Discrete Event Simulation Based Approach for Tracking Performance of Segmental Production at Precast Yard

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Abstract –

Efficient performance tracking and monitoring systems can facilitate timely decision-making by management. However, cycle time, which is commonly employed as a monitoring system in segmental production sites, can be time-consuming and only allows for the identification of inefficiencies, rather than supporting decision-making. In this context, operational management concepts with broad applications in manufacturing industries should be utilized. While several tools are offered by operational management, this paper focuses on the implementation of a process analysis tool as a performance tracking system for superstructure construction at a precast yard. Process analysis tools incorporate several operational performance measures, including cycle time, total idle time, direct labor content, and direct labor utilization. These performance measures serve as indicators for evaluating process productivity and can be estimated using an excel spreadsheet. Simulation tools, which enable visualization of the process and the identification of potential issues before implementation, can be valuable. In this regard, modeling in ExtendSim can be beneficial as the segmental production process can be easily visualized, aiding in the identification of station dependencies and allowing for the acquisition of performance measure results with a single click. This study therefore aims to explore the integration of process analysis tools with ExtendSim simulation as a performance tracking system at the precast yard. The values of these operational performance measures will provide management with multiple dimensions for enhancing the efficiency and effectiveness of the segmental production process.

Keywords –

Productivity, Production, Superstructure, Operational Management, ExtendSim, Simulation, Performance Measurement, Segmental Construction, Process Analysis, Modelling, Precast yard

1 Introduction

The construction industry lacks a practical framework for performance measurement [1][2]. This even applies to segmental bridge construction. The precast team uses cycle time as the only performance measure for monitoring segmental construction progress.

Though the production output can be increased by several means, one is by reducing cycle times i.e., either through product or process innovation. But the identification of problems and implement changes in the process will take time and it is just one measure to look at the performance of the precast yard. Also, several decisions have to be made to manage the production process, this decision will be regarding production planning, capacity, process design, operation strategy, and inventory control. Precast yard lacks this kind of monitoring system. Making the production system efficient, requires effective management. Manufacturing industries use operational management concepts which help in making these decisions and it is concerned with designing and controlling the process of production. All the concepts, tools, and techniques of operational management help make the production system efficient [3]. The major task at precast yard is shown in Figure 1.

1. Cutting and bending of rebars at the rebar yard.
2. Tying at rebar jigs.
3. Segment shutter & concrete work at casting bed.

Figure 1. Segmental Production Process

Hence, the current study explores an option of looking at the operational management tools which can be used in precast yards as performance tracking systems to point out the right areas for improvement. The two objectives of this study are as follows:

1. To develop a simulation model based on a process flow diagram of a short-line segmental production system and determine monthly performance parameters.
2. To determine operational performance measures of a segmental construction process using simulation.

For this paper, the scope is limited to improving the performance of precast yard superstructure production.

This paper can be broadly divided into seven sections. Section 2 provides a literature review, while Section 3 outlines the methodology used in the study. Section 4 elaborates on the process analysis tool implemented through Simulation. Section 5 presents the simulation results and offers improvement suggestions. Section 6 offers a detailed discussion of the study findings. Section 7 presents limitations and future research directions. Finally, Section 8 concludes the study.

2 Literature Review

In the current system, performance indicators related to processes include planned percent complete (PPC), waste, safety, and quality process improvement for enhancing site performance [1].

Also in that context, lean principles are effective in enhancing the performance of the construction process. These principles will improve the entire process of production, by eliminating waste in the process and ultimately increasing the performance of the business [4]. Many construction companies have also started integrating some of the principles of the Lean Production System (LPS). Companies applying these techniques can decrease their production cost, reduce rework, and increase production capacity.

Even research revealed that lean construction principles led to 41% improvement in process productivity, 14% enhancement in process efficiency, and 17% reduction in cycle time [5]. Lean production can improve operational performance [6]. The four dimensions of operational performance i.e., cost, quality, variety, and responsiveness are positively related to the lean production practice in the manufacturing industry [7]. And even its tools help in maximizing profit through high productivity and are applicable in any industry [3]. Hence, use of these tools in construction should be explored.

