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A CONCEPTUAL FRAMEWORK FOR CONCURRENT CONSTRUCTION PLANNING

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ABSTRACT: Concurrent construction (or overlapping) is an alternative project delivery process to reduce time-tomarket such that the owner can get higher profits; the increased profits due to shortened project duration would exceed the loss of profits from the increased cost, if any. For more effective concurrent construction, a new conceptual framework for concurrent construction planning is suggested. With multiple work methods available in each activity, the performance of overlapping between two activities in terms of cost is affected by the compatibility between work methods selected and the benefit to the project owner is determined by internal rate of return (RoR). The impact of the compatibility between work methods and the conceptual framework are explained by a hypothetical case study.

Keywords: Concurrent planning, Construction Projects, Overlapping, Multiple methods, fast-track construction

1. INTRODUCTION

Concurrent construction is to execute two or multiple activities simultaneously instead of sequentially to reduce project delivery time, and it has been accepted to be an effective approach to faster construction project delivery [1]

In construction projects several activities require the completed work from their upstream activities to build their own work. For example, the activity of pouring concrete cannot be done without installation of form and reinforcing rebar. In sequential execution, one construction activity starts when its upstream activity is completed, so that all the work to be completed in the activity is available. In this case, the work method in the upstream activity has little impact on the execution of the downstream activity's performance. However, if two activities are executed concurrently or by overlapping, the downstream activity starts when the upstream activity is not finished. Thus, the amount of work (Work-in-Progress, or WIP) which is released from the upstream activity and becomes available and usable by the downstream activity can affect the performance in the downstream activity. Furthermore, the amount of work released from the upstream activity can be affected by the ways in which both the upstream activity and the downstream activity are executed.

By following the definition of construction work methods, "the way in which construction work is carried out on a construction project" [2], there are several work methods available to execute a construction activity: with regard to amount of resources, sequence, technique, and so on. Therefore, work methods both in the upstream activity and in the downstream activity can affect the amount of work released from the upstream activity and available in the downstream activity. Some combinations of work methods in both the upstream activity and the downstream activity allow faster release of work completed into downstream activity, but more cost may be required. On the other hand, other methods don't allow release of the completed work until its job is 100% completed. Thus, some combinations of work methods can lead to a faster completion of the job, but may need additional cost.

Typically faster project delivery (or concurrent construction) requires higher cost [3] and the project owner can get higher profits due to shortened project duration which exceed the loss of profit from the increased cost, if any.

The objectives of this study is 1) to explain the impact of the relationships between two activities' work methods on the project performance in terms of cost, and 2) to suggest a concurrent construction planning approach with consideration of multiple work methods.

This paper is composed by the following sequence. The existing research about the concurrent construction, multiple work methods, and the impact of work-inprogress on project performance are reviewed. Then, the relationship between construction activities' work methods and its impact on work-in-progress for concurrent construction planning are discussed. The determination process for the benefit to the project owner is discussed. Then a simple procedure to determine the best set of work methods and the best degree of overlapping is suggested. A simple case for concurrent construction planning is exampled.

2. LITERATURE REVIEW

2.1. Characterization of Activities under Overlapping

Several researches have explained the characteristics of overlapping between activities in the pursuit of developing strategy for more efficient overlapping. Krishnan et al.[4],[5] argued that the effectiveness of overlapping between two activities are affected by *upstream evolution* and *downstream sensitivity*, which are inherent to the activities, in product development projects. *Upstream evolution* represents the change of errors in designing process and *downstream sensitivity* represents the degree of the impact of erroneous information released from the upstream activity. Therefore, it is argued the effectiveness of overlapping in product design projects are affected by those two factors. Bogus et al. [6] also used the *evolution* and *sensitivity* of characterization of construction design activities for identifying overlapping opportunities. Furthermore, Pena-Mora and Li [7] added another factor for the characterization of activities in designbuild projects, *upstream progress*, in addition to *upstream evolution* and *downstream sensitivity* to develop a planning and controlling tool for designbuild fast-track construction projects.

