NON-UNIT BASED PLANNING AND SCHEDULING OF REPETITIVE CONSTRUCTION PROJECTS

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ABSTRACT

One of the major goals of lean construction is for waste reduction. Repetitive construction projects are good candidate for applying the lean construction principles. Their repetitiveness makes the streamlining of the delivery process more lucrative. Repetitive scheduling methods are more effective in modeling and planning the repetitive activities and are more suitable for the scheduling and resource planning of repetitive construction projects. Nonetheless, almost all the repetitive scheduling methods developed so far are based on the primitive that a repetitive project is the construction of many identical production units. In practical, however, the production units in many repetitive projects may not be identical. Besides, many repetitive projects contain, more or less, portions of non-repetitive productions.

This research develops a non-unit based algorithm for planning and scheduling of repetitive projects. Instead of repetitive production units, repetitive or similar activity groups are identified and employed for scheduling. The algorithm can satisfy (1) the logical relationship of activity groups in a repetitive project, (2) the usage of various resource crews in an activity group, (3) the maintaining of resource continuity, and (4) the consideration of change over of different crews. Case study is conducted for demonstration and validation of the algorithm. Results and findings are reported.

KEY WORDS

Construction, Scheduling, Repetitive, Production unit, Resource

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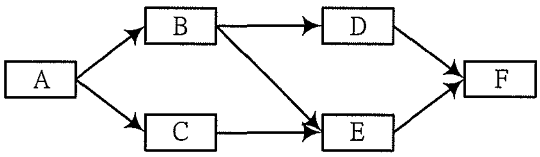
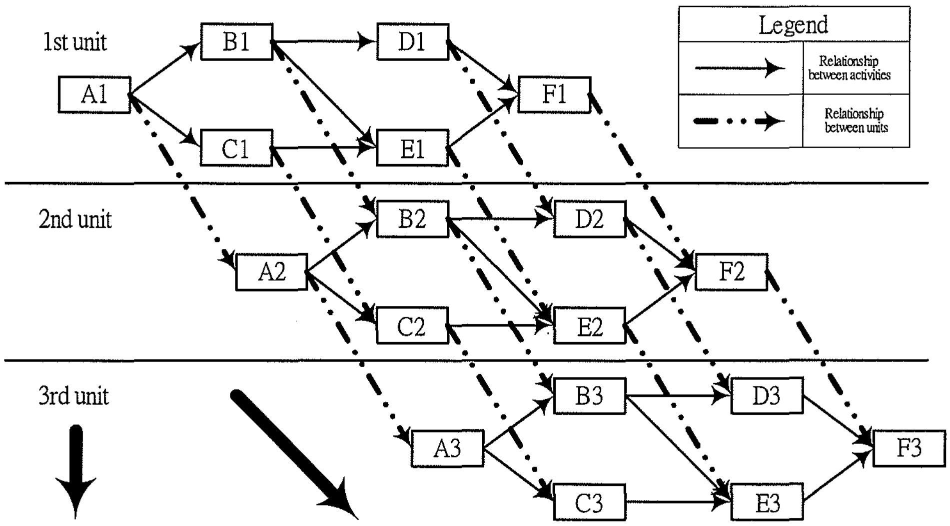
INTRODUCTION

One of the major goals of lean construction is for waste reduction. Repetitive construction projects are good candidate for applying the lean construction principles. Their repetitiveness makes the streamlining of the delivery process more lucrative. Repetitive scheduling methods are more effective in modeling and planning the repeat activities and are more suitable for the scheduling and resource planning of repetitive construction projects. In contrast to traditional CPM method, they address the need to maintain the work continuity and the uninterrupted resource deployment during the project construction of a repetitive project.

So far, almost all the repetitive scheduling methods developed are based on the primitive that a repetitive project is the construction of many identical production units. A unit network is employed to represent the production activities as well as their sequence for one production unit. The unit network is then repeated for each of the production units, as shown in Figure 1. Normally each activity in the unit network is assigned a crew. In the ideal situation, each crew can perform consecutively the same activity in different production units.



