Productivity Improvement through Minimizing Idle Time of Construction Resource Using Simulation Model

Civil and Environmental Engineering

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An undergraduate thesis submitted to the Department of Civil & Environmental Engineering of Islamic University of Technology (IUT), 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).

November, 2014

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Dedicated

To

Our Beloved Parents

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ABSTRACT

A series or parallel completion of different independent or dependent activities carries out a construction operation. These activities sometimes require common resources which make it difficult to schedule the construction operation effectively. Eventually it leads to inefficient use of resources which lengthens the project duration and increases cost. Therefore improving construction productivity to reduce duration and cost is very important for a construction project. Total Ineffective Time of a construction project can be minimized through proper planning and scheduling prior to construction. Additionally, it would also help the project manager to choose from different alternative plans on the basis of suitable combination and cost. Manual calculation and planning is complicated and time consuming considering the interaction of different work activities, resources and lengthiness of the project. This situation has motivated the study to figure out the usefulness of simulation models for minimizing project duration and cost. 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 MS EXCEL 2013 in this study. The model has considered various resource combinations for the analysis. The construction of a real life project has been selected as the case project for the study. The construction operation that has been selected for the model development is the concrete casting of a slab of a building under construction which consists of mixing concrete in mixing machine, hauling the concrete to dedicated floor, vibrating, spreading & finishing. Simulation has been run for different combination of resources. The results show that simulation model is very effective to select the optimum combination of resource that produces minimum project duration and cost. It is hoped that the study will be a guideline for the construction projects to ensure minimum duration and resources while casting of slabs.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Construction Management is the overall planning, co-ordination and control of a project from inception to completion aimed at meeting a client's requirements in order to produce a functionally and financially viable project that will be completed with minimum possible time and cost and to the required quality standards. Nevertheless, construction projects are somewhat difficult to manage due to the nature of the industry; such as complex and unique projects, mobile workforce, diverse sub-contractors and suppliers.

In order to complete a project with minimum time and cost, one must improve the productivity of construction operation. Productivity is generally a ratio of input to output measuring production efficiency. A resource is an entity that contributes to the accomplishment of project activities such as manpower, material, money, equipment, time or space. Inputs may be considered as the human & non-human resources like labor, materials, equipment, tools, designs, capital etc. Proper combination & utilization of these resources are precondition for obtaining optimum productivity, as the resources are inter-connected with each other. It is very essential to minimize the project duration & cost by improving construction productivity for any kind of construction project.

Construction projects contain numerous inter-dependent and inter-related activities. Projects employ voluminous resources. But they have in-built difficulties, uncertainties and risks. These pose series of problems concerning resources, like how much they are required, 'where they are going to come from', 'when they should be inducted at site', where they should be housed', 'how to optimize their utilization' and 'when to demobilize. Due to the resource-driven nature of construction management, Resource Management is really a difficult task. The construction manager must develop a plan of action for directing and controlling resources of workers, machines and materials in coordinated and timely manner in order to deliver a project within the frame of limited funding and time. The crucial factor in successful implementation of a construction project not only depends on the quality & quantity of work, but also largely depends on availability of resources. All activities involved in the project require certain amount of resources. Each activity is allocated with a specific resource and must be completed within the time limit, otherwise it may adversely affect the overall duration of the project (A. Ray Chaudhuri et al, 2012).

To prepare the exact plans & schedules simulation models are considered as the most efficient tool. The main advantage of simulation models is that they can analyze different combination of resources & produce the best combination with minimum cost & time. Since the interactions among various units on job sites are complex, computer aided simulation technique is highly recommended in construction industries. Other techniques such as real system experimentation or application of mathematical models including queuing theory, Line of Balance (LOB) are too expensive, time consuming & contain many assumptions. 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).

Recently some of the developed countries have already used simulation techniques in the construction industries. However, developing countries like Bangladesh are yet to start using this technique in the construction industries.

1.2 PROBLEM IDENTIFICATION

In context of Bangladesh, the major problem is that the people related with construction work don’t have that much courage to keep the records of a project that are necessary for proper productivity calculation. Even they are not used to with different tools for efficient calculation of productivity because of lack of expertise in such simulation software. Apart from this, there are so many problems associated with construction project such as hidden cost (misuse of material, thievery of different materials), incompetency of labor in case of operating, communication gap, unavailability of equipment, most of the equipment are not well functioned, lack of proper maintenance of equipment, distance between the storage facility & construction site. Due to the lack of proper planning, some other problems may arise such as requirement of large number of labors, increase in the quantity of equipment, some equipment may remain idle and duration of a particular activity may increase. All these problems increase the cost & duration of a project & thereby decrease productivity.

In Bangladesh, usual practice is to take decision on the basis of situation. That means in construction field equipment & resources are used based on priority of the work. Normally they prefer this manually decision making process over any kind of computer aided analysis. But this process is time consuming & desired productivity cannot be achieved. On the other hand, simulation technique takes less time, easier to calculate & produces more accurate results.