The characterization of activities in terms of evolution and sensitivity can explain the overlapping process in which information is released between activities such as designing process or design-build project. However, in construction activities the work (or product) from one operation is released to or become available by downstream activity. There is no existing research to characterize construction activities under overlapping for effective overlapping.

2.2. Work-in-progress (WIP) Amount

WIP inventory represents amount of work released from upstream activity and available to a construction activity. WIP inventory amount plays as a buffer between activities to absorb the impact of uncertainty , thus sufficient amount of WIP inventory allows stable workflow or improvement of utilization of resources [8]. Sakamoto et al. [9] argue that productivity improves with increase in size of buffer from zero to a medium size, and does not improve further with any more increase in size of buffer over the peak.

In addition to the impact of WIP amount on productivity, the relationship between project processes which affects WIP amount was studied. Ford [10] distinguishes WIP amount available from WIP amount released. He argues that WIP amount available is affected both by WIP amount released from the upstream activity and by the dependence relationship between the activities (*external precedence relationship*). For example, the WIP amount available in a downstream activity is determined by the progress of its upstream activity (or WIP amount released from the upstream activity) and the scheduled starting time of the downstream activity from the dependence relationship [11]. However, it was assumed that there is only one dependence relationship between activities which is inherent into activities.

2.3. Multiple Work Methods

There are multiple work methods available to execute each construction activity. Since each work method can impose different impacts on other activities, there are certain benefits to selecting the most efficient combination of work methods [12]. For example, the number of tower cranes in high-rise building construction [13], the type of forms in concrete work [14], and the method for installing windows of a multistory building [15] are among the factors affecting other activities' performance in construction projects.

According to Howell et al. [13], the relationship between two activities is affected by the output of the upstream activity and the process required by the downstream activity. This relationship also influences the performance of those activities, especially that of the downstream activity. Many researchers have investigated the factors which affect the relationships between activities. Their findings include 1) buffer size between activities (e.g., Howell et al. [13]; Horman and Kenley [8]; Sakamoto et al. [9]); 2) space (e.g., Riley and Sanvido [16]; Riley and Sanvido [17]; Zouein and Tommelein [18]; Guo [19]); 3) subsequence (Echeverry et al. [20]); 4) resources (e.g., Tam et al. [14]; Faniran et al. [21]); and 5) construction technique (Tam et al. [14]).The results of these research have found that efficient planning or sequencing activities with regard to these factors can improve the construction project performance.

3. CONSIDERATION OF MULTIPLE METHODS FOR CONCURRENT PLANNING

3.1. Definition of Work Methods

A construction work method is determined by several factors, such as resources (crews, equipment), space, sub-sequences, operation and technology. While “crashing” is a different strategy for time reduction from overlapping, allocating more resources is regarded as a separate work method in this study.

The ***base method*** is defined as the work method requiring the least cost in the normal sequential (nonconcurrent) schedule. Thus, the base method is the typical and most conventional work method.

The following example explains how each method is defined with regard to several factors. This example is for masonry activity for a 3 story building and four factors are considered for defining each work method.

Table 1. Examples of Different Work Method s

Factor	Method (I)	Method (II)
Type of equipment	Basic steel scaffolding	Mast-climbing work platform
Sequence	Vertical progress	Lateral progress
Batch size	Whole floor	Half floor
Crew size	2 crews	4 crews

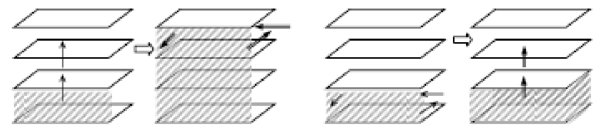
Table 1 shows two different work methods determined by four factors for brick enclosure of the building. To lay bricks on the exterior of the building, the contractor can choose basic steel scaffoldings or a mast-climbing work platform as shown in Figure 1.

(a) Basic steel scaffoldings (b) Mast-climbing work platform

Figure 1. Different types of Scaffoldings

Using the basic steel scaffolding costs less than a mast-climbing work platform, thus using basic steel scaffoldings is assumed to be more conventional method.

