An Online Monitoring System Using Sensor Technology And the Internet of Things (Iot) in the Risk-Based Production Process of Precast Spun Piles to Improve Production Productivity : A Case Study of PT. X

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ABSTRACT : *Precast spun pile concrete products play a vital role in supporting infrastructure development and sustainable construction. However, the production process still faces various risks, such as cracking during the stressing stage, spalling, concrete inhomogeneity, dimensional nonconformity, and the potential for defective products. This study aims to analyze the development of a risk-based monitoring system utilizing sensor technology and the Internet of Things (IoT) in the production process of precast spun piles to improve production productivity at PT. X. The results show that the spun pile production process consists of 7 main processes comprising 22 activities. The monitoring system has been integrated into the casting, stressing, spinning, curing, demolding, and stockyard processes. The identified risks were 62 risks were classified as low risk and 1 risk was classified as moderate risk. The analysis results indicate that the production process, risks, sensor technology, IoT, and monitoring system have a strong correlation with productivity, with an R value of 0.853 and an R-squared value of 0.728. The integration of sensors and IoT through a real-time monitoring dashboard can support an early warning system, process control, decision-making, and a improvement in output, efficiency, and product quality.*

KEYWORDS - *Spun pile production process, Risk, Sensor technology, Internet of Things (IoT), Monitoring system, Productivity improvement*

I. INTRODUCTION

Precast concrete is a type of concrete that is currently experiencing growth in production at both national and international concrete plants due to its advantages, such as construction speed, structural integrity, and environmental friendliness. The growth of the national precast industry is supported by the 2025–2029 National Medium-Term Development Plan (RPJMN). According to 2020 data from AP3I, Indonesia's precast concrete production capacity for spun piles exceeds 12 million metric tons per year.

According to Khairunnisa [1], there are four high-risk factors affecting precast production of spun piles: the occurrence of cracks during the stressing phase, spalling during the driving process, imperfect concrete shape, and dimensional deviations from specifications. According to [2], waste in the precast production process is caused by factors related to machinery, human error, processes, the environment, and materials.

The findings of [1] suggest an innovation focused on utilizing online-based technology in a product quality monitoring system to enable real-time monitoring of product quality. The system in question uses sensors connected to monitoring devices and a database that records the production process. The collected data serves as the foundation for monitoring and evaluating spun piles, where the data is processed using specific methods to identify anomalies in the production process.

The issues identified in previous research can serve as the foundation for this study to develop an online monitoring system with sensors integrated with IoT in the precast spun pile production process to address the challenges of precast spun pile production productivity at concrete plants and support circular economy goals in the construction industry.

II. LITERATURE REVIEW

The production process monitoring system used consists of basic system components, including sensors, data loggers, data analysis, monitoring and control, and product quality traceability [3]. Precast concrete products are categorized into 10 types, one of which is piles. Piles are a type of foundation that transfers loads from the superstructure into the ground and resists lateral loads and tensile forces. Piles are driven into the ground until they reach the hard subsoil layer [4]. According to [5], the precast spun pile production method begins with material preparation, continues through the core production process and product quality testing, and concludes with final production handling.

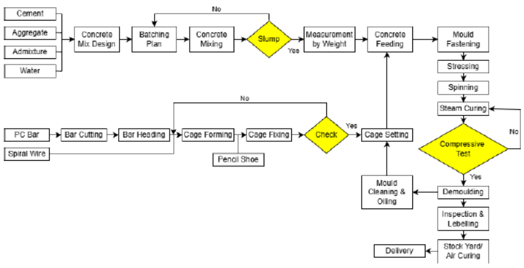

Figure 1.1 Spun Pile Production Process
Source: Work Flow of Spun Piles at PT X [5]

Productivity is the amount of output produced relative to the amount of resources utilized during production. To improve productivity, one can intelligently manage and combine various production factors so that the product's value-added consistently increases [6]. The productivity measurement indicator for precast spun pile production is output per shift per day. If production targets are not met, it is necessary to identify bottlenecks at each production station. The Overall Equipment Effectiveness (OEE) calculation is a common method used to identify sources of loss based on availability, performance, and quality data [7].

According to [8], there are several stages in implementing risk management: planning, identification, qualitative analysis, quantitative analysis, response planning, response implementation, and response monitoring. Through this analytical process, the project team can assess the overall potential impact of risks. Risks in the precast production process that affect productivity can be categorized as follows: operational and equipment reliability risks, traceability risks [9], quality and process variability risks, plant safety risks, and risks related to planning, scheduling, capacity, and human resources [10].