There are different ways to track the performance of the process, but it would not help the site management in decision making i.e., decision-related to resource allocation based on the project's scope and duration [8]. In this context, simulation tools which are widespread in various industries such as education, health, information technology, robotics, economics, business, logistics, and transport services can be helpful. The simulation outputs are the most valuable for production companies during the initial stages of business development. Also, the simulation methods can be utilized when there is a need to improve manufacturing and business processes and during the reengineering of technology and all business process [9][10]. Even many operations in construction projects show high potential for improvement through the application of lean principles and simulation, but it has not been used widely [11]. Simulation tools like ExtendSim are used for creating the real production process model and identifying the bottleneck and also help in redesigning the production process [12]. It has powerful capabilities to model and study complex systems [13].

The literature indicates a lack of performance indicators in the current system, and construction industries have turned to lean principles to enhance the construction process. While operational performance measures are linked to lean production and have been widely used in manufacturing industries, they are not commonly employed in construction processes.

In summary, through the literature study, it was found that simulation if used within lean approach helps in identifying problems in production processes, documenting the process, ranking the various opportunities for process improvement and finally helps in predicting the impact of accepted improvements before implementations. Therefore, it can be inferred that operational performance is positively related to lean production. In that reference, implementing operational management concepts to improve the construction process is one area that needs to be explored. Also, previous studies on simulation programs suggest that they can be useful in decision-making in the beginning stage. Therefore, using simulation for improving the segmental production process and for making decisions relevant to the production system is the other area to explore. Therefore, this study intended to fill the gap by integrating the process analysis tool of operational management with ExtendSim simulation as a performance tracking system for improving segment production rate at the precast yard.

3 Methodology

Figure 2 shows the methodology adopted for this study. The first stage of research consisted of a basic literature review to introduce previous studies and findings, after construction's professional opinion has been taken into consideration, and finally going through current adopted practices at the site level helps in defining the problem statement.

The second stage collecting data from the site. Data was collected and maintained in an excel spreadsheet during segmental production and were used to determine the average processing time (delay) at each station.

The final stage is the integration of operational performance measures with simulation., the first step is to draw a process flow diagram to understand the flow of materials from one station to another station. In the second step, the model was constructed using ExtendSim simulation according to the process flow diagram and inputting delay as constant. Third, to check the simulation model accuracy, a model was validated through a comparison between model outputs and site outputs i.e., obtained from the monthly production spreadsheet. After model validation, operational performance measures are estimated using a simulation function. And based on the results, a few scenarios are assumed to improve the performance measures and help the management in the decision-making process.

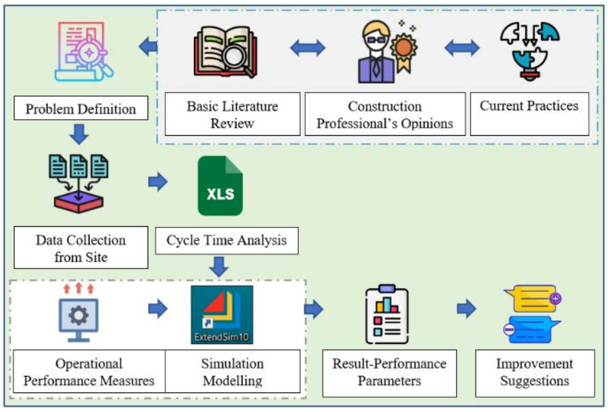


Figure 2. Methodology Adopted

4 Process Analysis Tool Implementation at Precast Yard

4.1 Operational Performance Measures

The performance measures that are determined in this study are the capacity at each station, process capacity, flow rate, utilization at each station, cycle time, total idle time, direct labor content, and direct labor utilization. All the terms used in this study are defined in Table 1.