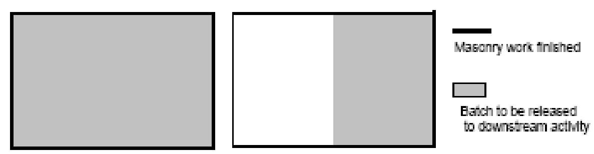
The second factor considered is the sequence of the masonry work. Bricks can be layered in one side of the building at first, and then in another side (vertical progress) as shown in Figure 2.a. Or bricks can be layered for the first floor at first, and for the second floor next (lateral progress) as shown in Figure 2.b.



(a) Vertical progress (b) Lateral progress

Figure 2. Different sequences for masonry work

The third factor considered is the batch size of the masonry work to be released to its downstream activity. The downstream activity (e.g., interior finish) can start after the masonry work of each floor is finished (batch size of a whole floor) as shown in Figure 3.a. Alternatively the downstream activity can start when a half of a floor is finished with masonry work (batch size of a half floor) as shown in Figure 3.b.



(a) Batch of a whole floor (b) Batch of a half floor

Figure 3 Different batch size for masonry work

Finally, the size of crews can be another factor for different work methods: using 2 crews or 4 crews. Of course, by using 4 crews the activity can be finished earlier, but some additional cost may be required fo rreasons such as productivity loss due to crowded space.

In this example, there are a total 16 methods available ($2\times2\times2\times2=16$). If the method (I) regarding each factor costs less than the method (II), then the base method would be to use 2 crews and basic steel scaffoldings with a batch size of a floor in vertical progress.

3.2. Impact of Different Work Methods on WIP Amount

According to Ford [10], amount of work completed in the upstream activity is not same as amount of WIP usable by the downstream activity. And the Amount of WIP usable by the downstream activity is affected both by the progress of the upstream activity and by the dependence relationship between activities. However, the dependence relationships between activities are not described in detail by Ford.

This study extends the Ford’s work with consideration of multiple work methods. In this study the dependence relationship between activities is assumed to be determined by the work methods in both activities, which are determined by several factors such as resource, sequence, type of equipments and so on. If upstream work method releases its finished work faster, but downstream work methods requires 100% of .WIP for starting the job, then the amount of WIP usable by the downstream activity will be 0 until the upstream activity is 100% completed. On the other hand, if the downstream work method is to start its work even with small amount of WIP, then the amount of WIP usable by the downstream activity will be non zero.

Amount of WIP usable by downstream activity in this study determined by two factors; 1) progress of the upstream activity (or amount of work completed in the upstream activity) and 2) the compatibility between the work methods. Figure 4 shows example curves of the amount of WIP usable depending on the compatibility between work methods.

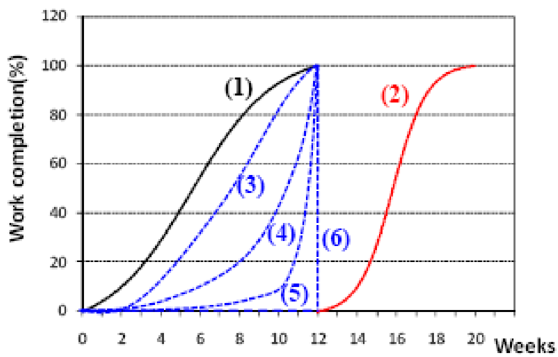


Figure 4. Example Curves of Amount of WIP usable

The two solid curves ((1) and (2)) represent progress of a upstream activity and downstream activity. And the four dotted curves ((3) – (6)) show example curves of amount of WIP usable by downstream activity. Depending on the compatibility between work methods and the progress of upstream activity, amount of WIP usable may have different shape. The curve (6) represents a pair of work methods which are incompatible with regard to amount WIP usable. If these work methods are selected, no overlapping is recommended. However, the curve (3) represents amount WIP usable from a pair of work methods which are more compatible each other. These work methods allow more WIP usable, thus facilitate more overlapping than the case of curve (6).