(a)Unit network or single repetitive network



(b)Traditional-defined repetitive Project that combined by several unit networks

Figure 1: Example of repetitive project with the unit network sequence format

In practical, however, the production units in many repetitive projects may not be identical. For instance, in a piling project, the excavation depth for each pile and the soil conditions encountered are not exact the same; In a pipeline-laying project, the numbers of manholes and the numbers of pipe sections usually are not the same, and it makes the identification of repetitive production units a bit tricky. Also, by employing different equipment methods and/or crews, the durations for laying-pipe in different sections differ; In a multi-housing project, the interior design for each house could be different, and therefore the required work load as well as the duration and cost will differ. Above those, many repetitive projects contains, more or less, portions of non-repetitive productions.

This research develops a non-unit based algorithm for planning and scheduling of repetitive projects. Instead of repetitive production units, repetitive or similar activity groups are identified and employed for scheduling in repetitive projects. The concept and the algorithm are described in the paper. Case study is conducted for demonstration and validation of the algorithm. Results and findings are reported.

LITERATURE REVIEW

Traditional network scheduling methods such as CPM, PERT, and bar charting are generally considered to be less effective for the planning of repetitive construction projects due to their lack of flexibility in modeling of repetitive activities. Many linear, or repetitive, scheduling methods, listed in Table 1, have been developed, each featuri ng their unique functions and/or applications.

Table 1: Review of Previous Work

Author(s) (1)	Method (2)	Unit-based (3)	Fixed work sequence (4)	Non-typical activity (4)	Assign multiple resource types in a workgroup (5)	Resource continuity (6)
Carr and Meyer (1974)	LOB	Y	Y	N	N	Y
O'Brien (1975)	VPM	Y	Y	N	N	Y
Selinger (1980)	Const. planning	Y	Y	Y	N	Y
Johnston (1981)	LSM	Y	Y	Y	N	Suggested
Stradal and Cacha (1982)	Time space scheduling	Y	Y	Y	N	Suggested
Arditi and Albulak (1986)	LOB	Y	Y	N	N	Y
Chrzanowski and Johnston (1986)	LSM	Y	Y	Y	N	Y
Reda (1990)	RPM	Y	Y	N	N	Y
El-Rays and Moselhi (1998)	Resource-driven scheduling	Y	N	Y	N	N
Harmelink and Rowings (1998)	Linear scheduling model	Y	Y	N	N	Y
Harris and Ioannou (1998)	RSM	Y	Y	Y	N	N
Hegazy and Wassef (2001)	Repetitive nonserial activity scheduling	Y	Y	N	N	N

Nonetheless, almost all of them are based on the primitive that a repetitive project is the construction of many identical production units (column 3 in Table 1). But in real world the production units may not be identical. Also, the work sequence among production units are fixed in those methods for scheduling, while in practice they could be ordered arbitrarily. Furthermore, assignment of multiple resource types for a workgroup is not allowed. But in real world, depending on the availability, it was executed frequently. Lastly, most of those methods emphasized the importance of maintaining the work continuity, and few of them addressed the issue of non-typical activities in real world practice.

THE "NON-UNIT" BASED REPETITIVE PROJECTS

The traditional view of a repetitive project is that the project is repetitive in production units. However, a non-unit based repetitive project takes the view that the project is repetitive in activities! As shown in Figure 2, activity groups are identified in a repetitive project. Each activity group contains activities of same function purpose, but different attributes of resource usage, construction condition, time, cost, and so on. Logic relationships are defined between activity groups as well as between the individual activities in different activity groups. But there is no hard logic relationship between activities in the same activity group. In a bridge construction, for instance, activity groups of foundation, pier, and deck are identified. Each group is consisted of similar activities for different spans. For each span, foundation has to be built before pier; pier has to be built before deck. But within an activity group, says foundation, there is no particular order among activities.