The core concept of Internet of Things (IoT) technology is to use the internet to collect concrete, physical, and event-based data. IoT, when connected to sensors, generates data on quality and productivity. Its application in the precast spun pile production process is focused on critical stations such as the spinning machine and the batching & mixing stations. IoT is also used for curing monitoring, work-in-progress (WIP) tracking, and safety monitoring [11].

Conceptually, the production process is closely linked to the productivity level of precast spun piles. A production process that runs according to procedures and encounters no obstacles at each critical station will have a positive impact on productivity. This is evident from the efficiency metrics (WIP, wait time, and defects) observed following the implementation of engineering improvements in the production process [12]. The engineering improvements involved connecting sensors to the IoT to identify factors affecting production at critical stations in real time. This real-time data is stored in the cloud and then processed using statistical analysis to generate insights that can help improve productivity.

III. METHODS

The methodology applied is a mixed-methods approach, incorporating qualitative data such as reviews, literature, interviews, and observations, as well as quantitative data such as questionnaires, statistical model calculations, and distribution model calculations.

The research variables used are production process (X1), risk (X2), sensor technology (X3), the Internet of Things (X4), and monitoring systems (X5) as independent variables, and productivity improvement (Y) as the dependent variable. In accordance with and the objectives and research questions of this study, these variables were selected to determine the extent to which the independent variables (production process, risk, sensor technology, IoT, and monitoring systems) influence the dependent variable (productivity improvement).

The research instruments included interviews, observations, questionnaires, and documentation. The distribution of questionnaires was based on categories relevant to the research questions in this study. The research questions are as follows:

RQ1: What are the current processes and activities involved in producing precast spun piles?

RQ2: What are the current processes and activities involved in integrating a production monitoring system for precast spun piles with the Internet of Things (IoT)?

RQ3: What is the current level of productivity for PT.X's spun piles?

RQ4: What system variables are required to develop a risk-based IoT-enabled monitoring system for the precast spun pile production process to improve PT.X's production productivity?

RQ5: What is the relationship between the production process, risks in the precast spun pile production process, the use of sensors in the production process, the implementation of IoT, and the monitoring system, and the productivity level of spun piles?

RQ6: What is the plan for developing a technology-based precast spun pile production process?

RQ7: What are the risk factors in the precast spun pile production process?

RQ8: How are sensors implemented in the precast spun pile production process?

RQ9: How is IoT implemented in the precast spun pile production process?

RQ10: How are the production process, risks, sensors, and IoT integrated into the monitoring system?

RQ11: How is the outcome of this integration validated in terms of production productivity?

Data collection techniques to address the research question involved gathering secondary data from previous studies and reports relevant to this research, as well as validation by experts in the precast concrete industry, such as workers with 10 years of experience in the precast concrete manufacturing industry.

➢ Face Validity: Assessing the extent to which the research instrument appears appropriate, clear, easy to understand, and suitable for measuring the intended variables, based on expert judgment

➢ Content Validity: Assessing the extent to which a research instrument comprehensively, relevantly, and representatively covers all aspects, dimensions, and indicators of the variables being measured.

➢ Construct Validity: Assessing the extent to which a research instrument is truly capable of measuring the concept of a theoretical construct that is intended to be measured, in accordance with the definition of the research variable.

IV. RESULTS AND DISCUSSION

The discussion section is the process of answering the previously formulated Research Questions (RQs). RQ1–RQ5 address the current state of the precast spun pile production process at PT X.

Answering RQ1. The existing production process at PT X is illustrated in the figure below:

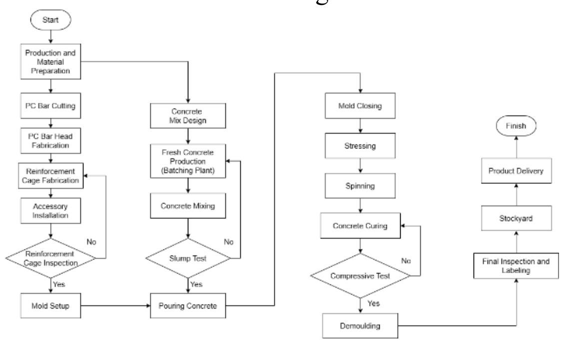

Figure 4.1 Workflow of the Precast Spun Pile Production Process at PT. X

Answer to RQ2. PT X's production processes already utilize IoT. However, the production processes that do not yet fully utilize IoT are the bathing, pouring, cutting-heading, curing-demolding, and stockyard stages. These processes do not yet have sensors, and data recording is done manually. Regarding the impact of these processes on productivity, no bottlenecks were found, and production times remain within normal limits.