3.3. Impact of the Compatibility between Work methods on Cost under Overlapping

It is generally accepted that the cost increases with more overlapping (or more amount of time reduction): cot increases convexly with more time reduction. Many researchers tried to explain this relationship (e.g. Roemer et al. [3] and Salazar-Kish [22]). Figure 5 shows example time-cost trade-off curves for different pairs of work methods.

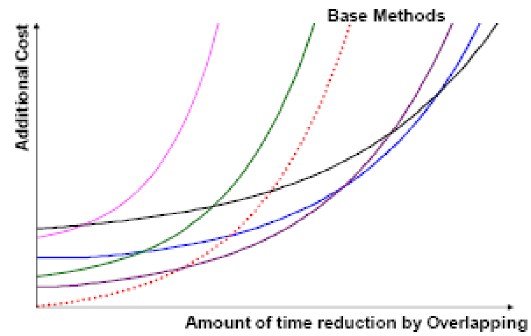


Figure 5. Examples of Time-Cost Trade-off Curves

The cost curves in Figure 5 represent combined additional cost of two activities required for time reduction by overlapping. All the curves increase convexly with more amount of time reduction based on the findings in existing researches.

The dotted curve represents additional cost of the base methods which requires the least cost. When no time reduction is required (or no overlapping), additional cost for the base work methods is $0.

As exampled in Figure 5, cost curves for some pairs of work methods which are compatible each other with regard to amount of WIP usable may have smaller increase rate than the base methods, but higher cost is required under sequential execution. .

3.4. Determination of the Benefits to the Owner

In concurrent construction execution, increased cost can be justified only if the profit to the owner due to earlier completion exceeds additional cost [23]. Therefore, in this study, the benefit to the project owner is determined in terms of internal rate of return (RoR). The benefit to the project owner is determined by the difference between RoR under sequential execution (no overlapping) and RoR calculated based on a pair of work methods and degree of overlapping. If the RoR value from concurrent execution is smaller than the RoR from sequential execution, the selected work methods and its degree of overlapping will not be recommended.

4. CONCURRENT PLANNING PROCEDURE

Finding the best set of work methods in sequential execution or finding the best degree of overlapping based on one work method in each activity have been investigated by many researches and industry practitioners: time-cost trade-off problems either to minimize cost or to minimize the duration (e.g. Zheng et al. [24], Feng et al. [25], [26]). However, consideration of multiple work methods for overlapping makes concurrent construction planning process more complex. Now, the project manager or the planner for concurrent construction projects needs to solve a combinatorial optimization problem requiring two-level search; to determine the best pair of work methods and to determine the best amount of time reduction.

In this study, a simple and general approach for the concurrent construction planning is proposed for the overlapping between two activities.

Step 1. To select a pair of work methods

Step 2. To determine the best degree of overlapping for a pair of work methods.
RoR value is calculated under sequential execution (amount of time reduction is zero) under the selected work methods. Then amount of time reduction is increased and its RoR value is calculated. By repeating the RoR calculation process, the best degree of overlapping can be determined.

Step 3. To determine the best pair of methods and the best degree of overlapping
By repeating Step 2, the highest RoR value for each pair of work methods is compared to others. Thus the best pair of work methods and the best degree of overlapping can be determined.

5. HYPOTHETICAL EXAMPLE

5.1. A Department Store Building for Example Project

A hypothetical example construction project is exampled to explain the concurrent construction planning with consideration of multiple work methods. The example project is to construct a 3 story department store with 16' story height and 95,000 square feet of floor area. The main activities in this project are shown in Figure 6. It is assumed that Structure, Exterior Enclosure, Interior Construction and Architectural Finish are on the critical path and Mechanical, Electrical and Fire Proofing are noncritical activities. The construction cost and duration of these activities are estimated based on Square Foot Cost [27] and unit cost estimation [28]. Estimated duration of the project is 24 months for the critical activities. The estimated cost are shown in Table 2.

Out of the four activities on the critical activities, if some activities are overlapped and their duration is reduced, then overall project duration can be reduced. Therefore, in this study, overlapping between Exterior Enclosure and Interior Construction is assumed to be overlapped.

