IMPACTS OF MATCHED BATCH SIZES ON TIME REDUCTION IN CONSTRUCTION PROJECTS

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ABSTRACT: Batching production is to process products in lots rather than by the piece and most activities in repetitive construction projects are performed by batching production. Batch size is a key factor which affects duration of construction project and it is recommended to use small batch size for early completion of construction projects. However, it is possible that batch sizes are different each other between activities, and no research about impacts of batch size matching has been conducted. This paper is to examine the impacts of batch size matching on construction duration. A computer simulation model which includes two activities was developed. Two hypotheses were tested under the Monte-Carlo simulation method: 1) small batch sizes which are not matched each other can reduce time depending on productivities and 2) synchronized batch sizes leads to earlier completion of project than unsynchronized batch sizes irrespective of productivities. The results identify an advantage of matching batch sizes with regard to project duration and show that batch size matching needs consideration of compatibility between productivities also.

Keywords*: Batch Size, Matched Batch Size, Productivity, Time Reduction*

1. INTRODUCTION

Construction process in construction projects is executed by multiple contractors (subcontractors or specialty contractors). It is typical that one subcontractor is responsible for one activity and next activity is executed by another subcontractor. Thus, the importance of similar or matched production rates between construction processes is one of key factors which affect success of the project [1]. In repetitive construction projects such as highway, high-rise office building or multi-unit condominium construction project, subcontractors repeat same or similar construction process in multiple locations (or units). This kind of repetitive construction processes in typical repetitive construction projects are based on batch production: production by batch, not by piece [2]. Batch size (or amount of products to be produced and released to a next process at one time) in one activity affects performance of a next process (or activity) as well as progress in the activity under batch production. Thus, overall project performance (especially duration) is affected by batch size.

Several researchers and practitioners identified that project duration can be reduced by using small batch size. While several case studies show that small batch sizes which are same each other for construction activities in one construction project reduced duration, it may not be realistic that all activities have same batch size [3]. Batch size of one activity may be affected by its typical production rate (or productivity), number of days needed for completing all the work in a project, or other related cost. And some subcontractor may want to use his best batch size which is not same as other subcontractors'. However, there is no research about how to coordinate among different batch sizes of construction activities. Thus, this research is to examine the impacts of different batch sizes on construction project performance in terms of duration.

This paper starts with background and existing research about batch production and impact of matched batch sizes on project duration. Then, problem statement and hypotheses are discussed. Then, research methodologies is explained and results is to be discussed. Discussion and conclusion will follow next.

2. BACKGROUND

2-1. BATCHING PRODUCTION

In most repetitive construction projects a subcontractor occupies a location (or a unit) where he installs his products (or builds his works). He installs not one product, but repeats the installation process of multiple produces in one location. Once he finishes his job in one location (or one unit), then he moves to a next location. And a next subcontractor occupies the location and the product the first subcontractor installed is released in to the second subcontractor. Since work between subcontractors is released based on location (or unit), amount of work (or size of location) to be done in one location which is occupied by one subcontractor is batch size [4]. For example, batch size of a high-rise office building can be each floor or two floors.

Impacts of using small batch size in repetitive construction projects were found by several researchers and practitioners. One of the main advantages of using small batch size is shortened duration [5], [6]. Small batch size leads to early release of work completed in one activity to a next activity. Therefore, small batch size can reduce work-in-progress (WIP) inventory between two activities. And it can lead to reduced cycle time and faster delivery of project. Another advantage of using small batch size is that defective products (or work) can be detected early. Typically a subcontractor inspects the work released from his preceding activity before he starts his work [7]. Thus, rework or correction of defective work can be performed early and construction duration can be saved due to early detection of defective work.

2-2. MATCHING BETWEEN BATCH SIZES

While batch sizes of subcontractors whose work are to be executed sequentially are same each other in some construction projects, it is possible that batch sizes of subcontractors are different each other. As Ward and McElwee [8] mentioned in their paper, subcontractors have a reluctance to change batch sizes for fear of working inefficiently. And inefficient work performance can lead to idle resources, increased cost, or/and increased duration.

In the case of different batch sizes between activities, unmatched batch sizes can lead to more WIP inventory amount and less start of a downstream activity. For example, if the batch size of a preceding activity is 25% of total work amount, and the batch size of a next activity is 50% as illustrated in Fig.1, the preceding activity will finish the work of 25% (its batch size) every week and release it to the next activity. However, the next activity cannot start its work after 1st week, because its batch size is 50% of work. Thus, the next activity has to wait until its preceding activity completes work of its batch size (50%), and it can start after 2 weeks as shown in Fig 1.

