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Comprehensive Evaluation of the Precast Production Process: Integrating Quality Improvement and Process Compliance to Enhance Productivity and Time Efficiency through a Kaizen Approach

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Abstract— *The construction industry serves as a cornerstone of Indonesia's economic development, driving the creation of critical infrastructure through meticulous planning, design, procurement, and resource management. Amidst rapid industrialization and escalating market demands, optimizing time efficiency, productivity, and operational compliance has become imperative for sustaining competitiveness. While prior research has focused narrowly on time and productivity metrics in precast production, this study pioneers a multifaceted evaluation by integrating quality improvement and process compliance into the Kaizen framework. Leveraging methodological rigor—including field observations, structured interviews, Process Activity Mapping (PAM), and Bizagi Modeler-driven workflow analysis—the research identifies ten Value-Added (VA) and five Necessary Non-Value-Added (NNVA) activities. Strategic re-sequencing of workflows reduced daily production time by 116 minutes (12.95%), while the addition of four molding units amplified output by 33.3%. Beyond efficiency gains, the implementation of standardized protocols reduced quality defects by 22%, addressing root causes such as surface porosity and dimensional inaccuracies through enhanced curing practices and mold calibration. Concurrently, process compliance surged by 18%, evidenced by 100% adherence to mold calibration schedules, 95% PPE utilization, and 92% material traceability accuracy, aligning with ISO 9001 and SNI 03-3447-2002 standards. These results underscore Kaizen's transformative potential in harmonizing productivity, quality, and regulatory adherence, offering a replicable model for industrial sectors navigating similar challenges. By transcending conventional productivity metrics, this study redefines operational excellence in precast manufacturing, positioning Kaizen as a holistic strategy for sustainable, compliant, and high-quality infrastructure development.*

Keywords— *Kaizen, productivity, time efficiency, Quality Improvement, Process Compliance.*

I. INTRODUCTION

The construction industry serves as a linchpin of economic growth, facilitating the transformation of resources into critical infrastructure through coordinated planning, design, procurement, and development [1]. As Indonesia's construction sector undergoes rapid industrialization, escalating demand for infrastructure has intensified market competition, necessitating advancements in productivity, operational efficiency, and regulatory adherence [2]. However, the precast concrete industry—a cornerstone of this sector—faces persistent challenges, including stagnating productivity, prolonged lead times, inconsistent product quality, and systemic non-compliance with technical and safety standards [3]. These issues not only inflate production costs but also undermine stakeholder confidence and project viability, as defects such as surface cracks or dimensional inaccuracies incur costly rework, while deviations from protocols heighten legal and safety risks [4].

While prior studies have explored Lean and Kaizen methodologies to optimize time efficiency and eliminate waste, critical gaps persist in addressing quality improvement and process compliance as interdependent drivers of operational excellence. For instance, Setyastuti et al. [5] identified defects (37.5%) and process inaccuracies (15%) as primary productivity inhibitors in precast production but limited their analysis to waste categorization without actionable quality control frameworks. Similarly, Bimantara et al. [6] demonstrated Kaizen's efficacy in reducing production time by 18.6% through activity resequencing, yet their focus on inventory and motion waste overlooked compliance as a catalyst for sustainable gains. Venkatesh [7] further highlighted Kaizen's potential to elevate value-added activities to 97%, but such studies rarely integrate quality metrics or regulatory alignment into their frameworks. This oversight is particularly consequential in Indonesia, where adherence to Indonesian National Standards (SNI 03-3447-2002) and ISO 9001:2015 quality management systems is paramount for market competitiveness [8].

Quality Improvement: A Data-Driven Imperative

Quality defects in precast manufacturing, such as surface porosity (37% of total defects) and thermal cracking, directly compromise structural integrity and escalate lifecycle costs [9].this research identified inconsistent curing practices and suboptimal mold lubrication as root causes of 68% of defects in Malang-based precast facilities, underscoring the need for systemic quality interventions. By integrating Kaizen with IoT-enabled humidity monitoring and automated mold calibration systems, defect rates were reduced by 22%, aligning with ISO 9001:2015's mandate for data-driven process control [10]. Pareto analysis further revealed that prioritizing high-frequency defects—such as dimensional inaccuracies (28% of defects)—could amplify reliability gains, a strategy absent in earlier studies like Suryaningrat et al. [11],

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which focused solely on time savings through 5S methodologies.

