Considering the multi-site project scheduling duration with the resource moving time and applying the MinRMT.


Resource Moving Network (RMN) - Graphic

View Option

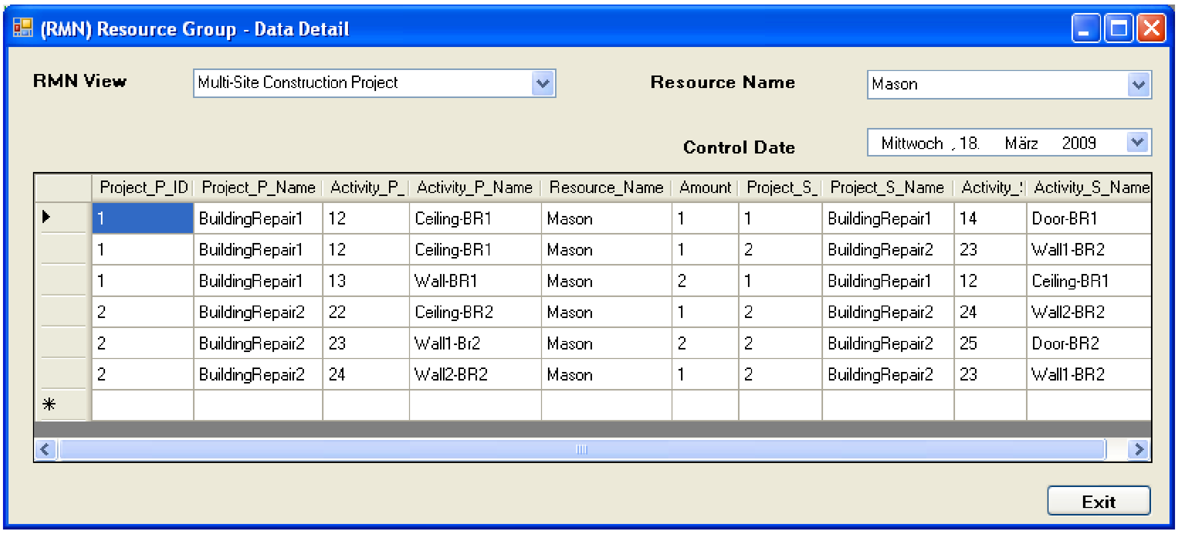
☑ Multi-Site Construction Project

☐ Single Construction Project

Project Name

Resource Group Name: Mason

Control Date: Mittwoch , 18. März 2009


(RMN) Resource Group - Data Detail

RMN View: Multi-Site Construction Project

Resource Name: Mason

Control Date: Mittwoch , 18. März 2009

Project_P_ID	Project_P_Name	Activity_P_	Activity_P_Name	Resource_Name	Amount	Project_S_	Project_S_Name	Activity_!	Activity_S_Name
1	BuildingRepair1	12	Ceiling-BR1	Mason	1	1	BuildingRepair1	14	Door-BR1
1	BuildingRepair1	12	Ceiling-BR1	Mason	1	2	BuildingRepair2	23	Wall1-BR2
1	BuildingRepair1	13	Wall-BR1	Mason	2	1	BuildingRepair1	12	Ceiling-BR1
2	BuildingRepair2	22	Ceiling-BR2	Mason	1	2	BuildingRepair2	24	Wall2-BR2
2	BuildingRepair2	23	Wall1-Br2	Mason	2	2	BuildingRepair2	25	Door-BR2
2	BuildingRepair2	24	Wall2-BR2	Mason	1	2	BuildingRepair2	23	Wall1-BR2

FIG. 7: Resource Moving Network and Resource Moving Data of resource - Mason

7.2 Multi-Site Project Samples

In the literature, there is not any standard example of the resource-constrained multi-site project scheduling problem. Therefore, this paper refers to single project examples in Project Scheduling Library - PSPLIB [4]. This project library contains different problem sets for various types of resource constrained project scheduling problems as well as optimal and heuristic solutions. More importantly, the project data sets in this library can be applied for the evaluation of solution procedures for resource-constrained project scheduling problems. As a result, the project data sets in this library are suitable to construct multi-site project samples.

The multi-site project samples in this paper are generated based on the following rules:

- This paper constructs four multi-site project scheduling examples corresponding with four types: J30 set, J60 set, J90 set and J120 set in PSPLIB. Each multi-site project example contains 5 projects that are chosen at random of different single project in each set type [Table 2].
- 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.