Table 1. Term Definition

Terms	Definitions
Processing Time (PT)	Time spent by the worker or crew on the task.
Capacity (C)	It is estimated as (m/processing time) with m being the number of resources (e.g., workers or crews) being devoted to the station.
Bottleneck	It is defined as the process step in the flow diagram with the lowest capacity.
Process Capacity (PC)	The process capacity is always equivalent to the capacity of the bottleneck.
Flow Rate (FR)	Minimum between demand rate and process capacity.
Utilization (U)	It is calculated as flow rate divided by capacity. The utilization tells us, how well a resource is being used.
Cycle Time (CT)	It is defined as the time between the output of two successive flow units.
Direct labor content (DLC)	It is defined as the time sum of all process steps.
Idle Time (IT)	It is defined as cycle time minus processing time. The time when a resource is not doing anything and waiting for another resource.
Total Idle Time (TIT)	The total idle time is the time sum of all idle time within a process.
Direct Labour Utilization (DLU)	It is defined as the direct labor content divided by the sum of direct labor content and total idle time. The average labor utilization tells us the overall performance or productivity of the process.

4.2 Process flow diagram

It is the visual representation of the process flow. In which, rectangles represent tasks and activities; triangles represent inventory and arrows indicate the flow of the process. Figure 3 is the process flow diagram for the short-line bed model.

Short-line bed (SLB)

In a short-line bed, the casting of the next segment can begin only after shifting a previously casted segment. The casting of pierhead and expansion joints (EJ) segments is done on a short-line bed.

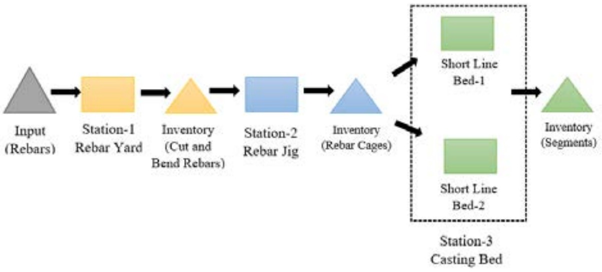


Figure 3. Short-line bed process flow diagram

For short-line segmental construction, work started at station-1 (rebar yard) on one cut-and-bend machine

(C&B), and these cut-and-bend rebars are shifted to station-2 (rebar jig) for tying purposes. Depending upon the front availability on station-2, cage-tying work will start. In general, short-line beds have one front available for cage tying. Once the cage is ready and the front is available at the casting bed, cage lowering is done at the casting bed (station-3). For segment casting work, two short-line beds are operational. Casting work goes parallelly at both beds. After casting and gaining sufficient strength for lifting, segments are shifted at the stacking yard for finishing purposes, and station-3 is made ready for cage lowering of the next segment.

4.3 Data collection

ExtendSim requires average processing time (delays) as input data. This data is manually recorded by the site engineer or supervisor in the daily-progress register and maintained in a cycle-time excel spreadsheet by the site-planning engineer. This spreadsheet gives information on the time taken for the completion of activities required for the casting of segments. Table 2 corresponds to the average processing time data recorded at the segmental construction site for the short-line bed.

Table 2. Average Processing time as input

Stations	Station's Name	Avg. PT (In hours)
1	Rebar Yard	30
2	Rebar Jig	35
3	Short line Bed	82

4.4 Modelling in ExtendSim

In this study, the ExtendSim 10.0.7 license version is used for modelling a short-line bed production system at the precast yard with the following basic assumptions.

1. Processing time (delay) as constant.
2. Sufficient demand per month of segments.
3. Most of the construction works are performed in a group not as an individual hence, the crew will be used in place of labor.

Steps required for modeling in ExtendSim:

- Firstly, using create, activity, queue, exit blocks in ExtendSim to imitate a process flow diagram for a short-line bed.
- Secondly, as construction works operate in day and night shifts, shift block is used to input details of workers' working time in a day.
- Lastly, simulating for 624 hours (assuming total working days in a month =26).

Figure 4 corresponds to the process flow diagram of the short-line bed in ExtendSim with all these settings.

