Improving Productivity of Construction Operation Using Simulation Model

Civil and Environmental Engineering

By

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An undergraduate thesis submitted to the Department of Civil & Environmental Engineering of Islamic University of Technology, Board Bazar, Gazipur in partial fulfillment of the requirements for the degree

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DECLARATION

We hereby declare that the undergraduate project work reported in this thesis has been performed by us and this work has not been submitted elsewhere for any purpose (except for publication).

October, 2012

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Dedicated

To

Our Beloved Parents

ACKNOWLEDGEMENT

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ABSTRACT

Different activities involved in a construction operation are interdependent and some activities require common resources which make it difficult to schedule the construction operation effectively. Eventually it leads to lengthen project duration and make inefficient use of resources. Therefore improving construction productivity to reduce duration and cost is very important for a project. Total Ineffective Time of a construction project can be minimized through proper planning & scheduling prior to construction. Manual calculation and planning is complicated and time consuming considering the interaction of different work activities. This situation has motivated the study to figure out the usefulness of simulation models for minimizing project duration. Simulation models can be an efficient tool to generate effective plans and schedules as they consider complex interactions among various units on the jobsite to evaluate the performance of the construction operation.

A simulation model has been developed using STROBOSCOPE simulation language in this study. The model has considered various activity interactions and resource combinations for the analysis. The construction of from real life project has been selected as case project for the study. The construction operation that has been selected for the model development is mainly sub-structure work which consists of piling work, earth excavation, bracing work. Simulation has been run for different combination of resources and interaction among different activities. The results show that simulation model is very effective to select the optimum combination of resource that produces minimum project duration. The simulation model is also effective to find out the amount of concurrent execution of activities to further shorten the project duration. It is hoped that the study will be a guideline for the construction projects to ensure minimum duration.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

This chapter briefly discusses about the background of the study and why this study is important. It also covers different problems faced during construction productivity improvement, what are the general consequences if productivity in construction operation is not improved properly. Objectives and scope of the study are mentioned at the end of the chapter.

1.2 BACKGROUND

For any construction project improving construction productivity is very important to minimize the project duration and cost. Productivity is generally a measure of the efficiency of production, a ratio of input to output. For a construction operation inputs may be different human and non-human resources such as labor, materials, equipment, tools, capital, designs etc. (Shou Qing, 1999). These resources should be utilized in a proper way (i.e. proper combination of resources must be ensured) to ensure an optimum productivity. Therefore proper planning and scheduling of the construction operation is necessary. Simulation models can be an efficient tool to generate these types of plans and schedules. Simulation models can analyze different combinations of resources and generate the best combination with minimum cost and idle time associated with each resource.

Use of computer simulation technique is highly recommendable in construction industries because of the complex interactions among various units on jobsites. It is one of the most useful techniques which can be used to evaluate performance of construction operations. Other techniques like real system experimentation or application of mathematical models including queuing theory, Line of Balance (LOB), are either too expensive, time consuming or contain many assumptions that limit their use in the construction site. Construction simulation is usually favored with the availability of modern computers that may simulate the operations realistically. It is also inexpensive, flexible, and requires less computational time (Hassan, 2006).

In the past few years computer simulation technique has become popular in the construction industries of some of the developed countries. However, construction industries in the developing countries like Bangladesh are yet to start using this technique in their construction projects.

1.3 PROBLEM STATEMENT

Construction industries rarely keep all the records of a project that are necessary for proper productivity calculation. They are hardly interested in improving productivity. The industries are also not used to with different tools for efficient calculation of productivity, such as simulation software for two reasons (Hassan, 2006) – (1) lack of credibility of this technique among the contractors, (2) to achieve the level of expertise required from the user is difficult.

There may arise different problems if proper planning is not done for achieving optimum productivity prior to the construction operation – larger number of labors may be required for completion of the project, volume of equipment may increase, equipment capacity may not be fully utilized, some equipment may remain idle due to lack of planning, duration of particular activity may increase which will result increase in the duration of the whole project, cost of particular activity may increase (due to increased number of labor or equipment) thereby increasing the cost of overall project.

Manual calculation of productivity has certain difficulties – it is both time consuming and complicated, there lies possibility of making mistakes. On the other hand, simulation software takes less time, calculation is easier and more accurate.

1.4 OBJECTIVES

The main objective of this study is to develop a simulation model to generate a plan through which minimum duration of a construction operation can be obtained. The specific objectives are:

- To improve productivity through a simulation model by reducing duration of the construction operation.
- To find out the optimum combination of resources for minimum duration.

1.5 SCOPE

The study will focus on reducing duration of a particular construction operation in order to increase productivity. Though the analysis of the whole construction project will give the overall picture of productivity improvement, this will be very complicated to model at this stage. However, modeling a particular construction operation considering the interactions between sub-activities and resource sharing is complex enough to understand the productivity improvement. The detail cost analysis is also beyond the scope of this study. Nevertheless, the proposed model can easily be incorporated with the cost component to see the tradeoff between reduced duration and cost of the project. STROBOSCOPE will be used for developing simulation model.

1.6 THESIS OUTLINE

The rest of the thesis has been organized as follows.

- Chapter 2 – Literature Review; the chapter discusses about construction productivity, usefulness of simulation modeling to improve construction productivity.
- Chapter 3 – Methodology; discusses the procedural steps of the study.
- Chapter 4 – Model Development and Data Analysis; it discusses the model development in detail, analysis of various combination of resources and activity interactions.
- Chapter 5 – Conclusion and Recommendation; discusses about the effectiveness of the study, and recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter discusses about the importance of project scheduling. What is construction productivity, why it is important to improve construction productivity, and how it can be improved are also described in detail. At the end of this chapter how simulation modeling can help to improve productivity and a short description of different types of simulation software are mentioned.

2.2 PROJECT SCHEDULING

Time, cost and quality are the three factors that determine the success or failure of a construction project (J. Hoffman, Alfred E., Timothy S., & Jeffery, 2007). For reducing construction time and cost, project scheduling is one of the most important tools.

