Selection of Compatible Construction Methods for Project Expedition

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In construction projects, work completed in upstream activity is a prerequisite to execution of downstream activity and is regarded as Work-in-Process (WIP) inventory between two activities. When construction activities are executed simultaneously by overlapping for earlier completion, productivity in downstream activity can be deteriorated due to insufficient WIP inventory. Therefore, providing sufficient WIP inventory facilitates overlapping between activities and, furthermore, project expedition. Since amount of WIP inventory usable by downstream activity is affected by work methods used in both upstream activity and downstream activity, selection of work methods which are compatible each other is a key to expedition of construction projects. This research attempts to examine some attributes of construction work methods which facilitate overlapping through computer simulation modeling. Some attributes of construction methods for project expedition are recommended.

Key Words: Construction Methods, WIP inventory, Scheduling, Rework, Simulation

Introduction

Earlier completion of construction projects provides more benefit to project owner (Reinschmidt and Trejo 2006) and executing multiple activities concurrently by overlapping is one approach to expedition of construction projects. In construction projects downstream activity requires finished work in upstream activity on which downstream activity builds its own work and the finished work from upstream activity is Work-in-progress (WIP) inventory. When two activities are overlapped for earlier completion, amount of WIP inventory may be insufficient for implementation of downstream activity, thus deteriorate productivity in downstream activity. Therefore, providing sufficient amount of WIP inventory is a key factor for facilitating overlap between activities.

Based on the definition of construction work method, “the way in which construction work is carried out on a construction project” (Froese and Rankin 1998), there are multiple work methods available in each activity. Product in WIP inventory is constructed by upstream activity’s method, and downstream activity takes only the products in WIP inventory which are needed based on its own method. Under sequential execution of two activities, all the prerequisite work from upstream activity is available when downstream activity starts. However, under concurrent execution downstream activity may have insufficient amount of WIP inventory. If the work methods in which upstream activity produces its products and downstream activity takes WIP inventory are compatible each other, upstream activity produces the products first which are required by downstream activity, or downstream activity takes the product first which is produced in upstream activity. Thus, compatibility between work methods affects amount of WIP inventory and effectiveness of overlapping (Shim and Reinschmidt 2009).

Work methods used in construction activities are usually determined by the parties who execute the activities such as subcontractors or trade contractors, and they determine their work methods based on their own myopic viewpoints: optimizing activity performance such as minimizing cost. Since performance of construction activities is affected by work method used in upstream (or downstream) activity under concurrent execution by overlapping, the best work method under sequential execution (i.e., the least expensive method) determined by each party may not be the best method under overlapping. Thus, subcontractors (or trade contractors) should consider compatibility between their work method and work method in upstream activity (or downstream activity) to maximize their profits.

In this paper impact of some attributes of construction work methods on effectiveness of overlapping is examined by a computer simulation modeling. The findings and discussion from the simulation will help construction project participants select more compatible work methods which facilitate project expedition. This paper is organized as follows; background is presented to provide the need for selection of compatible work methods for expedition. Then, the objectives and scope of this research are presented followed by description of simulation modeling. Then, a case study is implemented to examine relationship between some features of construction work methods and compatibility for expedition followed conclusion and discussion.

Background

Work-in-progress (WIP) inventory represents work completed and released from upstream activity into downstream activity. In construction industry WIP inventory plays a role as 1) pre-requisite to downstream activity (Gonzalez et al. 2006); 2) a buffer to absorb the impact of uncertainty in upstream activity (Horman and Thomas 2005, Tommelein et.al. 1999). To shield downstream activity's performance against uncertainty, it is desirable for downstream activity to start its work with more amount of WIP inventory. However, downstream activity should wait until more amount of WIP inventory becomes available, and expedition by overlapping is not viable. While previous research was performed to examine the impact of amount of WIP inventory on project performance (i.e., Sakamoto et al. 2002, Tommelein et al. 1999), multiple work methods available in one activity was not considered.

