International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 58, No. 3, March, 2025, pp. 633-642
Journal homepage: http://iieta.org/journals/jesa

Identification of Time Wastage Towards Lean Production for IBS: A Case Study of Precast Hollow Core Slab Production

Rohaida Affandi[1,2*], Izni Syahrizal Ibrahim[2], Masine Md Tap[3], Aliff Ridzuan Bunawan[4]

[1] Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan 94300, Malaysia
[2] Forensic Engineering Centre (FEC), Institute for Smart Infrastructure and Innovative Construction (ISiiC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Johor, Malaysia
[3] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Johor, Malaysia
[4] Faculty of Engineering, I-CATS University College, Kuching 93350, Malaysia

Corresponding Author Email: arohaida@unimas.my

https://doi.org/10.18280/jesa.580319

Received: 4 December 2024
Revised: 10 February 2025
Accepted: 18 February 2025
Available online: 31 March 2025

Keywords:
Industrialized Building System (IBS), lean production, time wastage, value stream map, cause-and-effect matrix, pareto chart

ABSTRACT

The introduction of Industrialized Building System (IBS) is thought to hasten the construction process when it is substituted from the traditional cast-in-place approach to the factory-made precast component. Since IBS components manufacturing may boost its productivity using Lean Production to cut down on-time wastage, there is a clear need to investigate their manufacturing efficiency in the construction industry. In this paper, the time wastage of manufacturing precast hollow core slab is placed under close inspection to assess areas of improvements. Upon developing the Value Stream Mapping (VSM) of the manufacturing process, the research then investigates the root cause of the time wastage by employing major waste checklist and then proceeds to develop an Ishikawa Diagram to better illustrate the findings. To give proper weightage and comparative priority for improvements, the Cause-and-Effect Matrix (CEM) method is applied and then described by a Pareto chart. The root cause of time wastage was then pointed out to be inefficient machinery utilization and traditional procedure in the bed cleaning process. Several corrective measures are then suggested to reduce time wasting in the production of precast hollow core slab.

1. INTRODUCTION

Industrialized Building System (IBS) is defined as the invention of Modular Coordination (MC) of which begins from planning to utilization in construction projects by applying standard manufacturing designs. The standard progression of a project would involve the component's designs, sourcing, manufacturing, fabrication and installation on that particular project [1, 2].

1.1 Lean production

Researchers reported on the trend of Lean methodologies having said that Lean production was also founded on the idea of Kaizen; which directly translates as continuous improvement [3]. A concept or philosophy which has been employed far and wide to gather information, constantly assessing all processes and in time apply continuous improvement [4, 5]. In addition, Lean emphasized on giving value to the customers through three types; value added, unnecessary non-value and finally necessary non-value activities [6]. Dogan and Yagli [7] mentioned to assist in the identification of activities that do or do not create value to the customer, one method stood out from the rest which is the Value Stream Mapping (VSM) method [7-9]. VSM employs graphical representation through value stream mapping icons constructing the overall progress of a product through the production line from the supplier to the customer [3, 10]. Proceeding the VSM establishment which also identifies as Current Value Stream Mapping (CVSM), an improved version reformed from CVSM is produced which is known as Future Value Stream Mapping (FVSM). Improvement results are quantifiable through CVSM and FVSM comparison [11, 12]. Ciano et al. [13] provided evidence that manufacturing companies with revenues from a range of 9.5 to 100 million Euros practiced Lean Production allowing them to employ continuous improvements in their businesses [14, 15]. These businesses ranged from manufacturing metal products, mechanical, electronic components to healthcare sealant. Through this assessment of processes and activities, it is evident that Lean can be a great asset in helping companies make the right choices and benefit greatly [9, 16, 17]. These studies highlight the importance of Lean Production in reducing waste and improving efficiency in manufacturing processes. However, there is limited research on the application of Lean tools in the context of IBS, particularly in the production of precast hollow core slabs. This study builds on these findings by applying Lean tools such as Value Stream Mapping and Cause-and-Effect Matrix to identify and address time wastage in IBS production [13, 18-21].

Badir et al. [22] reported production of houses grew ten times as much once new building systems and factory produced building components are employed in the construction industry. Despite the benefits, there is a sizable amount of waste produced during the manufacturing of any IBS components. This waste accumulation would lead to financial, quality and time losses if left unchecked. Henceforth, deploying Lean Production in any IBS construction is regarded as an excellent strategy in mitigating losses. Lead Production in simpler terms are the principle or techniques of which the aim is to lessen or eradicate waste [23, 24].

While application of Lean Production has been thorough in the manufacturing industry such as employing numerous tools and techniques to eliminate waste, that has not been the case for most of the IBS construction manufacturing in Malaysia [9, 15, 25]. Though countermeasures are in place to tackle the problem of solid waste produced from the construction industry, such waste that is hidden from sight such as manpower loss, non-strategic methods, improper material handling or ineffective machinery utilization still plague the industry [26, 27]. Researchers agreed that with the reduction of wastage from the construction industry not only will the manufacturers save capital and time but also contributing to saving the environment, to be in the correct path towards supporting Sustainable Development Goals (SDG) [2, 28-30].