Repeated delays and cost overruns are the characteristic of the construction industry (Kaming, Olomolaiye, Holt, & Harris, 1997), where in most construction operations, the contractor and subcontractors are obliged to finish the project by a certain date specified in the contract. Many contracts often include clauses of penalties for late finishing. Therefore the contractor should maintain a schedule to make sure that his or her project gets finished in due time. Some activities may require equipment or materials to be available just in time. Therefore prescheduling the ordering and delivery dates of the resources is necessary. Moreover some activities may require common resources. Therefore scheduling is required to ensure proper resource allocation without any conflict. Scheduling provides a baseline with which actual work performance can be compared, thereby helps to identify any deviation from the standards. As a result early measures can be taken to mitigate the adverse effects that may occur due to these deviations. Again approval of the owner of the project to the proposal of the prospective or bidding contractor largely depends on how reasonably accurate and realistic the schedule prepared by the contractor is. Owners may also use schedules to verify contractor's delay claims.

So to minimize the delays and cost overruns, in other words to improve construction productivity project team should maintain scheduling (Sofia Binti Osman, 2011).

2.3 PRODUCTIVITY

Productivity is a measure of the efficiency of production. It is a ratio of input to output. Inputs may be of various forms such as - labor, equipment, materials, tools, capital, design etc. However a simple example can be mentioned to clarify the concept of productivity. Let's suppose, on a specific day, at a project site 202 m^3 of concrete were placed by 9 workers in a 7.5 hour shift, then the productivity index = 202/(9×7.5) = 2.99 m^3/wh. There are various factors that influence productivity such as - technology used, government regulations, weather, unions, economic conditions and various internal environmental components (Shou Qing, 1999). For a construction project resource is limited. Productivity improvement is necessary to obtain maximum output with these limited resources. In productivity analysis of a construction operation the output is generally analyzed in terms of duration and the cost of that project. The less the cost and the duration are, the more the productivity is improved. In actual case as the duration of any operation is decreased by incorporating resources or other techniques, which eventually increases the cost of the project. So, for ensuring improved productivity, effort should be made to obtain an optimum condition so that both duration and cost of the construction operation are less.

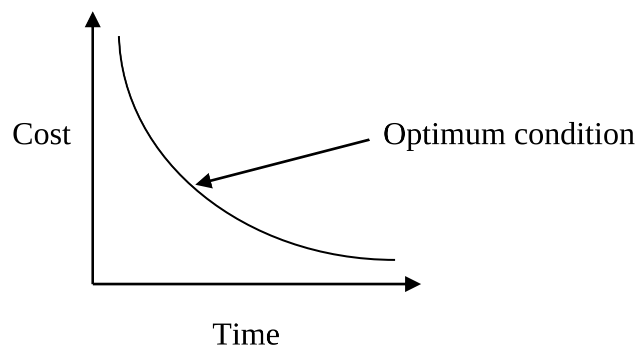


Figure 2.1: Optimum condition of productivity considering both cost and duration

2.4 IMPROVING CONSTRUCTION PRODUCTIVITY

To minimize the time period & total cost of a construction operation productivity improvement is a must. For any construction project resource is limited. Productivity improvement is necessary to obtain maximum output with these limited resources. Any improvement in construction productivity would make a substantial beneficial to the national economy. Higher production output, lower inflation rate and further productivity growth could be benefited from productivity improvement. Construction industries should subsequently improve the productivity to stay competitive in market. With a higher productivity, the local contractors are able to reduce the construction cost compared to foreign contractors.

For improvement of construction productivity it is necessary to find out the basic constraints in the path of productivity (Shou Qing, 1999). It can be described clearly with the following work-time model (Drewin, 1982):