Other researchers considered changing work method for improvement in project performance: Howell et al. (Howell et al 1993) examined interaction between subcycles in construction project and showed that more WIP inventory was available by changing work methods, thus projects could be finished earlier. Furthermore, Tommelein (Tommelein 1998) examined the impact of coordination for selection of construction work methods (sequence of installation) on project performance. She compared project performances of three cases; no coordination (random sequences in two activities), perfect coordination (exact same sequences in two activities) and pull-driven sequencing (coordinated sequences). The results from her research include that coordination between project participants regarding work sequence reduced amount of WIP inventory and lead to expedient completion. She suggests using a lean construction technique, pull-driven scheduling, in which upstream activity processes the parts first which is matched to the sequence in downstream activity and insisted that perfect coordination would not materialize during construction phase in real construction projects.

However, many construction projects are executed with co-operative pre-planning which includes designer, general contractor and subcontractors. By making an assumption that all project participants are willing to be co-operative in pre-planning stage to maximize overall project performance, work methods for all activities should be determined in pre-planning stage. Then, a question to be answered in pre-planning stage is who has priority in selection of work methods, or who should change method from his (or her) own best method to a more compatible method. As Shim (Shim 2008) insisted, subcontractors choose their best work methods as the least expensive method and the best work method of one activity may not be compatible with the best work method of its immediate upstream (or downstream) activity, changing best work method into another method which is more compatible with another activity may need additional cost, thus subcontractors may want to adhere to his (or her) own best method. Understanding some attributes of construction work methods to effective expedition will help subcontractors and project managers schedule their projects to increase overall project performance.

Research Problem, Objectives, and Scope

The research is to answer the question in construction project scheduling, "what are the attributes of construction methods which facilitate expedition?" Understanding attributes of construction work methods which leads to faster completion of project will be helpful to project scheduler and project participants. Therefore, the main objective of this research is to examine impact of some attributes of construction work methods on project expedition to help project participants schedule for earlier completion of project. This objective is achieved by 1) developing a computer simulation model with two activities and 2) conducting a hypothetical case study with the simulation model.

The research scope is limited to a simple project case with two activities: the simulation model is developed with two activities and expansion into more activities is remained for future research. And this research considers two attributes of construction work methods; 1) order of activities (either upstream or downstream) and 2) degree of compatibility in work method.

Simulation Model

In order to represent interaction and WIP inventory between two activities, a work flow model is developed as shown in Figure 1. A work unit moves from Work to be done in basework queue (WB) through inspection queue (QA), to WIP inventory in each time period. Depending on compatibility between work methods of two activities, work unit in WIP inventory is released to downstream activity. This simulation model is developed in Fortran and is composed of three main components: 1) rework cycle, 2) representation of work methods and 3) determination of amount of WIP inventory.

Rework Cycle in Construction Projects

In construction projects workers may produce erroneous work and it needs to be reworked. This rework cycle causes cost overrun and/or schedule overrun (Reichelt and Lyneis 1999). In order to represent uncertainty in quality, the rework simulation model developed by Reinschmidt (Reinschmidt 2004) was adopted in this research. Uncertainty (or variability) in construction process is represented with three random factors: 1) error rate in completing job (Basework), 2) error finding rate in quality assurance process (QA), and 3) error rate in rework. Basework is done depending on productivity in each activity and the completed work units may include defects or not depending error rate. If a work unit completed in basework includes defect, it moves to QA queue w/o error. The erroneous work unit can be detected through inspection and it moves to Rework Queue. However, the erroneous work may not be detected through inspection, and moves to WIP inventory. The work units with defect in WIP inventory is released to downstream activity, and basework in downstream activity is added (or installed). Then, it's defect is detected through inspection in downstream activity and it is returned to Rework Queue in upstream activity. The erroneous work which is determined randomly in the simulation model may cause delay in downstream stream activity's process depending on work methods and leads to overall project delay.

