Productivity Analysis of Pile Driving Equipment in Mumbai

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Abstract

Modern construction projects are complex in nature and success of a project depends greatly on proper and scientific planning. Proper use of appropriate equipment contributes to economy, quality, safety, speed and timely completion of the project. One of the most important tasks in the pre-construction planning process is equipment selection. Productivity has for many years been an issue for the construction industry. The industry is deeply concerned that construction productivity is not only below that of the manufacturing sector, but is also below the national average. The industry has identified several factors that have impeded construction productivity, namely, a shortage of suitably trained, skilled supervisors and workers; a weakening local construction workforce. Often when data become available, the site condition has changed and the improvement ideas obtained from productivity analysis are already obsolete. Timely productivity monitoring can provide construction engineers with insightful information so that corrective measures can be applied immediately to control on-going construction. Various analytical and simulation productivity analysis models were identified, studied and compared in view of their suitability. After the proper understanding of all these various models definitive steps can be taken to choose among the best available pile driving machinery for best output with good economy. Also a certain degree of validation is established among the various methods

Keywords— *Productivity, Construction operations, Method productivity delay model (MPDM), Time lapse, Five minute rating, Field survey Rating, Piling, Relative Importance Index*

I. INTRODUCTION

In simple terms, productivity can be expressed as the relationship between the output generated from a system and the input used to create output. Inputs generally refer to labor, capital, energy and materials which are brought into a system. These resources are transformed into outputs, i.e. goods and services. Productivity can be further classified into:

Total productivity (sometimes known as total factor productivity) is the ratio of total output to all input factors

Total productivity = total output / total input

Partial productivity is the ratio of total output to one class of input, e.g. labour productivity's a partial productivity measure.

Partial productivity = total output / partial input

Eilon et al (1976) stated that the major difficulties in applying the above simple productivity equations are:

• measuring output, especially with regard to changes with time in the sizes and types of individual products

• measuring inputs and accounting for the great diversity in types of materials facilities and equipment needed as well as the multiplicity of labour skills to be encompassed

• determining which particular input-output comparisons are most relevant in evaluating the performance of various operations of concern to management

• interpreting productivity figures in order to differentiate between the influences of internal and external factors.

In spite of the difficulties encountered in measuring productivity both industrialists and researchers alike believe in the advantages that it can bring. Eilon et al (1976) gave four reasons as to why it is necessary to measure productivity:

• *for strategic purposes,* in order to compare the performance of the firm with that of its competitors or related firms, both in terms of aggregate results and in

terms of major components of performance

• *for tactical purposes*, to enable management to control the performance of the firm by identifying the comparative performance of individual sectors of the firm, either by function or by product

• *for planning purposes,* to compare the relative benefits accruing from the use of different inputs, or varying proportions of the same inputs, currently and over longer periods, as the basis for considering alternative adjustments over future periods.

• *for other management purposes,* such as collective bargaining with trade unions.

Productivity is often wrongly defined as merely producing more and at a faster rate, without concern for quality. This incorrect definition could well lead to the belief that taking care of quality will slow down work pace and hence reduce output. Such a misconception disappears when productivity is correctly defined as "producing better" and not necessary "producing more".

Some people think that quality and productivity, like many other technical concepts, is only relevant for production activities and the manufacturing sector. However, many case studies show that quality and productivity improvement are equally important in other sectors of the economy, such as in finance, in the service sector and in construction. They apply to all sectors, organizations, work processes and employees.

Productivity and quality management enable the effective utilization of resources. More goods and services are produced for a reasonable amount of expended resources. Productivity and quality management enable an organization to be more profitable because quality improvement results in reduced rework, reduction in scrap, better utilization of tools and equipment, and less work in process inventory, which in turn leads to higher productivity.

In the modern-day competition amongst companies, industries and nations, it is insufficient to only understand the factors that affect productivity. There is a strong need to learn about productivity improvement in order to cope with all round competition. Borcherding (1976), Borcherding et al (1980) have identified methods for productivity improvement.