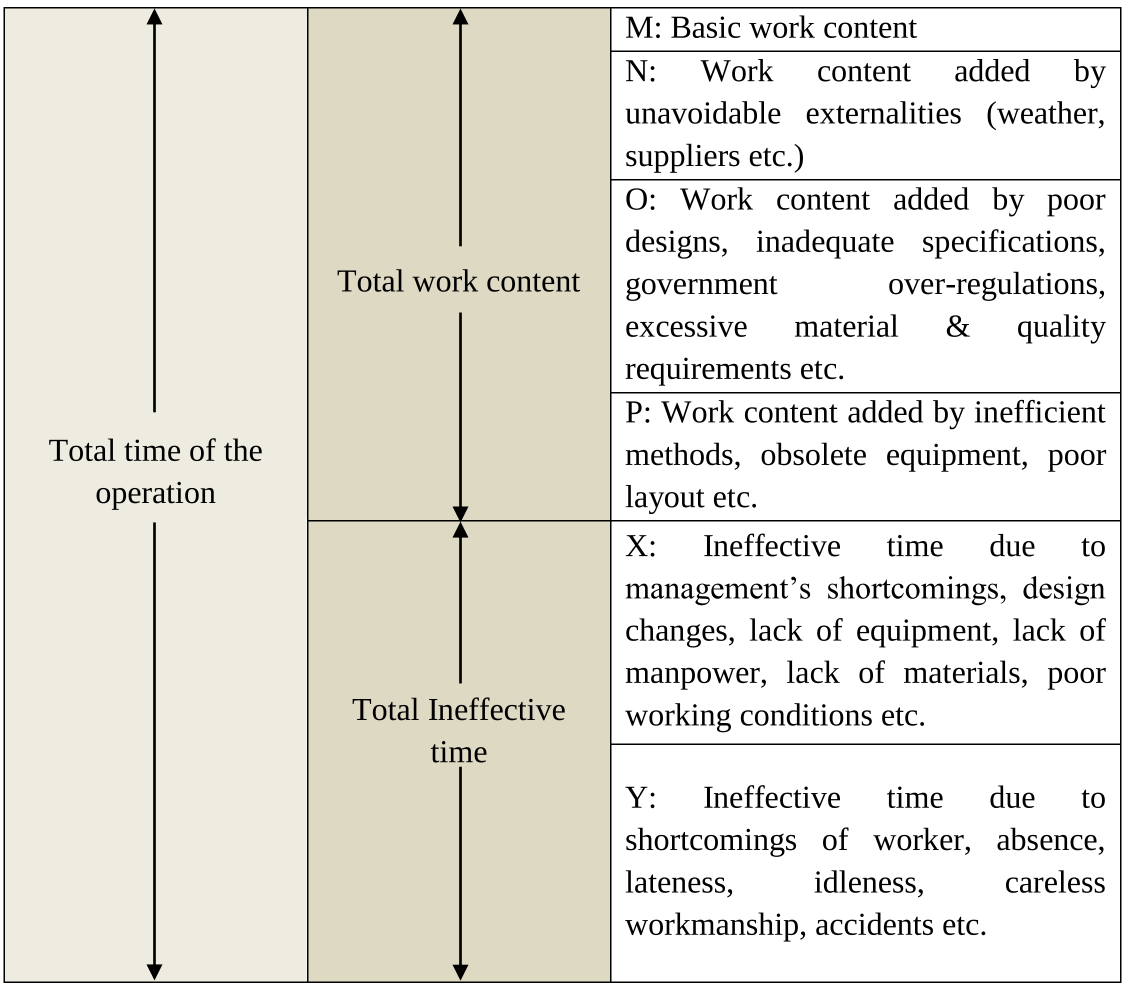


Figure 2.2: Work-time model

In the model the basic work content M is the minimum time required to complete an operation if working conditions are suitable, design is at an optimum, and if there is no time loss, which means an ideal condition which rarely occurs. The basic work content is increased by the conditions shown in sections N, O and P of the model. The time required to complete the work is further increased by the addition of ineffective time, which may occur due to management's shortcomings (X) or shortcomings of the workers (Y). Now N represents increase of time for unavoidable externalities which cannot be controlled, other than this the productivity can be improved by reducing any of the time segments O, P, X and Y shown in the model.

The time segment O can be reduced by producing more specified design, the government can also help by proper regulations and code. But when the construction operation is going on it is not feasible to reduce the time segment O or P. In that case it is easy to overcome management shortcomings through proper management which will eventually improve the productivity (Shou Qing, 1999).

Where construction management is concerned, good planning and scheduling can improve productivity of a construction project. Several other components related to construction management must also be considered to increase productivity. Some of these components are discussed here (Chao, 1997).

1. Assign or recruit the right people to do the job or provide training to improve workers' ability and skill.
2. Adopt motivational or personnel management measures to boost workers' morale. For example, tie compensation to performance; ensure that pay, fringe benefits,

safety, and working conditions are all at least adequate; and enlarge the jobs to include challenge, variety, wholeness, and self-regulation.

3. Use project scheduling techniques such as computer-aided construction project management (CPM) to optimize the times of related activities and make sure that works, tools, and materials allow continuous task performance so as to reduce the idleness of the labor force to a minimum.
4. Keep simple and efficient the communication among employees as well as with related parties.
5. Make the employees know that they are important to the organization and involve them in the making of decisions affecting their jobs such as method improvements.
6. Conduct productivity/performance study at the activity/operation level to produce benchmarks and to develop scientific models as part of the study to describe the detailed tasks performed for an activity/operation by individual or group in order to find out problem areas and propose ways to improve.

In general, to minimize the Total Ineffective Time, proper planning & scheduling prior to construction is required. Thereby proper planning & scheduling can ensure improved construction productivity.

2.5 SIMULATION MODELING TO IMPROVE PRODUCTIVITY

Computer based simulation technique has become popular in recent years in some of the developed countries. Computer simulation is generally a method of modeling a real life situation and developing a framework within which the system can be analyzed. Better decisions can be taken based on the developed system analysis. That's why it is considered as a useful tool that can be used to evaluate performance of construction operations. It is highly recommendable in the construction industries as it can deal with complex interactions among various activities, moreover it helps to develop various alternatives and compare among them to select the best alternative. Techniques like real system experimentation are expensive, time consuming, contain many assumptions that's why these techniques are not feasible for using in the construction site. On the contrary computer based simulation techniques are inexpensive, flexible, and needs less computational time.

Many researchers have developed different computer software to evaluate the productivity of any construction operation. Some of the most commonly used softwares are described below (Hassan, 2006):

1. CYCLONE was the earliest simulation program developed to measure performance of construction activities (Halpin, 1977). Many repetitive construction operations have been studied using CYCLONE yet the method is not able to address the properties of resources and needs significant time to maximize productivity. Thus, it is very difficult to model processes at a detailed level.
2. RESQUE is a methodology developed with resource handling capabilities (Chang, 1987). The methodology is an improvement to CYCLONE since it defines resource distinction and enhances simulation control.

3. CIPROS characterizes resources by representing activities through a common resource pool. It also allows real properties for resources presented at the pool (Odeh, 1992).
4. RISim simplifies the construction modeling method by considering resources as modeling elements and focuses on their interaction (Chua & Li, 2002). It simulates the interaction as operation logic and categorizes resources depending upon their inherent function.
5. More recent enhancements in the applications of construction simulation like STROBOSCOPE have considered diversity of resources and model resource selection schemes that resemble actual construction operations (Martinez & Ioannou, 1999).
6. SIMPHONY is an advanced simulation tool that provides an intelligent environment through the utilization of construction Special Purpose Simulation (SPS) tools (AbouRizk & Hajjar, 1999). It has also facilitated the construction simulation process by creating standard templates that can be directly used. Tommelein (1998) has shown the application of construction simulation in lean construction incorporating concepts like workflow variability and supply chain management.

Computer based simulation has helped the practitioners to evaluate productivity and suggest alternatives to improve them by conducting performance analysis. These advantages have been enhanced by integrating construction simulation with optimizing tools like genetic algorithms (GA). A hybrid structure that assimilates simulation with GA to find the best resource combination for a construction operation was first presented by Cheng (2003). In this system, the strings represent the set of resources and potential solutions to the problem and the one with better fitness value are more likely to produce better result in terms of system performance.