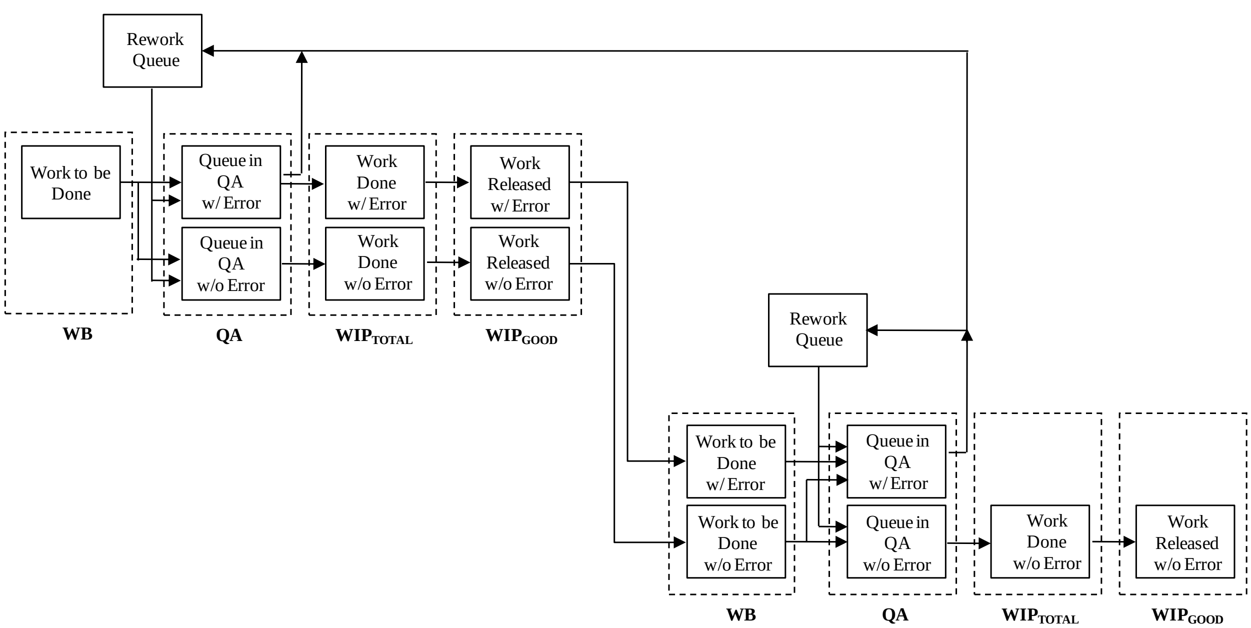

Figure1: Simulation model with two activities

Representation of Construction Methods

Construction methods can be defined with consideration of many factors such as amount of resources allocated, type of equipments, sub-sequence, or construction technique. However, in this research work methods are represented by sequence of work units for simplicity which was used by Tommelein (Tommelein 1998). If amount of work to be completed in each activity is 1,000 (units), then sequence of work performance in one work method may be from 1 to 1,000. However, another work method may process work units from 1,000 to 1. Based on the assumption that contractors typically uses the work method which is the least expensive (the Base Method), the productivity and/or duration to finish the job is assumed to be affected by work method selected.

Work-in-Progress

In the simulation model, two types of WIP inventories are set as discussed by Shim and Reinschmidt (Shim and Reinschmidt 2009): 1) WIP_{Total} and 2) WIP_{Good}. WIP_{Total} represents work completed in upstream activity, but not released into downstream activity and WIP_{Good} represents work released into downstream activity and usable by downstream activity. Therefore, work units in WIP_{Total} don't move to WIP_{Good}, until it is required by the work sequence in downstream activity. On the other hand, a work unit in downstream activity cannot be started if the work unit in upstream activity which matches to that in downstream activity was not completed. Due to the different work sequences in different work methods, amount of WIP inventory (amount of WIP_{Total}) may fluctuate, thus downstream activity may be delayed.

A Case Study

In order to examine the impact of attributes of construction work methods on expedition, a simple hypothetical case study is conducted in the simulation model.

Input Parameters and Implementation

It is assumed that two work methods are available in each activity. Two sequences to complete 1,000 work units in each activity are considered. Sequence A is from 1 to 1,000 with increment of 1. In Sequence B, work units with 1 in the first digit are installed and work units with 2 in the first digit are the next. In upstream activity, the Method #1 is defined to have Sequence A and the Method #2 with Sequence B. On the other hand, in downstream activity the Method #1 is with Sequence B and Method #2 is with Sequence A. It is assumed that the Base Method in the upstream activity is Sequence A and Sequence B is the Base Method in the downstream activity.

In addition to the work methods regarding different sequences, the simulation model has several input parameters to represent different work methods and uncertainty (or variability) in construction process. Productivity in each activity is assumed to be affected by work method selected. And it is assumed that it is more likely to make errors with less conventional method (non the Base Method) both in base work and rework processes. In the downstream activity it is assumed that all erroneous work units are detected through inspection process. The values for input parameters are set as shown in Table 1.

