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Risk-Based Method-Technology Integration on Spun Pile Production for Product and Service Quality

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Abstract

The research aims to identify the risk factors and the medium-high risks to use as the basis for the innovative method of spun pile manufacturing technology. The research uses the Delphi method to analyze and review the validity of content construction, pilot and respondent surveys, focus group discussions, and expert validation. The findings show utilizing and optimizing the technology on production machinery is influential for results on both product and service quality. The dominance category in the medium-risk technology indicates the need for improvement in the operator's competence. The result also indicates the largest medium risk is during the initial integration, Cutting and Heading at 84%, and the final step, Stressing and Spinning, at 59%. The research improvement to map the production process is related to the medium and high risks to know where and how the industry can improve. This risk-based technology and integration method is a proposed method using an approach to innovation management by reducing the risk values. Innovation by improving the standard operational procedure (SOP) was based on the relation of each activity during the integration within the risk category of medium-medium, medium-high, and high-high. We recommend improving SOP and utilizing information technology on precision for both subprocesses.

Keywords: Risk; Method-Technology; Integration; Spun Pile.

1. Introduction

Globalization and competition within the industry are the factors urging corporations to have an effective competitive management strategy. Therefore, companies need to have a better understanding of defining the competition, decisive factors, and measuring indexes [1]. Business management and sustainable learning can significantly impact a company's innovation and competitiveness as well as improve overall performance. The industry today faces complex challenges and therefore requires new methods to acquire and attain the competitiveness lead [2]. A precast production company has the large potential to push innovation in the construction method that is clean, safe, and highly efficient in the industry. However, precast supplier chain management often faces issues such as fragments, unsatisfactory tracking systems, and lacking real-time information [3].

The researchers found upon evaluation that the building construction industry has a low efficiency regarding material and automating systems during the production and manufacturing process. The industry also faces the challenge of lacking competent workers in mechanical and construction engineering, which leads to the need for an automated manufacturing process [4]. As it happens in Indonesia, there is a massive growth in building construction. This affects

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the surge of demand for correct materials to improve the infrastructure construction, and, from the existing infrastructure project, it requires innovation in concrete, such as pre-casting with high-quality material to improve the completion time ahead of schedule [5]. In the past decades, the application of the precast structure system had major improvements compared to the conventional system, such as quality control, rapid construction, and the exact application for the regular modular system. Modular construction that utilizes precast elements has multiple benefits, such as shorter manufacturing time, higher quality, flexibility, and a lower cost. But most of the process is still not automated, and the solution for this issue is going digital. In the past few years, the manufacturing industry has had a significant development in utilizing the smart network for the components, machinery, and processes in Industry 4.0. The key concept for Industry 4.0 is the digital twin-based service that represents the machinery and other components to create a dynamic network where each platform interacts and integrates [6]. The interaction also has to accommodate customer service to improve the customers' satisfaction with the spun pile production services. Customers will know the progress of the ordered spun pile using the tracking information [7]. This has been ongoing research that started long before this one took place.

Since 2006, the Indonesian government has launched a massive and rapid construction of 1000 affordable apartment towers nationwide. As an answer to this massive challenge and to keep the quality intact, top researchers developed several innovations in the precast structure [8]. The work method has a high impact on the quality changes, and the competition among the companies encourages each one of them to create a product with higher quality, ensure material availability, and have efficient scheduling to meet the demands [9]. While the company keeps on innovating, they are also facing challenges that lower their competitiveness. For example, despite the high demand, the precast concrete industry has difficulties sourcing type 1 cement, and Indonesia still lacks strand steel manufacturing companies as the primary material to support the precast installation.

Nurjaman et al. [10] showed that precast has better performance than the conventional system in fulfilling the construction needs in the globalization era. However, this method also has issues, such as the design aspect that has to consider how to connect all components, the transportation system, and the construction method. The issue with the national precast concrete company is the manufacturing process that is still conventional and less adaptive with technology, which lessens the company's competitiveness. One of the solutions to this issue is developing and applying the technology to manufacturing precast concrete and utilizing the information technology to create a new manufacturing process.

Eventually, a commercial company, specifically one manufacturing precast concrete, will get to a point where they must innovate to improve their quality, service, and aftersales. Innovation is when implementing a new product or service or a significant rise (in the product and service quality) or a new process, marketing method, or new organizing method in a business practice or an external relation [11]. Another definition of innovation is the process of finding a new idea, method, tool, or something within the innovation management to help others. The innovation process is the sum of changes that affect how a company manufactures the output, while product innovation has the opposite definition, which is the actual change in the product and service [12].