Answering RQ3. The production processes currently in place have met targets, and productivity levels show positive trends or are increasing periodically.

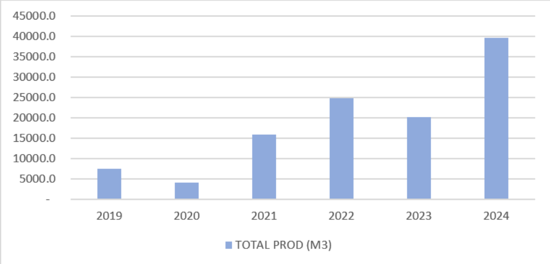

Figure 4.2 Total Spun Pile Production at PT. X

Answering RQ4. The system variables required for developing a risk-based monitoring system using sensor and IoT technology were identified through a literature review to determine relevant indicators. Based on the results of expert validation of the administered questionnaire, all experts agreed with the indicators tested. These indicators represent the system variables for developing a monitoring system using sensor and IoT technology in the risk-based precast spun pile production process to improve productivity. The indicators used are as follows.

Table 4.1 Indicators of the Variable Study

X1: Precast Spun Pile Production Process a) Production resource readiness b) Accuracy of production-stage execution c) Stability and continuity of the production process d) Compliance of production results with standards
X2: Risks in the Precast Spun Pile Production Process a) Material risk control b) Machinery and equipment risk control c) Process and operator risk control d) Quality and occupational safety risk control
X3: Sensor Technology a) Availability and Suitability of Sensors b) Reliability of sensor readings c) Automated data acquisition capability d) Ease of sensor implementation
X4: Internet of Things a) Device connectivity within the IoT system b) Reliability of data transmission and storage c) Data integration capability d) Ease of access to production data
X5: Production Productivity a) Achievement of production output targets b) Efficiency of production processing time c) Efficiency in resource utilization d) Product quality and production sustainability

Answering RQ5. The model of the relationship between variable X and variable Y uses statistical analysis methods, including data adequacy tests, normality tests, homogeneity tests, validity and reliability tests, correlation tests, factor analysis, and regression tests. The results of the questionnaire distribution regarding the relationship model were obtained from 40 respondents with 10 years of work experience in the concrete industry.

The results of the data adequacy test showed that all variables in the relationship model had an N' value less than N=40. Thus, the questionnaire data for each variable indicator were deemed sufficient and suitable for use.

Based on the results of the normality test, it was found that the significance value of the data was <0.05. Thus, it can be concluded that the data are non-normally distributed and do not require the assumption of a normal distribution.

Based on the results of the homogeneity test regarding job criteria or positions, it can be concluded that the data exhibit homogeneity and that there are no differences in perception among respondents with different job criteria or positions—including staff, section heads, and managers.

Based on the reliability test, a Cronbach's Alpha value greater than 0.6 was obtained, and the data were deemed reliable with a Cronbach's Alpha value ranging from 0.947 to 0.951.

Based on the results of the correlation test, variable X had a significance level of <0.05, specifically <0.01. This indicates that variable X has a strong level of significance with variable Y, and the relationship between the two variables is considered to be positive.

The results of the factor analysis using Principal Component Analysis (PCA) show that all indicators of variables X and Y form a single principal component with factor loadings ranging from 0.791 to 0.895.

In the simultaneous regression analysis, the variables yielded an R value of 0.853, indicating a very strong linear relationship between the production process, risk, sensors, IoT monitoring systems, and increases in production productivity. The R-squared value of 0.728 indicates that 72.8% of the increase in production productivity can be explained by production processes, risk, sensors, IoT, and monitoring systems, while the remaining 27.2% is influenced by other factors outside the scope of this study.

The differences in the results between simple and multiple regression indicate that each independent variable has a positive relationship with the dependent variable when analyzed separately. However, after all independent variables were included together, only the IoT and monitoring system variables were found to have a significant effect on Y. This suggests that the contributions of the production process, production process risk, and sensor technology variables were likely masked or explained by other variables with stronger effects in the model.