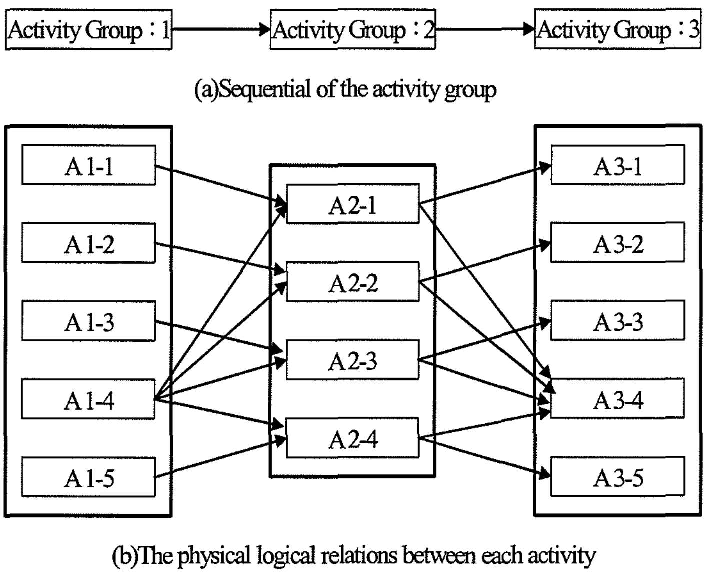


Figure 2: Illustration of A Non-unit Based Repetitive Project

A non-unit based repetitive project has the following characteristics:

- The operations of activities in an activity group are similar, but not the same.

  El-Rayes and Moselhi (1998) addressed the activity group that sets the operation to the same duration as the "Typical Repetitive Activity," and those with different duration as the "Non-typical Repetitive Activity." They also pointed out that the

"Non-typical Repetitive Activity" is common in the repetitive projects, thus it is inadequate to treat the repetitive operations within one activity group as the same, and the difference between each activity item should be considered during construction planning.

- The work logical relationships are more generalized.

  In traditional repetitive scheduling methods, every activity in the unit network follows the same production order. For instance, in Figure 1 the work order of activity A is to work on production unit 1, then unit 2, then 3, and so on. The rest of the activities in the unit network also share the same order. However, in the non-unit based repetitive scheduling, activities are no longer bounded by the above constraint and are more generalized, which is closer to the real world practices.

- There is no hard logic relationship between activities in the same activity group.

  By assigning different work order for activities in one activity group, the schedule and the project cost will be different as a result. However, it is not intuitive to set the proper order to obtain the optimized schedule and/or cost. In the non-unit based repetitive scheduling, no hard working order is assigned to the activities in an activity group. It is a decision variable for the planner or decision maker to determine.

- Various working crews can be employed in each activity group.

  In most traditional repetitive scheduling methods, each activity group is performed by one crew. They do not take into account that in real world practices various crews with the same or different equipments and methods, depending on their availability, could perform the similar activity in an activity group. It will impact on the scheduling of activities, and therefore the project duration and cost.

- Cost and time for routing the various resource crews among production units is considered.

  To mobilize, de-mobilize and routing the various resource crews on a job site inevitably creates corresponding time and cost. Since the non-unit based repetitive scheduling employs various resource crews in activity group, and there is no hard logic relationship between activities in the same activity group. It becomes even more important to take into account in the scheduling the routing time and cost of resource crews.

DEVELOPMENT OF THE NON-UNIT BASED SCHEDULING ALGORITHM

The objectives for the development of a non-unit based scheduling algorithm are:

1. To comply with the logical relationship of activity groups in a repetitive project,
2. To allow for the usage of various resource crews in an activity group,
3. To maintain the continuity for resource usage, and

4. To consider the time and cost for change over of various resource crews in job.

The procedures of the developed scheduling algorithm are described below.

Step 1. IDENTIFY ACTIVITY GROUPS AS WELL AS THEIR SEQUENCE RELATIONSHIPS

Activities in a repetitive project are grouped into activity groups according to their functionality. It is possible some activity groups have more activities than the others. For those non-repetitive activities, it is also possible to designate separate activity groups for each of them. In addition, a network describing the sequence relationships of all the activity groups is created, such as Figure 2(a).