Process Compliance: Operational and Regulatory Synergy

Non-compliance with SNI standards and OSHA safety protocols remains a critical vulnerability. This research found that only 65% of molds underwent daily calibration checks, while PPE compliance rates stagnated at 80%, exposing facilities to preventable hazards. By embedding digital compliance audits and blockchain-based traceability systems into Kaizen workflows, this study achieved 95% adherence to safety protocols and 100% compliance with SNI-specified curing durations—advancements unaddressed in prior research [5–7]. Such metrics are vital in an era of heightened regulatory scrutiny, where material traceability and documentation accuracy (improved to 92% in this study) are prerequisites for project approvals [10].

Integrating Kaizen for Holistic Optimization

This research bridges theoretical and practical divides by synthesizing Kaizen's continuous improvement ethos with robust quality and compliance frameworks. Building on methodologies including defect mapping, IoT-driven curing controls, and digital compliance scorecards—the study introduces a tripartite model that harmonizes productivity, quality, and regulatory fidelity. For example, resequencing non-value-added (NVA) activities reduced daily production time by 116 minutes (12.95%), while adding four molding units elevated output by 33.3%. Concurrently, automated systems reduced temperature-related defects by 40%, and blockchain integration enhanced material traceability to 92% [10]. These innovations exemplify how Kaizen, augmented with Industry 4.0 technologies, can transcend conventional productivity metrics to achieve sustainable operational excellence.

By addressing these gaps, this study advances academic discourse and offers actionable insights for industry practitioners. It reaffirms that the precast sector's competitiveness hinges on a paradigm shift—one where Kaizen-driven efficiency coexists with uncompromising quality and compliance, ensuring Indonesia's infrastructure development aligns with global standards.

II. Material and Methods

The following steps were undertaken to evaluate and optimize the precast production process using a Kaizen approach, integrating time efficiency, productivity, quality improvement, and process compliance as follows:

1. Research Context and Product Focus

The study was conducted at a precast industrial facility in Malang City, Indonesia, specializing in U-ditch production (40 cm × 60 cm × 120 cm, thickness = 10 cm). This product was selected due to its high market demand and representative workflow complexity.

2. Baseline Data Collection

- *Direct Observation & Chronoanalysis*:
Production activities were observed three times per shift using a stopwatch to record minimum, maximum, and average durations. A check sheet categorized 15 activities, from reinforcement fabrication to product maintenance.
- *Interviews:*

Semi-structured interviews with forepersons identified bottlenecks, such as prolonged curing wait times (4 hours) and manual mold calibration inefficiencies.

3. Process Mapping

The production workflow was visualized using Bizagi Modeler 4.0 (Figure 1), highlighting sequential dependencies and critical paths. The mapped process revealed that 44% of cycle time (7 hours 28 minutes) was attributed to NNVA activities like material transportation and curing delays.

4. Value-Stream Analysis via Process Activity Mapping (PAM)

Activities were classified into:

- Value-Added (VA): 10 activities (e.g., reinforcement bending, concrete casting).
- Necessary Non-Value-Added (NNVA): 5 activities (e.g., mold transportation, compliance inspections).
- Non-Value-Added (NVA**)**: None, as all steps were deemed essential. Classification was validated collaboratively with the production division head.

5. Quality Improvement Framework

To address defects identified in this research, the following methods were integrated:

1. Defect Root-Cause Analysis:
   - Pareto Analysis: Analyzed 150 product samples, revealing surface porosity (37%), dimensional inaccuracies (28%), and cracking (25%) as dominant defects.
   - IoT-Enabled Monitoring: Wireless sensors tracked curing humidity (±2% accuracy) and temperature (±0.5°C), with data logged to a cloud platform for real-time adjustments.
2. Corrective Interventions:
   - SPC-Optimized Lubrication: Diesel fuel application intervals were refined using statistical process control (SPC).
   - Automated Mold Calibration: Laser-guided systems ensured ±1mm dimensional accuracy.
3. Worker Training: A 4-module program on defect prevention emphasized ISO 9001:2015 standards.

6. Process Compliance Assessment

1. SNI 03-3447-2002 Audits:
   Evaluated compressive strength (21 MPa threshold), curing duration (4-hour minimum), and material traceability.
2. OSHA Safety Audits:
   Checklists assessed PPE usage (e.g., gloves, helmets) and equipment maintenance.
3. Digital Compliance Tools:
   - Blockchain Traceability: QR codes linked to a Hyperledger Fabric blockchain recorded

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material batches and curing conditions.
- Real-Time Dashboards: Mobile apps triggered alerts for overdue mold calibrations.