Manufacturing of an IBS components involved few phases of which the most essential one is the production phase of the components [31, 32]. This phase consumed the most time, involved the most processes, and had the most activities occurred during the production. By concentrating on time wastage at any section of the production line, there is a strong likelihood that reducing time wastage will boost productivity during the manufacturing of IBS component [33, 34]. Therefore, applying Lean Production principle in this case, it is possible to reduce lead times, increase productivity, and eliminate wasteful resources while producing the best possible outcomes.

This paper is aimed to identify time wastage known as non-value adding activities (NVAAs) in the production line of a precast hollow core slab (HCS), as a first step towards Lean Production development.

2. METHODOLOGY

This research proceeds with the methodology in identifying time wastage of a precast HCS production as shown in Figure 1. Only HCS production is reported since at the time the research only managed to negotiate site visits to examine a designated HCS production line, through a series of discussions with the production company representative.

There are six major stages of the methodology which are the preliminary studies, permission request, site visit, data collection, and data analysis and finally the findings are distributed among interested parties. In the earlier stage of the research, the objective and scope of the study was defined and identified of which to be the framework of the study. After that, numerous inquiries were sent to several identified on-going project together with the IBS manufacturers to gain permission for site visit and data collection.

Out of all the inquiries sent, the research was presented with the opportunity to document the construction of Kajang Hospital of which the precast HCSs were used and the production was made in a factory located at the southern part of Peninsular Malaysia. As site visit ensued, every detail of the processes in the manufacturing of precast HCS was documented which includes the progression of operation, movement of material, cycle time, manpower and machinery management. The data was collected based on interview sessions with a range of expertise from the management and engineering level to the general workers with physical observation of every process from start to finish. Cycle time for each process is supported with data collection using stopwatch with a set number of trials for consistency. As a means to an end, the data collected was then processed and analysed for verification and validation. During the site visit, the manufacturing process of precast HCS was documented, including operation progression, material movement, cycle time, and manpower and machinery management. Data was collected through interviews with management, engineers, and workers, as well as physical observations. Cycle times were recorded using a stopwatch, with multiple trials for consistency.

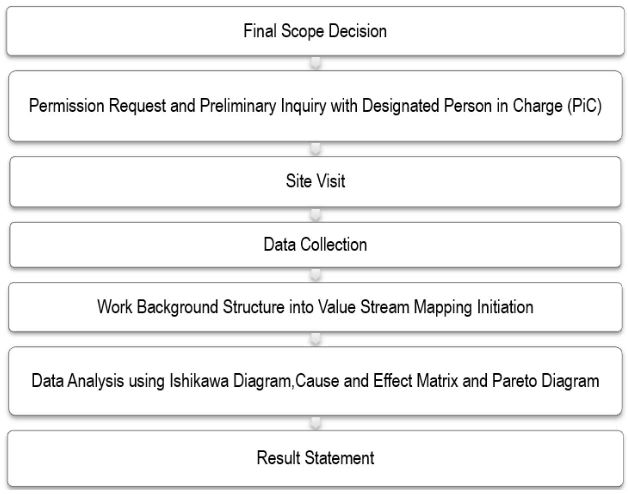

Figure 1. Research methodology

In the analysis, the research proceeds with defining the observed activities into a Work Backdown Structure (WBS) framework. To further analyse and identify the time wastage that was presented during the production of precast HCS, Value Stream Mapping (VSM) method was utilized. VSM is a tool to identify and eliminate waste in a process cycle. Understanding and streamlining work processes with Lean Manufacturing tools and methods is beneficial following the establishment of the VSM [6, 8].

Furthermore, to identify the specific area of improvements in the production of the precast HCS, manufacturing an Ishikawa Diagram or better known as fishbone diagram was used to provide a straightforward graphical representation of the sources for the time wastage. Identification of time wastage in the production of precast HCS will be split into several categories of which the root cause will be promptly highlighted. The Cause-and-Effect Matrix (CEM) was used to prioritize the root causes of time wastage by assigning weightage scores based on their correlation with process outputs such as timely delivery, minimal idle time, and product quality. The Pareto Chart was then constructed to visually highlight the most significant causes of time wastage, allowing for targeted improvements.

Following the results from the Ishikawa Diagram, a Cause-and-Effect Matrix (CEM) method was applied to further strengthen the analysis to identify the root cause of time wastage in the manufacturing of precast HCS. Scores of which are given in weightage represented the correlation from the input process with the respective time wastage outputs. Finally, a Pareto Chart is constructed as a graphical simplification to help defined the constructed CEM. This is in line with the views of Varma and Lal [35], of which agreed that by utilising the CEM and Pareto Analysis, the root cause of time wastage in the manufacturing stage of any given production can be systematically identified effortlessly [10, 36].