2.6 SUMMARY

In this chapter definition of productivity and importance of construction productivity were discussed in short. The construction industries are hardly interested in improving productivity, which results delay in the project duration. In order to reduce construction time and cost, project scheduling is an important tool. Different problems may arise if proper scheduling is not done – it may require larger number of labor and resources for project completion, equipment capacity may not be fully utilized – all these will eventually lead to the increase in project duration and cost. Computer based simulation technique is a very useful tool for developing efficient schedule which will ensure both minimum cost and duration. Simulation software can generate different alternatives and helps to select the best alternative. However this type of analysis can also be done manually but it is both time consuming and complicated, where simulation software takes less time, calculation is easier and more accurate. Most of the previous studies have mainly focused on the identification of different factors affecting construction productivity and their intensity. A similar study has been conducted by Herbsman and Ellis (1990). Very few studies were conducted describing efficient technique for calculating productivity. This study will mainly focus on how construction productivity can be calculated efficiently using simulation model.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The chapter discusses about the procedure that has been followed to conduct the study. It describes about how problem is formulated and data was collected, by which means the model will be developed and analysis will be conducted.

3.2 METHODOLOGY

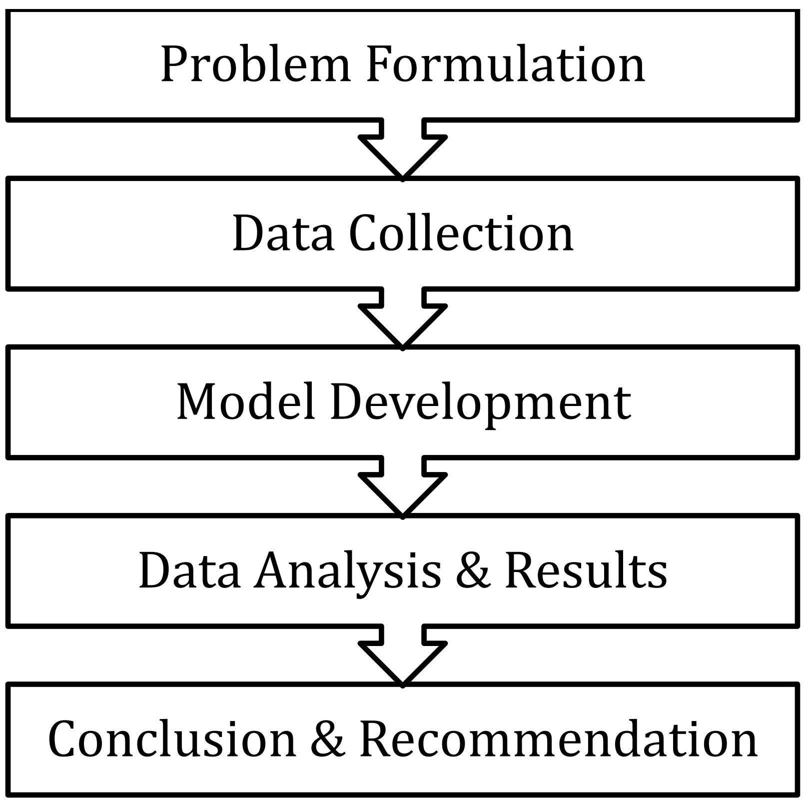


Figure 3.1: Flowchart of the methodology of the study

Figure 3.1 shows the methodological flowchart of the study which includes problem formulation, data collection, model development, data analysis & results, conclusion & recommendation. The topics are discribed in detail below -

3.2.1 Problem Formulation

The study will focus on minimizing the duration of a construction operation in order to increase productivity. The best combination of resources and activity interaction that will result minimum duration will be chosen.

A simple example is shown below to clarify how the best alternative will be chosen amongst various alternatives. Here the calculation is done manually. In this study a software based analysis will be conducted.

A subcontractor has to install an 1800 m waterline. The trench to be excavated will be 2 m deep and 1.3 m wide. A 1 m^3 excavator is used with several 10 m^3 dump trucks. The soil at the site is lean clay with a swell of 25%. The excavated material must be hauled 5 km from the trenching site. Assume 50-min hour for efficiency, speed of truck (full) is 30 km/hr, its speed is 50 km/hr when it is empty and the dumping time is 2 minute. The amount of dump trucks for which maximum productivity within a shorter time & lower cost can be achieved has to be determined (Chua D., 2006).

The problem can be solved manually in the following way –

Combination 1: Using 1 truck and 1 excavator

Excavator cycle:

Dig = 30 s

Swing = 20 s

Dump = 15 s

Swing = 20 s

Cycle time, $t_{excavator}$ = 30 + 20 + 15 + 20 = 85 s

Accounting 50-min hour efficiency, $t_{excavator}$= 85 × 60/50 = 102 s

Truck cycle:

1 excavator = 1 m^3 and 1 truck = 10 m^3;

Then, time to load 1 truck = 10/1 × 102 = 1020 s = 17 mins

Haul (full) = 5/30 × 60 = 10 mins

Dump = 2 mins

Return = 5/50 × 60 = 6 mins

t_{truck} = 17 + 10 + 2 + 6 = 35 mins

Accounting for job efficiency

t_{truck} = 35/50 × 60 = 42 mins

So, the cycle time of a truck (= 42 mins) is much higher than the time required by the excavator to load a truck (= 17 mins).

Therefore, excavator remains idle for some time.

Daily production:

If working shift is 7 hr/day.

P_{daily} = 7 × 60 / 42 = 10 truckloads = 100 m^3 or 100/1.25 m^3 = 80 m^3

[Here, swelling = 25%]

Total duration:

Total excavation = 1800 × 2 × 1.3 = 4680 m^3

Total duration = 4680/80 = 58.5 days

Cost:

Let's assume daily cost for

Foreman, spotter = $230

Excavator with operator = $1200

Truck with operator = $700

Then, Daily cost = 230 + 1200 + 700 = $2130

Unit cost = 2130/80 = $26.6/$m^3$

Total cost = 58.5 × 2130 = $124,605

Combination 2: Using 2 trucks and 1 excavator

Excavator cycle:

$17 \times 2 = 34$ mins

Truck cycle:

42 mins

So, Excavator remains idle.