1.3 OBJECTIVES

The main objective of this study is to develop a simulation model to improve productivity through which resource optimization of a construction operation can be obtained. The specific objectives are:

- To improve productivity through resource optimization.
- To find the best combination of resource with cost to reduce idle time using a simulation model

1.4 SCOPE OF THE STUDY

The study will focus on resource optimization of a particular construction project 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 proposed model will focus on both time & cost analysis through resource optimization. MS Excel 2013 will be used for developing the simulation model.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses about the importance of construction productivity and resource optimization through minimizing idle time. What is construction productivity, why resource optimization is important to improve construction productivity and how we can minimize idle time 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 CONSTRUCTION PRODUCTIVITY

Productivity is a measure of the efficiency of production. It has been widely used as a performance indicator to evaluate construction operation through the entire construction phase. Construction companies have to track productivity continuously to gauge their performance capacity to maintain profitability and to prepare for future biddings. (Kim et al. 2011)

Productivity is a ratio between input & output.It is important to indicate the input & output to be considered when calculating productivity because there are many inputs,such as labour,materials,equipments,tools,capital & design relating to a construction system. Transforming input into outputs is also complex. However a of simple example can be mentioned to clarify the concept of productivity. Lets suppose on a specific day, at a project sight 202 m^3 concrete were placed by 9 workers in a 7.5 hours shift. Then the productivity index = 202/(9*7.5) =2.99 m^3/wh. This process is influenced by technology used , by many externalities such as government regulations,weather,unions,economic conditions & management. Nevertheless productivity is often associated to only a particular input (e.g. worker hour) & a particular output(e.g. floor area in m2). It has been assumed as a closed system with all factors held invariable except for the identified input & output.(Centeno,2004)

Measures of productivity include:

- Work place per person
- Value-added per person
- Value-added per combined unit of labor & capital inputs, expressed as an index
- Econometric measures using production functions(Page, 2010)

In productivity analysis of a construction operation the output is generally analyzed in terms of duration & cost of that project. The less the cost & the duration are, the more 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 & cost of the construction operation are less.

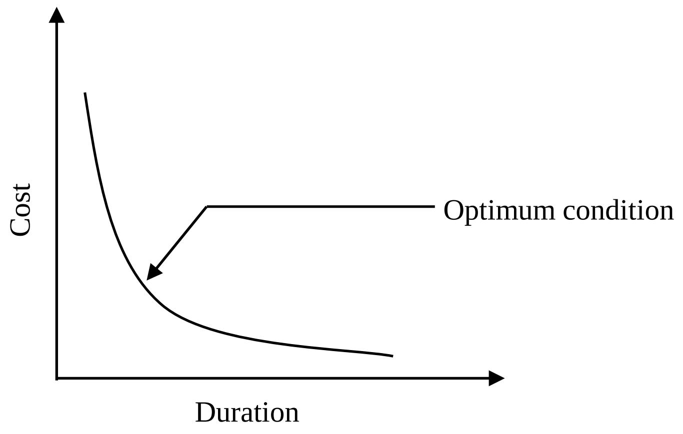


Figure 2.1: Optimum condition of productivity considering both cost & duration

2.3 IMPROVING CONSTRUCTION PRODUCTIVITY

When construction management is worried, good planning, scheduling & controlling can improve productivity on a construction project. Several other components associated to construction management must also be considered when a persistent effort is made to increase productivity (Fisk, 2000). Some of these components are as follows:

- Allocate or recruit the right people to do the job or provide training to improve worker's capability & skill.
- Adopt motivational or personnel management measures to increase worker's moral. For example, tie compensation to performance, guarantee that pay, fringe benefits, safety & working conditions are all at least plenty;& enlarge the jobs to include challenge, variety, wholeness & self-regulation.
- Use project scheduling techniques such as computer-aided construction project management (CPM) to optimize the times of connected activities & make sure that works, tools & materials let continuous task performance so as to reduce the joblessness of the labor force to a minimum.
- Remain simple & efficient the communication among employees as well as with linked parties.
- Make the workers know that they are important to the organization & engage them in the making of decisions affecting their jobs such as technique improvements.
- Conduct productivity/performance study at the activity/operation level to create benchmarks & to develop scientific models.

According to Alfold (1988). Three categories of measurements encompassing six dimensions are enough to describe every aspect of construction performance. These dimensions are as follows:

- Quality:
  1. Accuracy: Measures how narrowly the job conforms to plans, specifications, code requirements & established industry standards for workmanship.
  2. Workmanship: Measures important differences in the worth of the finishes job shaped by master-craftsmanship skills.
- Quantity
  3. Productivity: Measures differences in the rate at which the work is accomplished over time.
  4. Schedule: Measures how closely the job adheres to a best possible construction schedule.

- Resources
    5. Manpower: Measures differences in labor cost not reflected in the measurement of productivity.
    6. Material, tools, & equipment: Collect measurements of construction resources other than manpower (Centeno, 2004).

Considering every aspect of construction performance and measuring dimensions, following top areas can be found where improvement can be worked out.

1. Labor Management, Conditions and Relations

This category can be divided into some divisions such as:

1.1 Incentive programs

1.2 Remote Locations

1.3 Access to job-site

1.4 Labor management and relations

1.5 Resource scheduling (shifts and overtime)

1.6 Training and certification of workforce

2. Project Front-end Planning (Loading) and Work Face Planning

Front end planning is the process of developing sufficient strategic information with which the project team can address project scope and requirements that allows the project to be executed successfully.