3. RESULTS AND DISCUSSION

Based on the preliminary inquiry with the selected IBS manufacturing company, the process flow was established prior to the site visit for data collection. The flow of the production processes for the precast HCS are shown in Figure 2.

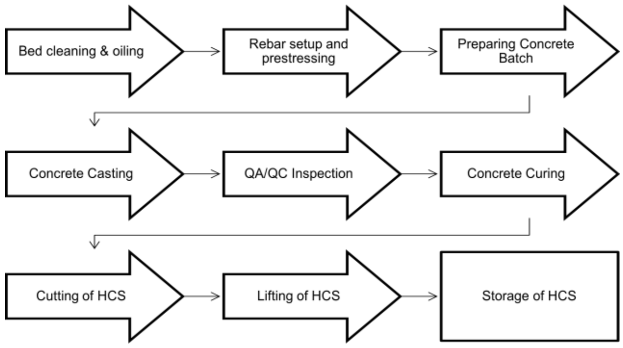

Figure 2. Process flow of precast HCS production

As shown by the process flow chart in Figure 2, it can be seen that the process started with bed cleaning and oiling. The process continued with the rebar arrangements and prestressing of the prestressed steel before concreting and casting commences. After the QA or QC inspection passed with an approval stamp, the precast HCS was cured until targeted strength of the concrete was achieved and later finalized with the segmentation and storage.

Subsequently, site visit and physical verifications of each process were documented. Each process in Figure 2 was compiled physically as shown in Figure 3.

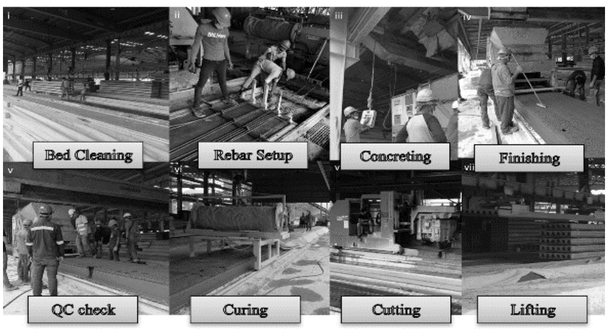

Figure 3. Physical observation of the process flow for precast HCS production

The process of manufacturing precast HCS started with bed cleaning by two to three general workers using machinery. This is then followed by manual hand pump spray for the oiling as shown in Figure 3(i). After the bed is cleaned and set, prestressed rebars were installed according to the required design specifications using the extruder machine. The rebars were stressed along the bed, clamped and tightened using hydraulic jack at the end point of the manufacturing bed as demonstrated in Figure 3(ii).

Once the rebar specification was in order, shown in Figure 3(iii) is the commencement of the concreting phase. Specification approved concrete mix from the batching plant was poured into the extruder machine using a system of conveyor belt. The concrete casting phase ensued immediately after with up to eight workers; with each one worker handling the extruder machine and conveyor belt, respectively, four to five workers employed to apply the finishing surface, while a supervisor was observing the whole process to maintain quality. General workers were seen using hand tools such as spades and brooms to assist in the finishing surface as demonstrated in Figure 3(iv).

Once the concrete casting work reached a certain range, a QA or QC inspector inspected the constructed precast HCS to notify the workers of any additional amendments that needs rectification. Figure 3(v) exhibits an example of a QA or QC inspector checking the strength of the newly casted precast HCS by projecting his body weight onto the slab. After the quality of the precast HCS was checked thoroughly, a blanket of plastic canvas was wrapped upon the slab for curing purposes as shown in Figure 3(vi).

The following day after the precast HCS completed its curing period and achieved the design concrete strength, sections of the slab were cut using a cutting machine operated by an operator as shown in Figure 3(vii). Finally, an overhead crane was used to transport the segmented precast HCS for storage. The precast HCSs were then stacked vertically up to six to seven pieces as shown in Figure 3(viii), awaiting to be transferred to the site. The production details of this particular case study of the precast HCS and its operation processes for the mentioned project are listed in Table 1 and Table 2, respectively.

Table 1 lists the details of the operation processes of the precast HCS including the dimensions, manpower consumption and machineries involved in the production. Meanwhile, Table 2 provides the details of each operation process of the assembly production line. This data points will then be structured to develop the Work Breakdown Structure (WBS) and Cycle Time (CT) summary as shown in Table 3 and Table 4, respectively.