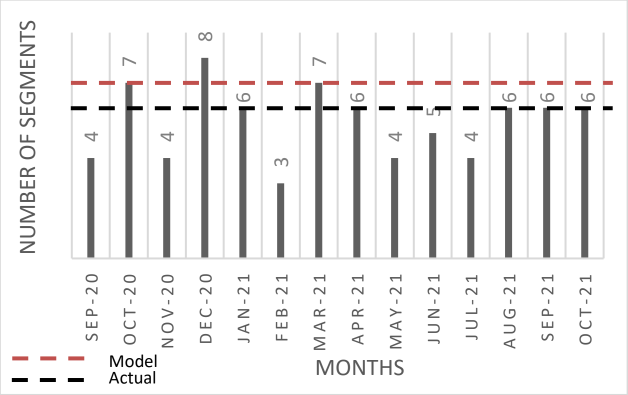


Figure 5. Short-line bed production (Actual)

4.4.1 Model Validation

To make sure that the model made in ExtendSim mimics the real segmental production process, inputs

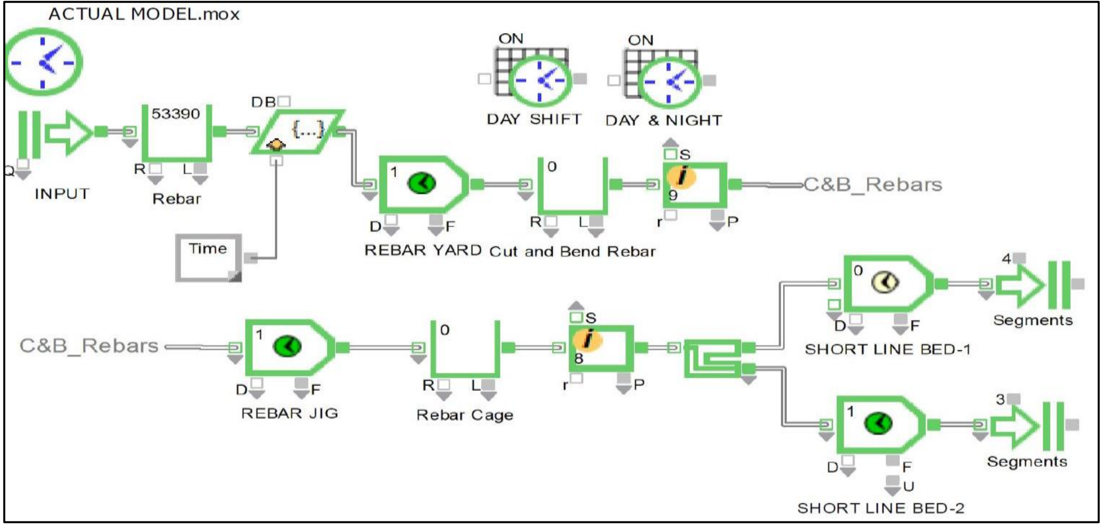


Figure 4. Short-line bed production system (Predicted by Model)

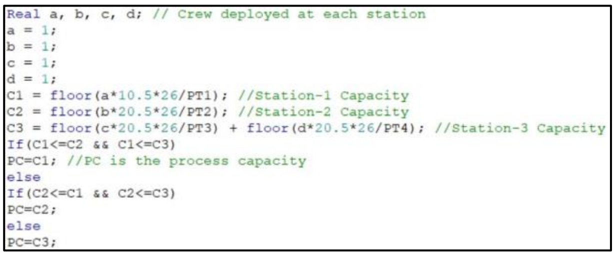
from the segmental production site was used in the modelling. If the model made in ExtendSim simulation gave nearly the same output as the precast team executed at the site, it will confirm model validation and can be used further for determining performance parameters.

Short-line Bed (SLB): Rebar yard works in the day shift; jig station and casting bed station work in both shifts. Figure 5 corresponds to the actual production capacity of the short-line bed.

It is indicated from Figure 4 and Figure 5, that the average monthly production capacity obtained from a site (i.e., 6 segments are produced per month) and from the model (7 segments per month) are closer. Hence, the model is validated and can be used for obtaining performance measures.