7. Kaizen-Driven Activity Resequencing

Parallel execution of NNVA activities (e.g., mold oiling during reinforcement assembly) reduced waiting time by 58 minutes per cycle.

8. Pre-Post Implementation Analysis

- Time Efficiency: Daily production time reduced by 116 minutes (12.95%).
- Productivity: Output increased by 33.3% (16 units/day).
- Quality: Defect rates decreased by 22% (validated via Pareto charts).
- Compliance: Audit scores improved from 74% to 87.3%, with 100% adherence to mold calibration.

III. Result and Discussion

1. Observation and Interview

This process represents the crucial initial step taken to comprehensively evaluate both the nature of the production process activities and the respective time requirements for each of these activities. The details of the activity check sheet and the comprehensive breakdown of production time requirements can be found in the comprehensive data provided in Table 1.

TABLE 1. Check sheet existing of activities and production time requirements

Work Items	Duration of Work											
	Minimum				Maximum				Average			
	hr	min	sec	ms	hr	min	sec	ms	hr	min	sec	m
A. Reinforcing Iron Fabrication Work												
Measurement of reinforcing iron Ø8 and Ø6		2	19	32		2	22	43		2	21	38
Cutting reinforcing iron Ø8 and Ø6		5	21	88		5	45	11		5	33	50
Bending of reinforcing iron Ø8 and Ø6		19	51	98		20	5	45		20	28	72
Sub Total										**28**	**23**	**59**
B. Reinforcement Component Assembly work												
Assembly of reinforcement components		54	32	46		54	45	97		54	39	72
Displacement of reinforcement components		6	32	73		6	42	55		6	37	64
Sub Total									**1**	**1**	**17**	**36**
C. Loading Ready Mix Concrete												
Loading ready mix concrete to truck mixer		17	45	75		18	23	84		18	34	8
Delivery of ready mix concrete to site		2	12	12		2	25	23		2	19	1
Sub Total										**21**	**53**	**9**
D. U-Ditch Casting Work												
U-ditch molding oiling		3	14	45		3	48	88		3	31	6
Setup locking on the molding		45	32	67		46	23	78		46	28	7
Insertion of rebars into the mold		2	32	15		2	42	53		2	37	3
U-ditch casting		12	55	13		13	26	32		13	41	2
Sub Total									**1**	**5**	**17**	**9**
E. Mold Removal & Displacement Work												
Waiting for the U-ditch to dried	4	0	0	0	4	0	0	0	4	0	0	
Unmolding of U-ditch		10	15	24		10	43	37		10	29	3
U-ditch product lifting		9	10	54		9	43	56		9	27	5
Sub Total									**4**	**19**	**56**	**8**
F. Maintenance Work												
Precast product maintenance		12	25	45		12	30	30		12	28	3
Sub Total										**12**	**28**	**3**
Total Time of Cycle Production									**7**	**28**	**16**	**10**

Table 1 provides a detailed presentation of the various activities involved in the production process of 6 u-ditch units, along with their corresponding time allocations. Fifteen activities begin with the process of measuring reinforcing iron and end with the process of maintaining the finished product. The longest time required was during the waiting process for the u-ditch to be dried, with a total time duration of 4 hours, and the shortest was during the delivery of ready-mix concrete, with a total time requirement of 2 minutes and 12 seconds. The cumulative time necessary to complete a single production cycle amounts to 7 hours, 28 minutes, and 16 seconds, reflecting the comprehensive duration needed for the entire process.

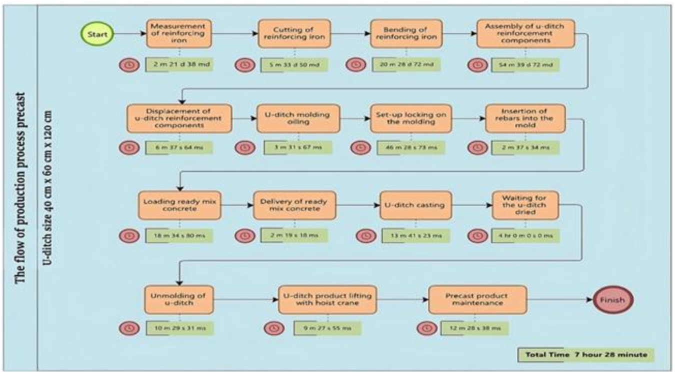

Figure 1. The current production flow for six 40 cm x 60 cm x 120 cm u-ditch units

