Application of Operational Management Tools at Precast Yard

Ashutosh Kumar Rai, Varun Kumar Reja, and Koshy Varghese

Abstract Achieving higher productivity and higher production rates can help in maximizing profits at the construction site. The current practices at construction sites carry large sources of waste and inefficiencies which is the major cause of a decline in productivity and decrease in production rate. Segmental bridge construction sites are not an exception. Therefore, this study aims to achieve higher productivity, overcome inefficiencies, and standardize best practices to achieve a higher production rate at segmental precast yard sites by adopting principles and tools of operational management. In this study, seven sources of waste are identified at the precast yard which directly or indirectly affect productivity. The importance of implementing other key concepts of operational management which include responsiveness versus crew productivity graph, and quartile analysis is illustrated. And further productivity measurement tools which include key performance indicators (KPIs), overall people effectiveness (OPEs), and overall equipment effectiveness (OEEs) are introduced to implementation in the construction industry, particularly in the precast yard.

Keywords Waste · Productivity · Production · Operational management · Segmental bridge construction · Precast yard

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1 Introduction

The construction industry is filled with complex and mega projects. Most project suffers either from cost overruns or schedule overruns [1] and in case the project makes a profit, the margin is very less. The profitability of a project depends upon productivity [2, 3]. The productivity at the site was decreased by several causes one of which is high construction waste [4]. Also, the works at the construction site are never performed as they are planned. And the major reason contributing to it is the lack of benchmarking tools [5]. As a result, site personnel adopt random strategies for carrying out project work. Hence, construction practitioners are looking at the success of benchmarking from the manufacturing industry to adopt and improve construction performance [6, 7]. In this context, the implementation of tools of operational management at precast sites can become useful. It has been said that harmony, cooperation, high efficiency, and maximum output would take place with the implementation of its tools [8]. Therefore, this paper attempts to:

Identify seven sources of waste at superstructure production sites to explore opportunities for implementing operational management.

Apply standardization tools of operational management to remove waste and inefficiencies at the precast yard.

Implement productivity tools of operational management to improve segmental construction performance.

This paper is divided into five sections. In the first section, the research problem is introduced, and the objectives for this study are presented. Section 2 presents the review of existing literature on productivity measurement and benchmarking. Section 3 identifies seven sources of waste that affect productivity. Section 4 presents the improvement suggestion. Section 5 presents the discussion and conclusion of the study.

2 Literature Review

Researchers have done several studies on benchmarking, productivity, and lean production. Some of which are discussed below.

Park et al. [9] in their study established a common set of construction productivity metrics. Their combined efforts help in developing Construction Productivity Metrics System (CPMS). And their further analysis made CPMS a standard construction productivity data collection tool. A study conducted by Enshassi et al. [10] presented an empirical approach for benchmarking productivity. In their study, the disruption index (DI), performance ratio (PR), and project management index (PMI) have been considered as project benchmarks. He establishes a connection between DI and PMI and further told that higher values of both DI and PMI are indications of sub-standard labour performance and poor management. Markovic et al. [11] have used the "destination matrix" as a productivity measurement system. According to them, management is responsible for determining the best performance and best practices in the industry and for setting the benchmarking process. Engineering Productivity Metric System (EPMS) was developed by CII to assess engineering productivity at multiple levels, but it cannot produce overall project level measurement. To overcome this limitation, Liao et al. [12] in their study developed a standardized approach of using "z-scores" to aggregate the engineering productivity measurement. With this, it created metrics for benchmarking productivity.

Nikakhtar et al. [13] in his paper present a systematic approach for the application of lean production principles in construction processes emphasizing waste reduction. Leksic et al. [14] in their paper presented a statistical model. The model shows that TPM, Poka-Yoke, Kaizen, 5S, Kanban, Six Big Losses, and Takt Time are statistically significant lean tools for waste reduction or even elimination. Ray et al. [15] in their paper presented an overview of lean manufacturing which help the precast concrete plant to reduce waste and improve production operations.