3. Management of Construction and Support

In this category, industry professionals have identified many areas for improvement and suggested the proper management of:

- Tools
- Equipment
- Access to site and site layout
- Camp facilities
- Travel
- Health programs
- Scaffolding
- Safety
- Management of change and rework minimization
- Material management and Supply Chain Management
- Quality
- Contract administration
- Progress measurement

4. Engineering Management

- Be ready before starting the project. Incomplete engineering leads to delays and rework
- 80% of engineering complete before mobilizing to site
- 100% of "Issued For Construction" (IFC) drawings and specifications issued on time and must be completed before construction

5. Effective Supervision and Leadership

- Oversight with experience and authority
- Accountability of scope, time and cost
- Make key decisions on time in all phases of construction
- Adequate and experienced supervision
- Effective team based for frontline supervision.
- Ensure adequate field supervision and management of workforce.
- Competent management
- Empower project managers to control all aspects of the project

6. Communication

- Clear lines of communications
- Minimize levels of communication
- Give labor force clearer and more direct instructions
- Good communication between owner and contractor

7. Contractual Strategy and Contractor Selection

- Use Construction Management approach, cost reimbursement with maximum upset and bonus scale
- Break the project into smaller projects (smaller /and areas). Use multi-phase approach
- Hold the contractor accountable and impose liquidated damages
- Use lump sum contracts
- Use contractors that have history of dealing with problems efficiently

8. Constructability in Engineering Design

- Involve operation and construction in detailed engineering
- Provide adequate time & resources to complete constructability reviews and allow early contractor involvement.
- Limit exposure of personnel to elements by maximizing the work under controlled environment. Productivity in a controlled atmosphere (workshop) is higher than field.

9. Government Influence

The factors that influence productivity in projects do not end at the responsibilities of the owner company managers, labor and EPC firms. It extends to include the Government. Industry provided the following suggestions regarding the Government influence.

- Government and industry needs to plan work together to ensure projects flow together and there are no peaks and valleys in work force.
- Remove cross provincial barriers and trade barriers on skilled labor and professional qualifications or make them consistent. Federal responsibilities to allow for easier access to labor forces from all regions of the country to ease labor availability issues.
- Ensure sustainable development (both economically and environmentally) i.e., less development and with more effort on each development.

10. Modularization, Prefabrication, Pre-build in Shops

- Use standardization where possible in plant design and construction and do not reinvent the wheel each time.
- Modularize as much as possible
- Do as much work in vendor's shops to avoid field work (pre-wiring, modularized skids).
- Use consistent construction crews
- Use more prefabricated units

As we discussed the top 10 areas of improvement we can say that proper planning before starting the project and management along the construction period is the key to improve productivity. Among the different sectors we are willing to plan on the proper supply and management of resources and their optimum utilization. We discussed about the resource optimization in the following part.

2.4 RESOURCE OPTIMIZATION

Resources management is one of the most important aspects of construction project management in today's economy because the construction industry is resource-intensive and the costs of construction resources have steadily risen over the last several decades. Often the project planner utilizes the time and precedence based schedule as a basis for the management of resources for the project, (Patrick, 2004).

A Construction Resource Management system automates and dramatically simplifies the process of tracking and managing a construction company's business-critical resources. Combining asset and materials data into one, easily accessible, centralized database, these systems provide detailed information every department needs to ensure that physical construction resources—not just tools and equipment—yield the maximum value possible.

It is essential to prepare feasible resource plans based on schedule plans and budgetary limitations for construction projects. In practice, additional temporary resources are typically purchased to support resource plans, shorten project duration or possibly decrease total cost. That is, this practice is sometimes referred to as "project duration compression". Therefore, outsourcing actions such as temporary subcontracting are generally considered and executed to eliminate deficiencies in the initial resource plan. For example, adding crews and construction equipment can be regarded as outsourcing actions for improving project performance. (Liu & Wang, 2007)

Every project schedule has its own precedence constraints, which means that each activity can be processed when all its predecessors are finished. In general the purpose of project scheduler is to minimize its completion time or make span, subject to precedence constraints.
A more general version assumes that to develop one or more activities, resources such as tools, equipment, machines, or human resources are needed. Each resource has limited capacity; consequently at a certain moments one activity may not begin their processing due to resource constraints even if all their predecessors are finished, (Franco et al, 2006). (Tahreer Mohammed Fayyad, IUG, 2010**)**

2.5 SIMULATION MODELING TO IMPROVE PRODUCTIVITY

Decision- making process is an essential part of any construction operations. (Hassan, 2007) Simulation is important and useful techniques that can help users understand and model real life systems. Once built, the models can be run to give realistic results. This provides a valuable support in making decisions on a more logical and scientific basis. It is the imitative representation of the functioning of one system or process by means of the functioning of another, such as a computer simulation of a construction project. With simulation, one can examine a problem that is often not subject to direct experimentation.

Simulation models can also be used as a tool to assist construction managers in making informed decisions. This approach offers a fast and inexpensive means of studying the performance of the operation and the response of the system to change in resources and equipment allocations. (Hassan, 2007)
Simulation can be a very effective tool to plan for productivity. Moreover, simulation studies have been conducted to understand better the effect of various factors on productivity. Simulation can also be used to support claims due to loss of productivity from bad weather, unexpected delays, changed conditions, changes in the contract, and other factors. Similar studies can be conducted to analyze the effect of particular human factors on productivity. (Dozzi and AbouRizk, 1993)

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

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 and 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.

7. MS Excel 2013 is also an advanced tool which is used for various purposes. It's a computer based simulation tool which helps the practitioners to evaluate productivity and suggest alternatives to improve them by conducting performance analysis. It can plot cost vs. time graph from the data that's been collected. Which is very useful to choose the optimum combination of resources. It's one of the easiest tool in the field of simulation.