4.4.2 Determining performance measures

Operational performance measures are estimated through equation function under the value library. For determining these measures, processing time (delay) and crew deployed are used as input. Figure 6 demonstrates capacity and process capacity calculation.



```
Real a, b, c, d; // Crew deployed at each station
a = 1;
b = 1;
c = 1;
d = 1;
C1 = floor(a*10.5*26/PT1); //Station-1 Capacity
C2 = floor(b*20.5*26/PT2); //Station-2 Capacity
C3 = floor(c*20.5*26/PT3) + floor(d*20.5*26/PT4); //Station-3 Capacity
If(C1<=C2 && C1<=C3)
PC=C1; //PC is the process capacity
else
If(C2<=C1 && C2<=C3)
PC=C2;
else
PC=C3;
```

Figure 6. Determining Operational performance

Similarly, other performance measures can be determined. Due to space constraints, the link to the repository for estimating operational performance measures for short-line beds is: https://github.com/ashurai21/Performance-Measures

5 Result and Improvement Suggestions

5.1 Results

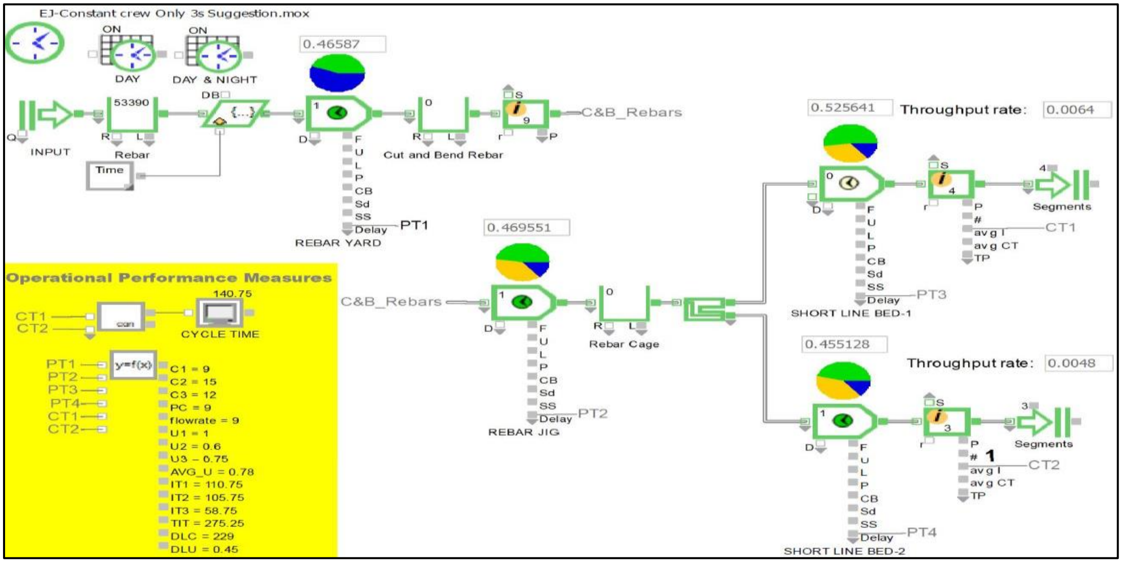
Operational performance measures are estimated with a single click in ExtendSim for the short-line bed shown in Figure 7. The result of the simulation models is presented in

Table 3.

Table 3. Short-line Bed Results

Operational Performance	Output	Unit
Capacity, C1	9	Segments/month
Capacity, C2	15	Segments/month
Capacity, C3	12	Segments/month
Process Capacity	9	Segments/month
Flow Rate	9	Segments/month
Cycle Time	140.75	Hours/Segment
Utilization, U1	1	-
Utilization, U2	0.6	-
Utilization, U3	0.75	-
Total Idle Time	275.25	Hours/Segment
DLC	229	Hours/Segment
DLU	0.45	-