The above literature suggests that though lean principles can help in waste reduction, and benchmarking helps in increasing productivity, but there is no such practice adopted to minimize waste and inefficiencies and increase productivity at the same time in the construction sites by using benchmarking as a tool. Hence, the current study explores an option of looking at benchmarking tools from other industries which can increase productivity, optimize resources, and help in minimizing waste and can be practically implemented at segmental precast sites to improve construction performance.

3 Seven Sources of Waste at the Precast Yard

The segmental precast yard faces a lot of challenges in improving productivity and its performance because most of the waste at the precast yard is hidden and difficult to identify without measuring. It is obvious that if these wastes are eliminated or minimized, both productivity and performance can improve [16, 17]. The seven-waste defined by lean literature is waiting, overproduction, inventory, over-processing, motion, transportation, and rework [18]. Hence, the current paper identified wastes in the precast yard and categorized them into these seven categories (Table 1).

And Figs. 1, 2, 3, 4, 5, 6, 7 and 8 summarize the seven sources of waste at the precast yard.

The wastes identified above are the major cause of slow progress at the precast yard. Hence, in the next sections, improvements are suggested keeping in mind the tool practitioners can use to minimize or eliminate these wastes and help in achieving higher productivity and hence maximize production outputs.

Table 1 Seven sources of waste at precast yard

Type of waste (With definition)	Figures showing waste at precast yard
Type of waste (With definition) **Over Production**: Producing sooner or in greater quantities than the client demands If the number of segments produced exceeds segment stacking capacity. Then, this is considered to be overproduction waste. In this case, the erection site has to be developed for segment storage purposes. This happens when the erection schedule did not match the construction schedule **Transportation**: Unnecessary movement of people and/or materials between process steps 1. Tire-mounted crane unavailability results in an unloading of rebars at the segment stacking area, which cause unnecessary movement of rebars 2. Transporting inner panels, cage-lifter, and segment-lifter with the help of a hydra or tire-mounted crane from one bay to another bay 3. Transporting bulkhead from stacking bed to casting bed location	Figures 1 and 2
Rework: Correction processes within the main process. Rework is always the result of a failure to do something right in the first place 1. Bar placed wrongly at the time of tying 2. Cutting/bending of rebars not done as per approved BBS 3. Wrong inner panels used for segment cause rework of shuttering, buffing, etc 4. Inner shutter inserted wrongly 5. The wrong bulkhead was used 6. Bulkhead alignment and level not maintained before inner shutter fixing causes reopening of an inner shutter	Figures 3 and 4
Type of waste (With definition) **Over-processing**: Doing more than the client requires. Over-processing is a form of waste that might have positive reasons for workers having high standards than the customers or employees being overly proud of their work. Even after nut-bolting, using extra turnbuckles to support formwork **Motion**: Unnecessary movement of people or parts within a process. Rebar yard location is generally outside the bay in a typical casting yard layout, which means cut and bent rebar has to come to the jig area after covering some distance means which causes unnecessary motion	**Examples of waste at precast yard** Figures 5 and 6

(continued)

Table 1 (continued)

Type of waste (With definition)	Figures showing waste at precast yard
Inventory: Too many flow units in the system 1. Segment stacked at stacking yard (SY) is considered to be inventory 2. No fronts availability for casting results in full occupancy of jigs, which further results in more cut and bend of rebars as inventory	Figure 7
Waiting: Employees or resources just sit around waiting for something to happen. Waiting is an unproductive use of time 1. Delayed in issuing materials from the store which include rebars, binding wires, etc. 2. Common inner panels for segments casting at multiple fronts result in waiting, and only one segment can be casted at a time 3. Workers are waiting due to delays in getting concrete from the batching plant	Figure 8

Fig. 1 Occupied stacking yard

4 Improvement Suggestions

The current study adopts responsiveness versus crew productivity graph, and quartile analysis to implement standardization and remove inefficiencies, and the productivity tools that are implemented in this study are OEEs, OPEs, and KPIs.