Step 2. DEVELOP THE RESOURCE CHAINS

Since various resource crews can be employed for activity operations, each activity group will have an associating resource group. As shown in Figure 3(a), activity group 2 has an associating resource group 2. There are two resource types in the group, R2-1 and R2-2, which are available for operations of activity group 2. Once the scheduler decides on the decision variables of resource assignment and activity priority, resource chains for each resource type can be determined. In Figure 3(a), for instance, resource type R2-1 is assigned to do activities A2-1 and A2-3, while resource type R2-2 for activity A2-2 and A-4. In addition, the operation priority for activity group 2 is set to be activity A2-1, activity A2-2, activity A2-3, and then activity A2-4. Thus, as shown in Figure 3(b), R2-1 will perform A2-1 first and then A2-3, and R2-2 will perform A2-2 first and then A2-4. Figure 3(c) shows a more detailed resource chain formulation, taking into account the resource mobilization and movement. For instance, the R2-1 resource chain will first mobilize from outside to activity A2-1, performs A2-1, moves from A2-1 to A2-3, performs A2-3, and finally demobilize out of the job site. It is noted that alternative settings on the decision variables of resource assignment and activity priority will result in different schedules of resource chains.

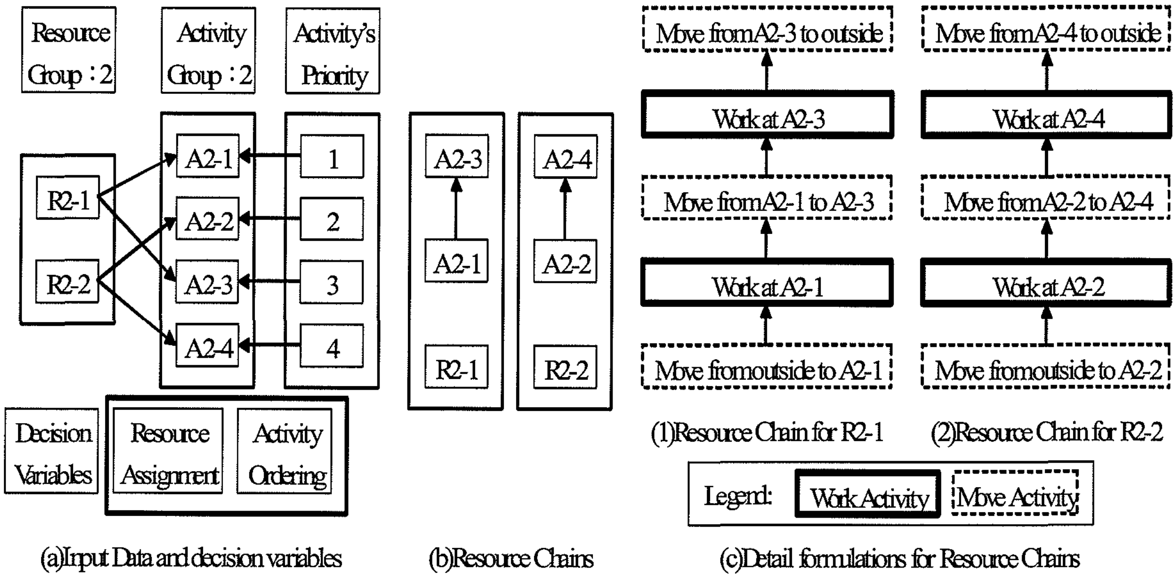
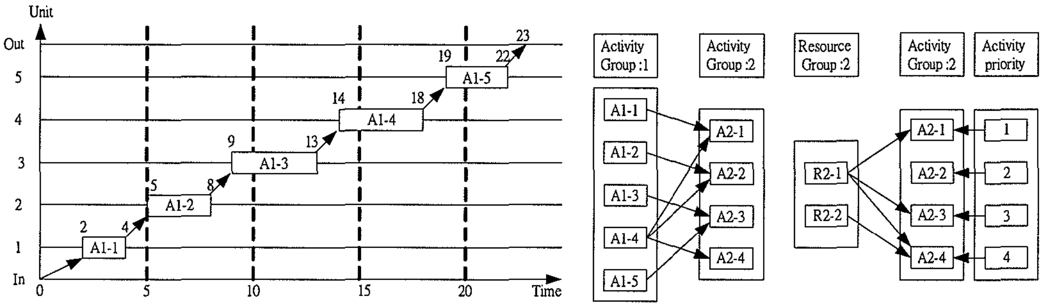