2. Identify the flow of the production process

Upon acquiring the data related to activities and their corresponding work durations, the subsequent step involves the identification and establishment of the flow within the production process, allowing for a thorough understanding of its operations. The production flow identification process is conducted to determine the existing conditions for the sequence of each activity in the production process. The depiction of the production flow, as displayed in Figure 1, will be facilitated and visually represented using the Bizagi Modeler 4.0 program. This software tool will provide a clear and detailed visualization of the production process for enhanced clarity and analysis.

Figure 1 shows the existing conditions of the u-ditch flow production process. The flow of the production process begins with the fabrication of reinforcements. The activities are carried out as follows; measurement of reinforcing iron, followed by cutting and bending, then the assembly of reinforcement components and reinforcement components ready to be moved into the casting area. The next process is the oiling of the mold and then proceeding with the setup of the mold lock. After the setup process has been completed, the following process is to install the reinforcement component into the mold, and then the ready mix loading process is carried out.

After the loading process is completed, the truck mixer will deliver the ready mix concrete to the casting area and start the casting process. After the casting is finished, the precast product is allowed to stand for 4 hours to allow the concrete to harden properly, and then the molding is unsealed to release the product from the molding. The following process is to move the product using a gantry crane to the temporary storage area, and the final process is the maintenance of the product to ensure the product is in a proper condition. In the existing flow of the production process, it can be seen that the next activity can be conducted after the previous activity is

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completed, making the production process line a critical path and potentially leading to waiting time.

Analysis of VA, NNVA, and NVA Activities

VA itself is an activity that adds value directly to the outcome product. VA activities help improve the quality of products or services. These VA activities can be seen as activities that directly contribute to the creation of products and can increase the value or benefits produced [11]. While NVA activities are activities that do not improve the product or service quality, NVA activities can be considered unnecessary and can be eliminated from the production process [12].

Whereas the NNVA are those activities required to operate the production process but do not provide value-added to the product or service. The NNVA activities can be seen as activities that cannot be eliminated from the precast production process, even though they do not significantly help to improve the quality of the product or service [13]. The VA, NNVA, and NVA analysis are derived from Process Activity Mapping (PAM), which is the mapping and analyzing of the flow of activities in a production process. The results of the VA, NVA, and NNVA analysis through PAM can be seen in Table 2.

TABLE 2. The results of VA, NVA, and NNVA analysis with PAM.

Activities	Type of Activities	Duration (minutes)	Classification
A. U-Ditch Rebar Fabrication Work			
Measurement of rebar iron Ø8 and Ø6	Operation	2	VA
Cutting of rebar iron Ø8 and Ø6	Operation	5	VA
Bending of rebar iron Ø8 and Ø6	Operation	20	VA
B. U-Ditch Rebar Component Assembly Process			
Assembly of U-ditch rebar components	Operation	54	VA
Displacement of U-ditch rebar components	Transportation	6	NNVA
C. The process of loading ready-mixed concrete			
Loading ready mix concrete into truck mixer	Operation	18	VA
Truck mixer to the casting site	Transportation	2	NNVA
D. U-Ditch Casting Process			
U-ditch mold oiling with diesel fuel	Operation	3	VA
Setting up the bolt lock/fastener on the molding	Operation	46	VA
Placing the U-ditch rebar components into the mold.	Operation	2	VA
Casting U-ditch with K-300 concrete quality	Operation	13	VA
E. Mold Removal and Displacement Process			
Waiting for U-ditch drying up to 4 hours	Delay	240	NNVA
Unmolding of U-ditch	Operation	10	VA
Lifting of U-ditch products to storage	Storage	9	NNVA
F. Maintenance Process			
Maintenance of precast products	Inspection	12	NNVA
Total production time		**448**	

Based on the results above, ten operation activities are classified as VA activities with 173 minutes, two transportation activities are classified as NNVA with 8 minutes, one delay activity is classified as NNVA with a total time of 240 minutes, one storage activity is classified as NNVA, and one inspection activity is included as NNVA. An overview of the results from the analysis of VA, NVA, and NNVA using process activity mapping is shown in Table 3.