From Table 3 and Figure 7, rebar jigs (station-2) can produce fifteen cages in a month, but due to less capacity of the rebar yard (station-1), only the tying of eight cages



```
C1 = 9
C2 = 15
C3 = 12
PC = 9
flowrate = 9
U1 = 1
U2 = 0.6
U3 – 0.75
AVG_U = 0.78
IT1 = 110.75
IT2 = 105.75
IT3 = 58.75
TIT = 275.25
DLC = 229
DLU = 0.45
```

Figure 7. Short-line bed Operational Performance Measures Values

is completed and at one jig tying work is in progress. Further, the only casting (station-3) of seven segments is achieved, one segment casting is work-in-progress, even though it can cast twelve segments. It shows waste in utilization at station-2 and 3, which is the major reason for an increase in cycle time, and idle time in the process. The rebar yard (station-1) has the lowest capacity as compared to other stations. Therefore, it is the bottleneck station, and the capacity of the entire process will depend on it. Direct labor utilization values indicate productivity of the process which is just 0.45 in this case.

5.2 Suggestions

In this section, two scenarios are considered for a short-line bed to achieve the following objectives.

1. The first objective is to reduce cycle time and idle time.
2. The second objective is to increase the capacity, hence process capacity, flow rate, utilization, and direct labor utilization.

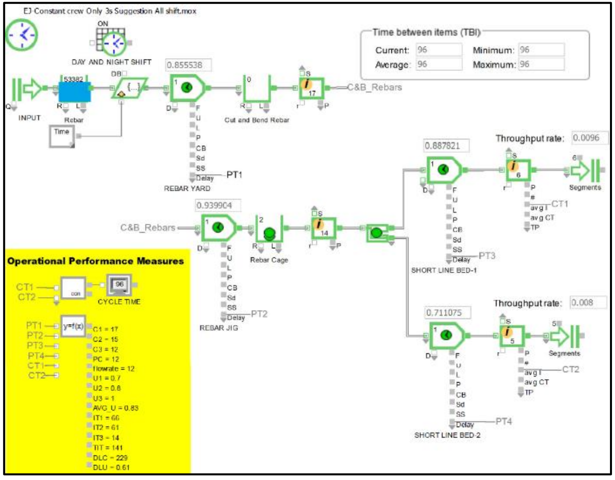
Percentage improvement (%I) is calculated for all the operational performance measures to determine whether the measures are improved or not after switching from the actual site scenario to the proposed site scenario.

For cycle time, idle time (objective is to decrease the values of these measures), and percentage improvement is estimated by using the following equation (1).

%I = (Actual-Proposed)/Actual x 100 %... (1)

For capacity, process capacity, flow rate, utilization, and direct labor utilization (the objective is to increase the values of these measures), percentage improvement is estimated by using the following equation (2).

%I = (Proposed- Actual)/Actual x 100 %... (2)



Time between items (TBI)
Current: 96 Minimum: 96
Average: 96 Maximum: 96

Throughput rate: 0.0096

Throughput rate: 0.008

CYCLE TIME 96

C1 = 17
C2 = 15
C3 = 12
PC = 12
flowrate = 12
U1 = 0.7
U2 = 0.8
U3 = 1
AVG_U = 0.83
IT1 = 66
IT2 = 61
IT3 = 14
TIT = 141
DLC = 229
DLU = 0.61

Figure 8. Scenario-1 Short-line bed

Scenario-1 All stations are operational on both day and night shifts without deploying any additional resources.

Figure 8 shows the operational performance values obtained through simulation in this scenario. Percentage improvement values are presented in Table 4.

Table 4. Scenario-1 Short-line Bed

Operational Performance	Actual	Scenario-1	
		Proposed	% I
Capacity, C1	9	17	88.88
Capacity, C2	15	15	0
Capacity, C3	12	12	0
Process Capacity	9	12	33.33
Flow Rate	9	12	33.33
Cycle Time	140.75	96	31.79
Utilization, U1	1	0.7	-30
Utilization, U2	0.6	0.8	33.33
Utilization, U3	0.75	1	33.33
Total Idle Time	275.25	141	48.77
DLC	229	229	0
DLU	0.45	0.61	35.55

In scenario-1 short-line bed, the bottleneck station is changed to station-3 (casting bed) from station-1. Cut and bend rebars are always available in buffer for tying purposes, and extra cages are always ready for casting purposes. Figure 9 illustrates the percentage improvement from the actual to the proposed scenario.