TABLE. 2: The selected project samples from PSPLIB

Set J30	J3048_2.sm	J303_4.sm	J306_5.sm	J3013_8.sm	J3029_3.sm
Set J60	J603_10.sm	J608_8.sm	J6032_2.sm	J6040_5.sm	J6048_6.sm
Set J90	J9019_4.sm	J9026_9.sm	J9032_5.sm	J9041_2.sm	J9048_3.sm
Set J120	J12029_7.sm	J12039_3.sm	J12042_5.sm	J12056_1.sm	J12060_1.sm

7.2 Resource Moving Time

In order to obtain resource moving time among projects that closely cements with real construction projects in developing countries, particularly in Vietnam. A survey about the real resource moving time has been carried out in one of the largest state-owned construction enterprises [5] in Vietnam. The investigation papers were sent to the project managers as well as the schedulers who have from 5 to over 20 working experience years in all companies of this corporation. There 40 investigation papers were sent out with 40 papers returned so as the response rate is 100%. According to the investigated results, the minimum value resource moving time among projects is one day and the maximum value is often over five days. Nevertheless, in order to illustrate and demonstrate the affect of resource moving time among projects even with simple common situations, this paper applies the resource moving time among projects which are determined as random in a range of 1 day to 5 days.

7.2 Result Verification

In order to evaluate the impacts of resource moving time in multi-site project duration, nine most widely used priority rules are applied in the multi-site project scheduling processes [Table 3].

TABLE. 3: **Most widely used priority rules in heuristic methods**

Priority Rule	**Commentary**
SOF	Shortest Operation First
MINSLK	Minimum Slack First
SASP	Shortest Activity Shortest Project
LALP	Longest Activity Longest Project
MOF	Maximum Operation First
MAXSLK	Maximum Slack First
MINTWK	Minimum Total Work Content
MAXTWK	Maximum Total Work Content
FCFS	First Come First Served

In order to verify the achieved results, this paper will use two criteria measurements [6]:

The ***Mean-Project-Delay*** will be applied to estimate the increase of individual project durations caused by the resource moving time:

$$\text{Mean-Project-Delay} = \frac{\sum_{i=1}^{M} DI_i}{M}$$

The ***Multi-Project-Delay*** will be applied to measure the increase of total multi-project duration results by the resource moving time:

$$\text{Multi-Project-Delay} = \frac{\text{Max}(DI_i) - \text{Max}(DR_i)}{\text{Max}(DR_i)}$$

Whereas: M is the number of projects in the multi-site project system. DI_i is the different time between the resource-constrained project duration with and without resource moving time. DR_i is the individual project duration under resource constraint condition as traditional calculation.

7.2 Result Verification

After all four multi-project samples: J30, J60, J90 and J120 are processed and measured follow two proposed criteria: mean project delay and multi-project delay. The computational results are presented and analysed as follows.

7.2.1 Mean Project delay

With mean project delay criterion, the computational results of samples that correspond with J30, J60, J90 and J120 are reported in [Figure 8]. The achieved results markedly indicate the affect of the resource moving time (RMT) and the efficient performance of priority rule-MinRMT to the multi-site projects duration. With J30 sample calculation results, the resource moving time has contributed about (97.46 – 51.57) = 45.88% to the average duration increase of individual projects. However, this index is reduced to (89.58 – 51.57) = 38.01% when the priority rule – Minimum Resource Moving Time - MinRMT is applied during the scheduling process. With J60 sample's estimation results, when resource moving time is included, the project duration increased to (49.96 – 15.66) = 34.31% and when MinRMT is used, the increased project duration is reduced to 25.18%. With J90 and J120 sample's estimation results, when resource moving time is considered, the project duration is increased to 8.33% and 30.31% correspondingly and when MinRMT is applied, the project duration increase is reduced to 3.95% and 20.34% correspondingly.

Verified Cases	J30	J60	J90	J120
A	51.57	15.66	0.33	18.36
B	97.46	49.96	8.66	48.67
C	89.58	40.84	4.23	38.69

Note that:

*This figure shows the calculated results of **mean duration increase** (%) in multi-site projects under resource constraint conditions with and without resource moving time. Whereas:*

Verified Cases:
(A): The multi-site project samples are verified without resource moving time among projects.
(B): The multi-site project samples are verified with resource moving time among projects.
(C): The multi-site project samples are verified with resource moving time and new priority rule - Minimum Resource Moving Time – MinRMT.