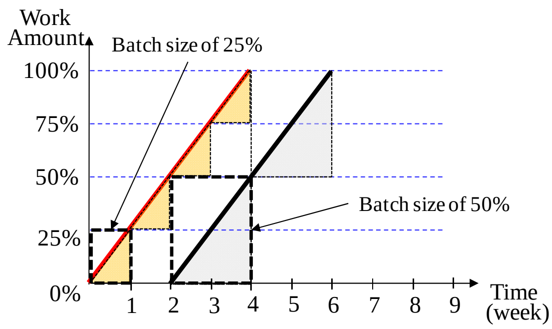

Fig. 1 Example of unmatched batch sizes

In repetitive construction projects batch size is represented and constrained by size of location (or number of units). And typically subcontractors don't share his work area (locations or units) with another subcontractor for fear of productivity loss due to congestions or other issues. Therefore, duration of overall project is affected by compatibility between batch sizes of activities. While different batch sizes or unmatched batch sizes is not rare in repetitive construction projects, there is only a few research on impact of unmatched batch size on project performance. It is identified by many researchers that matched or compatible batch sizes (or progress rates) can reduce duration. However, it has not been investigated if subcontractors have to reduce their batch sizes which are not same each other for time reduction.

2-3. BATCH SYNCHRONIZATION

When batch sizes are not matched or not same each other, it is suggested that batch sizes should be arranged with a regular drum beat for early completion of project [7]. This batch synchronization is *to match batch sizes to multiples of the smallest trade batch* [7]. It is recommended to use synchronized batch sizes for time reduction. And in their case study it is shown that synchronized and bigger batch sizes reduces duration more than unsynchronized and smaller batch sizes. This is due to the inefficiency caused by miss-matched batch sizing. While batch size is a key factor which affects progress of construction project, is it only factor for consideration? As discussed by Howell and et al. [1], matched pace between progress rates of construction activities is one of the key factors for improving construction project performance. Thus it is questioned that synchronized batch sizes always lead to faster completion than unsynchronized batch sizes irrespective of production rates (productivities)? This question was not answered by Ward and McElwee [8], and this paper is to find the answer to the question.

3. RESEARCH OBJECTIVES AND HYPOTHESES

Contractors (or subcontractors) may choose different batch sizes which may not be beneficial for time reduction. And project managers and subcontractors need to determine batch sizes of activities when they plan a schedule. However, there is no research which can provide insight to project participants with regard to managing batch sizes. Therefore, the objective of this research is to examine the impacts of batch size matching on time reduction in construction projects. To achieve this objective, two hypotheses are to be tested: 1) small batch sizes which are not matched each other can reduce time depending on productivities, and 2) synchronized batch sizes leads to earlier completion of project than unsynchronized batch sizes irrespective of productivities.

4. METHODOLOGY

The two hypotheses are tested by a computer simulation. A computer model which simulates interaction between two construction activities with regard to batch size is developed based on the computer simulation model developed by Reinschmidt [9]. Fig. 2 shows the diagram of the computer simulation model. The diagram shows multiple components of activity #1 and the same components of activity #2 are skipped due to limited space. It includes several features which happen in real construction projects: rework cycle, inspections both by internal worker and by worker in a next activity, and uncertainty in production rates.

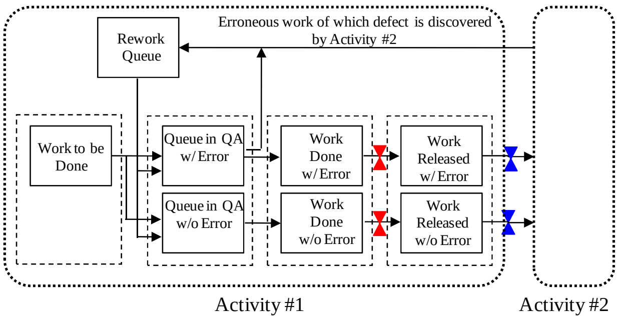

Fig. 2 Diagram of the simulation model

This simulation model is run in the Monte-Carlo approach to reflect uncertainties mentioned above. In addition to the features of the simulation model, the model is run in different cases to reflect different combinations of two activities in terms of productivities as shown in Table 1. It is assumed that productivity in a construction activity distributed normally. While mean values of productivity both in activity #1 and activity #2 varies in the cases, mean value of total duration of project is set to be the same in all the five cases.

Table 1. Productivities for the five cases

	Productivity of Activity #1		Productivity of Activity #2	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Case 1	30	3	10	3
Case 2	20	3	12	3
Case 3	15	3	15	3
Case 4	12	3	20	3
Case 5	10	3	30	3

This simulation model includes other random variables which are set to be uniformly distributed: error rate in base work (5%), error detection rate in QA (90% for activity #1, 100% for activity #2), error rate in rework (2%), error detection rate in inspection by activity #2 crew (100%).