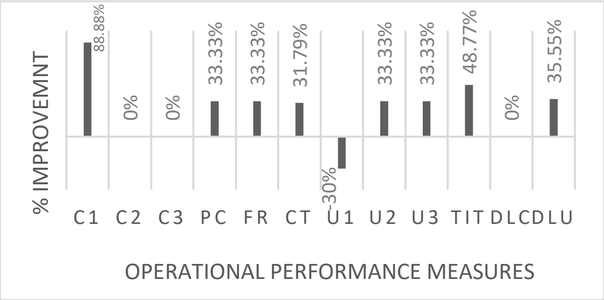
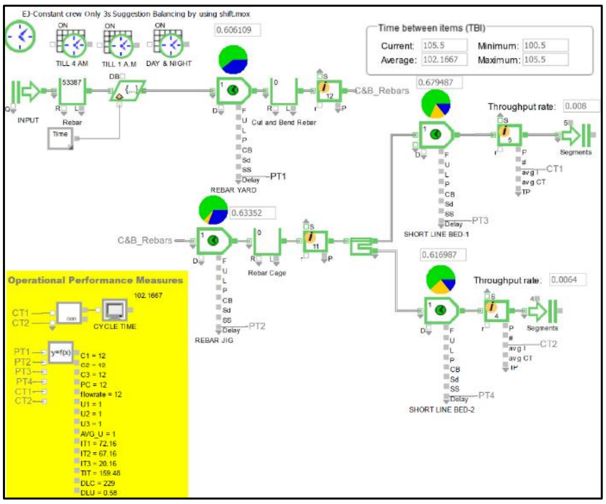


Figure 9. % Improvement Scenario-1 SLB

Percentage Improvement shows that in the proposed scenario almost all of the desired objectives are achieved. However, utilization at station-1 decreased by 30%.

Scenario-2 Balancing capacity by allowing work at each station till the time requires, to meet the demand. Hence, in this scenario assuming:

- Rebar yard is operational till 4 A.M.
- Rebar jig is operational till 1 A.M.
- The casting bed is operational on both day and night shifts.



EJ-Constant crew Only 3s Suggestion Balancing by using shift.mox

Time between items (TBI)
Current: 105.5
Average: 102.1667
Minimum: 100.5
Maximum: 105.5

Throughput rate: 0.008

Throughput rate: 0.0064

Operational Performance Measures
CYCLE TIME 102.1667
C1 = 12
C2 = 12
C3 = 12
PC = 12
flowrate = 12
U1 = 1
U2 = 1
U3 = 1
AVG_U = 1
IT1 = 72.16
IT2 = 67.16
IT3 = 20.16
TIT = 159.48
DLC = 229
DLU = 0.58

Figure 10. Scenario-2 Short-line bed

Table 5. Scenario- 2 Short-line bed

Operational Performance	Actual	Scenario-2	
		Proposed	%I
Capacity, C1	9	12	33.33
Capacity, C2	15	12	-33.33
Capacity, C3	12	12	0
Process Capacity	9	12	33.33
Flow Rate	9	12	33.33
Cycle Time	140.75	102.2	27.41
Utilization, U1	1	1	0
Utilization, U2	0.6	1	66.67
Utilization, U3	0.75	1	33.33
Total Idle Time	275.25	159.5	42.05
DLC	229	229	0
DLU	0.45	0.58	28.88

Figure 10 shows the operational performance values obtained through simulation in this scenario. Percentage improvement values are presented in Table 5.