The State and Resource Based Simulation of Construction Processes (STROBOSCOPE) software product is an advanced simulation tool that can dynamically determine the state of the simulation and the properties of the resources involved in an operation (Martinez 1996). The state of the simulation defines parameters such as number of trucks waiting to be serviced, the repetition of an activity, and the time of the simulation as related to the system being modeled. This software product was specifically designed to simulate construction operations and makesuse of concepts found in Structured Query Language (SQL) to select resources for operations and aggregate their properties. The flexible and object oriented C++ language was used as the simulation language to implement the design objectives and to consider the diversity of resources and their characteristics, allow simulation to control the sequence of tasks, show resource and material, utilization, consumption and production.(Hassan,2007)

2.6 SUMMARY

In this chapter, productivity & ways of improving productivity by resource optimization through minimizing idle time are discussed briefly. The construction industries are hardly interested in improving productivity, which results delay in the project duration. In order to improve productivity resource optimization is very important. In our country resource optimization is not practiced properly due to lack of proper planning which results in increase of time & cost and decrease of productivity. On the other hand amount of resources is not adequate in our country. In context of Bangladesh resource management is usually done as per the plan made manually by the project managers on the sites. Generally, they don't adopt any computer aided plan for resource utilization. Interactions among the various resources used in construction sites are too complex to be modeled using classical queuing models. For any construction operation, decision-making is a very essential part. Simulation technique can be used as a tool to make the model of interconnected resources and thus helps to make decision. In Bangladesh simulation model based work is not introduced widely or even not done yet. Our aim is to introduce the effectiveness of simulation modeling in construction work in Bangladesh to optimize the resources.

CHAPTER THREE

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

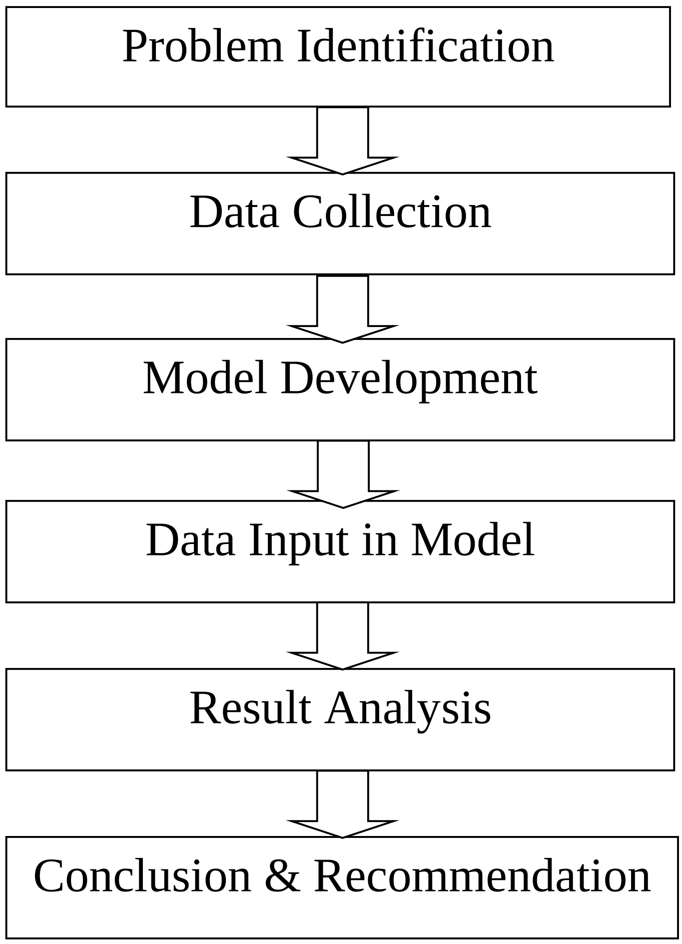


Figure 3.1: Flowchart of the methodology of the study

3.2.1 Problem Identification

The study will focus on resource optimization of a particular process in a construction project to minimize the time & cost of the project in order to increase productivity. The best combination of resources and activity interaction that will result in minimum duration & cost will be chosen.

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

A subcontractor has to install an 1800 m waterline. The trench to be excavated is 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 is 30 km/hr (when full) & 50 km/hr (when empty) and the dumping time is 2 minutes. 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;

So, 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

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

Accounting 50-min hour 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.

Daily production, P_{daily} = 7 × 60 / 42 = 10 truckloads = 100 m^3

Considering the swell, P_{daily} = 100/1.25 m^3 = 80 m^3

Total duration:

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

Total duration = 4680/80 = 58.5 days

Cost:

Let's assume daily costs as follows:

Foreman or 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

<u>Combination 2: Using 2 trucks and 1 excavator</u>

Excavator cycle:

17 × 2 = 34 mins

Truck cycle:

42 mins.

So, Excavator remains idle.

Thus 2 trucks are loaded in 42 mins

Daily production:

P_{daily} = 2 × 7 × 60/42 = 20 truckloads = 200 m^3

Considering the swell, P_{daily} = 200/1.25 m^3 = 160 m^3

Total duration:

4680/160 = 29.25 days

Cost:

Daily cost = 230 + 1200 + 2 × 700 = $2830

Unit cost = 2830/80 = $17.7/m3

Total cost = 29.25 × 2830 = $82,778

<u>Combination 3: Using 3 trucks and 1 excavator</u>

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

Considering the swell, P_{daily} = 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/m3

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.