The key input variable of this simulation model, batch size, is set to have following values: 100%, 50%, 25%, 20% and 10%. Combination of two numbers from these different values represents unmatched batch sizes. And inclusion of 25% of batch size provides the cases where batch sizes are not synchronized (for example, 25% versus 20%).

The simulation model was run for total 125 scenarios (=5 (different batch sizes for activity #1)*5 (different batch sizes for activity #2)*5 (cases)) and run 30,000 times per each scenario.

Mean values of project completion time from simulation runs are compared among scenarios based on statistical significance test to determine if two values are significantly different or not.

5. RESULTS

5-1. Hypothesis #1: small batch sizes which are not matched each other can reduce time depending on productivities.

Project completion times from each simulation run was collected and compared among different scenarios. For example, Fig. 3 shows resulted distribution of completion time for different combinations of batch sizes in the Case #1. Activity #1's batch size is 25% and batch size of the activity #2 is varied from 100% to 10%. When the activity #2's batch size is 100%, the mean value of completion time is 269 (no unit) with standard deviation value of 51.64. If a small batch size of 50% for the activity #2 is used to reduce duration, mean of completion time is reduced to 238. However, there is no statistically significant difference among mean values of completion time for batch size of 25%, 20%, and 10% for the activity #2.

Also, Table 2 shows the summary of this comparison. The bigger value of batch size is identified for each situation illustrated in the above example. And mean value of completion time is determined by the bigger batch size out of two activities.

The same result as in this illustrated example is identified for all 125 scenarios. This result indicates that amount of time reduction becomes the maximum when matched batch sizes. And reducing a batch size for one activity which is not matched with the other activity's batch size does not help reducing duration. Compatibility of productivities between two activities does not make any impact on duration. The hypothesis #1 should be rejected.

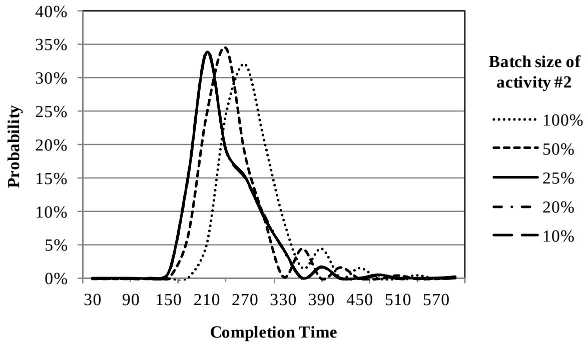

Fig. 3 Distribution of completion time for batch size of 25% for activity #1 in Case #1

Table 2. Summary of mean completion time

Activity	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2
Batch size	25%	100%	25%	50%	25%	25%	25%	20%	25%	10%
Bigger batch size	100%		50%		25%		25%		25%	
Completion time (mean)	269		238		223		223		223	

5-2. Hypothesis #2: synchronized batch sizes leads to earlier completion of project than unsynchronized batch sizes irrespective of productivities.

Fig. 4 through Fig. 7 show the results of the simulations for each case. For example, in the Case #1 as shown in Fig.4, mean value of completion for the combination of batch size of 50% (activity #1) and bath size of 25% (activity #2), ***synchronized batch sizes***, is 238. When batch size of activity #1 is 50% and batch size of activity #2 is 20%, ***unsynchronized batch sizes***, the mean value of completion time is also 238. When these two combinations are compared, there is no significant difference in completion time with regard to mean value. And out of all 25 different combinations, the same result is observed. Therefore, it can be interpreted that using synchronized batch sizes does not help reducing time in the Case #1 in which preceding activity's (activity #1) productivity is faster than downstream activity (activity #2).

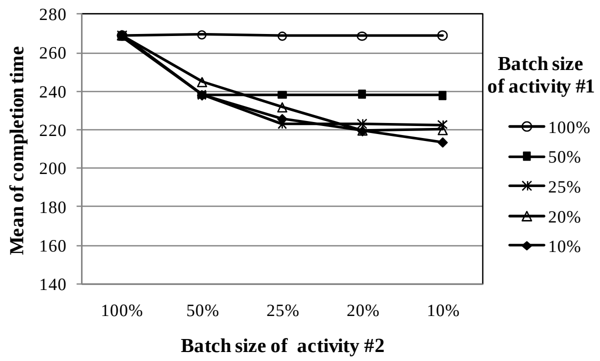

Fig. 4 Completion times for the Case #1

However, in the Case #3 where productivity of the upstream activity is same as that of the downstream activity, a different result is observed. As shown in Fig. 5, if two batch sizes are not synchronized, it leads to longer duration than using synchronized batch sizes. For example, batch size of 50% (activity #1) along with batch size of 25% (activity #2) leads to completion time of 203. However, batch size of 50% (activity #1) along with batch size of 20% (activity #2) concludes to completion time of 211. Therefore, it can be interpreted that synchronized batch sizes can reduce duration more than unsynchronized batch sizes if productivities of two activities are similar each other.