Fig. 2 Panel shifting between bays

Fig. 3 Tying blister portion on a bed

Fig. 4 Wrongly fixed panels

Fig. 5 Extra turnbuckles used

4.1 The Trade-Off Between Responsiveness and Crew Productivity

It will help in finding the optimum number of labours required in a crew to finish the job. For cutting and bending of one span (say 15 segments) assuming three different crews with different manpower strengths deployed at three different locations working on separate resources. Time taken by all the crews deployed to do cut and bend should be recorded. Average crew productivity of all the crews should be

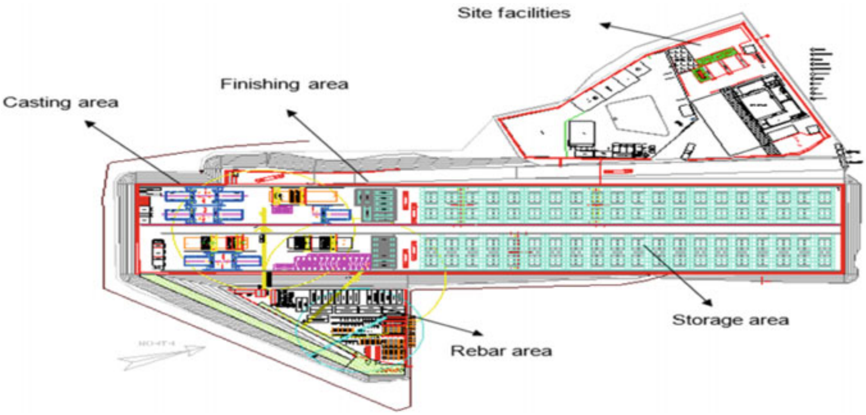


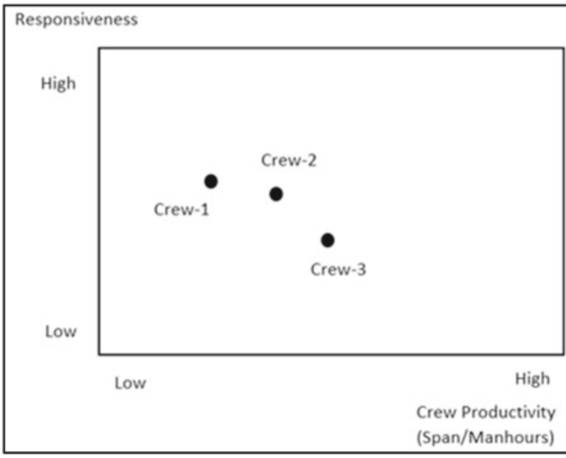
Fig. 6 Rebar yard to jig motion

Fig. 7 Segments stacked at SY

recorded throughout the process, i.e. from start to completion. Based on this, graph is plotted between responsiveness and crew productivity.

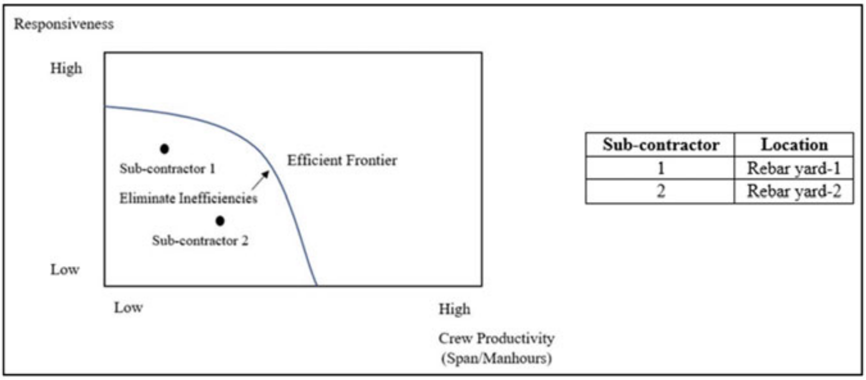
This will give the optimum number of labour required (crew capacity) to do the cutting and bending work of one span, instead of deploying additional resources (Fig. 9). Similarly, crew capacity at different locations for different works in precast yards can also be determined.

Fig. 8 Workers waiting for material



Crews	Man-powers
1	8
2	6
3	4

Fig. 9 Determining the optimum number of labours



Sub-contractor	Location
1	Rebar yard-1
2	Rebar yard-2

Fig. 10 Determining efficient frontier

4.2 Overcoming Inefficiencies

In the construction industry, it is common to deploy more than one sub-contractor for the execution of similar works. Assuming two sub-contractor's crews working for cut and bend work. Time taken to complete cutting and bending by both sub-contractor's crews have to be recorded. Average crew productivity of both the crews should be recorded throughout the process, i.e. from start to completion. Based on this, graph (Fig. 10) is plotted between responsiveness and crew productivity for both sub-contractors.