Table 1. Precast HCS production details

Item	Details
Project	Kajang Hospital
IBS Product	Hollow Core Slab (HCS)
Dimension	6600 mm (L) ×1200 mm (W) ×200 mm (H)
Total HCSs	53 units
Duration for the precast HCS production	November 2019 – December 2019
Manpower	Supervisor: 1 Assistant Supervisor: 2 General Worker: 19
Machinery	Crane: Gantry Crane (2) Casting Work: Extruder (2), Bucket (1), Concrete Complex (1) Rebar Setup: Bed Cleaning Machine (1), Hydraulic Nozzle (1)

Table 2. Precast HCS component processing operation

No	Process	Type of Operation
1	Bed Cleaning & Oiling	Manual
2	Rebar Setup & Pre-Stressed	Manual & Semi-Auto
3	Concrete Preparation	Automatic
4	Concrete Casting	Semi-Auto
5	QA or QC Inspection	Manual
6	Curing of precast HCS	Manual
7	Cutting of precast HCS	Semi-Auto
8	Lifting & Storage of precast HCS	Semi-Auto

WBS divides all tasks into main tasks that will organize each individual work delivery in a way that helps to define and coordinate the project's full work scope. To identify time wastage for any type of production work will need an identification of the major processes impacted by inadequate or incompetent work delivery. Devi and Reddy [37] explained the importance of WBS in estimating cost, risk and time of a project. This can be accomplished by referring to an organized and adequately defined scope of the total project that was structured by an appropriate WBS interpretation. By observation, the CT results from more than 40 sets of observation for each process on the manufacturing of the precast HCS, are summarised in Table 4. Using the parameters and data gathered prior to the observations, Current State Value Stream Mapping (CSVSM) was then executed as portrayed in Figure 4.

Table 3. WBS for precast HCS production

1	Precast HCS Production
1.1	Bed setting
1.1.1	Bed cleaning
1.1.2	Bed oiling
1.2	Prestressed steel bar setting
1.2.1	Prestressed steel bar is placed according to the design specification
1.2.2	Prestressed steel bar is stress using hydraulic jack
1.2.3	Prestressed steel bar inspection after the stressing process
1.3	Concrete Preparation
1.3.1	Concrete mix inspection
1.3.2	Concrete mix delivery
1.4	Concrete Casting
1.4.1	Extruder machine placed on the bed
1.4.2	Slump test conducted
1.4.3	Precast HCS production
1.4.4	Precast HCS surface finishing
1.5	Curing of precast HCS
1.6	Cutting of precast HCS
1.7	Lifting and storage of precast HCS
1.7.1	Labelling of precast HCS components
1.7.2	Lifting and storing of precast HCS at the warehouse
1.8	Product delivery to site or client

Table 4. Summary of average CT

Process	**Bed Setting**	**Rebar Setting**	**Concrete Preparation**	**Concrete Casting**	**QA or QC Inspection**	**Curing of Precast HCS**	**Cutting of Precast HCS**	**Lifting & Storage of Precast HCS**
Average Cycle Time, $\bar{x}$ (mins)	3.841	6.370	8.752	5.566	9.158	1286.17	3.853	3.405
Uptime %	95	95	100	95	95	95	95	95
Workers	2	4	1	8	2	4	3	2