Though the overall productivity of the segmental production process is increased to 0.58 in this scenario, still, it is not desirable to have a balanced process. This is because, if there is uncertainty in rebar procurement at the site, cutting and bending get delayed, which ultimately delays tying works. Therefore, it will be more beneficial to add slack capacity (rebar cages) at the jig station, which means it needs to be imbalanced to deal with this uncertainty. Figure 11 illustrates the percentage improvement from the actual to the proposed scenario. A positive value of % improvement indicates that almost all of the desired objectives are achieved in scenario 2. However, capacity at station-2 is decreased by 33.33%.

The other possible scenario in which productivity of the process can be increased is by deploying additional resources which are not covered in this study.

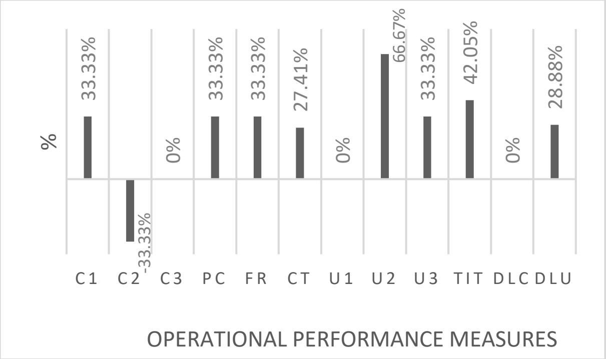


Figure 11. % Improvement Scenario-2 SLB

6 Discussion

This section deals with evaluating the usefulness of operational performance measures at the precast yard. Through performance measures, the actual capacity of each station is determined and by comparing it with on-site production, waste incapacity can be determined. Depending upon the resource availability and front availability, the process flow diagram will vary at sites. The model made in ExtendSim helps in visualizing the process flow of the segmental production process, which further helps in identifying the dependencies of stations on each other and determining monthly performance parameters. The process capacity depends upon the bottleneck station, hence knowing this parameter will help the precast team to look at the bottleneck station first, rather than focusing on other stations. Hence, the precast team should focus on achieving higher process capacity, i.e., achieved either by doing process innovation (which will cut down processing time) or allowing workers to work in more shifts to meet demand. Higher process capacity means achieving a greater number of segments casting in the same timeframe.

In this study, demand assumed was sufficient, but if demand is lower than production capacity, i.e., segments produced are more than segments erected, the flow rate of the process will depend upon segment erection. And in this case, the segment has to be stacked as inventory in the stacking yard. This may trouble site management for segment storage as the inventory at the site will exceed stacking capacity. Hence, the flow rate will help the precast team in tracking the mismatch between demand and capacity. High cycle time and idle time values indicate waste in the process, which ultimately affects profit margins. These two-performance measures will tell the site team that there is still scope for improvement in the process flow. Based on the productivity of the process, the precast team can decide on the requirement of deploying an additional crew and additional resources or allowing the crew to work in more shifts to meet the demand. All these measures will help the precast team in eliminating waste and inefficiencies and in scaling up the profit margins. Finally, with the help of these measures site-management can track the segmental construction progress which helps in making right strategies, and thus saving the project from schedule and cost overruns.

7 Limitations and Future Directions

The current scope of this study is restricted to the precast yard, but the process flow could be expanded to include segmental erection. This addition would provide a more comprehensive view of the superstructure's performance, allowing for better monitoring and tracking by management. Also, to further enhance the analysis, in future, 3D simulation software (e.g., AnyLogic) could be utilized to visualize the precast yard stations and compare the differences in results obtained.

8 Conclusion

The research presented in this paper tries to find the operational performance measures of the segmental production process with the help of ExtendSim simulation for a short-line bed production system. The key findings of this study are:

- The process flow diagram of segmental production with the help of ExtendSim simulation helps in visualizing the entire process. And thus, the flow of material or products from one station to another, or dependencies of stations on each other are analysed.
- Based on these values, management can focus on increasing the capacity of the bottleneck station.
- These performance measures will help management on focusing on the right areas for improvement and in supporting their decision. These decisions can be regarding deploying additional crew or asking crew to work over shifts.

Through the study done, it is confirmed that process analysis tools can be integrated with ExtendSim simulation and can be used as a performance tracking system at the precast yard.

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