Putra & Isvara [13], who focus on manufacturers with a risk-based spun pile production line but have still not integrated the method and technology, require further study. This paper will explain the process and the result of the risk-based innovation process based on the ISO 56002:2019 clause 8.3 innovation process in two variable aspects of technology and method in manufacturing spun piles in precast companies in Indonesia.

2. Literature Review

2.1. Innovation Management System

Standardization plays a crucial part in forming the policy that regulates technology and how it affects society. This is because it involves numerous stakeholders in the trend. The related standardization process involves three standardization modes based on the studies, which are committee-based, market-based, and government-based [14]. The fourth-generation industry, or Industry 4.0, promotes the usage of information technology in the manufacturing process to get the specific product that will satisfy new customers by changing the traditional automating model into a related service model. This new model allows for communication between clients, manufacturing plants, and suppliers, creating an ecosystem that covers "smart" intelligence and allows the company to have a flexible manufacturing system through interconnection and data sharing. In this new environment, standardization is key for an integrated world [15]. Researchers found a correlation between innovation and the company's standardization and how it affects the connecting development and that it does not pose any threat to conventional systems [16].

The innovation management system in the ISO 56002 standard acts as a guide, providing the communication and general framework to build the innovation capacity. The standard elaborates on the principles of innovation management and elemental systems. Upon publication in 2019, ISO 56002 has become part of numerous discussions and evolved to the pros and cons of standardizing the management system to implement the innovation [17]. ISO 56002:2019 has ten clauses that act as the variables in the innovation management system [18]. The innovation process in ISO 56002:2019 is in Clause 8.3, which became the first clause adopted in this research.

This research utilizes the related process with various aspects in innovation on supporting the innovation process as in Figure 1 and also puts the Oslo Manual as one of the considerations. This study does an innovation process based on ISO 56002:2019 by integrating the technology and methods variables on spun pile manufacturing based on the expected risk value in the surveys on precast concrete manufacturing companies in Indonesia.

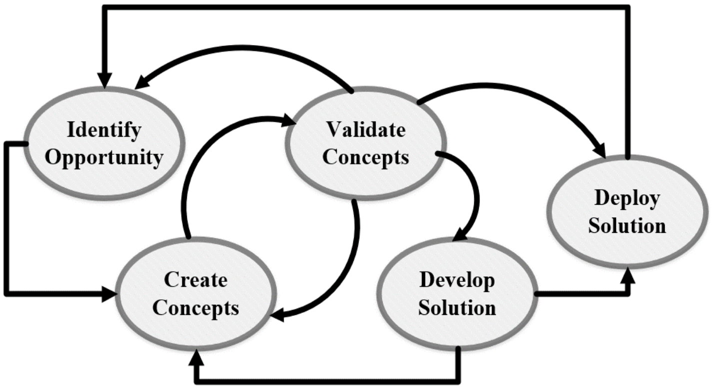

Figure 1. Innovation Process (Innovation management — Innovation management system — Guidance): ISO 56002:2019

2.2. Product Innovation, Service Innovation and Competitiveness

The innovation strategy for products and services is a crucial factor that could help a company improve its performance and manage the pressure from the competition [19]. Considering several factors, such as the industry's lacking skilled workers in mechanical engineering and construction, it's obvious how the industry is developing an automated manufacturing process. Concrete has become the primary construction material in the world; therefore, there is a tendency for the process to slowly turn to automation in precast manufacturing. The high innovation improvement that is apparent individually and within the company produced numerous robotic applications and automatic systems in the precast industry [4]. What is commonly shown is how they need an automation process involving technology such as using robots to make it time efficient and keeping the quality [20]. Additional real-time observation of the manufacturing process ensures product quality and improved efficiency [21]. The innovation on product quality must align with the organization's ideals to provide quality service, identifying the responsible department and person in charge of documentation for the quality system management, assigning the quality authority, developing and implementing quality system management, and keeping quality service with other departments within the organization [22]. After applying the economic value to the service, many companies try to get a competitive lead through service innovation [23]. It is a common perception among clients that service innovation includes updated service, relative lead, and customer complicity that are deeply related to the impact of the value, satisfaction, and customer loyalty to the comp company [24]. These aspects are crucial to improving service quality and ensuring customer satisfaction. The importance of providing an innovative service and customer evaluation to contribute to the innovation. The synthetic definition in the innovation service emphasizes helping the company to determine the primary factor that effectively influences the customers' satisfaction and project their behavior to improve the company's competitiveness [25].