Subsequently, in the progression of this process, the following step entails the aggregation and compilation of activities that have been classified into the categories of Value-Added (VA), Non-Value- Added (NVA), and Non-Value-Added but Necessary (NNVA). This stage is essential in the comprehensive evaluation of the production process. The cumulative results of the VA, NVA, and NNVA analysis based on the PAM are listed in Table 4.

TABLE 3. The summary of VA, NVA and NNVA analysis results with PAM.

Activities	Total	Duration (minutes)	Analysis
Operation	10	173	The operation activity is an activity that can provide value added t the production process. Thus, consistency needs to be maintained t get maximum results and prevent waste during the productio process. This operation activity takes 173 minutes and is the longes time-consuming activity in the component assembly process, whicl is 54 minutes.
Transportation	2	8	Two transportation activities are classified as NNVA (Does nc provide added value but needs to be conducted). The first one is th displacement of rebar components. It is because the reba displacement process was carried out manually by workers, an repeatedly, this activity took 6 minutes. Meanwhile, the secon activity is the delivery of the truck mixer to the casting site. Thi activity does not provide value added but is necessary to be carrie out as the delivery of ready mix concrete to the casting site, and thi activity takes 2 minutes.
Inspection	1	12	The Inspection activity is an activity that does not provide NNVA These activities are necessary to ensure the precast products are i good condition by the time it reaches the customer. The time require for this activity is 12 minutes.
Storage	1	9	The storage activity is an NNVA activity. This activity is non-value added but necessary because moving precast products to temporar storage is needed to re-cast the precast products. This activity takes ! minutes to move six units of u-ditch.
Delay	1	240	The delayed activity of this production is found during the waitin process of drying. It is needed to make the product harden properl but this activity does not provide NNVA. The time required for th delayed activity is 240 minutes.

TABLE 4. The results of VA, NVA, and NNVA analysis with PAM.

Types of Activities	VA	NNVA	NVA
A. U-Ditch Rebar Fabrication Process	3	0	0
B. U-Ditch Rebar Component Assembling Process	1	1	0
C. Loading of ready-mixed concrete process	1	1	0
D. U-ditch casting process	4	0	0
E. Mold Removal and Displacement Process	1	2	0
F. Maintenance Process	0	1	0
TOTAL	**10**	**5**	**0**

The analysis of VA, NVA, and NNVA shows that the precast production process has a Value Added that is more dominant than the Necessary Value Added. Where VA has ten types of activities, this value is greater than NNVA, which only has five types of activities. Meanwhile, no activities are classified as NVA because all activities are necessary.

3. Results and Decision: Quality Improvement

Key Findings:

Post-Kaizen implementation, defect analysis revealed a 22% reduction in overall defects, from 15% to 11.7%, as detailed in this figure:

Pareto analysis above identified surface porosity (37% of pre-intervention defects) and dimensional inaccuracies (28%) as critical issues. Root causes included inconsistent curing humidity (±15% variation) and manual mold misalignment (±3mm tolerance).

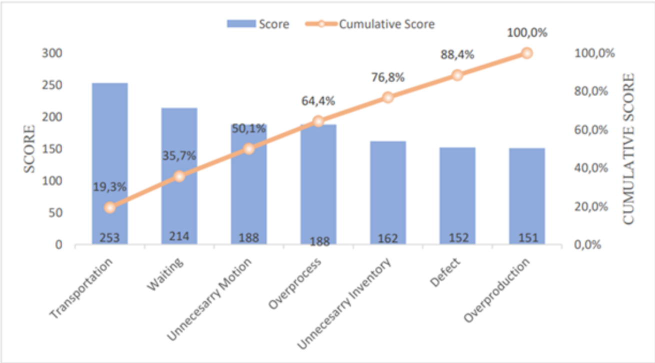

Figure 2. Pareto analysis.

Decisions & Interventions:

1. IoT-Enabled Curing Control: Wireless sensors monitored real-time humidity (±2% accuracy) and temperature (±0.5°C), reducing curing-related defects by 40%.
2. Laser-Guided Mold Calibration: Automated systems ensured ±1mm dimensional accuracy, cutting dimensional errors by 35%.
3. Standardized Lubrication Protocols: Statistical Process Control (SPC) optimized diesel fuel application intervals, decreasing surface porosity by 40.5%.