This will help in comparing which sub-contractor is performing better in terms of completing the segment faster or how much it lacks from the best sub-contractor. This should be done at every site to find the best sub-contractors to do the job. And the good practices of the best sub-contractor would be transferred to the other sub-contractors.

4.3 Evaluating Proposed Redesign and Technologies

Time taken to do shutter fixing and de-shuttering for both cases should be recorded, i.e. with the current frontier and new frontier. Average crew productivity for both cases should also be recorded. Based on this, the graph between responsiveness and crew productivity is plotted for both cases.

If the new frontier graph lies above than current frontier, means with this technology responsiveness and crew productivity both are improved (Fig. 11). It can be implemented in all those activities or processes which can be improvised with the use of technologies.

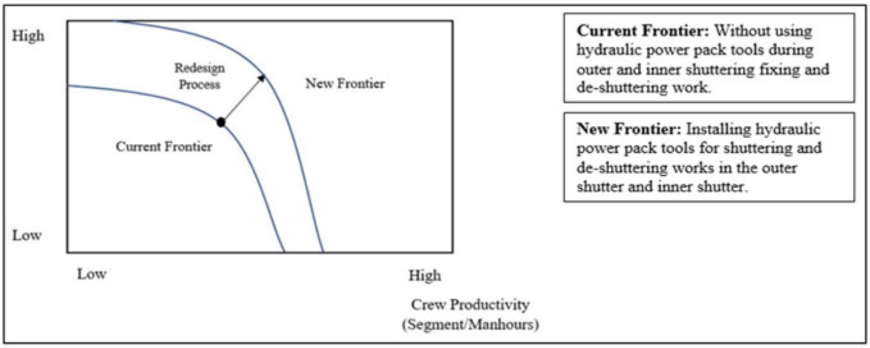


Fig. 11 Determining new frontier by redesigning process

4.4 Quartile Analysis

The main focuses of any construction site were on minimizing average processing time and minimizing idle time. For that, they do adopt some strategies, but they overlooked the approaches adopted by different sub-contractor deployed at the site. It can become important for the identification of best practices if the time differences between sub-contractors for doing the same work are recorded and evaluated. Thus, the quartile analysis compares the highest quartile performing sub-contractor with the bottom quarter sub-contractor.

4.4.1 Implementing Quartile Analysis at Precast Yard

Sub-contractors deployed at the precast yard for segmental construction will differ in the processing time to cast a segment or to complete the casting of one span. Each of the sub-contractor deployed has different ways of doing the task. Hence, collecting a sample of segmental production processing times by each sub-contractor will help in analysing variation in processing times and the reasons which cause such variations. And if the best practices from the top performers are transferred to the bottom performers, the average productivity of the work will rise.

4.5 Main Problems at the Precast Yard

Productive time data of each work are not maintained by the project sites.

Sometimes inexperienced sub-contractor is deployed for production works.

Steps in which quartile analysis can be implemented:

The first step is to record productive time data for similar works done by each of the sub-contractors deployed at the precast yard.
Plot it dramatically to compare the top and the bottom quartile at the site. This will help in determining the variation in the process.
The aim is to reduce this variation by moving the bottom quartile up to the median or to the top quartile, which ultimately boosts productivity.

5 Implementing Productivity Tools

5.1 Overall Equipment Effectiveness (OEE) Framework

OEE is a powerful tool that helps to analyse the utilization and downtime of a machine and to see the potential for productivity improvements. This framework helps in evaluating the productivity of machines and other resources. The first step is to record the total available time of the gantry crane in an excel spreadsheet. Secondly, recording idle time, time spent on maintenance, gantry breakdown, unnecessary motion, etc., to determine waste of time. Thirdly, calculating productive time. The productive time of the resource is the difference between the total available time and the waste time. The fourth step is to determine the overall equipment effectiveness (OEE) of the resources. It is calculated as the ratio between productive time and total available time. Lastly, the OEE diagram can be prepared with the help of spreadsheet data (Fig. 12).