Above example consists of only one cycle. That's why manual calculation is possible. But if the combination consists of more than one cycle then more equipment & resources will be used & the model will be more complex. In such case 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 Agargaon area of Dhaka city, Bangladesh. It was a 5-storied residential building of which the slab casting was ongoing. The building was being constructed on 1440 sq ft.

All possible and necessary 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, labor cost per day, equipment cost, 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

MS Excel 2013 will be used to develop simulation model in this study. Different combinations of resources and activity interactions will be considered for the model development. All type of activity & equipment used in the project will be incorporated in the model.

3.2.4 Data input in model

After developing the model in MS Excel 2013, different combinations of resources & activity interactions will be used to obtain results. All the corresponding information of time & cost will be included in the final model.

3.2.5 Result Analysis

The results obtained from using different combinations in MS Excel 2013 model will be explained in detail. The combination that will result in minimum duration & cost through optimum use of resources will be considered as the optimum combination.

3.2.6 Conclusion & Recommendation

The effectiveness of the model will be described in conclusion and recommendation. 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 FOUR

MODEL DEVELOPMENT & 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 optimum combination of time and cost of the project is also discussed broadly.

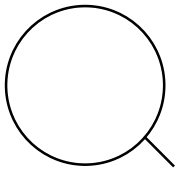
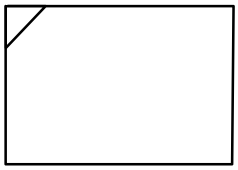
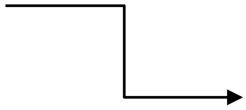
4.2 MODEL DEVELOPMENT

From the example shown in the section 3.2.1, it can be seen that if the calculation is done manually it will be tedious and time consuming. A construction project usually contains many activities and these activities may have different complex interactions among them. Moreover, some resources may be shared in different activities. So a simulation model has been developed in this study to represent a construction project and to analyze the result found from the simulation model.

A construction operation has been modeled by MS Excel 2013 and visualized by Microsoft Visio 2003. 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	

4.3 PROJECT DESCRIPTION

For the case study we had selected the construction of a residential building project. The construction site was located at the Agargaon, Dhaka.

The construction operation that had been selected for the model development was the casting of slab of 5^{th} floor of the building. The estimated duration of the slab casting was 2 days (= 48 hours). Casting of the slab consisted a series of combination of different activities.

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

1. Mixing
2. Hauling to 5^{th} floor
3. Vibrating & finishing

The following resources were used for the project:

Table 4.2: Different resources and activities to be performed

Resources	Activities
Excavator	Excavation
Human Hauler	Hauling the concrete
Human Loader	Loading the concrete
Mixing Machine	Mixing of concrete
Vibrator	Vibrating the slabs

At first, mixing of concrete to be casted was done at the mixer machine. The slab thickness in the design was 4.5 inch on average. So, the total slab volume or concrete to be produced was 50.2 m^3. The mixing process included the resources like mixing machine and human loader. After one mixing cycle, the mixed concrete was carried to the 5^{th} floor. This included human loader and hauler resources. After casting the concrete on the slab area, vibration was done followed by finishing.