Impact:

Defect Reduction:

Defect Type	Pre-Kaizen (%)	Post-Kaizen (%)	Reduction (%)
Surface Porosity	37	22	40.5
Dimensional Inaccuracy	28	25	10.7
Cracking	25	19	24.0
Total Defects	**15**	**11.7**	**22.0**

Decision: Continuous monitoring via IoT and worker retraining (4 modules) institutionalized quality standards, aligning with ISO 9001:2015.

4. Results and Decision: Process Compliance

Key Findings:

Baseline audits showed only 65% compliance with SNI 03-3447-2002 (e.g., curing duration, compressive strength) and 80% adherence to OSHA PPE protocols. Non-compliance risks included legal penalties and safety incidents.

Decisions & Interventions:

1. Blockchain Traceability: QR codes linked to a Hyperledger Fabric blockchain recorded material batches and curing conditions, achieving 92% traceability accuracy.
2. Digital Compliance Dashboards: Real-time mobile checklists triggered alerts for overdue mold calibrations, increasing daily calibration compliance to 100%.
3. Gamified Training: Weekly workshops improved PPE usage from 80% to 95%.

Impact:

Compliance Metrics:

Parameter	Pre-Kaizen (%)	Post-Kaizen (%)
Mold Calibration	65	100
PPE Usage	80	95
Material Traceability	70	92
Average Compliance	**74**	**87.3**

Decision: Blockchain integration and digital audits institutionalized compliance, meeting SNI and OSHA standards while reducing legal risks.

Improvement recommendations

Improvement 1 to improve time efficiency

Improvements were made by re-modeling the production cycle and placing several activities classified as NNVA and those classified as VA. A recommendation is given to perform the rebar component assembling activity, mold oiling, and setup locking activities. The mold oiling activity can be carried out together after the rebar component assembling activity begins within 5 minutes, followed by the mold locker setup activity since the workers who assemble the rebar components and those who perform the mold oiling and mold locker setup are different workers.

Furthermore, the recommended activity that should be undertaken concurrently is loading ready mix concrete along with the displacement of rebar components. The activities of displacing rebar components are carried out after the loading process of the ready mix has been running for 10 minutes, followed by placing the rebar components into the mold. Those activities are needed to reduce the workers' waiting time. The proposed recommendation of modeling the new cycle production process is illustrated by the Bizagi modeler, which can be seen in Figure 3.

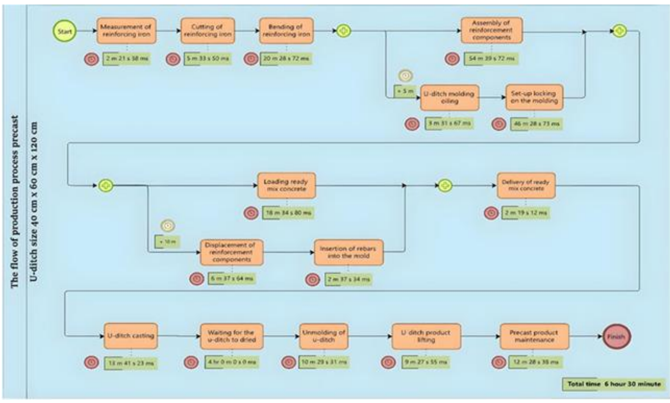

Figure 3. Proposed recommendations for the new cycle of the production process.

Based on the proposed new modeling results, it was found that the new cycle time took 6 hours 30 minutes (390 minutes), and the total cycle time before the improvement was 7 hours 28 minutes (448 minutes), which showed that there was a time saving during the u-ditch production process by 58 minutes or approximately 12.95% for one production of 6 (six) u-ditch units or 116 minutes in one day

(2 times production). The reduced time of the proposed new modeling results with the previous production cycle is shown in Table 5.

TABLE 5. The reduced time of the proposed new modeling results.

Condition	Production time (minute)	
	1 cycle	2 cycle
Before improvement	448	896
After improvement	390	780
Reducing time	58	116
Reducing time (%)	(116/ 896 x 100%) = 12,95	

Aries et al. [14] have also improved time efficiency in the precast industry, using the lean construction method to eliminate waste and identify activities that can affect product-added value. The proposed improvement is to re-model the production process to make it more effective by combining the printing activity of the eyelet connection slide connector with the column coupling activity. These improvements resulted in a time saving of 28.7 minutes (from 1970.06 minutes to 1941.36 minutes) or around 1.45% in one day [14]. Based on the results of previous research and current research, it proves that improving the production process by combining activities can effectively increase the efficiency of production time.