Figure 3: Illustration of Resource Chain Development

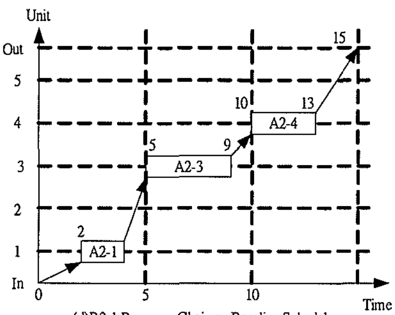
Step 3. PLACE RESOURCE CHAINS FOR PROJECT SCHEDULING

After the formulation of resource chains in each activity group, one may follow the schedule sequence of activity groups and apply the following sub steps for the scheduling of each resource chain.

1. Calculate the baseline schedule: By setting the entering time of a resource to the project site to 0, the start and finish times of each action in the resource chain can be calculated. For instance, it can be seen from Figure 4(c) that the resource chain R2-1 is first mobilized from outside to activity A2-1, performs A2-1, moves from A2-1 to A2-3, performs A2-3, moves from A2-3 to A2-4, performs A2-4 and finally demobilize out of the job site. Those actions and their associated durations are shown respectively as row (1) and (2) of the table in Figure 4(e). The start and finish times for each action can then be calculated and are shown as row (3) of the table in Figure 4(e). Figure 4(d) shows the resulting baseline schedule for resource chain R2-1.



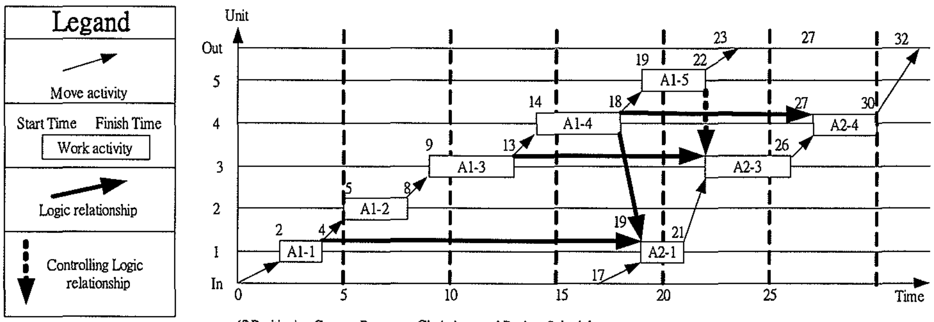
(a)Precedence Resource Chain on Project Schedule (b)Activity Logic Relation (c)Resource and priority assignment



(d)R2-1 Resource Chain on Baseline Schedule

(1)	Activity		In-> A2-1	A2-1	A2-1-> A2-3	A2-3	A2-3 ->A2-4	A2-4	A2-4 ->Out
(2)	Duration		2	2	1	4	1	3	2
(3)	Baseline schedule	Start time	0	2	4	5	9	10	13
		Finish time	2	4	5	9	10	13	15
(4)	Precedence activity			A1-1,A1-4		A1-3,A1-5		A1-4	
(5)	Last finish time for precedence activity			Max(4,18) =18		Max(18,22) =22		18	
(6)	Calculate the possible start time for the resource chain			18-2=16		22-5=17 (Max)		18-10=8	
(7)	Total project schedule	Start time	17	19	21	22	26	27	30
		Finish time	19	21	22	26	27	30	32

(e)Calculation Table for positioning R2-1 Resource Chain from Baseline Schedule to total project schedule



(f)Positioning Current Resource Chain into total Project Schedule

Figure 4: Illustration of Placing Resource Chains for Project Scheduling

2. Calculate the earliest possible start time of each activity: Based on the latest finish time of precedence activities, the earliest possible start time of each activity can be determined. As shown in Figure 4(e), the precedence activities for activity A2-1, A2-3, and A2-4 can be determined from Figure 4(b) and are shown as row (4) of the table in Figure 4(e). The latest finish time of the precedence activities for each of A2-1, A2-3, and A2-4 can then be calculated from Figure 4(a), the finished schedule for precedence activity groups, and are shown as row (5) of the table in Figure 4(e). The results are also the earliest start time of each activity.
3. Determine the earliest possible start time of resource chain: By using the results in sub step 2 and checking the baseline schedule in Figure 4(d), the earliest possible start time for the resource chain R2-1 can be calculated, and are shown as row (6) of the table in Figure 4(e). For instance, the earliest possible start time for activity A2-3 is on the 22nd day. From the baseline schedule of resource chain R2-1 the start time of activity A2-3