However there are some shortcomings in the use of productivity analysis models as listed below:

• measure accurately both input and output parameters used in productivity calculations, i.e. equipment man-hours input and work quantity completed
• represent calculated productivity in a form that is useful to the researcher so that results can be linked to the progress of an activity and reflect site productivity
• use simple and effective data collection procedures, without the need for special training;
• identify the major factors influencing productivity in an objective manner and be capable of establishing cause and effect relationships between individual factors and the calculated productivity;
• relate productivity variability to specific causes
• utilize existing data or data that is easily obtainable from site without antagonizing the workforce

II. EXPERIMENTAL PROGRAMM

Panas and Pantouvakis (2010) summarized the methodologies for productivity analysis into three broad classifications: qualitative, quantitative, and mixed-method research approaches. For this particular study the following productivity analysis models have been chosen and reviewed

- Method Productivity Delay Model (MPDM)
- Five Minute Rating
- Time Lapse
- Field survey

A. *Method Productivity Delay Method (MPDM)*

The method productivity delay model was proposed as a way to combine both time study and productivity measurement (Adrian & Boyer, 1976). The method mainly deals with the sources of delay and provides useful statistics for measuring productivity. This model was developed for application by a small to mid-size construction firm that cannot afford professional services.
Simple statistical methods were used in this model to make it accessible to construction personnel. It was developed to measure, predict and improve the productivity of the construction operations. The MPDM measures, predicts and improve productivity of the construction operations in four stages, namely, data collection, data processing, model structuring, and finally model implementation.

- Phases in MPDM
  - ➢ Identification of production unit & production cycle
  - ➢ Identification of leading resource
  - ➢ Identification of type of delay
  - ➢ Data collection
  - ➢ Data processing, model analysis, recommendations

- Delays in this method are classified as
  - ➢ environmental
  - ➢ equipment
  - ➢ labor
  - ➢ material
  - ➢ management.

Some of the advantages & disadvantages of this method have also been identified as listed below:

Table 1: Advantages Disadvantages of MPDM

Sr. No	Advantages	Disadvantages
1.	Suitable for small to mid-size construction firm	Does not consider interaction and interdependencies between operations
2.	Provides more info than any other work sampling technique	Leads to optimization of process but not whole system
3.	Can identify the cause of delay and relative contribution of lack of productivity	
4.	Experiences shows relative simpler method	

B. *Five Minute Rating*

Oglesby et al. (1989) defined the five-minute rating technique as a quick and less exact appraisal of activity that is based on the summation of the observations made in a short study period, with the number of observations usually too small to offer the statistical reliability of work sampling. The observer that does a five-minute rating should have a watch and a form for recording observations during work. The detail steps are explained in Dozzi and AbouRizk (1993).

Oglesby et al. (1989) expanded the definition that if the delay noted for an individual in any block of time exceeds 50 percent of the period of observation, then the rating for that individual is classified under delay; if not, then the appropriate block is classed as effective, whereas the method explained in Dozzi and AbouRizk (1993) would leave the cell empty if the crew member has been inactive for over half the interval. Finally, the effectiveness percentage for the whole crew is found by multiplying 100 to the ratio of the sum of effective times for each individual and for the crew divided by the total time of observation, which is also called the effectiveness ratio.