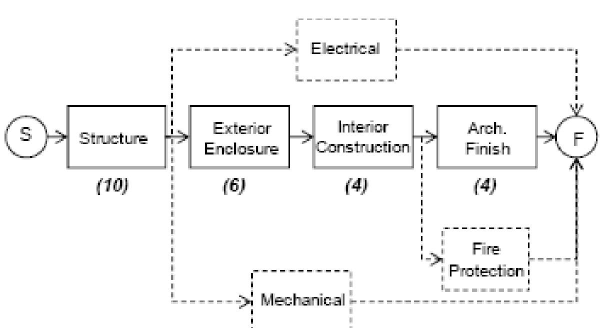


Figure 6. The Critical Path Network of the Example Project

Table 2. Cost Estimation of the Example Project

Activity		Duration (months)	Cost
1	Structure	10	$1,748,000
2	Exterior Enclosure	6	$1,229,063
3	Interior Construction	4	$ 267,663
4	Architectural Finish	4	$1,785,145
5	Others (MEP)		$2,453,755
Total		24	$7,483,625

5.2. Work Methods in the Activities for Overlapping

Exterior wall of this example project is assumed to be a face brick veneer with concrete block backup as shown in Figure 7. To install the masonry the contractor (or subcontractor) will need scaffoldings.

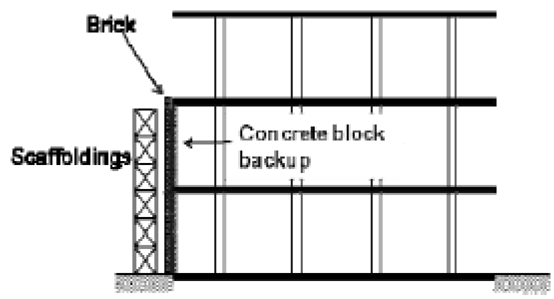


Figure 7. Sketch of Exterior Enclosure

With the design of two-layer walls (exterior face brick and interior concrete block) as shown in Figure 7, it is assumed that the simultaneous laying of both brick and block is the least expensive method, since sequential laying of both brick and block may require additional work to cope with connectors, such as wiremesh, between the two layers.

However, the downstream activity (interior construction) does not require the completion of layering of both brick and block, but it does require the completion of the inner concrete block layer. Thus, there are two options of sub-sequence available to the subcontractor: simultaneous laying of both bricks and blocks, and laying of blocks before bricks.

In addition, scaffoldings are indispensable equipment for laying bricks (or blocks). Since installation and dismantling of scaffolding require additional cost, it is assumed that contractor(s) prefers the completion of the wall on one side of the building enclosure and moving the scaffoldings to work on another side. However, scaffolding may be installed on all sides of the building perimeter at the same time for earlier completion of the enclosure at the expense of additional cost. As shown in Figure 8.(a) and Figure 8.(c), the least cost method is assumed to complete laying masonry on one side from the first floor to the third floor and to move to a next side. However, if all the masonry wall on a floor is built and then the wall on the next floor as shown in Figure 8.(d), scaffolding should be installed on all perimeters of the building as shown in Figure 8.(b).

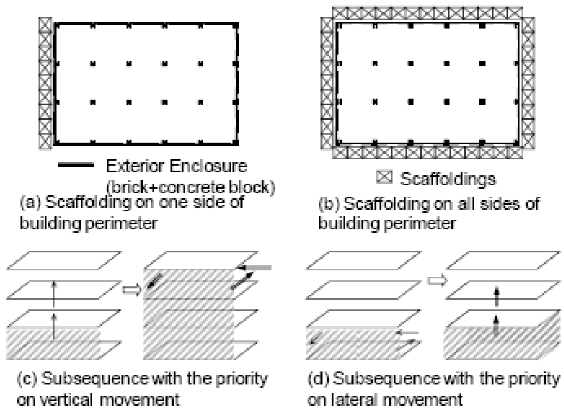


Figure 8. Scaffoldings and Subsequence for Exterior Enclosure

Depending on these factors three work methods are assumed to be available in the activity of Exterior Enclosure as following.