is on the 5th day. Therefore, the earliest possible start time of the resource chain is on the 17th (22-5) day. In the similar fashion the earliest possible start time of the resource chain can be calculated as well from activity A2-1 and A2-4. They are on the 16th and on the 8th day respectively. Thus, the 17th day (maximum of 17, 16, and 8) is the earliest possible start time of resource chain R2-1. Meanwhile, as a result, a controlling logic relationship is formed between activity A1-5 and A2-3, which places a critical logical constraint between the two resource chains.

4. Calculate the project schedule of the resource chain: With the determined earliest start time of resource chain, the start time and finish time of each work actions in the chain can now be calculated in accordance to their durations. The calculation results are shown in row (7) of the table in Figure 4(e). Figure 4(f) depicts the scheduling result.
5. Repeat sub steps 1-4 for each resource chain in the project, following the sequence order of activity groups.

CASE STUDY

A testing case of three work groups, fourteen activities is employed for demonstration and validation of the developed algorithm. The contents of activity groups and their logical relationships are shown in Figure 2 and detailed in Table 2 and 3.

Table 2: Activity Groups Data in the Testing Case

Activity group	No. of Activity	Pre-group	Resource Types Used	Resource code
A1	5	-	1	R1-1
A2	4	1	2	R2-1□R2-2
A3	5	2	1	R3-1

Table 3: Activity Data in the Testing Case

Activity Group 1	Precedence Activity	Activity Group 2	Precedence Activity	Activity Group 3	Precedence Activity
A1-1	-	A2-1	A1-1□A1-4	A3-1	A2-1
A1-2	-	A2-2	A1-2□A1-4	A3-2	A2-2
A1-3	-	A2-3	A1-3□A1-4	A3-3	A2-3
A1-4	-	A2-4	A1-4□A1-5	A3-4	A2-1□A2-2□A2-3□A2-4
A1-5	-			A3-5	A2-4

Since the durations for movement of different resource crews are considered in the developed algorithm, one has to input the corresponding duration data. Table 4 lists activity duration and the duration for resource movement in the testing case. It is noted that in the table the duration from activity x to the same activity x means the duration for activity x. For instance, the duration of "from activity A1-2" "to activity A1-2" is 2 days, and it represents the duration of activity A1-2.

Table 4: Duration Data For Activity and Resource Movement in the Testing Case (Unit: Day)

(a) Ressource R1-1

		To Activity					
	->	Out	1-1	1-2	1-3	1-4	1-5
From Activity	In	-	1	1	1	1	1
	1-1	1	2	1	1	1	1
	1-2	1	1	2	1	1	1
	1-3	1	1	1	2	1	1
	1-4	1	1	1	1	2	1
	1-5	1	1	1	1	1	2

(b) Resource R2-1

		To Activity				
	->	Out	2-1	2-2	2-3	2-4
From Activity	In	-	1	1	1	1
	2-1	1	6	1	1	1
	2-2	1	1	6	1	1
	2-3	1	1	1	6	1
	2-4	1	1	1	1	6

(c) Resource R2-2

		To Activity				
	->	Out	2-1	2-2	2-3	2-4
From Activity	In	-	1	1	1	1
	2-1	1	6	1	1	1
	2-2	1	1	6	1	1
	2-3	1	1	1	6	1
	2-4	1	1	1	1	6

(d) Resource R3-1

		To Activity					
	->	Out	3-1	3-2	3-3	3-4	3-5
From Activity	In	-	1	1	1	1	1
	3-1	1	2	1	1	1	1
	3-2	1	1	2	1	1	1
	3-3	1	1	1	2	1	1
	3-4	1	1	1	1	2	1
	3-5	1	1	1	1	1	2

Three scenarios below are tested on the testing case. Table 5 shows their data input.