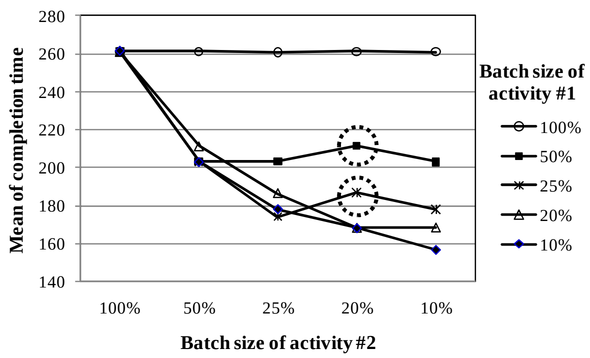

Fig. 5 Completion times for the Case #3

The same result as in the Case #3 is found both in the Case #4 and #5 as shown in Fig. 6 and Fig. 7 respectively. The Case #4 and Case #5 represent the situation in which the downstream activity's (activity #2) productivity is faster than the upstream activity's (activity #1) productivity.

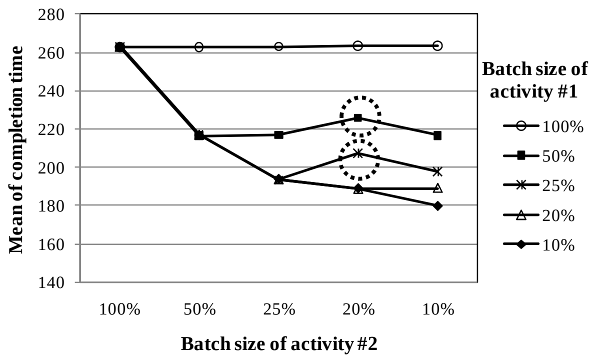

Fig. 6 Completion times for the Case #4

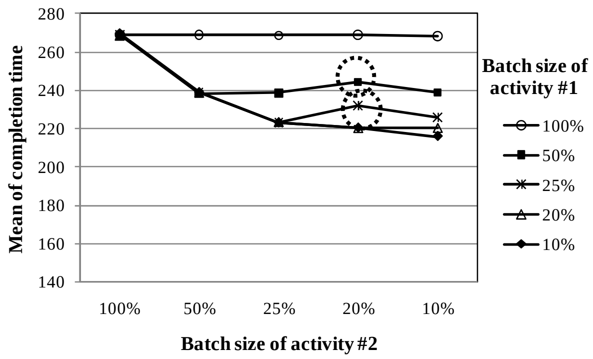

Fig. 7 Completion times for the Case #5

Therefore, it is found that using synchronized batch sizes does not always reduce duration more than using unsynchronized batch sizes. Instead, it depends on compatibility between productivities in activities. Thus, the hypothesis #2 should be rejected.

6. CONCLUSION AND DISCUSSION

The impacts of compatibility of batch sizes on construction project duration are examined through a computer simulation along with two hypotheses.

The first hypothesis, *small batch sizes which are not matched each other can reduce time depending on productivities*, is rejected. From this result, it can be concluded that there is no benefit of using a smaller batch size in one activity than that of the other activity with regard to time reduction. When project manager or/and subcontractors prepare(s) construction plan, it is recommended that activities should be paced with same batch sizes, if possible. When considering possible additional cost or productivity loss for reducing batch size, reducing batch size in one activity further than matched ones does not provide any advantage.

The second hypothesis, *synchronized batch sizes leads to earlier completion of project than unsynchronized batch sizes irrespective of productivities*, is also rejected**.** Reducing batch size or changing batch size may cause additional cost to subcontractors. (Otherwise, why don't they use the smallest batch size?) Furthermore, it is not always realistic to use same batch sizes among all activities. Instead, batch sizes can be changed to be 'synchronized' and it may cause less additional cost than changing a batch size into same batch size as in other activities. Therefore, it is recommended to change (or reduce) batch sizes to be synchronized to reduce duration if downstream activity's productivity is similar to or faster than upstream activity's productivity. However, if upstream activity's productivity is faster than a next activity's productivity, it is not recommended to change (or reduce) batch size into synchronized ones.

One of the limitations in this research is the impacts of matched batch sizes on duration is examined only for two activities. While developing a simulation model including more than two activities is required, it is believed that the findings from this research can be also used for interaction between two activities in a bigger (more than two activities) project. And in the case of bigger projects, the question would become what the optimal batch sizes is or how to determine the optimal batch sizes.

One of the barriers to implementing batch size reduction is the inability of general contractor to understand the impacts of changing batch sizes into project performance [8]. The findings from this research can provide insights about coordination for batch sizes among subcontractors.

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