Method 1: Vertical movement and simultaneous laying of brick and block with scaffolding on one side of the perimeter and one crew (the base method)

Method 2: Lateral movement and simultaneous laying of brick and block with scaffolding on all sides of the perimeter and one crew

Method 3: Lateral movement and laying of brick after laying of block with scaffolding on all sides of the perimeter and one crew

The downstream activity for overlapping in this case study is Interior Construction. The first factor to describe different work methods is type of lifting equipments for interior partition wall construction. Scaffoldings or similar equipments are required for the partition wall of a 16' story height. It is assumed that steel tabular scaffolding is the common and the least expensive equipment for partitioning. However, a selfpropelled lift can also be used at extra cost with the benefit of higher productivity or less duration than tabular scaffolding.

In addition, the next factor to describe work methods is enclosed space against outside weather. Interior construction usually needs enclosed space to protect the walls or other products against exterior weather such as rain or snow. However, interior construction may start with only three sides of the enclosure completed, if the area of floor is large. Thus, it is assumed that interior construction can start after three sides of the building enclosure are finished. This requirement for starting Interior Construction allows a smaller batch size and facilitates faster release of WIP. As shown in Figure 9, if the Interior Construction requires complete building enclosure against outside weather, then it can start only when the Exterior Enclosure is 100% completed or needs whole floor for a batch (Figure 9.(a)). However, if the Interior Construction requires building enclosure at least three sides as shown in Figure 9.(b), earlier start of Interior Construction is allowed. This factor is related with batch size or minimum amount of work needed for starting the job. If the batch size of the interior construction is one whole floor area, then the interior construction requires the completion of all sides of the enclosure as shown in Figure 9.(a). However, if the batch size is a half of one floor area, then the interior construction can start with three sides of the exterior walls built as shown in Figure 9.(b). Thus, a small batch size can facilitate overlapping between the exterior enclosure and interior construction.

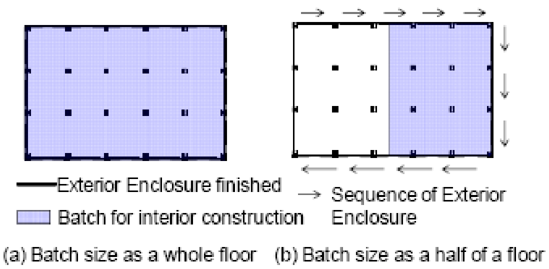


Figure 9. Different batch sizes of interior construction

The last factor to describe work methods in Interior Construction is crew size. Using two crews is assumed to perform the work for interior construction faster by two weeks with the cost of lower productivity (or additional cost). With these three factors, three work methods are developed as following.

Method I: Batch size of a whole floor with tabular scaffolding and one crew (the base method)

Method II: Batch size of a half-floor with tabular scaffolding and one crew

Method III: Batch size of a whole floor with selfpropelled lift and one crew

Based on these three methods in each activity (Exterior Finish and Interior Construction), total nine pairs of work methods ($3\times3= 9$) are available for the overlapping between Exterior Finish and Interior Construction.

5.3. Amounts of WIP usable Depending on Work Methods

Amount of WIP usable in the downstream activity (Interior Construction) for each pair of work methods is determined based on the work methods developed as shown in Figure 10. The straight line in Figure 10 represents the progress in the upstream activity (Exterior Enclosure). Since the estimated duration of the activity is six months, the progress will be 100% at the end of sixth month.

If the work method #1 and I (both are the base methods) are selected, Exterior Enclosure will be executed on one side of the building followed by next side of the building. However, the work method in Interior Finish needs whole floor with all sides of exterior walls enclosed to start its job. Due to the incompatibility between the work methods, the earliest time when Interior Finish has some amount of WIP usable will be at the 100% completion of the upstream activity. However, if the work method II for Interior Construction is used along with the work method #1, the Interior Construction is willing to start its work with only three sides of walls enclosed and a batch size of a half floor. Therefore, the work completed by the upstream activity will become usable when 50% of the wall which is thirdly sequenced on the first floor is completed (refer to the Figure 9.(b)).