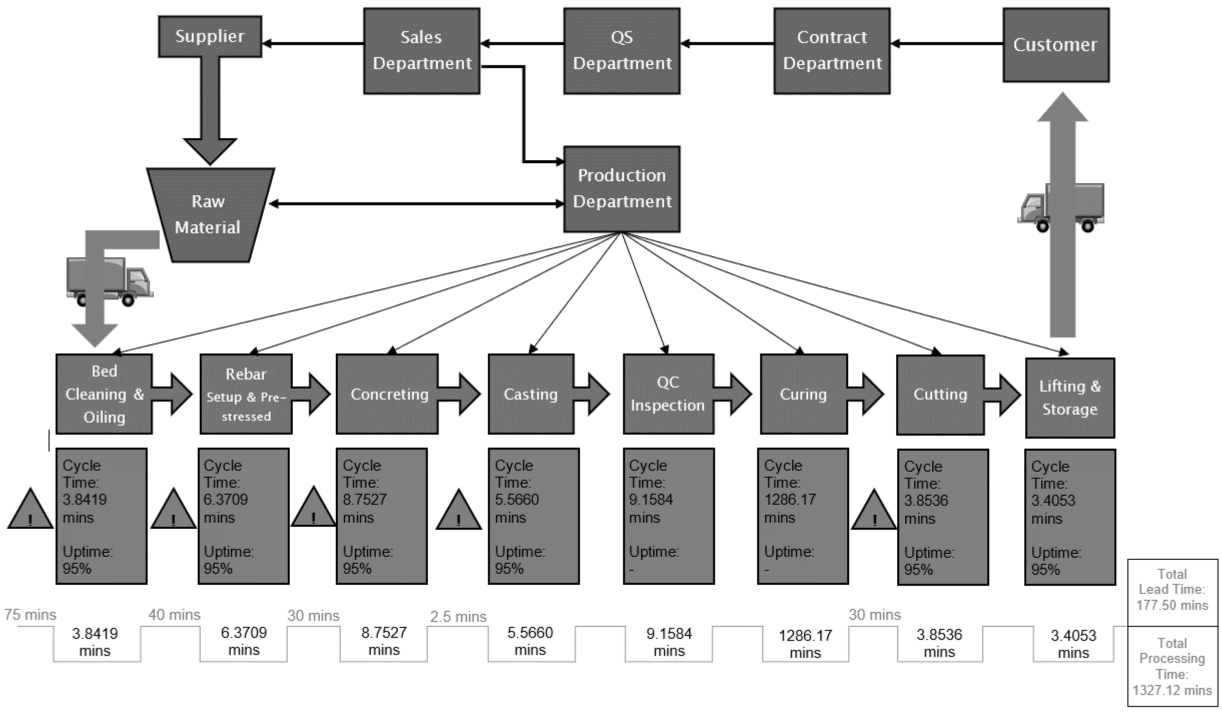

Figure 4. CSVSM findings of precast HCS production

As shown in Figure 4, the mapping for the overall manufacturing process of the precast HCS was developed. The chronology of each process involved was clearly defined with emphasised on time wastage marked by the red triangles between the processes. Each average process cycle and waiting time were finely depicted by summing up the total lead time and value-added time. The total lead time for this particular component production is 177.50 minutes, while the total processing time is 1327.13 minutes.

Putting together the total lead time and total CT enabled the research to proceed in calculating Value Added (VA) ratio for the manufacturing of the precast HCS. VA ratio is calculated to map out whether there was time wastage in the process. The calculation for VA ratio is shown in the following equation:

$$VA\ Ratio = \frac{Total\ Processing\ Time}{Total\ Lead\ Time} = \frac{1327.12\ mins}{177.50\ mins} = 7.5$$

The VA ratio of 7.5 indicates that the total lead time is shorter than the total processing time. This shows that there is a considerable amount of time wastage in the process. It is also worth to note the VA ratio from the CSVSM findings can also be used as a comparison to calculate the hypothetical improvement percentage from the Future Value Stream Mapping (FVSM), of which was not pursued in this study.

From the CSVSM findings, it can be identified that the highest CT of the overall process is the curing time. This is because the curing process of the precast HCS will require approximately one day for the hydration cycle and reaching its intended targeted strength. As seen in Figure 3(vi), the manufacturing company had taken an initiative to wrap the precast HCS using plastic canvas in order to provide an ample condition for curing as the process can be affected by weather and temperature changes from its surroundings. From the observations and interviewing the personnel involved in the manufacturing company, the study reached an understanding that the CT of each process was finely tuned and unwarranted for improvement. Therefore, this study shifted its focus to examine the waiting time between each process. The summary of the average CT for waiting time is listed in Table 5.

Table 5. Summary of average CT for waiting time

No.	Process	Average CT, $\bar{x}$ (minutes)
1	Before bed setting	75.0
2	Between bed setting & rebar setting	40.0
3	Between rebar setting & concrete preparation	30.0
4	Between concrete preparation & concrete casting	2.5
5	Between curing & cutting of precast HCS	30.0
	Total Lead Time ($\sum \bar{x}$)	177.50

Table 6. Checklist for major waste findings (Productivity development team, 2002)

Working Areas	The Seven Deadly Wastes							Total Waste Magnitude	Improvement Ranking
	Overproduction	Inventory	Conveyance	Defects	Processing Waste	Operation Waste/ Moving	Idle Time/ Waiting Time		
Before process of bed cleaning & oiling	0	0	0	0	0	0	3	3	3
In between process of bed cleaning & oiling and rebar setup & pre-stressed	0	0	3	0	3	0	2	8	1
In between process of rebar setup & pre-stressed and concrete preparation	0	0	0	0	0	0	2	2	4
In between process of concrete preparation and concrete casting	0	0	0	3	3	0	0	6	2
In between process of curing and cutting of precast HCS	0	0	0	0	0	0	2	2	4

When providing numerical values followed by measurement units, a regular space or non-breaking space should be left between each value and its measurement unit. This rule also applies to the unit for litre, which is recommended to be capitalized as 'L'. However, no space is used for percentages and degrees Celsius (e.g., 35%, 234°C).

Following the examination of the waiting time, it was apparent that the largest was before the bed setting and also between the bed setting and rebar setting processes with an average CT of 75 minutes and 40 minutes, respectively.

Upon close inspection, the largest waiting time before the bed setting was found to be closely connected with the process of rebar setting as the workers involved with the bed cleaning and oiling will only start their work when the rebar setting workers were ready to start. This idle time before the bed setting was then considered redundant as this process could not stand on its own without the direct commencement of the rebar setting. Therefore, the quality of bed setting will be detrimental with the longer gap in between both processes.

Following that, the second highest waiting time was the idle time between the beds setting and rebar setting with an average CT of 40 minutes. Upon close observation, multiple factors were contributing to this high lead time including mismanagement of manpower changeover, overlapping crane practice and poor management of materials placement layout.