Answering RQ6: The production process development plan for precast spun piles based on the technology proposed by the author was almost entirely approved by the experts. The technologies and equipment used in the spun pile production process include a cutting machine, heading machine, forming machine, spreader beam, batching plant, overhead crane, impact wrench, stressing machine, and spinning machine. The processes proposed for improvement relate to the use of truck mixers and boiler machines. The truck mixer should be integrated into the batching plant since the casting takes place in the same area. Meanwhile, the use of a boiler machine is irrelevant because PT. X already uses additives in the fresh concrete mix and no longer uses steam.

Answering RQ7. Risk factors during the production process were identified through an analysis of existing occupational risks at PT X. The assessment was conducted by surveying 43 respondents to evaluate the impact and frequency of these risks. Data adequacy, homogeneity, and validity-reliability tests were performed on the respondents' assessment data. After all tests were conducted, the data collected from the respondents was categorized as sufficient, homogeneous, valid, and reliable. The impact and frequency assessments from the respondents were then multiplied by the values in the following risk matrix to determine the total impact value and total frequency value.

Probability	Threats				
Very High 0.90	0.05	0.09	0.18	0.36	0.72
High 0.70	0.04	0.07	0.14	0.28	0.56
Medium 0.50	0.03	0.05	0.10	0.20	0.40
Low 0.30	0.02	0.03	0.06	0.12	0.24
Very Low 0.10	0.01	0.01	0.02	0.04	0.08
Negative Impact	Very Low 0.05	Low 0.10	Moderate 0.20	High 0.40	Very High 0.80

Figure 4.3 PMBoK 6th Edition Risk Level Matrix
Source: Project Management Institute [8]

After obtaining the total impact values and total frequency values, the average impact and average frequency values were determined from these totals to categorize the risks. It was found that there were 63 occupational risks, with 62 categorized as low and one as medium. Production process risks at PT. X are categorized as low because a production process monitoring system has been established that can monitor risks in real time, and equipment is calibrated and sample testing is conducted before operation. The level of occupational risk was assessed using an expert questionnaire and statistical analysis, revealing a strong correlation between occupational risk and productivity.

Answering RQ8. The application of sensors in the precast spun pile production process began with a literature review on sensors, building on the findings from RQ6 regarding the technology used in the spun pile production process. The sensor technologies used include an infrared sensor to detect objects when the PC Bar is about to be cut, a potentiometer to determine the position or distance of the PC Bar on the heading machine, an inverter (VFD) to control the rotational speed of the wire caging machine, a 3D load scanner to accurately measure the volume of raw materials, an ammeter to precisely read the electrical current as an indicator of slump value, a load cell to measure the force or weight of fresh concrete before pouring to ensure the concrete poured into the product meets specifications; an extensometer to measure the elongation (stretch) of prestressed steel, with results recorded automatically and accurately; and an RPM meter to measure the rotational speed of the spinning machine per minute.

Answering RQ9: The results of the assessment of IoT implementation in the spun pile production process are consistent with the existing monitoring system at PT X. The implementation points are configured automatically, enabling the system to monitor equipment, record data, and integrate production data with product quality data. Data generated at production stations/equipment is obtained from sensors installed on the equipment and can then be transmitted to the operator display and the main dashboard display via a receiver. Through the interconnection between sensors, DLPU, switch hubs, receivers, dashboards, and QC barcodes, the spun pile production process can become more measurable, documented, and traceable, while supporting improved efficiency, quality control, and product information transparency. The following outlines the concept for the development and implementation of IoT to transmit data signals to the monitoring dashboard.

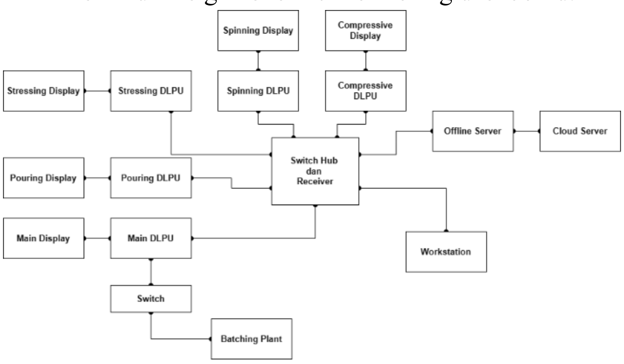

Figure 4.4 Integration of IoT into the Monitoring System

Answering RQ10. The objective of RQ10 is to develop a mapping of the integration of production processes, risks, sensors, and IoT in the precast spun pile production monitoring system. Expert validation was conducted to ensure that the results of the production process flow mapping were consistent with the concept of integrating production processes, risks, sensors, and IoT into the production monitoring system