The following procedure can be used to implement the 5-minute rating technique:

a) Identify the members of crew and prepare a structure similar to table 2
b) Observe the crew as they work for (5 minute intervals) and if the crew is active for more than 50% of time than mark the column “X” else keep empty
c) Add the “X” observations and divide by the total observations to obtain effectiveness

Table 2: Sample Five Minute Rating Data Collection Form

Time	Pile Driver	Total observations: 6 Observed effective: 4 Effectiveness/ 5-minute rating: 4/6 = 66.67
9:30-9:35	X	
9:35-9:40	X	
9:40-9:45		
9:45-9:50		
10:20-10:25	X	
10:25-10:30	X	

Some of the advantages & disadvantages of this method have also been identified as listed below:

Table 3: Advantages Disadvantages of Five Minute Rating

Sr. No	Advantages	Disadvantages
1.	Quick , easy	Less exact
2.	Since worker will not know whether they are watched, workers will not react to observers presence	Not based on statistical sampling theory and relies on simple observation
3.	Provides insight to effectiveness of crew and identify areas where more observation is needed	Also result does not apply to drawing conclusion from large samples

C. *Time lapse method*

The British Standards Institution describes time-lapse photography as a method that records activity by a cine-camera adapted to take pictures with longer intervals between frames than normal. Usually the frame rate is about 24 fps and 30 fps

Some of the advantages & disadvantages of this method have also been identified as listed below:

Table 4: Advantages Disadvantages of Time Lapse Method

Sr. No	Advantages	Disadvantages
1.	Well suited for long cycle & irregular cycle studies	Expensive due to equipment & film cost
2.	Groups of workers andequipment can be recorded simultaneously	Time lag between recording and development of film
3.	Eliminates most errors because of multiple observer readings	Possibilities of partial or incomplete data due to technical inadequacy
4.	Filmed photos/videos used for training method	
5.	Permanent record of interrelated activities is obtained for later activities	

D. *Field Survey*

Field surveys and questionnaires are organized ways of involving the foreman or craftsman in the site evaluation and productivity improvement process. Craftsmen are probably the persons most familiar with their work activity. They can easily identify sources of delay and obstacles in their progress. Likewise a foreman is the person most familiar with the crew and the problems that restrict improvement in their productivity.

Common methods adopted for field survey include:
a) Foreman Delay Survey
b) Craftsman Questionnaire

III. METHODOLOGY

For this particular study a questionnaire was developed with discussion with stakeholders and industrial professionals and the same was distributed, their results accumulated, assessed.

The study was done in the following manner

a) Identification of factors that impede construction productivity

b) Categorize the factors into sub heads for classification and simplicity

c) Distribution of questionnaire to stakeholders (contractor's clients, sub contactors etc.)

d) Collect, analyze the data collected from the survey to calculate results

e) Conduct site visits to validate, observe and study productivity methods

Survey research is defined as collection of different data by asking people questions. The data collection process used in this research had the option of two basic methods: questionnaires and personal interviews. A questionnaire was preferred as the best effective and suitable data-collection technique for the study. It was concluded that the questionnaire was described as a self-administered tool with web-design questions, an appropriate response. A questionnaire in a web-survey format comparatively requires less duration and saves cost for the researcher while permits respondents to response the questionnaire at their personal ease. However, for this approach the reply rate is usually lower as compared to face-to-face interviews.

A. Survey Planning

For the research study, email technology was used to send the survey questionnaire. Collecting general information on various factors affecting equipment productivity in building construction all over Mumbai was the basic aim of the survey. The purpose and approach used in the survey was fully explained to the respondents. Guidelines were provided to the respondents to ensure that the procedure was followed properly to reduce errors. During the survey period, some oversights were provided to help ensure the process was going smoothly and consistently. Results included the overall statistics as well as individual statistics.

B. Pilot Survey & Questionnaire Design

To improve the questionnaire section, a pilot study was accompanied. This section contained identification of different causes, collection, and conclusions of data. The application of this section benefited in better formation of the web-survey development , were sent by e-mail to laborers, contractors, architectures, owners, project managers, and project engineers of various building construction organizations.

C. Research Survey

After review of the pilot survey, certain fields were identified and a questionnaire consisting of 60 questions were prepared. These questionnaire were then circulated to 20 participants (client, contractor and engineer) in the Mumbai area and these responses were received within 15 days.