The research proceeds with the identification of time wastage by employing an approach from Productivity Development Team (2002), by creating ranking of waste magnitude as shown in Table 6. This was later used to develop checklists of major wastage findings for each process as listed in Table 7.

Based on Table 7, the 'seven deadly wastes' of each process was identified and given weightage from 3 (define as lots of waste) to 0 (define as no waste). It was identified that the process in between bed cleaning and rebar setup was deemed to have the highest total waste magnitude and therefore needs of improvements. This was then followed by the process between concrete preparation and concrete casting. The least of the major waste in terms of ranking for the area of improvement was the time before the process of bed cleaning.

The study was then proceeds to further focus on the wastage in between the process of bed cleaning and rebar setup. Each of the 'seven deadly wastes' attributed to the total waste magnitude for the process; therefore, a separate checklist to further identify the area of improvements are documented in Table 8, Table 9 and Table 10 for each conveyance, processing and idle time, respectively.

Table 7. Levels of waste magnitude (Productivity Development Team, 2002)

Waste Magnitude	Remark
0	No waste found
1	Very little waste
2	Some waste
3	A lot of waste

Table 8. Conveyance waste-finding checklist

Description of Waste	Yes	No	Magnitude	Improvement Plan
1. Pile up during conveyance		√	0	-
2. Overlapping of conveyance devices in mid transfer	√		3	Flow production Kanban
3. Previous and/ or next process is on another floor	√		2	
4. Conveyance requires manual assistance	√		3	Multi-skilled workers
5. Conveyance distance is too long		√	0	-
	Total		8	

Table 8 to Table 10 lists the waste magnitude together with the proposed improvement plans for each waste that was considered as a general contributor to the total time wastage of the production. Amongst the description of waste that needs improvement includes the flow of production, modes of process, manpower management and machinery setup. In addition, idle time waste-findings checklist tops the waste magnitude with total of 9, slightly higher that conveyance at 8 and the lowest was the processing waste at 3.

The research proceeds to explore into the listed improvement plan by getting feedbacks from the executives of the company at the management level and the workers at the processing level. Identification on the area of improvements from the feedbacks given by the workers will allow to figure out of the sources for each wastage. Figure 5, shows the Ishikawa Diagram or the fishbone diagram as a visual aid in showing the sources for the high queue time of the focused improvement area. Varma and Lal [35] also mentioned about the use of cause-and-effect matrix, fishbone diagram, why-why analysis and failure mode effect analysis to identify the root cause of wastage complications in the industry.

Table 9. Processing waste-finding checklist

Description of Waste	Yes	No	Magnitude	Improvement Plan
1. Process is not required for product function		√	0	-
2. Process includes unnecessary operations		√	0	-
3. Process can be replaced by something less wasteful	√		3	Improvement of jigs using automation
4. Part of process can be eliminated without detracting from product		√	0	-
	Total		3	

Table 10. Idle time waste-finding checklist

Description of Waste	Yes	No	Magnitude	Improvement Plan
1. Work piece delay from previous process	√		3	Quick changeover
2. Machine busy status		√	0	-
3. Missing item(s)		√	0	-
4. Lack of balance with workers	√		3	Line balancing Quick changeover
5. Lack of planning		√	0	-
6. Lack of standard operations		√	0	-
7. Worker absence		√	0	-
8. Too many workers (more than two)		√	0	-
9. Obstruction of flow	√		3	Line balancing
	Total		9	