Thus 2 trucks are loaded in 42 mins

Daily production:

$P_{daily} = 2 \times 7 \times 60/42 = 20$ truckloads = 200 m^3 or 200/1.25 m^3 = 160 m^3

Total duration:

4680/160 = 29.25 days

Cost:

Daily cost = $230 + 1200 + 2 \times 700 = \$2830$

Unit cost = 2830/80 = \$17.7/m^3

Total cost = $29.25 \times 2830 = \$82,778$

Combination 3: Using 3 trucks and 1 excavator

Excavator cycle:

17 × 3 = 51 mins

Truck cycle:

42 mins

So, Trucks remain idle.

Thus 3 trucks are loaded in 51 mins

Daily production:

P_{daily} = 3 × 7 × 60 / 51 = 24.7 truckloads = 247 m^3 or 247/1.25 m^3 =197.6 m^3

Total duration:

Total duration = 4680 / 197.6 = 23.7 days

Cost:

Daily cost = 230 + 1200 + 3 × 700 = $3530

Unit cost = 3530/197.6 = $17.9/$m^3$

Total cost = 23.7 × 3530 = $83,661

From the above results Combination 3 can be chosen as the productivity is higher and required time is less, although the total cost is higher than that of Combination 2.

Similarly for further precision the results for 4, 5 or more trucks can be checked or the number of excavators can be increased but the process will be very much lengthy, time consuming and the analysis will be ambiguous.

Similar analysis can be done in an easier way and more precisely by developing a simulation model. It also helps in decision making in a simpler manner.

3.2.2 Data Collection

Data was collected from a project site at Doinik Bangla More, Motijheel, Dhaka. It is a 25 storied commercial building with 3 basements named “Bangladesh Shipping Corporation Building”.

Different information were collected in order to develop a model and analyze productivity; such as equipment type and capacity, number of equipment and labor associated with each activity, daily work-shift, total work volume, estimated duration of each activity and the entire project. The site engineers and the project manager were consulted to know about the operation of the activities, selected for this study.

3.2.3 Model Development

STROBOSCOPE will be used to develop simulation model in this study. There are different modeling elements in order to model a construction operation such as NORMAL, COMBI, LINK, QUEUE etc. which will be described in detail in chapter 4. Different combinations of resources and activity interactions will be considered for the model development.

3.2.4 Data Analysis and Results

After the development of the model different combinations of resources and activity interactions will be analyzed to obtain best combination. The results obtained from the data analysis will be explained in detail. The combination that will result in minimum duration using minimum resources will be considered as the optimum combination.

3.2.5 Conclusion and Recommendation

The effectiveness of the model will be described in conclusion. How people can be benefited using the simulation model to improve productivity and manage the construction project in a better way will be discussed in detail. Possible enhancement of this study or future research guideline will also be recommended.

CHAPTER 4

MODEL DEVELOPMENT AND DATA ANALYSIS

4.1 GENERAL

This chapter discusses how the model has been developed in detail. Analysis of different combination of resources and activity interactions to obtain minimum duration of the project is also discussed broadly.

4.2 PROJECT DESCRIPTION

Construction of a 25 storied commercial building with 3 basements named “Bangladesh Shipping Corporation Building” has been selected as case project for this study. The construction site is located at Doinik Bangla More, Motijheel, Dhaka. The owner of the building is Bangladesh Shipping Corporation. The architectural and the structural designs were prepared by Department of Architecture and Public Works Department respectively. The estimated duration of the project is 36 months.

The construction operation that has been selected for the model development is mainly sub-structure work and it consists of three different phases such as piling work, earth excavation, bracing work.

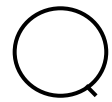
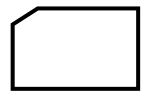
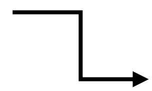
For piling operation they used a boring rig and a concreting funnel. Piling includes placement of casing, concreting and boring – 5 to 6 hours are required for the entire process. There were total 93 shore piles and 4 bracing piles. Placement of bracing includes four phases – placement of angles, placement of I-sections, placement of main bars and welding. The entire operation requires about 4 weeks. Excavation was conducted in two phases. The volume of excavation of each phase was 95,625 ft^3 (85'×75'×15'). Truck and excavator were used for the operation. Cost of local labor was 250 taka/day. Daily work shift was of 7 hours.

4.3 MODEL DEVELOPMENT

The operation has been modeled by STROBOSCOPE and visualized by Microsoft Visio 2007. The model has been developed using different modeling elements such as NORMAL, COMBI, LINK, QUEUE etc. Resources have been represented by QUEUE. Each activity of the operation has been represented either by COMBI or by NORMAL in the simulation model. When an action is followed by a QUEUE then only COMBI is used, otherwise NORMAL is used. LINK has been used to connect network nodes. It indicates the direction in which a type of resource flows.

The symbols of different modeling elements used in this study for the model development are shown in table 4.1 and the detail of the model is shown in figure 4.1.

Table 4.1: Modeling Elements

Element Name	Symbol
QUEUE	
COMBI	
NORMAL	
LINK	

The construction operation can be divided into three phases. These are:

1. Pile construction
2. Earth excavation
3. Placement of bracing

Again, pile construction involves the following sub-activities:

a. Boring

b. Placement of casing

c. Concreting

And the bracing work involves the following sub-activities:

a. Angle placing

b. I-section placing

c. Bar placing

d. Welding

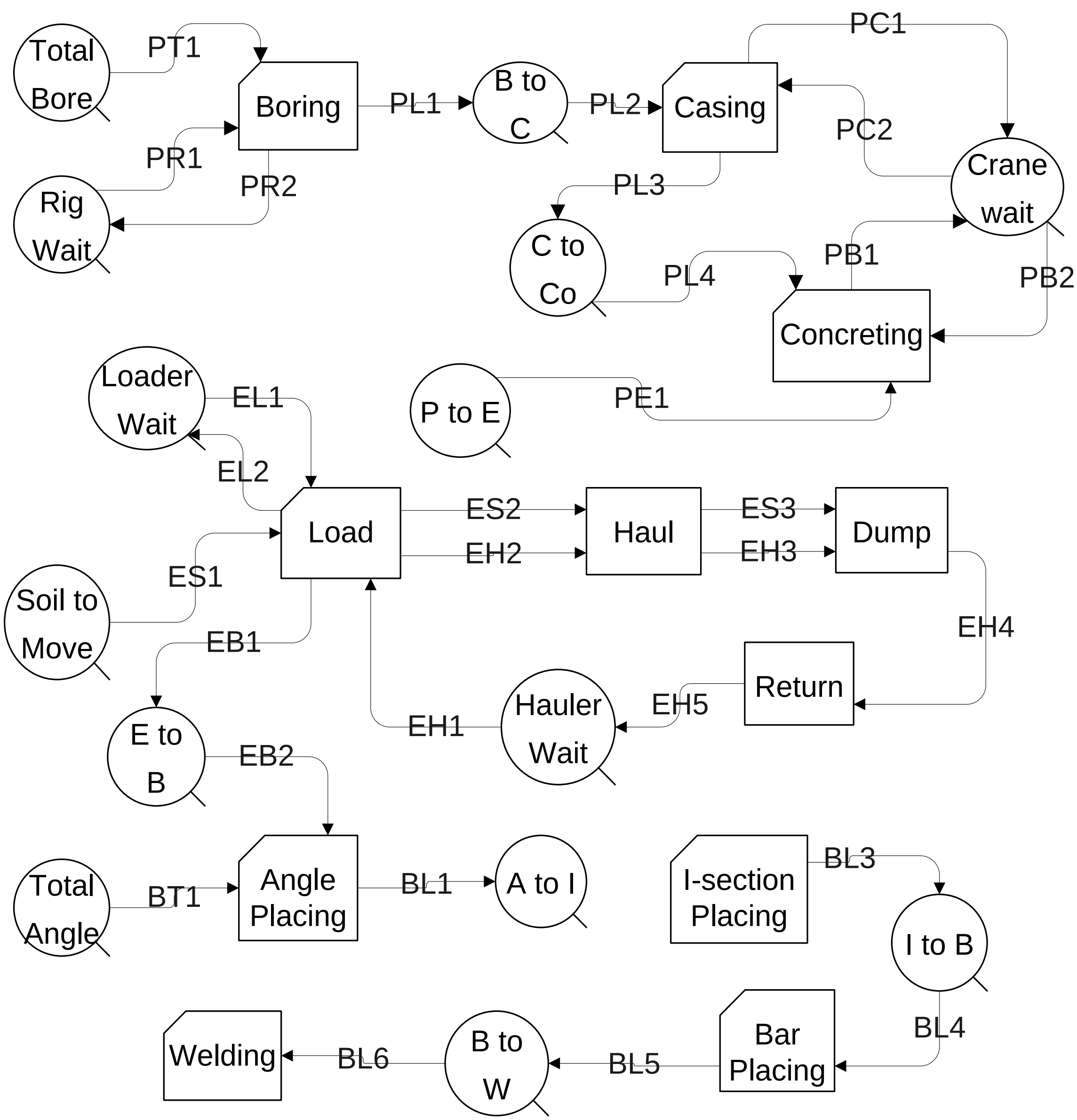


Figure 4.1: Model of the construction operation

Two types of resources have been used for pilling. They are:

a. Hydraulic rig (required for boring)
b. Crane (used for casing and concreting)

The excavation cycle involves the following activities:

a. Load
b. Haul
c. Dump
d. Return

Two types of resources have been used for excavation. They are:

a. Excavator (for the purpose of excavation and filling)
b. Truck (used for hauling and dumping)

Durations for each activity of the sub-structure work are shown in table 4.2. The durations provided here have been collected by interviewing project engineer and relevant workers on the site. Those who have been interviewed were experienced in their respective fields.

Table 4.2: Different activities and their duration

Activities	Duration (Minutes)
Boring	210
Casing	30
Concreting	60
Load	20
Haul	30
Dump	5
Return	20
Angle placing	15
I-section placing	180
Bar placing	180
Welding	60

The project starts with pilling and the first activity of pilling is boring so without starting boring following sub-activities cannot start. Hydraulic rig is required only for boring. On the other hand crane is required for both casing and concreting. Therefore, if a single crane is used for the whole project the casing and concreting cannot be started simultaneously. Now the time required for boring is less compering total time required for casing and concreting. So when one crane is used hydraulic rig may sit idle. One the other hand if two cranes are used, it will speed up the construction operation as two piles can be completed concurrently. Eventually idle time for rig will reduce. If more cranes are used, then some crane may sit idle as excavation may not be completed by using a single hydraulic rig. In that case, more hydraulic rigs may be required in order to cope with the number of cranes. So an optimal combination of hydraulic rig and crane is to be determined in order to minimize the idle time of the resources.

Similar scenario can be seen in case of the resources (truck and excavator) of the excavation phase.

Optimal combination of resources should be selected based on duration of the operation. A detail analysis for different combination of resources is necessary in order to select an optimal combination of resources that will result minimum duration for the project.

4.4 DATA ANALYSIS AND RESULTS

The simulation model is incorporated with three major sub-structure activities viz. placement of shore piles & bracing piles, excavation and placement of bracing. These activities are linked to one another. Again different kinds of resources are required to carry out these activities. For pilling operation cranes and rigs are required. For this study, it has been assumed that the maximum number of available rigs or cranes for the piling work is 4. Again, for excavation haulers and loaders are required, and for simulation purpose the maximum number of available loaders has been assumed to be 3.

Pilling is the first activity of this project. Without finishing pilling other activities cannot start. So for starting excavation pilling is needed to be finished. Now during excavation soil will be removed so the piles will be uncovered. Therefore the concrete of the piles should attain sufficient strength before that. It has been considered that within 8 days most of the piles will attain sufficient strength and excavation can be started. It will be better to start excavation from the place where initial piles were constructed. Now as without pilling no other activities can be started so in this study it has been considered that the pilling will be carried out on a go. For that reason simulation has been run for pilling cycle separately. In the table 4.3 the duration of piling is shown for different combinations of resources.