Researchers found that customers' preferences indirectly affect product quality. Utilizing the technology has become the medium between clients' preferences and product quality. The strategic business model was found to have a significant positive impact on the quality, and this relation is also caused by technology mastery. It suggests that the manufacturing company can improve product quality through innovation, competitive strategy to lead, and utilizing technology. All of those factors can be highly beneficial to ensure sustainable company growth [26]. Several of these researchers found a correlation between various parts of the organization and utilizing technology as the supporting strategy to put the company in the competition [27]. This means the company's competitiveness can be achieved by converging to improve the value of product and service quality by integrating technology into the process.

2.3. Risk Identification

Risk management is the basic consideration before taking any decision. It helps the risk manager to make smart decisions and achieve the expected goals [28]. Risk management is necessary as projects always come with risks. Identifying risks is crucial in risk management to determine which risk factor has the most impact and document the characteristics based on all available possibilities [29]. A construction project tends to require a longer project than a regular project in other sectors. It is a crucial sector to follow the standard risk management process. However, it is still lacking, and the professionals require sophisticated solutions. The verification and validation of the risk analysis and expected risk plan will complete the current risk standard. It will improve the risk management process during the construction work [30]. The risk value calculation refers to the PMBOK standard through monitoring the frequency and the risk effects [31].

Observation on the environment upon implementing the spun pile manufacturing method variable as in Figure 2 is as follows:

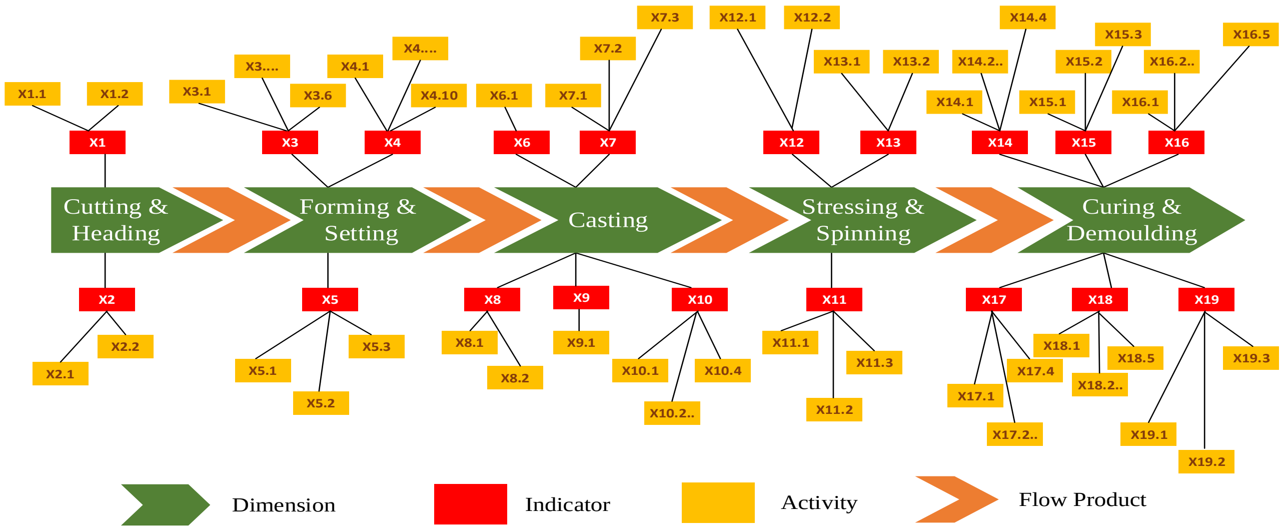

Figure 2. Risk Potential Dimension on the Spun Pile Manufacturing Method

Upon observing the production line, there are five dimensions in the sub-production process and 66 activities with risk potential in the spun file manufacturing method. Observation on the environment upon implementing the spun pile manufacturing technology variable as in Figure 3 is as follows:

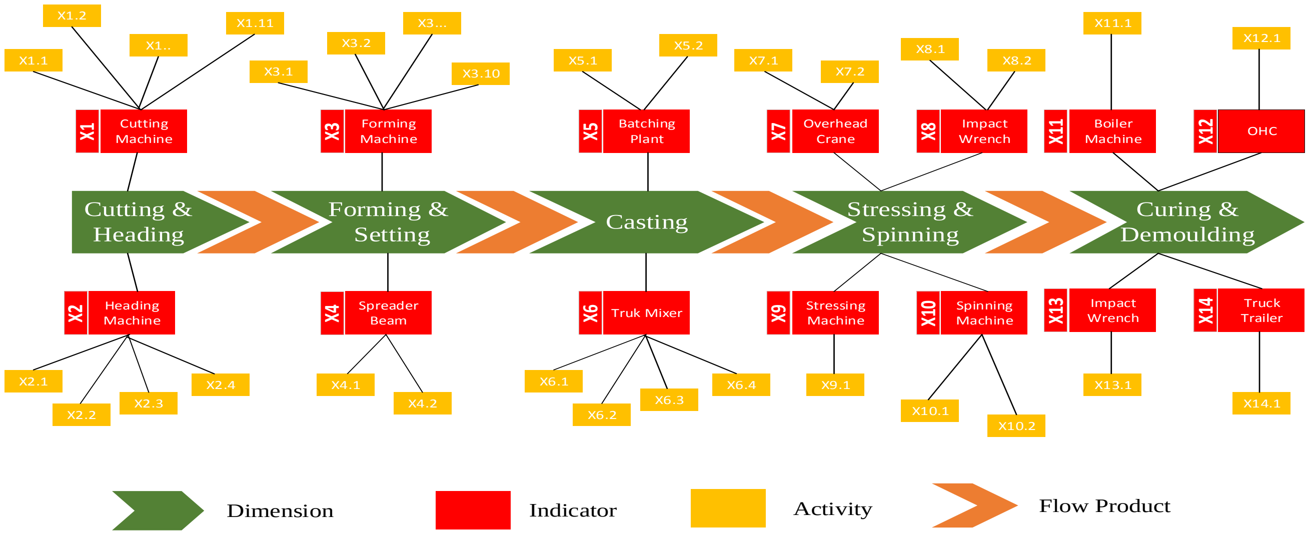

Figure 3. Risk potential dimension of Spun Pile Manufacturing technology

Upon observing the production line, there are five dimensions in the sub-production process and 44 activities with risk potential in the spun file manufacturing technology.

2.4. Risk Calculation

The impact final value is calculated based on the average survey value, using the formula as follows:

$$\text{Impact}_{\text{average}} = \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right) \tag{1}$$

where; n is respondents, x_i is respondent's answer, Risk value is the average risk frequency times the average risk impact.

$$\text{Frequency}_{\text{average}} = \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right) \tag{2}$$

where; n is respondents, x_i is respondent's answer.

$$\text{Score}_{\text{risk}} = \text{Impact}_{\text{average}} \times \text{Frequency}_{\text{average}} \tag{3}$$

Risk is classified into three categories: High, medium, and low risk.

$$\text{Score}_{\text{risk}} \rightarrow \text{Classification} = \begin{cases} \text{High Risk} \\ \text{Medium Risk} \\ \text{Low Risk} \end{cases} \tag{4}$$

The risk value proportion if calculated against the success and failure of 100 of spun pile production uses the following calculation:

$$\text{High Risk}_{\text{Prop}} = \frac{\text{High Risk}_{\text{Total}}}{\text{High Risk}_{\text{Total}} + \text{Medium Risk}_{\text{Total}} + \text{Low Risk}_{\text{Total}}} \times 100\% \tag{5}$$

$$\text{Medium Risk}_{\text{Prop}} = \frac{\text{Medium Risk}_{\text{Total}}}{\text{High Risk}_{\text{Total}} + \text{Medium Risk}_{\text{Total}} + \text{Low Risk}_{\text{Total}}} \times 100\% \tag{6}$$

$$\text{Low Risk}_{\text{Prop}} = \frac{\text{Low Risk}_{\text{Total}}}{\text{High Risk}_{\text{Total}} + \text{Medium Risk}_{\text{Total}} + \text{Low Risk}_{\text{Total}}} \times 100\% \tag{7}$$

Dimension and Proportion Risk Value

The risk value from Equations 1 to 7 will be put into ranks to know how the activity contributes to the risk to the general spun pile manufacturing process. It means disregarding the risk value from the survey to the average dimension. However, the manufacturing process has to follow a specific sequence, which means the potential risk may happen following the ongoing sequences. Thus, one way to calculate each risk value is by calculating the average risk value for all activities against their dimensions. Henceforth, the research will compare the average value from the maximum risk in a dimension with the amount of risk value from the formula.