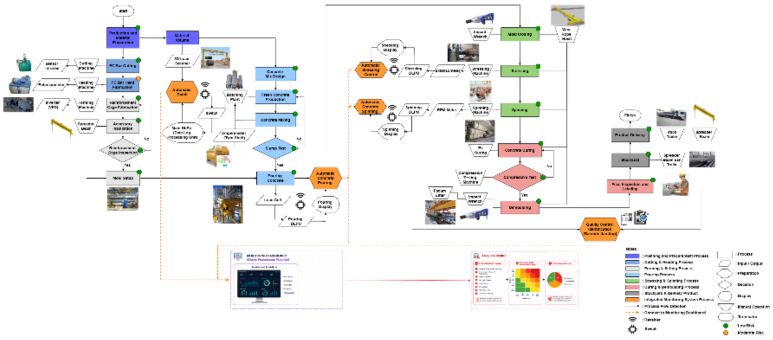

Figure 4.5 Integration of Monitoring System Development

Based on the results of the mapping of the integration of production processes, risks, sensors, and IoT in the monitoring system shown in Figure 4.3, it was concluded that PT. X implements an Automatic Control System in its monitoring system integration.

- **Automatic Batch**, system makes the production process more accurate and minimizes waste, which supports consistent quality and productivity.
- **Automatic Concrete Pouring,** ensures that the concrete poured into the product meets the specified standards.
- **Automatic Stressing Control,** minimizes human error, thereby reducing the risk of workplace accidents.
- **Automatic Concrete Spining,** Converts analog instrument data into digital data that can be monitored in real time.
- **Quality Identification,** A process for identifying product quality through a mobile app, helping to improve product quality assurance and data recording.

The integration of production processes, risks, sensors, and IoT into a monitoring system based on the Automatic Control System concept enables real-time access to all production process data, allowing the data on the monitoring dashboard to serve as an early warning system. This comprehensive database can be used for analysis aimed at improvement, development, and strategic decision-making.

Answering RQ11. The validation of the integration results regarding production productivity levels was conducted by five competent and experienced experts in the field of concrete; these same experts also validated the results of the mapping of the integration of production processes, risks, sensors, and IoT into the existing monitoring system described in RQ10. The validation testing was conducted to determine whether the integration was in accordance with the assessment indicators for production productivity levels.

All experts agreed that the implementation was in line with the production productivity assessment indicators. The decision-making stage was carried out using the Delphi Method.

Based on the final expert validation of the integration results regarding production productivity levels, it was found that integration processes such as automatic batching, automatic concrete pouring, automatic stress control, automatic concrete spinning, automatic quality identification, automatic control systems, and comprehensive data dashboards and early warning systems have an impact on productivity levels. The integration of monitoring systems contributes to increased productivity, specifically in terms of production output, time efficiency, labor efficiency, machinery and equipment efficiency, material efficiency, and product quality.

V. CONCLUSION

Based on the results of quantitative data analysis, expert validation, and statistical modeling, the following conclusions were drawn to address the Research Questions (RQ):

1. The precast spun pile production process at PT X consists of 7 processes with 22 activities.
2. The current integrated production process consists of the casting, stressing, spinning, curing, demolding, and stockyard stations.
3. Current productivity levels, as measured by output factors, the number of units, and target achievement, are in line with the targets set by the company.
4. The variables tested in this study to develop a risk-based monitoring system using sensor technology and IoT have been shown to increase production productivity, as evidenced by 24 success indicators across 6 variables.
5. The results of the correlation and regression analyses show that production processes, risks, sensor technology, IoT, and monitoring systems are all variables that are strongly correlated with and significantly influence increases in production productivity.
6. The technology used in the spun pile production process includes a cutting machine, a heading machine, a forming machine, a spreader beam/hoist, a batching plant, an impact wrench, a stressing machine, and a spinning machine.
7. There are 63 risks in the production process, consisting of 62 risks categorized as low risk, while 1 risk falls into the moderate risk category.
8. The sensors used in the spun pile production process include infrared sensors, potentiometers, inverters (VFDs), 3D load scanners, ammeters, load cells, extensometers, and RPM meters.
9. IoT technology is implemented to transmit data signals (DLPU) from each workstation—via the sensors or equipment used—to the operator's display and then to the monitoring dashboard using switches and receivers.
10. The integration of production processes, risks, sensors, and IoT into the monitoring system is implemented through an automatic control system. This automatic control system is accessible via a single monitoring dashboard where all production process data can be monitored in real time; this serves as an early warning system and can be used for analysis, improvement, development, and decision-making.
11. Validation results show that the integration of research variables leads to increased productivity. The factors contributing to this increase are production output, time efficiency, labor efficiency, machine and equipment efficiency, material efficiency, and product quality.