Table 4.3: Duration of piling operation for different combination of resources

Cranes	Rigs	Duration (Days)
1	1	48.714
1	2	24.714
1	3	21.286
2	3	16.714
2	4	12.714
3	4	12.714

The result found from table 4.3 shows that the combination of 2 cranes and 4 rigs provides the least duration (12.714 days). This duration can be used all through the project and to simplify the calculation the number of cranes and rigs has been kept constant to 2 and 4 respectively.

After completion of pilling work excavation will start. For excavation loader and hauler are required. It has been assumed that maximum no of loader is 3. Now the simulation has been run for excavation cycle using different combinations of loaders and haulers. In the table 4.4 the duration of excavation is shown for different combinations of resources

Table 4.4: Duration of excavation for different combination of resources

Loaders	Haulers	Duration (Days)
1	1	120.216
1	2	60.197
1	3	40.178
1	4	32.046
1	5	32.046
2	5	24.150
2	6	20.160
2	7	17.319
2	8	16.112
2	9	16.112
3	9	13.495
3	10	12.169
3	11	11.078
3	12	10.785
3	13	10.785

From the table 4.4 it can be seen that, when the number of haulers becomes four times the number of loaders the duration doesn't decrease unless the number of loader is increased further. It can also be seen that, if 3 loaders are used in combination with 12 haulers then least duration can be obtained. If the number of haulers is increased further, the duration will not decrease rather it will add to the cost.

Resource is limited for any construction project. For different combinations of resources the project duration will also be different. Again, different activity interactions have also influence on the project duration. Sometimes the project duration is less when the activities are carried out sequentially. Sometimes it may be less if two or more activities or sub-activities are carried out concurrently rather than sequentially. It depends on the type of the activities. So it is important to figure out for which combination of resources and for which activity interaction reduces the project duration. In this study four different cases have been considered for simulation.

In case 1, both activities and sub-activities have been considered to be finished in sequential manner. No two activities will be started concurrently. The project will be started with pilling. Excavation will be started after waiting for 8 days to allow curing of piles. Then bracing will be completed sequentially.

In case 2, firstly full piling will be completed. After that excavation will start. When half of the excavation is finished placement of bracing will be started with angle placing. When 47 angles (half of the total angles) are placed, the model will check whether rest of the excavation is finished or not. If finished, then the bracing will continue, if not it will wait until the excavation is finished.

In case 3, full piling and full excavation have been considered to be carried out sequentially. After that the bracing will be started. When angle placing will be completed, the I-section placing will be started. When 6 I-sections is placed, bar placing will start. When 6 bars will be placed, the model will check whether the I-section placing has been completed or not. If completed, the bar placing will continue, if not it will wait until the I-section placing is completed. After finishing bar placing all the joints will be welded.

In case 4, firstly full piling will be carried out. After that excavation will start. When half of the excavation is finished, bracing will be started with angle placing. When 47 angles are placed, the model will check whether rest of the excavation is finished or not. If finished, then the angle placing will continue, if not it will wait until the excavation is finished. Then the I-section placing will be started. When 6 I-sections will be placed, bar placing will start. When 6 bars will be placed again the model will check whether the I-section placing has been completed or not. If completed, the bracing activity will continue, if not it will wait until the I-section placing is completed. After bar placing is finished all the joints will be welded.

Case 1: Full piling → Full excavation → Bracing[1]

Case 2: Full piling → Half excavation → 47 angles placing[1] → Second half of excavation → Rest of the bracing[1]

Case 3: Full piling → Full excavation → Bracing[2]

Case 4: Full piling → Half excavation → 47 angles placing[2] → Second half of excavation → Rest of the bracing[2]

[1]When bracing will start it will continue through angle placing then I-section placing and then bar placing. Total number of I-sections are 12 and bars are also 12, in this case 12 I-section will be placed and then the bar placing will be started.

[2]When 6 I-sections are placed, bar placing will be started. When 6 bars will be placed, the model will check whether placement of all the 12 I-sections has been completed or not. If completed, the placement of the rest 6 bars will be started, if not it will wait until the I-section placing is completed.

Durations obtained for different cases using different combination of resources have been shown in tables 4.5, 4.6, 4.7 and 4.8.

Case 1: Full piling → Full excavation → Bracing[1]

Table 4.5: Duration for case 1 using different combination of resources

Loaders	Haulers	Cranes	Rigs	Duration (Days)
1	1	2	4	161.407
1	2	2	4	101.388
1	3	2	4	81.369
1	4	2	4	73.237
1	5	2	4	73.237
2	5	2	4	65.341
2	6	2	4	61.351
2	7	2	4	58.509
2	8	2	4	57.303
2	9	2	4	57.303
3	9	2	4	54.686
3	10	2	4	53.360
3	11	2	4	52.269
3	12	2	4	51.976
3	13	2	4	51.976

Case 2: Full piling → Half excavation → 47 angles placing[1] → Second half of excavation → Rest of the bracing[1]

Table 4.6: Duration for case 2 using different combination of resources

Loaders	Haulers	Cranes	Rigs	Duration (Days)
1	1	2	4	159.693
1	2	2	4	99.673
1	3	2	4	79.655
1	4	2	4	71.523
1	5	2	4	71.523
2	5	2	4	63.626
2	6	2	4	59.636
2	7	2	4	56.795
2	8	2	4	55.588
2	9	2	4	55.588
3	9	2	4	52.972
3	10	2	4	51.646
3	11	2	4	50.555
3	12	2	4	50.261
3	13	2	4	50.261

Case 3: Full piling → Full excavation → Bracing[2]