Table 1

Input Parameter Values

	Method	Sequence	Productivity (work units/unit time)	Error rate in basework	Error finding probability	Error rate in rework
Upstream activity	1	A	20	10%	90%	8%
	2	B	16	20%	90%	10%
Downstream activity	1	B	20	10%	100%	8%
	2	A	16	20%	100%	10%

With the two different work methods available in each activity, there are total 4 pairs of work methods (=2×2): ***1*** (for upstream activity) ***+1*** (for downstream activity), ***1+2***, ***2+1***, and ***2+2***. The first pair of work methods, ***1+1***, represents the Base Methods.

The model was simulated one time for each pair of work methods (total 4 simulation runs). Both the two activities are to complete 1,000 work units and their productivities (or basework rate) are assumed to be different depending on work method as shown in Table 1.

Results of the Simulation

Due to the different sequences based on the Base Method (Method #1 for the upstream activity and Method #2 for the downstream activity), the downstream activity experiences degraded productivity from beginning until amount of WIP inventory usable increases abruptly as shown in Figure 2. The amount of WIP inventory usable by the downstream activity (WIP_{Good}) does not follow immediately the progress of the upstream activity. The amount of WIP_{Good} increases slowly until around 45 time units, then it increases abruptly. Accordingly, the downstream activity proceeds as expected as its estimated productivity (20 units per one time unit). In addition to the case with the Base Method, the comparisons among upstream progress, downstream progress and WIP inventory usable by downstream activities for the other pairs of work methods are available in Appendix.

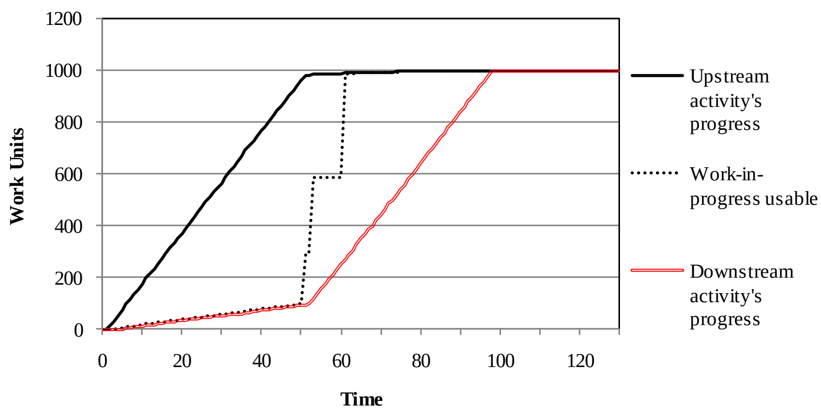

Figure 2: Completed Work in the Upstream Activity and the Downstream Activity based on the Base Methods

When amounts of WIP inventory usable by the downstream activity (WIP_{Good}) are compared among different pairs of work methods as shown in Figure 3, using same sequences both in the upstream activity and in the downstream activity leads to earlier WIP inventory usable by the downstream activity (either '***1+2***', or '***2+1***'). However, in the case of work methods of ***1+2***, faster WIP inventory usable by the downstream activity is observed than the case of work methods of ***2+1*** due to higher productivity in the upstream activity: productivity of upstream activity for method #1 is 20 (units per one time unit) and productivity for method #2 is 16 (units per one time unit). In addition, in the case of work methods of ***2+1***, the amount of WIP inventory usable by the downstream activity is observed to have more fluctuation than the case of ***1+2***. It is due to the assumption that non-the Base Method (less conventional method) has higher error rate in base work (20% for method ***2***) than the Base Method (10% for method ***1***).

Different amounts of WIP inventory depending on work methods selected are presented in Figure 4. If both methods use the same sequence (in the cases of ***1+2*** and ***2+1***), the WIP inventory amount (WIP_{Total}) is smaller than the other case.

Finally, the plot in Figure 5 shows the completed work in the downstream activity. In the cases of using compatible work methods (with same sequences, with pairs of work methods ***1+2*** and ***2+1***), the project is completed earlier than the other cases. However, the completion time in the case of work methods of ***1+2*** is 75 time units, while the completion time for work methods ***2+1*** is 79. The pair of work methods ***2+1*** has a similar slope for progress in downstream activity as the work methods ***1+2***. However, the pair of work methods of ***2+1*** has more fluctuation than the pair of work methods ***1+2*** due to higher error rate in the upstream activity. Accordingly, it is observed to take more time to finish all the work units in downstream activity in the case of work methods ***2+1***.