D. Data Analysis

The ranking of factors was calculated based on Relative Importance Index

$$RII = \frac{\sum_{i=0}^{i=A} ni * I}{A * N}$$

Where, RII= Relative Importance Index
N= total respondents
A= Highest response (i.e. =5)
n= Respondents selecting options i
I= Individual responses (i.e. = 0, 1, 2, 3, 4, 5)

E. Site Visits

An imperative part of the study was to conduct site visits to identify and quantify the problems associated with equipment productivity.

For this purpose a residential project (Project A) was chosen

IV. DATA COLLECTION

On the basis of study conducted and data accumulated via the questionnaire survey the factors identified were ranked based on the Relative importance Index and the following observations were observed.

Also productivity assessment on project 'A' lead to the following observations.

Table 5: Technical Factors Affecting Equipment Productivity

TECHNICAL FACTORS		Relative Importance Index (RII)	Ranking
SR.NO.	FACTORS		
1	Construction Technology(construction method, material, system of equipment)	0.57	12
2	Availability of power tools &/or spares	0.58	9
3	Work interruptions(design changes ,methodology change etc)	0.69	1
4	Equipment breakdown (maintenances)	0.6	7
5	Available quantity of daily work (work load)	0.57	11
6	Constructability (integrated design construction)	0.56	13
7	Unclear or out-dated technical specifications	0.49	17
8	Work conditions	0.63	4
9	Project specifications	0.64	3
10	Design complexity level	0.47	18
11	Clarity of technical specifications	0.58	10
12	Distance between site & cities	0.68	2
13	Total project duration (total works hrs)	0.59	8
14	Poor buildability design	0.51	16
15	Type of project (industrial ,residential ,heavy construction ,infrastructure)	0.53	15
16	Extent of variation/change	0.54	14
17	Project Scale	0.6	6
18	Access to site	0.62	5

Table 6: Human Factors Affecting Equipment Productivity

HUMAN FACTORS		Relative Importance Index (RII)	Ranking
SR.NO.	FACTORS		
1	Operator experience and skills	0.69	1
2	Injury or accident involving operator	0.46	11
3	Unfriendly working atmosphere (hostile conditions)	0.47	10
4	Over time (4 hrs after 8 hrs/day)	0.55	5
5	Operator payment system (daily wages ,lump sum)	0.58	2
6	Operators age	0.4	12
7	Effect of operator availability to work capacity	0.56	3
8	Physical Fatigue	0.52	7
9	Reluctance to work on holidays	0.55	4
10	Degree of operator education	0.51	8
11	Rest during work hrs	0.54	6
12	Engagement of operatives in personal discussion	0.5	9

EXTERNAL FACTORS			
SR.NO.	FACTORS	Relative Importance Index (RII)	Ranking
1	Weather effects, climatic conditions (temperature, humidity etc.)	0.5	3
2	Political issues and surrounding events (Revolution, strikes, sit-in)	0.6	2
3	Force Majeure	0.62	1

Table 8: External factors affecting equipment productivity

Table 7: Managerial factors affecting equipment productivity

MANAGERIAL FACTORS			
SR.NO.	FACTORS	Relative Importance Index (RII)	Ranking
1	Payment Delays	0.62	4
2	Clarity of instructions and information exchange	0.54	13
3	Planning ,work flow and site congestion	0.62	5
4	Availability of materials and ease of handling	0.64	3
5	Equipment logistic (storage, shortage)	0.67	2
6	Poor supervision of operatives	0.52	16
7	Leadership and competency of construction management	0.54	14
8	Correctional work to improve poor or bad work	0.68	1
9	Offered services to operatives (social insurances ,medical care)	0.55	12
10	Incentive Programs	0.59	10
11	Simultaneous involvement of operator in several work areas	0.61	6
12	Co-ordination problem with supplier	0.53	15
13	Construction management type (individual ,firm)	0.59	9
14	Unscheduled breaks	0.61	7
15	Idle time	0.61	8
16	Unrealistic deadline for project completion	0.58	11