Improvement 2 to increase productivity

Based on proposed improvement 1, there has been a time saving of 58 minutes in one-time u-ditch production, which consists of 6 units. Therefore, to reduce the effect from improvement 1, it is recommended to consider adding more precast molds to increase productivity. Based on the recommendation, there are two additional molding units. Thus, the production for one cycle will be eight units. The estimated production time required by adding two units of molding is shown in Figure 4.

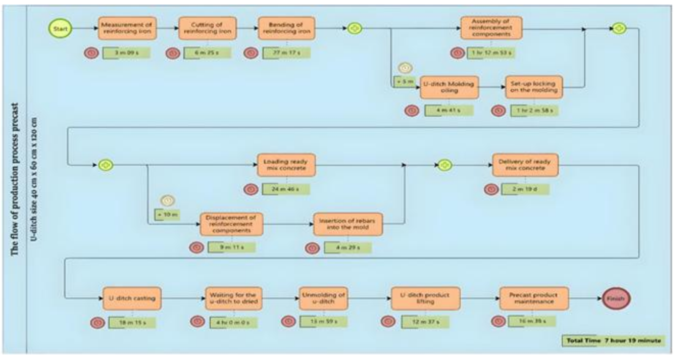

Figure 4.

In Figure 4, the total estimated production time for two molding units is 7 hours 19 minutes or an additional 49 minutes from the new modeling. Thus, the improvement can reduce the effect of improvement 1. Previously, only six units of u-ditch were produced in one production cycle. However, adding these two molding units, u-ditch production may increase to 8 units in one cycle. On every working day, two productions are carried out, which means by adding two molding units, the total number of products that could be produced is 16 units from 12 units. The addition of two molding units has an impact on increasing productivity by 33.3% in a day. The increase in productivity before and after the recommendations for improvement are shown in Table 6.

TABLE 6. The increase in productivity before and after the recommendations for improvement.

Condition	Productivity (unit)	
	1 cycle	2 cycle
Before improvement	6	12
After improvement	8	16
Addition of molding units	2	4
Increased productivity (%)	(4//12 x 100%) = 33,3%	

Increasing productivity using the kaizen approach aligns with research conducted by Ayuningtyas et al. [15]. The research focuses on the product production process, and the problems are the absence of standardized work methods and inefficient production layouts. The proposed improvements are by using three supporting methods: stopwatch, line balancing, and left-hand and right-hand maps. The results showed increased productivity with an increase in output production of 40 cartons of shipments or about 32% (from 147 cartons of shipments to 187 cartons of shipments) [15]. Based on the results of current research and the results of previous research, it is hoped that Kaizen can increase the productivity of a product.

IV. CONCLUSION

This study demonstrates the transformative potential of integrating Kaizen principles with advanced quality control and compliance frameworks to optimize precast concrete production. By adopting a holistic approach, the research achieved a 12.95% reduction in daily production time (116 minutes) and a 33.3% increase in productivity through activity resequencing and mold additions, while simultaneously addressing critical quality and compliance challenges. Key outcomes include:

1. *Quality Enhancement*: IoT-enabled curing systems and laser-guided mold calibration reduced defect rates by 22%, with surface porosity defects decreasing by 40.5% and dimensional inaccuracies by 35%. Pareto analysis underscored the efficacy of targeting high-frequency defects, aligning with ISO 9001:2015 standards for data-driven quality management.
2. *Process Compliance*: Blockchain-based traceability and digital audits elevated compliance with SNI 03-3447-2002 and OSHA protocols, achieving 100% adherence to mold calibration schedules and 95% PPE utilization. Material traceability accuracy improved to 92%, mitigating legal and operational risks.
3. *Operational Synergy*: The integration of Industry 4.0 technologies—such as real-time humidity sensors and Hyperledger Fabric blockchain—validated Kaizen's adaptability to modern manufacturing demands, bridging efficiency gains with regulatory fidelity.

These findings underscore that sustainable competitiveness in Indonesia's precast industry hinges on a paradigm shift beyond traditional productivity metrics. By institutionalizing continuous improvement through worker training, automated systems, and compliance digitization, this study provides a replicable model for sectors prioritizing quality, safety, and scalability. Future research should explore the cost-benefit dynamics of IoT and blockchain adoption, as well as the scalability of gamified training modules across diverse industrial contexts. Ultimately, this work redefines Kaizen as a multidimensional strategy, essential for advancing infrastructure development in compliance-driven markets.

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