Scenario 1□ Only one resource type is used for each work group. As a result, only R2-1 is used for activity group 2.

Scenario 2□ The operating priority of activity A1-4 is moved to the highest, and that of activity A3-4 to the lowest. The rest of input data is the same as those in Scenario 1.

Scenario 3□ One more resource, R2-2, is employed for the operation in activity group 2. The rest of input data is the same as those in Scenario 2.

Table 5 Input Data for The Three Scenarios of the Testing Case

Activity	Scenario 1		Scenario 2		Scenario 3	
	Operating Priority	Assigned resource	Operating Priority	Assigned resource	Operating Priority	Assigned resource
A1-1	1	R1-1	2	R1-1	2	R1-1
A1-2	2	R1-1	3	R1-1	3	R1-1
A1-3	3	R1-1	4	R1-1	4	R1-1
A1-4	4	R1-1	1	R1-1	1	R1-1
A1-5	5	R1-1	5	R1-1	5	R1-1
A2-1	1	R2-1	1	R2-1	1	R2-1
A2-2	2	R2-1	2	R2-1	2	R2-2
A2-3	3	R2-1	3	R2-1	3	R2-1
A2-4	4	R2-1	4	R2-1	4	R2-2
A3-1	1	R3-1	1	R3-1	1	R3-1
A3-2	2	R3-1	2	R3-1	2	R3-1
A3-3	3	R3-1	3	R3-1	3	R3-1
A3-4	4	R3-1	4	R3-1	5	R3-1
A3-5	5	R3-1	5	R3-1	4	R3-1

The scheduling results of the three scenarios are shown as Figure 5. Each color line represents the schedule for a resource chain, from entering the project site to exiting. The flat segments in a line represent the operation of activities, while the sloped segments depict the movement of that resource either in or out of the project site, or between activities. The total project duration for Scenario 1, 2, and 3 is 45 days, 39 days, and 28 days respectively.

It can be seen from Figure 5 that all resources maintain their work continuity. In Scenario 1, since A1-4 is the precedence activity for all the activities in activity group 2 (Table 3), it means activity group 2 can not start until the finish of A1-4. Also, since all activities in activity group 2 are precedence activities for A3-4, A3-4 can not commence until the finish of activity group 2. As a result, the starting time of the resource chain for activity group 3 is delayed. The total project duration of Scenario 1 is 45 days.

In Scenario 2, the operation priority of A1-4 is moved from the 4^{th} to the first, thus the commencement of activity group 2 can move forward substantially (6 days). Also, the operation priority of A3-4 is moved from the 4^{th} to the 5^{th}, so activity A3-5 can start earlier. But it does not seem to have any impact on the project duration. The total project duration is reduced to 39 days (45-6).

In Scenario 3, resource R2-2 is added to the activity group 2 for the operation. As shown at the bottom part of Figure 5, the resource chains R2-1 and R2-2 progress side by side. The time for processing activity group 2 is reduced from 29 days in Scenario 2, to 18 days in Scenario 3. Thus, the total project duration is reduced by 11 days (29-18) to 28 days.