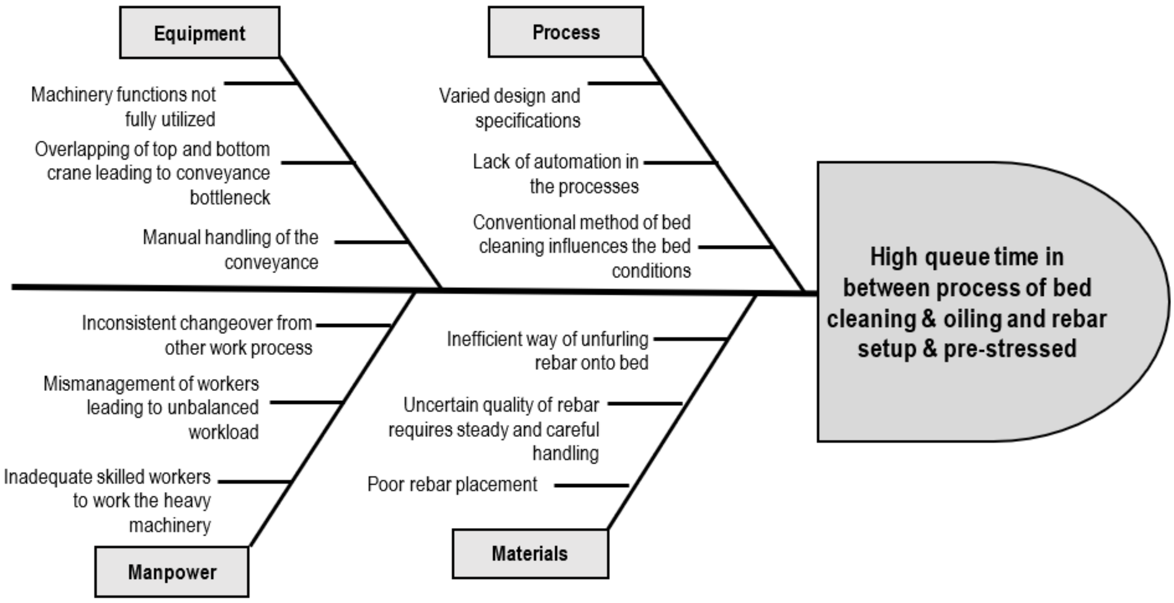

Figure 5. Ishikawa diagram

Table 11. Cause-and-effect matrix (CEM) findings

	Customer Prioritization No.		Minimal Idle Time 1	On time Delivery 5	Quality of Production 9		
Process Step		Process Input				Total	%
1	Equipment	Machinery functions not fully utilized	5	5	9	111	15.8
2		Overlapping of top and bottom crane leading to conveyance bottleneck	5	1	0	10	1.43
3		Manual handling of the conveyance	5	0	5	50	7.15
4	Process	Varied design and specifications	0	9	1	54	7.73
5		Lack of automation in the processes	5	1	9	91	13.0
6		Conventional method of bed cleaning influences the bed conditions	0	5	9	106	15.1
7	Manpower	Inconsistent changeover from other work process	9	5	1	43	6.15
8		Mismanagement of workers leading to unbalanced workload	5	5	5	75	10.7
9		Inadequate skilled workers to work the heavy machinery	5	1	5	55	7.87
10	Materials	Inefficient way of unfurling rebar onto bed	1	5	1	35	5.01
11		Uncertain quality of rebar requires steady and careful handling	5	5	0	30	4.29
12		Poor rebar placement	5	5	1	39	5.58
		Total	50	47	46	699	100

The fishbone diagram depicted in the Figure 5 was split into four main categories which are the equipment, process, manpower and materials. Each category was due for an improvement and therefore elimination of these sources for wastage will pave the way to incorporate Lean Manufacturing into the process.

As a means to eliminate time wastage identified by the fishbone diagram, this study opted to adapt the approach of Cause-and-Effect Matrix (CEM). In addition, Varma and Lal [35] also incorporates the idea of using CEM to investigate the root cause of wastage in the industry. CEM represents the relationship between elements that contributed to an issue (the cause) and the desired outcome or action (the effect). Four major contributions were identified in this study as the causes which include equipment, process, manpower and materials.

The effects from these causes include timely product delivery, less downtime and quality of product. The operation Engineer and supervisor in this project with at least five years of experience helped and rectified the inputs throughout the study of this CEM. Scores are given accordingly depending on the correlation of the process input to the respective process outputs. Table 11 shows the matrix that was developed, while Table 12 shows the proposed magnitude of correlations to be assess based on the effect.

Table 12. Magnitude of correlation

Ranking	Description
0	No correlation
1	Slight correlation
5	Moderate correlation
9	Heavy correlation

Table 13. Process input details on wastage frequency and percentage

Process Input	Total Frequency	Valid %	Cumulative Total Frequency	Cumulative %
Machinery functions not fully utilized	111	15.88	111	16%
Conventional method of bed cleaning influences the bed conditions	106	15.16	217	31%
Lack of automation in the processes	91	13.02	308	44%
Mismanagement of workers leading to unbalanced workload	75	10.73	383	55%
Inadequate skilled workers to work the heavy machinery	55	7.87	438	63%
Varied design and specifications	54	7.73	492	70%
Manual handling of the conveyance	50	7.15	542	78%
Inconsistent changeover from other work process	43	6.15	585	84%
Poor rebar placement	39	5.58	624	89%
Inefficient way of unfurling rebar onto bed	35	5.01	659	94%
Uncertain quality of rebar requires steady and careful handling	30	4.29	689	99%
Overlapping of top and bottom crane leading to conveyance bottleneck	10	1.43	699	100%

Table 14. Root causes of time wastage in precast HCS manufacturing and improvement measures

No.	Root Cause of Time Wastage In Precast HCS Manufacturing	Improvement Measures
1	Machinery functions not fully utilized	Knowing the capacity of usage for each heavy machinery Develop a standard of operations (SOP) in machinery utilization Routine maintenance of heavy machinery Training of workers to better utilized heavy machinery
2	Conventional method of bed cleaning influences the bed conditions	Explore new system or machinery which can improve the efficiency of bed cleaning Develop a standard of operation (SOP) for bed cleaning Training of personnel which specializes in efficient bed cleaning

Expert opinions from employees who are in direct responsibility to the manufacturing of the precast HCS were shared upon the research and used to evaluate the root cause of wastage based on a rating scale of 0 (no correlation) to 9 (very high correlation). The root cause weightage is multiplied with the customer prioritization magnitude to calculate the total percentage of each and every process wastage. Table 12 shows that the causes that contributed to the most time wastage in the production are the machinery functions not fully utilized and the conventional method of bed cleaning with a score of 111 and 106, respectively.