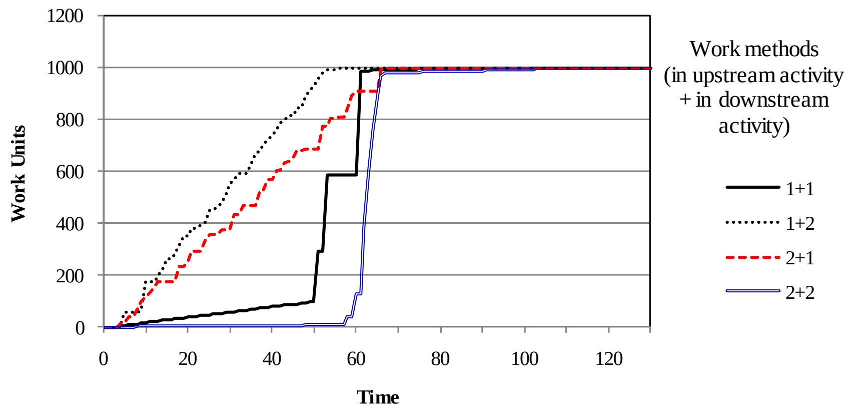

Figure 3: Comparison of Amounts of WIP Usable by the Downstream Activity (WIP_{Good})

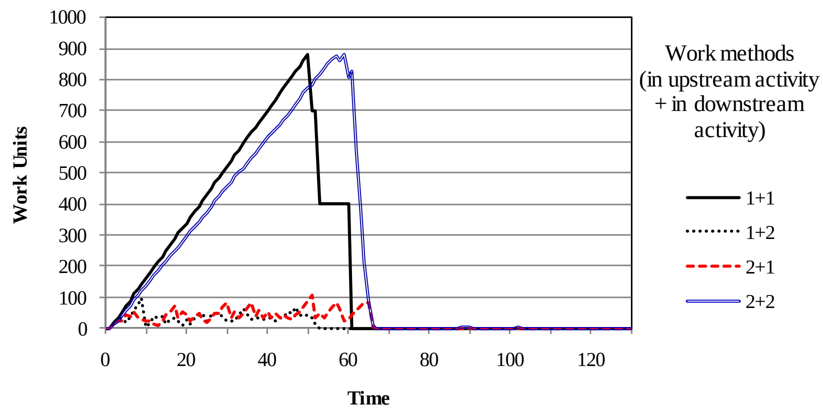

Figure 4: Comparison of WIP Inventory not Usable by the Downstream Activity (WIP_{Total})

Therefore, in this case study it is recommended to select the work method ***#1*** for the upstream activity and work method ***#2*** for the downstream activity for earlier completion of the project. The next choice is the pair of work methods ***2+1*** and the pairs of work methods ***1+1*** and ***2+2*** are not recommended.

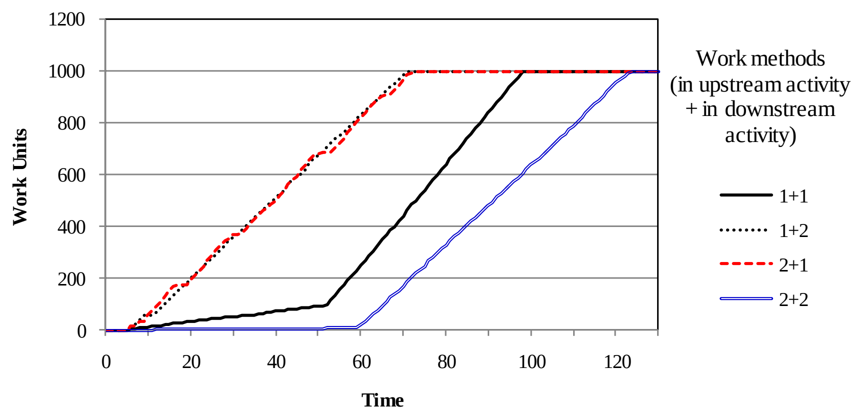

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Figure 5: Comparison of Completed Works in the Downstream Activity

Conclusion and Discussion

This paper presented selection of compatible work methods for expediting construction project and impact of some attributes of work methods on expedition to help project participants schedule for expedited construction projects. The recommendations for faster completion of construction project found from the case study are:

- Compatible work methods between upstream activity and downstream activity should be selected.
- Work method with faster progress rate should be selected in upstream activity.
- Work method with more reliable performance should be selected in upstream activity.