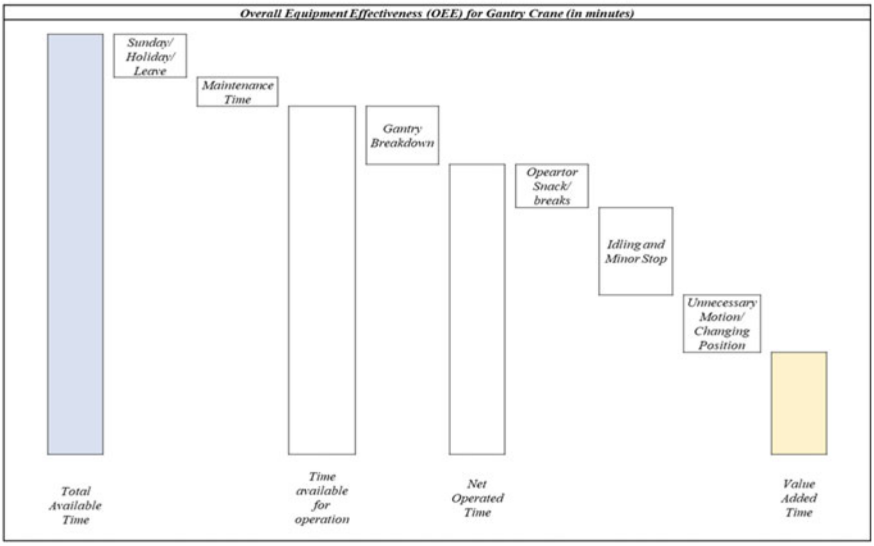


Fig. 12 OEE framework for gantry crane

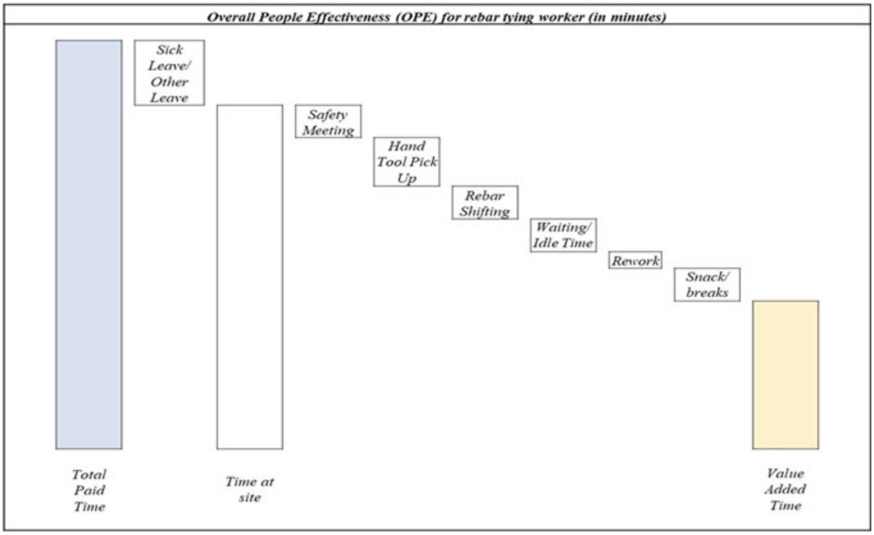


Fig. 13 OPE framework for rebar tying worker

5.2 Overall People Effectiveness (OPE) Framework

Overall people effectiveness (OPE) for each worker, working in the casting yard, can be estimated by following the steps described in the section. Figure 13 shows the value-added and non-value-added time dramatically for rebar tying workers.

The non-valued added time shown in above frameworks can vary for both machinery and worker. Hence, relevant changes can be made for calculating the value-added time for both machinery and workers.

5.3 Key Performance Indicators (KPIs)

This tool helps in visualizing the relationship between operational and financial variables. The main branch of the KPIs tree is profit. Profit is the difference between revenue and costs. Revenue in casting yards was driven by the number of segments casted multiplied by the rate of the segment. Cost is the sum of fixed cost and variable cost. Fixed cost includes equipment hire charge and staff payment. Variable cost includes sub-contractor payment, consumable material costs, and electricity bills (Fig. 14).