Table 9: MPDM Data Collection Sheet

Production Cycle	Cycle Time (sec)	Environ. Delay	Equip. Delay	Labour Delay	Mat. Delay	Mgmt. Delay	Processing Col.
1	1220						55.83

2	1425		0.3				149.17
3	1356				1		80.17
4	1652		1				376.17
5	1725	1				1	449.17
6	1189						86.83
7	1300						24.17
8	1359				1		83.17
9	1456			1			180.17
10	1659	1	1				383.17
11	1461			0.5			185.17
12	1296						20.17
13	1230						45.83
14	1541		1			1	265.17
15	1342			0.5			66.17
16	1420						144.17
Total cycles= 16	**22631**	**2**	**4**	**2**	**2**	**2**	

Table 10: MPDM Data Processing Sheet

	Production Total time (1)	Number of Cycles (2)	Mean Cycle Time (3)
Overall production cycles	22631	16	1414.44
Non delayed production cycles	7655	6	1275.83

Table 11: MPDM Delay Information

Time Variance	**Environ. Delay**	**Equip. Delay**	**Labour Delay**	**Mat. Delay**	**Mgmt. Delay**
No of Occurrence	2	4	2	2	2
Total Time Added	832.33	1069.25	305.83	163.33	714.33
Probability of Occurrence	0.13	0.25	0.13	0.13	0.13
Relative Sensitivity	0.29	0.19	0.11	0.06	0.25
Expected % of Delays	0.04	0.05	0.01	0.01	0.03

Table 12.1: 5 Minute Rating Data Sheet

Time	Equipment data
9:30-9:35	X
9:35-9:40	X
9:40-9:45	
9:45-9:50	X
10:20-10:25	
10:25-10:30	X
10:30-10:35	X
10:35-10:40	
10:40-10:45	X
12:00-12:05	X

12:05-12:10	X
12:10-12:15	X
12:15:12:20	
14:15-14:20	X
14:20-14:25	X
14:25-14:30	
15:00-15:05	
15:05-15:10	X
15:10-15:15	X
15:15-15:20	
10:00-10:05	X
10:05-10:10	
10:10-10:15	X
10:15-10:20	X
10:20-10:25	
11:15-11:20	X
11:20-11:25	X
11:25-11:30	
11:30-11:35	

Table 12.2: 5 Minute Rating Calculation

Total observations	28
Observed effective	18
Effectiveness\5 minute rating	0.6428571

V. RESULTS & FINDINGS

Table 14: Summarization of questionnaire responses

SR.NO	FACTOR	RII
1	Managerial factors	0.59
2	Technical factors	0.57
3	External factors	0.57
4	Human factors	0.53

b) Further the important sub factors within each class is listed below

Technical Factors

Ranking	Factor	RII
1	Work interruptions(design changes, methodology change etc.)	0.69
2	Distance between site & cities	0.68
3	Project specifications	0.64
4	Work conditions	0.63
5	Access to site	0.62

Table 13.1: Field Rating Data Sheet

Cycle	Observations
1	1
2	1
3	0
4	0
5	1
6	0
7	1
8	0
9	0
10	0
11	1
12	1
13	1

Table 13.2: Field Rating Calculations

Total observations	13
Total Working Observation	7
Field Rating (%)	63.846154

1. Based on the questionnaire survey conducted on 20 respondents using personal interview, mail correspondence etc. the survey results obtained were analyzed and the findings are as under:
   a) Of the four heads identified managerial factors (average RII=0.59) were found to be most critical followed by technical factors (RII=0.57) and external factors (RII=0.57) and human factors (RII=0.53) was the least impactful factor.