While this research assumed that all project participants are willing to co-operate for scheduling, change of work methods from the Base Method (the most inexpensive work method) to another work method will require additional cost. Additional cost for expedition should be carefully distributed or charged to project participants as discussed by Tommelein et al. (1999). Trade contractors who are responsible for only one or a few activities will typically myopic viewpoint and may not be interested in optimizing overall project performance (Tommelein 1998). Distribution of additional cost (or benefit from expedition) among subcontractors should be for future research and selection of work methods for more than two activities will need more attention for future research.

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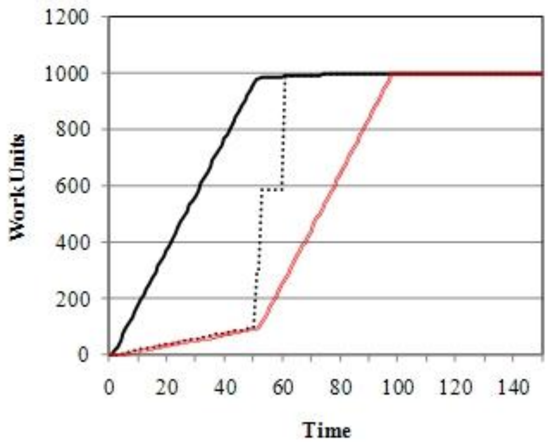
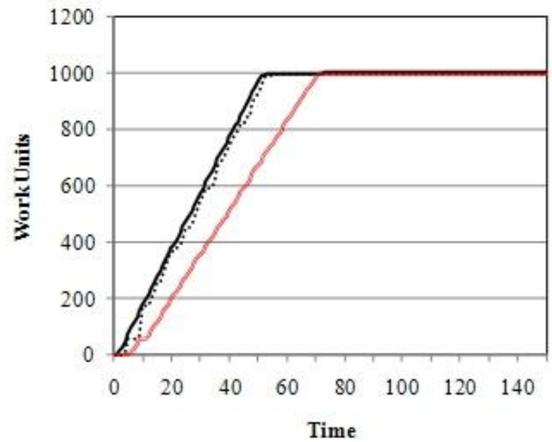
Appendix

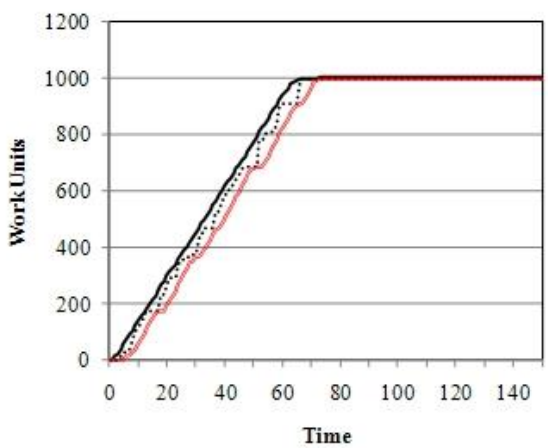
Comparison of upstream activity and downstream activity's progress and WIP inventory usable by dowsnstream activity (WIP_{Good}).



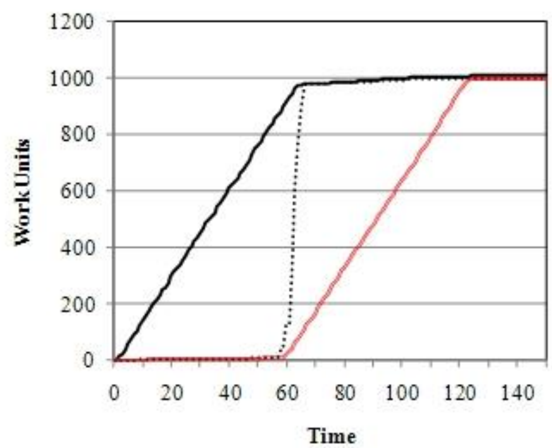
Work methods of ***1+1***



Work methods of ***1+2***



Work methods of ***2+1***



Work methods of ***2+2***