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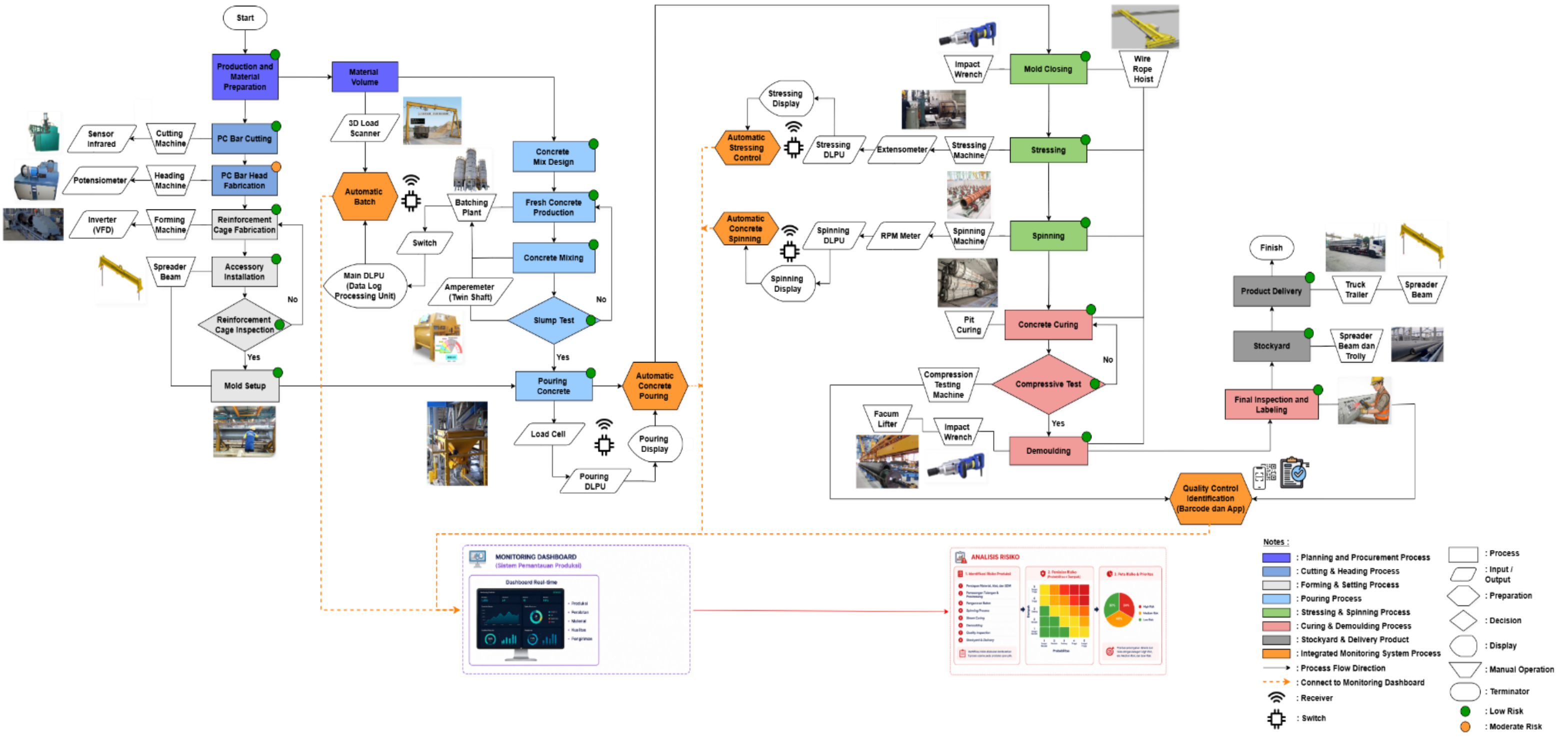

***Integration of Monitoring System Development**