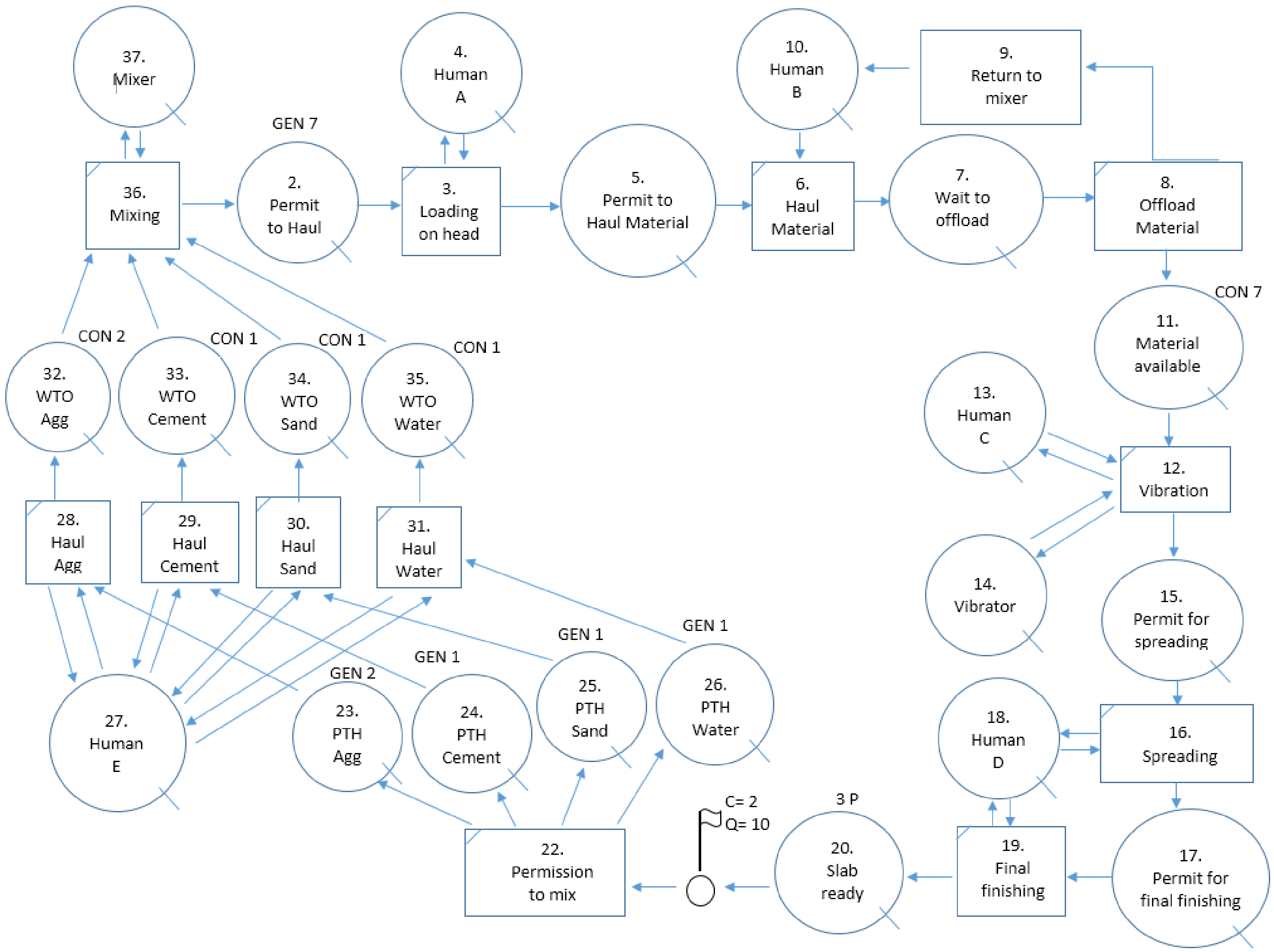


Figure 4.1: Model of construction operation

The model shown in the figure 4.1 is a simulation model in which we have used COMBI for representing different activities which are using different resources like mixing, offload material, vibration, etc. QUEUE is used to represent different resources like mixing machine, human hauler, human loader, vibrator, etc. Other activities are represented by NORMAL. LINKS are used to show the activity sequence and to connect the resources and activities. Some additional QUEUE are also included in the model to maintain the sequence of the model.

Durations for each activities of slab casting are shown in table 4.3. 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 4.3: Different activities & their durations

Parameters	**Duration**
Mixing time	4 mins
Load time	9-10 sec (per bowl)
Haul time	Fifth floor: 2 mins
Off load	3 sec (per bowl)
Return to mixer machine	Fifth floor: 40 sec
Vibration	1.5 mins
Spreading + Finishing time	30 sec
Haul Aggregate	10 sec
Haul Cement	8 sec
Haul Sand	10 sec
Haul Water	2 sec

4.4 DATA ANALYSIS & RESULTS

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

1. Mixing
2. Hauling to 5^{th} floor
3. Vibrating & finishing

Each operation is linked to another and so one activity cannot be started without completing the previous one. Again different kinds of resources are required to carry out these activities. We considered the whole operation together in the simulation model. Mixing machine was required for mixing of concrete. For all kinds of hauling, human haulers were required. For all kinds of loading, human loaders were used. For vibration, vibrator was used.

We considered different combinations of four resources which included human hauler, human loader, mixing machine and vibrator. The actual project was carried out using 7 human haulers, 2 human loaders, 1 mixing machine and 1 vibrator. The total duration of the operation was 2 days.

We assumed different numbers of resources to analysis the project with a view to finding out a combination that will provide optimum cost as well as optimum duration. Although it would be beneficial to consider different numbers of resources, unlimited numbers were not chosen. Because in doing so, after a certain level, the more the numbers of resources, the more the cost would rise without any significant change in the operation duration. Moreover, if unlimited numbers of resources were taken, the site of the project might become congested and thus resource allocation would be complex. So, we took a maximum as well as minimum number of resources into consideration.

The maximum and minimum numbers of resources that we had taken into account is shown in the following table:

Table 4.4: Different resources and their maximum and minimum number

Name of the Resource	Maximum number	Minimum number
Human Hauler	20	6
Human Loader	4	2
Mixing Machine	2	1
Vibrator	1	1

Here, the maximum number of mixing machine is 2 and minimum number is 1. When we ran different combinations of resources in the simulation model, we found that hiring highest 2 mixing machines would result in maximum acceptable amount of cost. On the other hand, using at least 1 mixing machine was mandatory for the completion of the operation. So we took 1 as the minimum number of mixing machine. Following the same considerations, we chose the other maximum and minimum numbers of the other resources.

For each resources used in the construction project there is a resource acquisition cost. There can be two types of resource acquisition cost. One is the buying cost and the other is the renting cost of the specific resource. Since all the resources were hired or rented by the owner, we considered different costs for different resources according to the cost data taken on the site. Resource acquisition cost is separated from the operating cost of the equipment. Resource acquisition cost depends on the type of resources. If the number of resources is increased, resource acquisition cost will also be increased.

The cost data acquired from the site is as follows:

Table 4.5: Different equipment and their costs

Equipment	Renting Cost
Mixing Machine	2500 tk per day
Vibrator	1500 tk per day

Table 4.6: Different labors and their costs

Labors for -	Cost per day
Mixing	500 tk / person
Hauling & offload	700 tk / person
Vibration	600 tk / person 300 tk / person (assistant)
Spreading & finishing	600 tk / person 300 tk / person (assistant)

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 types 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, three different cases had been considered for simulation.

In case 1, the number of human haulers were varied from 6 to 13, keeping the other numbers of resources constant. In case 2, the number of human haulers and loaders were varied from 6 to 20 and 2 to 3 respectively, keeping the other numbers of resources constant. In case 3, the number of human haulers and mixing machines were varied from 6 to 20 and 1 to 2 respectively, keeping the other numbers of resources constant.