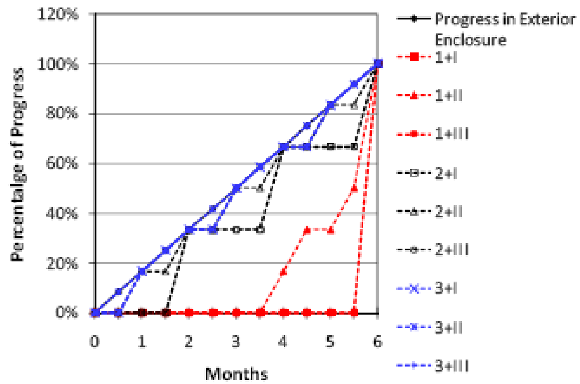


Figure 10. Amounts of WIP usable

If the work method #2 for Exterior Enclosure is used, then both the brick face wall and concrete block wall will be laid floor by floor. This sequence allows faster release and facilitates overlapping.

The example amounts of WIP usable by the downstream activities as shown in Figure 10 show that amount of WIP usable is determined both by work methods (or compatibility between work methods) and the progress of the upstream activity.

5.4. Additional Costs for Time Reduction

The amounts of WIP usable which are determined by the compatibility between work methods are then used to determine additional costs for overlapping. The determination of additional costs required for overlapping is based on the following assumptions.

The base methods (in each of the two activities) have the highest productivities, since they are the most conventional methods. If less conventional work method is selected, its productivity is lower than that of the base method.

If no work is usable by the downstream activity, the resources allocated such as laborers and equipments become idle. And more resources than originally planned will be assigned in next month to catch up schedule.

If amount of WIP usable is less than 80% of amount of work to be done, the productivity becomes deteriorated and more loss in productivity is made with less amount of WIP usable.

Based on the above assumptions, additional costs required for time reduction in each pair of work methods are determined as shown in Figure 11.

Additional cost for the pair of work methods (1+I) is zero, because additional cost of one pair of work methods is determined against the normal cost (or the cost using the base work methods under sequential execution). However, additional costs required for other pairs of work methods are positive number.

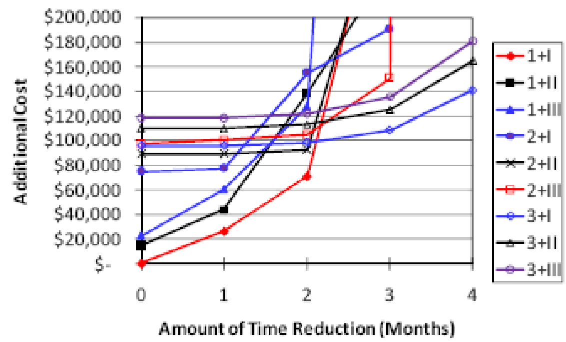


Figure 11. Additional Costs for Time Reduction

All additional costs required for time reduction in Figure 11 increases convexly with more amount of time reduction. However, some pairs of work methods which are more compatible each other may have slower increase rate than others. Then, those pairs of work methods are more likely to contribute into higher benefits to the project owner; low additional cost required for reducing time can be justified by bigger benefit due to faster project delivery.

5.5. Determination of The Best Work Methods and the Best Degree of Overlapping

The additional costs required for time reduction shown in Figure 11 along with the amounts of time reduction are used to determine the benefit to the project in terms of Internal Rate of Return (RoR).

To calculate internal rate of return values in this example case study, following assumptions are made.

Economic life of the building is 240 months (or 20 years)

Amount of future monthly revenues is $150,000 for 240 months after construction phase.

Construction cost is paid out with monthly payments of same amounts.

Economic life of the facility and future monthly revenues are not affected by faster delivery of the project.

Figure 12 shows simplified cash-flow diagrams both for normal schedule (without overlapping) and for expedited schedule based on the above assumptions. Then, RoR values are calculated from amount of time reduction and additional cost required for time reduction in Figure 11. The RoR value based on normal schedule (or without overlapping) and the base methods is 21.28%.