Table 4.7: Duration for case 3 using different combination of resources

Loaders	Haulers	Cranes	Rigs	Duration (Days)
1	1	2	4	157.192
1	2	2	4	97.173
1	3	2	4	77.155
1	4	2	4	69.023
1	5	2	4	69.023
2	5	2	4	61.126
2	6	2	4	57.136
2	7	2	4	54.295
2	8	2	4	53.088
2	9	2	4	53.088
3	9	2	4	50.472
3	10	2	4	49.146
3	11	2	4	48.055
3	12	2	4	47.761
3	13	2	4	47.761

Case 4: Full piling → Half excavation → 47 angles placing[2] → Second half of excavation → Rest of the bracing[2]

Table 4.8: Duration for case 4 using different combination of resources

Loaders	Haulers	Cranes	Rigs	Duration (Days)
1	1	2	4	154.549
1	2	2	4	94.530
1	3	2	4	74.512
1	4	2	4	66.380
1	5	2	4	66.380
2	5	2	4	58.483
2	6	2	4	54.494
2	7	2	4	51.653
2	8	2	4	50.446
2	9	2	4	50.446
3	9	2	4	47.829
3	10	2	4	46.503
3	11	2	4	45.412
3	12	2	4	45.118
3	13	2	4	45.118

From the tables 4.5, 4.6, 4.7 and 4.8 it can be seen that, the least durations obtained for cases 1, 2, 3 and 4 are 51.976, 50.261, 47.761 and 45.118 days respectively. So, case 4 (Full piling → Half excavation → 47 angles placing[2] → Second half of excavation → Rest of the bracing[2]) generates the least duration. So amongst the four cases the best alternative according to minimum duration will be case 4 with a resource combination of 3 loaders, 12 haulers, 2 cranes and 4 rigs.

Another important thing revealed from table 4.5, 4.6, 4.7 and 4.8 is that overlapping of activities and sub-activities reduce duration. If these four tables are observed carefully clear distinction can be made between the duration of project with overlapped activities and project with no overlapped activities. Among above four cases maximum overlapping between activities and sub-activities has been done in case 4 which provided the least project duration. Such overlapping in activities can be done in several ways, this study showed only a few. Maintaining logical sequence in activities is of great importance during overlapping.

Now the selection of an alternative may vary from project to project. Some projects consider that the duration should be least, no matter how much resources are required. Again some projects are flexible that they consider delay for one or two days is not a problem if number of resources can be reduced to some extent. For case 4 if 10 haulers are used instead of 12 haulers the project will be delayed only by one day. But it can reduce the number of hauler by 2, which is significant for the projects that consider delay for some days is not a problem.

4.5 SUMMARY

From section 4.4 it can be seen that different combination of resources influence the duration of the construction operation. As the number of resources are increased the duration of the construction operation decreases. But for every construction project resource is limited (for this study maximum available number of cranes & rigs has been set to 4 and maximum number of loaders has been set to 3). Again sometimes increasing only one resource keeping the number of other resources fixed does not decrease the duration of the construction operation (as the tables 4.5, 4.6, 4.7 and 4.8 show that, when the number of haulers becomes four times the number of loaders the duration doesn't decrease unless the number of loader is increased). On the contrary it may result additional cost. So it is important to sort out the best combination of resources to obtain minimum duration of a construction operation. Moreover, different activity interactions also affect the project duration. Sometimes, it may take less time to complete a construction operation if two or more activities or sub-activities are carried out concurrently rather than sequentially (as from section 4.4 it can be seen that case 2, 3 and 4 require less time to be completed than case 1). Therefore, to find out best activity interaction is also important to reduce the project duration and to improve construction productivity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 GENERAL

This chapter summarizes the outcomes of the study. The effectiveness of the study and how people can be benefited from this study are discussed in short. Possible enhancements of this study and future research guideline are also mentioned in the recommendation part.

5.2 IMPROVING CONSTRUCTION PRODUCTIVITY

In today's competitive market, people are trying to complete their project with minimum duration and cost. To do so, productivity must be improved. However, construction companies hardly focus on improving productivity. Sometimes the company has to pay certain penalty for late finishing. Taking this fact into consideration, the study has focused on how construction productivity can be improved. The main purposes of this study were – to improve the productivity of a construction operation by reducing duration of the construction operation; to develop a simulation model for developing a proper schedule that will minimize the duration of the operation; and to find out the optimum combination of resources for minimum duration.

A simulation model has been developed for a construction operation. The model has considered different combination of resources and complex interaction between different activities. From the analysis of these different alternatives best alternative that result minimum duration with minimum resources have been sorted out. In other words these alternatives if implemented, can result a much higher productivity than that for the actual case.

5.3 EFFECTIVENESS OF THE STUDY

The simulation model that has been developed for the study, can effectively be used to prepare proper schedule, thereby it can be helpful to finish the construction operation within specified time and increase productivity. Optimum combination of resources can be selected by observing idle time of each resource, which will maximize the output. As it can provide a proper planning prior to the construction project begins, resource requisition can be asked at the beginning; thereby delay of operation can be avoided. Again it can help the project manager to allocate resources accordingly. Therefore conflict due to resource sharing among different activities can be minimized. As the resource needed onsite can be known beforehand, smooth working condition can be ensured. In general, this type of simulation model can be an effective tool for reducing construction duration.

5.4 RECOMMENDATION

This study has only dealt with a particular construction operation for the model development. Detailed study can be conducted taking the whole project into consideration. If simulation model is developed for the entire project, there will be more interaction between different activities and more resource sharing among the activities. Again the study has only focused on minimizing the duration. More detailed analysis can be conducted considering both duration and cost. Sometimes cost of a project may increase initially for increasing the number of resources. But finally due to the decrease in the project duration, overall cost of the project may decrease. Again sometimes the overall cost may also increase with the increase of resources. In that case, decision making should be based on which one is more important for the project – reduced duration or minimizing the cost. If the project needs to decrease the overall duration, then the number of resource has to be increased, in that case cost would be high. If the project needs to reduce the cost, then number of resources has to be decreased, so duration of the project would be higher. Thus consideration of both duration and cost for the analysis may result in more alternatives. Therefore, further study can be conducted to remodel the entire project considering both duration and cost in order to obtain a comprehensive analysis and to improve construction productivity more effectively.

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