The analysis continued with the development of the Pareto chart based on the CEM analysis as a visual aid in highlighting the root cause for time wastage in the production. Table 13 summarises the time wastage sources of the precast HCS production categorised from the highest total frequency to the lowest, while Figure 6 illustrates the Pareto chart of the time wastage sources.

Various figures can be accepted. Several examples cited from papers published in previous IIETA journal issues are as follows. Please pay special attention to how much line spacing is allowed in different cases.

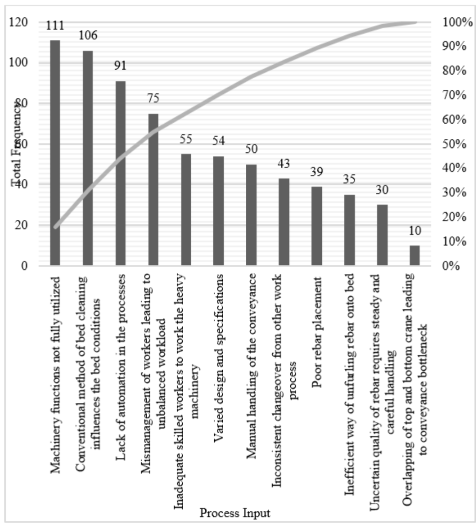

Figure 6. Pareto chart of time wastage sources from precast HCS production

Figure 6 shows the Pareto chart developed from Table 13, highlighting the root causes of time wastage in the production that is needed to be the prioritization for the improvement's efforts. The line from the graph represents the cumulative percentage of wastage from the processes while the bar represents the total frequency of the given process input. It is evident that inefficient machinery utilization and conventional method of bed cleaning contributed to the highest percentage of time wastage in the precast HCS production. Suggested improvements for the production are given in Table 14. The identified time wastage, particularly in machinery utilization and bed cleaning, has significant practical implications for production efficiency and cost. Inefficient machinery use leads to prolonged cycle times, while the traditional bed cleaning process contributes to delays between production stages. Addressing these issues through improved machinery utilization and automated bed cleaning systems could reduce lead times and enhance overall productivity.

This study contributes to the field by applying Lean production tools, such as Value Stream Mapping and Cause-and-Effect Matrix, to identify and address time wastage in the production of precast hollow core slabs within the IBS framework. The findings provide a practical reference for manufacturers aiming to optimize production processes, reduce lead times, and enhance overall efficiency in IBS component production.

4. CONCLUSIONS AND RECOMMENDATION

This study identified key areas of time wastage in the production of precast hollow core slabs, with inefficient machinery utilization and traditional bed cleaning methods being the primary contributors. To optimize production processes in IBS, we recommend implementing standard operating procedures (SOPs) for machinery use, exploring automated bed cleaning systems, and providing targeted training for workers. Future research could focus on the long-term impact of these improvements on production efficiency and cost. Introducing IBS can speed up the construction process where it replaces the conventional cast in-situ method with the factory's ready-made precast component. However, the need to investigate the efficiencies in manufacturing the IBS component is noteworthy in the construction industry as this can enhance productivity through optimization of component production with less time-consumption. The research had identified five areas of time wastage as shown in the CSVSM which occurred in between processes during the production of the precast HCS component. According to the total waste magnitude in the major waste finding checklist, the area to prioritize for improvement is the high queue time occurring in between two processes of bed cleaning & oiling and the process of rebar setup & pre-stressing. The activities such as conveyance, processing, and idle time are the NVAA that contributed to these time wastages.

Therefore, analysis using the Ishikawa Diagram was utilized to find out the root cause of these high queue times in between the processes. The root causes of input include equipment, process, manpower, and materials. Furthermore, upon discussion with the production Engineer, the CEM showed the root cause time wastage with identification from the customer's prioritization. The highest correlation in contributing to the total time wastage is identified as the following: Inefficient machinery utilization, Conventional method of bed preparation. Both of these correlations were illustrated clearly in the Pareto analysis. Counter measures in improving time wastage were also identified in this study which includes; the proper understanding of machinery utilization, development of standard operation procedures (SOP) in handling each and every step of the production line.

ACKNOWLEDGMENT

The authors would like expressed appreciation to Universiti Teknologi Malaysia (UTM), Universiti Malaysia Sarawak (UNIMAS), and Ministry of Higher Education (MOHE), for the financial support to feasibly conduct this research.

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