If RoR value from a pair of work methods and an amount of time reduction is smaller than 21.28%, then overlapping under that situation is not recommended.

The RoR values for each pair of work methods are calculated for all amounts of time reduction. The maximum value of time reduction by overlapping is 4 months, because the estimated duration of the upstream activity (Exterior Enclosure) is 4 months. Figure 13 shows the RoR values of each pairs of work methods.

The RoR value for the normal schedule (without overlapping and based on the base work methods) is 21.28% and some higher RoR value than that are found for the work methods of 3+I, 3+II, and 3+III.

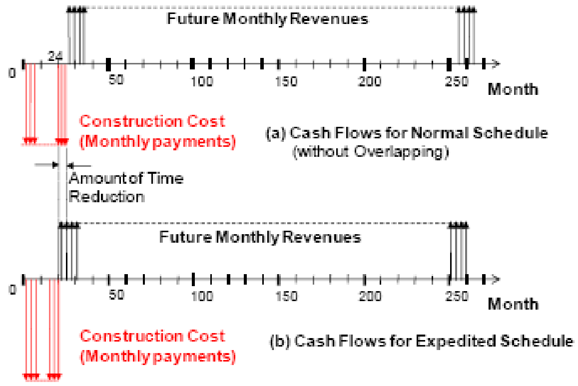


Figure 12. Cash-flow Diagrams both for Normal Schedule and Expedited Schedule

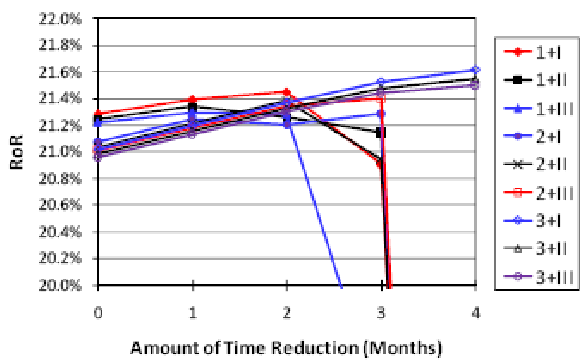


Figure 13. RoR values of Each Pair of Methods

The RoR values for the work methods of 3+I, for example, are not bigger than the RoR from the normal schedule under no overlapping. But it increases with more amount of time reduction until the maximum amount of time reduction. This indicates that the pair of work methods are compatible each other and facilitates overlapping The best RoR value out of the nine pairs of work methods is 21.61% for four month's time reduction with the work methods of 3+ I. Therefore, it is recommended to use the work method 3 and I for Exterior Enclosure and Interior Construction respectively and to overlap those activities by four months for higher benefits to the project owner.

6. CONCLUSIONS

Concurrent construction can improve benefits to the project owner from faster project delivery. To improve the benefits to the project owner, this study suggests a new approach to concurrent construction planning.

Effectiveness of overlapping between activities is affected by amount of WIP (work-in-progress) from the upstream activity and amount of WIP usable in downstream activity is also affected by the relationship between the activities. The relationship between activities are determined by work methods selected, and the compatibility between work methods should be considered for concurrent construction planning.

Furthermore, the basic sequence for concurrent construction planning is also suggested. With the consideration of multiple work methods, the concurrent construction planning to find the optimal solution becomes a combinatorial optimization problem requiring two level search; to find the best degree of overlapping and to find the best set of work methods.

This combinatorial optimization problem can be solved by determination of Internal Rate of Return (or RoR) from a set of methods and an amount of time reduction. This suggested approach for concurrent construction planning can motivate the development of new work methods or new technology by contractors or subcontractors. If a new work method which requires more cost than typical and conventional method, but is more compatible with downstream activity's method in terms of overlapping, then it can provide higher benefit to the project owner.

An example case study is performed for the explanation for this new approach to concurrent construction planning. While the case study can provide insight for concurrent construction planning, the data of additional cost required for time reduction are determined by several assumptions. Since this cost data plays pivotal role in finding the optimal solution, future study about the cost will be required.

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