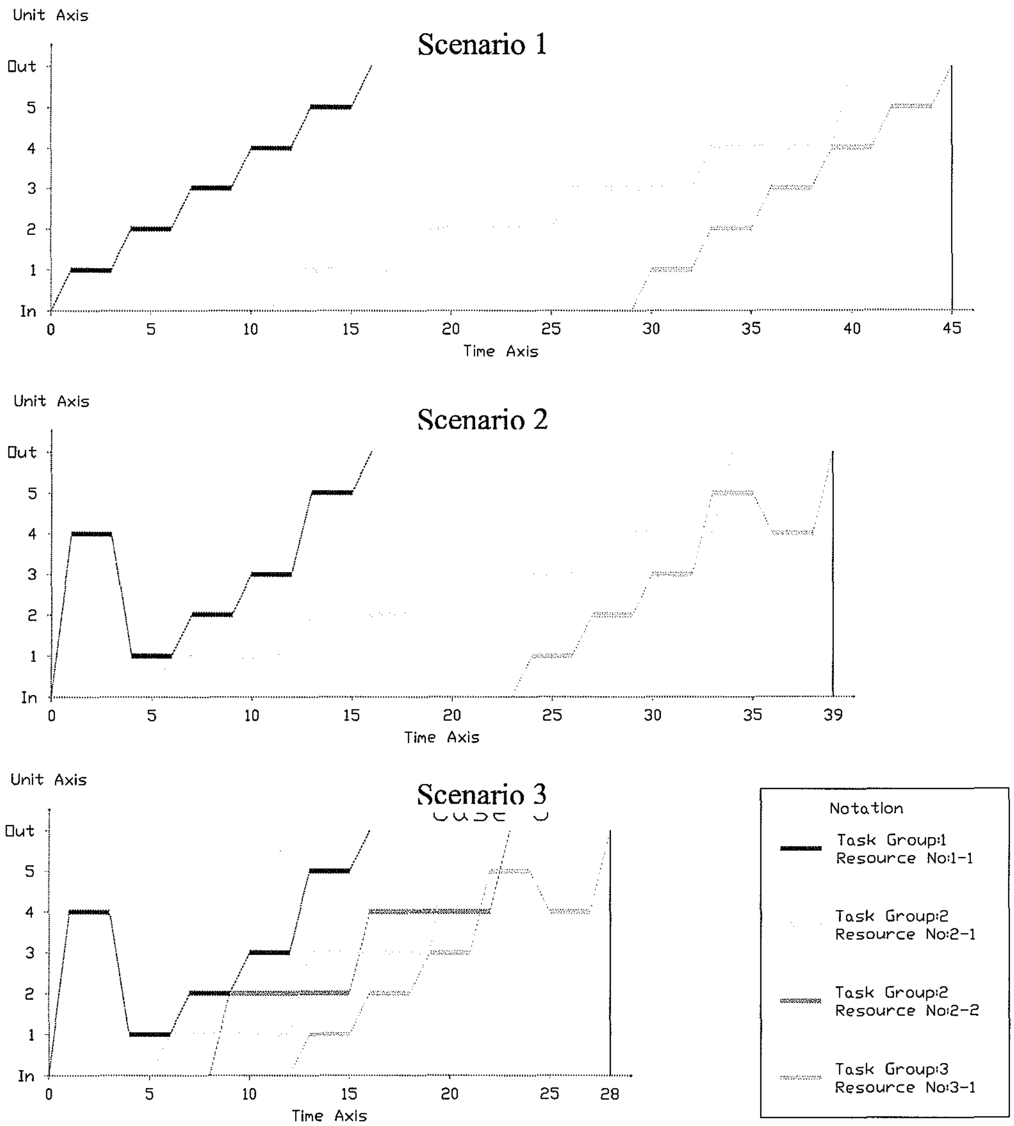


Figure 5: Scheduling Results of The Testing Case

CONCLUSIONS

This study develops a non-unit based algorithm for planning and scheduling of repetitive projects. In contrast to the traditional view of a repetitive project as many repetitive production units, a non-unit based repetitive project takes the view that the project is repetitive in activities! A non-unit based repetitive project has the following characteristics.

- The operations of activities in an activity group are similar, but not the same.

- The work logical relationships are more generalized.
- There is no hard logic relationship between activities in the same activity group.
- Various working crews can be employed in each activity group.
- Cost and time for routing the various resource crews among production units is considered.

Testing of the three scenarios shows that setting of different operating priority of activities in an activity group may impact significantly the scheduling results. While in the real world, the operating priority of similar activities in activity group is frequently not that obvious. It becomes a decision variable for the scheduler and planner to make. In addition, the testing results show that by adding more resources in the operation, the schedule will most likely be expedited and the project duration shortened. It is another important decision parameters that will impact the scheduling results greatly.

The use of resource chains for showing the progress schedule of a repetitive project is easily visualized. It is convenient for different resource crews to plan for their respective time to enter and to exit the site, which may enhance the effectiveness of planning and scheduling.

ACKNOWLEDGEMENTS

This research is partially supported by The National Science Council (NSC) of Republic of China, at the grant No. NSC 90-2211-E008- 058. The authors would like to express our gratitude to The NSC.

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