Case 1: Number of human haulers – varied

Considering Case 1, we ran analysis by simulation and obtained the following results.

Table 4.7: Duration and cost for Case 1

Human Hauler	**Human Loader**	**Mixing Machine**	**Vibrator**	**Duration (hours)**	**Cost (taka)**
6	2	1	1	19.16	26090
7	2	1	1	17.49	27000
8	2	1	1	16.24	27000
9	2	1	1	15.27	28400
10	2	1	1	14.49	29800
11	2	1	1	13.85	31200
12	2	1	1	13.32	32600
13	2	1	1	12.87	34000

From the above results it can be seen that, as the duration decreased from first row for most of the combinations, cost increased comparing to the other combinations. For some combinations like 7 human haulers, 2 human loaders, 1 mixing machine, 1 vibrator & 8 human haulers, 2 human loaders, 1 mixing machine, 1 vibrator, although the cost was same i.e. 27000 taka, the duration varied (17.49 hours & 16.24 hours respectively).

Case 2: Number of human haulers and loaders – varied

Considering Case 2, we ran analysis by simulation and obtained the following results.

Table 4.8: Duration and cost for Case 2

Human Hauler	Human Loader	Mixing Machine	Vibrator	Duration (hours)	Cost (taka)
6	2	1	1	19.16	26090
8	2	1	1	16.24	27000
10	2	1	1	14.49	29800
12	3	1	1	11.28	22950
14	3	1	1	10.41	23000
16	3	1	1	9.79	23760
18	3	1	1	9.31	25440
20	3	1	1	8.92	24860

From the above results it can be seen that, as the duration decreased from the first row, cost did not increase significantly because the number of human haulers was increased significantly here. Also, the increased number of human loaders from 2 to 3 had impact on the results. As the number of these two resources was increased, the work duration decreased to the least of 8.92 hours because of the increased work efficiency, so their daily labor payment decreased too (i.e. 24860 taka) as compared to the first row (i.e. 26090 taka).

Case 3: Number of human haulers and mixing machines – varied

Considering Case 3, we ran analysis by simulation and obtained the following results.

Table 4.9: Duration and cost for Case 3

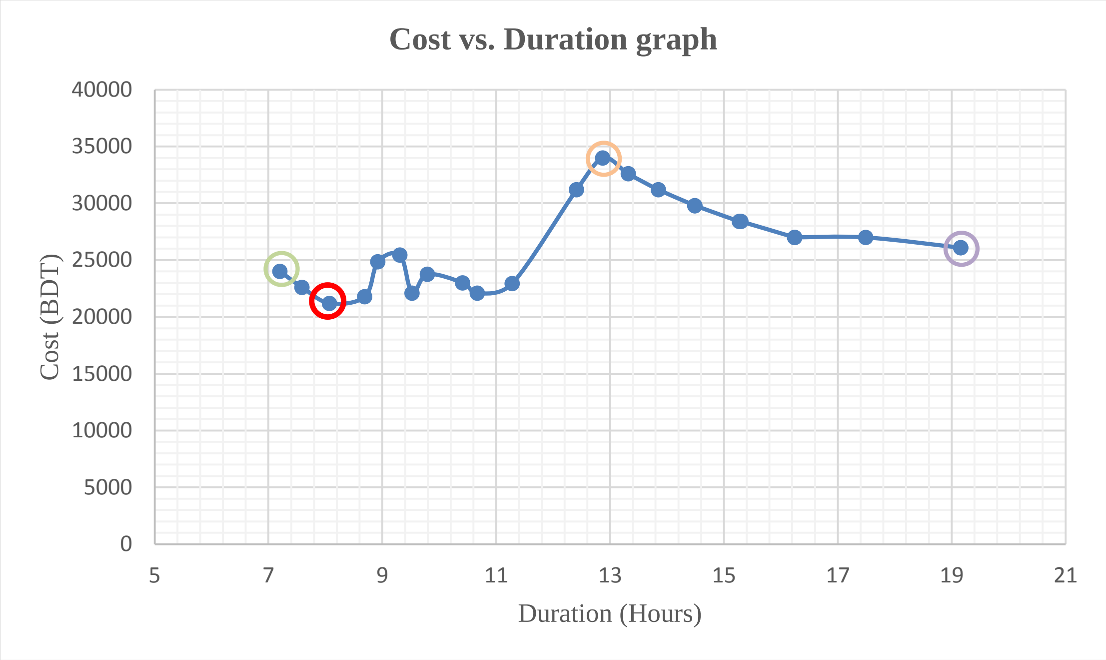
Human Hauler	Human Loader	Mixing Machine	Vibrator	Duration (hours)	Cost (taka)
6	4	2	1	15.3	28400
8	4	2	1	12.41	31200
10	4	2	1	10.67	22100
12	4	2	1	9.52	22080
14	4	2	1	8.69	21780
16	4	2	1	8.07	21200
18	4	2	1	7.59	22600
20	4	2	1	7.20	24000

From the above results it can be seen that, as the duration decreased from the first row, cost changed in a fluctuating order. Where there were 10 human haulers, 4 human loaders, 2 mixing machine and 1 vibrator, the cost was 22100 taka. But where there were 14 human haulers, 4 human loaders, 2 mixing machine, 1 vibrator, the duration and cost had decreased to lesser amount. Although the number of human haulers was increased from 12 to 14, both the duration and cost decreased. This happened because of the increased work efficiency due to labor increase.