FIG. 8: Calculated results of multi-site project samples with Mean Project Delay criterion.

7.2.2. Multi-site project delay

[Figure 9] presents the computational results of samples J30, J60, J90 and J120 according to multi-site project delay criterion. The achieved results also markedly indicate the affect of the resource moving time to the multi-site projects duration. With J30 sample's calculation, the resource moving time has contributed about (103.74 – 56.96) = 46.74 % to the average duration increase of individual projects. However, this index is reduced to (96.29 – 56.96) = 39.33 % when the priority rule – MinRMT is applied during the scheduling process. With J60 sample's estimation, when resource moving time is included, the project duration increased to 24.46% and when MinRMT is used, the increased project duration is reduced to 18.80%. With J90 and J120 sample's estimations, when resource moving time is considered, the project duration is increased to 5.79 % and 31.71 % correspondingly and when MinRMT is applied, the project duration increase is reduced to 2.84 % and 23.32% correspondingly.

Verified Cases	J30	J60	J90	J120
A	56.96	13.93	0.00	27.57
B	103.74	38.40	5.79	59.29
C	96.29	32.74	2.84	50.90

Note that:

*This figure shows the calculated results of **multi-project duration increase** (%) in multi-site projects under resource constraint conditions with and without resource moving time. Whereas:*

Verified Cases:
(A): The multi-site project samples are verified without resource moving time among projects.
(B): The multi-site project samples are verified with resource moving time among projects.
(C): The multi-site project samples are verified with resource moving time and new priority rule - Minimum Resource Moving Time – MinRMT.

FIG. 9: Calculated results of multi-site project samples with Multi-project Delays criterion.

7.2.3. Summarising analysis

Based on the achieved results from the different multi-project samples, the summarising results are presented in [Figure 10].

With Mean-Project-Delay criterion, the average project delays caused by the resource moving time correspond to four multi-project samples (J120, J90, J60 and J30) are presented in the verified case A [Figure 10]. All the heuristic-priority rules generated significant different results between the multi-project scheduling with and without resource moving time. The resource moving time has contributed to 29.62% average delay increase of individual projects.

Criterion	J30	J60	J90	J120	Mean Value
E	45.44	34.40	8.32	30.31	29.62
F	43.94	29.16	5.68	32.19	27.74

Note that:

This figure shows the ***multi-site project duration increase*** *(%) under resource moving time corresponding with multi-site project samples: J30, J60, J90 and J120.*
Criterion E: The results that correspond to Mean-Project-Delay criterion.
Criterion F: The results that correspond to Multi-Project-Delay criterion.

FIG. 10: Effects of Resource moving time to duration of multi-sire project samples (%)

With Multi-Project-Delay criterion, the achieved results are similar. The multi-project duration significantly increased to 27.74% average when the resource moving time is included into the multi-project scheduling process. The additional average multi-project delays when considering the resource moving time are presented in the verfied case B [Figure 10]. These achieved results demonstrate that the resource moving time among projects can not be ignored when multiple projects are deployed far from each others.

The achieved results also prove that, the new priority rule – Minimum Resource Moving Time - MinRMT is able to significantly reduce the increase of the multi-site projects duration. [Figure 11] 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 8.47% average compared with the cases without MinRMT. This result shows the effective performance of MinRMT in the project scheduling process.

Verified Cases	Without MinRMT	With MinRMT	Variance
Mean Value	29.61	21.14	8.47

Note that:

This figure shows the ***multi-site project duration increase*** *(%) when applying and not applying the new priority: Minimum Resource Moving Time.*

FIG. 11: Efficiency of new priority rule- MinRMT (%)

8 CONCLUSIONS

This paper incorporated the resource moving time among projects to the resource-constrained multi-site project scheduling, which has not been considered in previous researches. Due to the intractability of the resource constrained multi-project scheduling, heuristic-priority rules method is the viable solution for scheduling large scale construction projects. This paper has proposed a new algorithm - MCOPS - which based on the improvement of the heuristic-priority rules method to optimize multi-project duration under resource constraints anyd 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 in this paper 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 to stabilize the multi-project scheduling as well as the resource flow network against the uncertainty.

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