Human Factors

Ranking	Factor	RII
1	Operator experience and skills	0.69
2	Operator payment system (daily wages, lump sum)	0.58
3	Effect of operator availability to work capacity	0.56
4	Reluctance to work on holidays	0.55
5	Over time (4 hrs after 8 hrs/day)	0.55

Managerial Factors

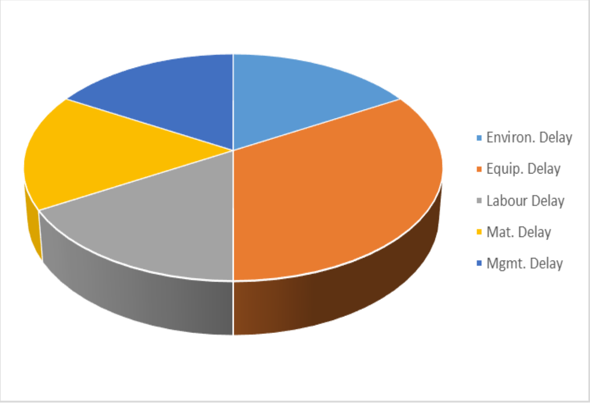
Ranking	Factor	RII
1	Correctional work to improve poor or bad work	0.68
2	Equipment logistic (storage, shortage)	0.67
3	Availability of materials and ease of handling	0.64
4	Payment Delays	0.62
5	Planning, work flow and site congestion	0.62

External Factors

Ranking	Factor	RII
1	Force Majeure	0.62
2	Political issues and surrounding events (Revolution, strikes, sit-in)	0.6
3	Weather effects, climatic conditions (temperature, humidity etc.)	0.5

2. Further site inspections on project A indicates that there is a higher chance of equipment delay (25% probability) and hence the management must pay critical attention to the equipment

Figure 1: Productivity Delay Model



3. Also the 5 minute rating and field rating for project A were found to be 64.3% and 63.8% respectively, which are considered as fairly considerable.

REFERENCES

[1] Shi, J. J, "Activity-based construction (ABC) modeling and simulation method", *J. of Constr.Engrg. And Mgmt*., ASCE, Vol. 125, No. 5, pp. 354-360, 1999. 137_WD2.

[2] Halpin, D. W., and Riggs, L. S., *Planning and Analysis of Construction Operations*, Wiley,New York, 1992.

[3] Lutz, J. D., Halpin, D. W., and Wilson, J. R., "Simulation of learning development in repetitive construction", *J. of Constr. Engrg. And Mgmt*., ASCE, Vol. 120, No. 4, pp. 753-773,1994.

[4] Abraham Assefa TSEHAYAE and Aminah Robinson FAYEK "A Research Framework for Work Sampling and its Application in Developing Comparative Direct and Support Activity Proportions for Different Trades"

[5] James J. Adrian, LeRoy T. Boyer(1976) "Modeling Method Productivity"

[6] Indian Brand Equity Foundations, Construction Equipment Market
"Productivity Improvement of Pre-cast Concrete Installation" Souma M. AlhajAli ,Ayman A. Abu Hammad, Ghaleb J. Sweis) and Murad S. Samhouri

[7] "Productivity in Construction" by Dozzi, S.P.; AbouRizk, S.M.

[8] "Construction Operation Simulation Tool – Cost" by Tao-ming Cheng, Shien-Tang Wu, and Yi-Wei Tseng

[9] Evaluation of Factors Affecting on Construction Equipment Acquisition Methods in Malaysia by Masoud Navazandeh Sajoudi , Mohammadali Kazerooni Sadi, Arham Abdullah, Mohammadreza Kasraei, HodaRezaie

[10] "Estimation of Optimal Productivity in Labor-Intensive Construction Operations" by Krishna Prasad Kisi

[11] "Construction Labor Productivity and its Improvement" by M.C. Thiyagu, Mr. M. Dheenadhayalan

[12] "Pile Construction Productivity Assessment" by Tarek M Zayed, Daniel W Halpin