It is seen that change in duration is satisfactory as well as the change in cost may be acceptable. So, this combination of resources might be suitable for the project.

All these obtained results were plotted on a graph of cost vs. duration. The graph is shown below-

Figure 4.2: Cost vs. duration graph for Case 1, 2 & 3



After plotting the graph, all 20 points were analyzed from the curve acquired. Although the costs were low, the points in the right-end of curve were neglected because of their high duration. The combination which had the highest cost (i.e. 34000 taka) was 13 human haulers, 2 human loaders, 1 mixing machine & 1 vibrator from Case 1. The combination which had the highest duration (i.e. 19.16 hours) was 6 human haulers, 2 human loaders, 1 mixing machine & 1 vibrator from Case 2. The combination which had the lowest duration (i.e. 7.20 hours) was 20 human haulers, 4 human loaders, 2 mixing machine & 1 vibrator from Case 3.

From the curve, an optimum point was chosen considering both low cost and low duration. This optimum point was of Case 3 with resource combination of 16 human haulers, 4 human loaders, 2 mixing machine & 1 vibrator with duration 8.07 hours and cost 21200 taka.

4.5 SUMMARY

From section 4.4, it can be seen that different combination of resources influences the duration as well as the overall cost of the construction operation. Generally, as the number of resources are increased the duration of the construction operation decreases. But it also affects the cost of the construction operation. As the number of resources are increased the cost of the construction operation increases also. But for every construction project resources are limited. Again if the number of certain type of resource is increased then the cost increase is much higher compared to the reduction in total duration. It can also be seen that for various types of cases, one certain kind of combination of resources may not give the optimum result for all other cases. Moreover, different combination of cost for different types of expense for the operation (resource acquisition cost, operating cost, overhead cost) also affect the project overall cost. Sometimes it takes more money to complete the project using the same combination for a particular case of cost consideration comparing to the other cases. So it is important to sort out the best combination of resources to obtain minimum duration of a construction operation as well as an acceptable construction cost.

CHAPTER FIVE

CONCLUSION & RECOMMENDATION

5.1 GENERAL

The summarization of the outcome of the study is done in this chapter. What's the effectiveness of this study and how people can be benefited from this study are discussed in short. Possible enhancement 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. Companies do not invest necessary time on planning for improving productivity. Without a proper plan for improving productivity the project sometimes need more time for completion as a result the cost increases. 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 purpose of this study were- to improve the productivity of a construction operation by optimizing resources trough minimizing idle time; to develop a simulation model for developing a proper schedule that will minimize the duration of the operation as well as keep the expense of the project in an acceptable limit; and to find out the optimum combination of resources for minimum duration and cost.

A simulation model has been developed for a Concrete casting of 5th floor Slab area of a residential building in Agargaon. The model has considered different construction activities interaction and combination of resources. From the analysis, best possible combinations have been sorted comparing the duration and cost. It can be found from the results that optimum combination of resource can be significantly shortened along with minimizing total cost of the Concrete casting of that Slab.

5.3 EFFECTIVENESS OF THE STUDY

The simulation that has been developed for this study can effectively be used to prepare proper schedule, thereby it can be helpful to finish the construction operation within limited time and increased productivity. Optimum combination of resources can be selected by observing the respective duration & cost of the combinations, which will maximize the productivity. As it can provide a proper combination of resources at the beginning of the construction project, resource acquisition can be made at the beginning; thereby delay of operation can be avoided. Again it can help the project manager to allocate the resources efficiently. Therefore misuse of different resources can be minimized which will reduce cost. As the resource needed onsite for maximizing productivity 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 & cost, thereby improving construction productivity.

This study has focused on minimizing the duration and keeping the cost within an acceptable limit. From the analysis it has been observed that if the number of resources is increased, the cost of a project may increase but the duration is decreased. Again if the number of resources is decreased, the cost may go down but the duration will be increased. Moreover using an optimum number of resources may result in minimum duration with acceptable cost. Decision making is actually dependent on the choice of the owner. If it is important for the project to minimize the duration, the number of resources should be increased that may cause higher cost. Again if it is needed to decrease the cost, the number of resources should be lessened that may result in higher duration. On the other hand, if it is required to minimize the cost as well as the duration, optimum number of resources could be used that may provide with a balanced duration and cost. That’s why we have studied this analysis considering both cost and duration. Thus consideration of both duration and cost for the analysis may result in more alternatives.

In case of Bangladesh, usually simulation model is not adopted to prepare scheduling. In most cases decisions are made onsite based on the priority of work to be done. As a result sometimes problems associated with resource scheduling, resource allocation, etc. arise. These types of problems can be solved if simulation model can be done properly.

5.4 RECOMMENDATIONS FOR FUTURE STUDIES

Our study has only dealt with a particular construction operation of a project to develop the model. Detailed study can be performed taking the whole project into consideration. If simulation model is developed for the whole project, there will be more interactions among different activities as well as among the resource sharing.

The activities related to our analysis were mostly sequential. If the activities were parallel, the model would have been more versatile and this analysis would be more useful. In our country, most of the construction works are labor dependent and thus labor is considered as a useful resource. But in our analysis we have ignored labor resource. Moreover, if large numbers of resources are used, the site may become congested and thus the productivity will be dropped. But in our study we didn’t consider this fact and chose the number of resources randomly. Consideration of both duration and cost for the analysis may result in more alternatives.

Considering aforementioned limitations, future study can be done for improving construction productivity more effectively.

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