Depending upon financial variables at the precast site, the other branch of KPIs is added. Hence, KPIs will help in monitoring cash-inflow and cash-outflow per month and estimating the profit or loss made per month.

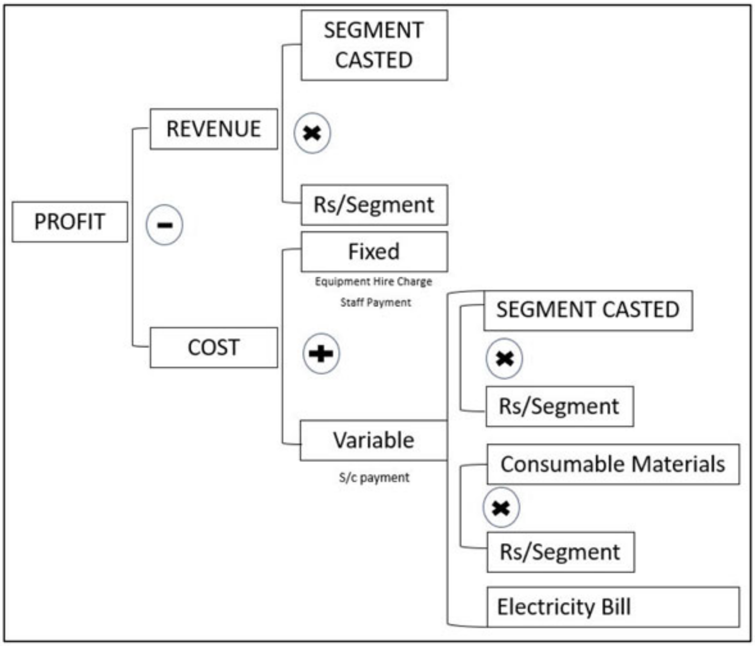


Fig. 14 KPIs tree

6 Discussion and Conclusion

This paper shows that a precast yard can employ practical concepts and productivity tools of operational management to increase productivity and hence its performance. These tools can be applied simply and easily by the precast team. This paper also emphasizes locating seven sources of waste in the precast yard. The main tools of operational management quartile analysis, OEEs, OPEs, and KPIs are discussed in brief. Overall, the paper focused on providing the guidelines in which these tools can be implemented in the precast yard to improve their efficiency and effectiveness.

The responsiveness versus crew productivity graph ensures that the site is utilizing their resource effectively. It helps in determining crew capacity, removing inefficiencies by transferring practices from best sub-contractors, helps in re-evaluating design or choosing technologies.

Quartile analysis implementation ensures that sub-contractor's approaches for executing work can be looked at while composing standard working procedures. The goal of site management should be to Fig. out how exactly the top-performing sub-contractors achieve their results and to find a way in which other sub-contractors deployed at the site for the execution of similar works can learn something from them. The variation of processing times across sub-contractors allowed seeking for productivity improvement.

OEEs diagram will show the effective time of the machine and downtime reasons dramatically. With the help of the machine's diagram, the site team can see where improvement can be provided faster. Hence, the site team must prepare an OEE framework for other machinery which they used at the precast yard. The following types of machinery are required for the superstructure construction process: Cutting machine; bending machine; backhoe loader; tire-mounted crane; gantry crane-100 T; gantry crane-25 T/40 T; batching plant (30 cum/h); transit mixers (4/6 m^3); and concrete pump with boom placer. Hence, the OEE framework should be prepared for all these types of machinery.

Similarly, OPEs framework can be implemented for every worker's working at the precast yard to determine their non-value-added work. Based on this site management can take necessary actions to enable faster construction.

The following waste at the precast yard can be minimized or eliminated by implementing these tools:

The graph between responsiveness versus crew productivity and quartile analysis helps in eliminating or minimizing rework, transportation, and motion waste.
OEEs will help in removing waiting waste.
KPIs will help in monitoring overproduction and inventory waste.

Further investigations should focus on how precast managers apply these tools at the site and how these tools benefit the project in achieving its target and thus saving from cost and schedule overruns.

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