$$f_i = \text{frequently}_i \tag{8}$$

where $i = |\text{low Risk}|\text{Medium Risk}|\text{High Risk}|$

$$\text{Dimension}_{\text{Mean}} = \begin{cases} f_{\text{Medium Risk}|\text{High Risk}} < f_{\text{Low Risk}} = \sum f_{\text{Low Risk}} + f_{\text{Low Risk}} \\ f_{\text{Medium Risk}|\text{High Risk}} > f_{\text{Low Risk}} = \sum f_{\text{Medium Risk}|\text{High Risk}} + f_{\text{Low Risk}} \end{cases} \tag{9}$$

Calculating the risk integration proportion in each dimension.

$$\text{Dimension}_{\text{Method}} = \sum \text{Low Risk}_{\text{Method}} + \sum \text{Medium Risk}_{\text{Method}} + \sum \text{High Risk}_{\text{Method}} \tag{10}$$

$$\text{Dimension}_{\text{Tech}} = \sum \text{Low Risk}_{\text{Tech}} + \sum \text{Medium Risk}_{\text{Tech}} + \sum \text{High Risk}_{\text{Tech}} \tag{11}$$

$$Dimension_{Risk} = Dimension_{Method} + Dimension_{Tech} \tag{12}$$

where $\text{Dimension}_{\text{Method}}$ is Dimension of Method, $\text{Dimension}_{\text{Tech}}$ is Dimension of Technology.

$$\text{Low Risk}|\text{Medium Risk}|\text{High Risk}_{\text{Dim}} = \sum \text{Low Risk}|\text{Medium Risk}|\text{High Risk}_{\text{Dim}} \tag{13}$$

To find the proportion of each risk category in all dimensions,

$$\text{Category}_{\text{LR}\,|\text{MR}|\text{HR}} = \frac{\sum \text{Low Risk}_{\text{Dim}} | \sum \text{Medium Risk}_{\text{Dim}} | \sum \text{High Risk}_{\text{Dim}}}{\text{Dimension}_{\text{Risk}}} \times 100\% \tag{14}$$

where LR is Low Risk, MR is Medium Risk, HR is High Risk, Dim is Dimension.

Based on Equation 9, if the highest average is low risk, then the value for medium or high risk will be the average low risk value. If the highest average is within the medium or high-risk category, then the low risk will value the average for medium or high-risk. The risk value calculated with Equations 8 and 9 is valid to calculate the production sequence proportional risk for each method and technology of spun pile manufacturing.

2.5. Spun Pile Manufacturing Process

The spun pile production process in Indonesia does not significantly differ from that in other countries. It requires steps such as preparing the mold, chain building, casting, spinning, and steam curing. The difference lies in how much of this process is automated. In general, Indonesian companies are less automated than similar processes in developed countries. Several reasons causing this situation include limited access to the technology and the high investment cost. The method starts by reviewing the existing production, which is reviewing the failed spun pile production. All factories produce the spun pile using the same process and same steps. Based on the research by Satyadharma [32], the mass-produced pile goes through several primary processes such as reinforcement building, mold building, casting, reinforcement stressing, and compression with a spinning system. One of the crucial parts of the production process is the production capacity. This aspect relies on how the production line can optimize each process, which is Cutting & Heading, Forming & Setting, Casting, Stressing & Spinning, and Curing & Demolding [32-34].

2.6. Integration Innovation Concept

Management control is crucial to managing technical information with a direct impact on product quality. Within the industry organization, the information flow relies on the set process and the connection among them. As the knowledge on the product quality improves, it's easier to manage the quality. Therefore, the knowledge to analyze the process to identify each process for better management [35]. The company must simultaneously answer the challenges of improvement as well as the more complex issues on the cost and short growth cycle on the heightened technical complexity. It is expected that using the integration method will reduce some of the automatic tasks and the life cycle cost, as well as lessen the time to start up the machinery and improve product consistency [36]. This shows the importance of integration in the first steps of the construction process and the concept for innovation on the material, related technology, and the product, as the prerequisite to creating new and better ideas on the process. The companies in this industry have the process of the integrated framework to contextualize and conceptualize the new product development or reconfigure the work process to improve the quality [37]. The necessity for a framework integration is to facilitate the AMT (advanced manufacturing technology) integration into the system. The implication is it reduces the dilemma of making the early decisions regarding the smart production system. The integration can also improve flexibility and reduce the time needed to configure new AMT into the existing system [38].

The integration in this study is integrating the method work activity with the technology on spun pile manufacturing to improve the product and service quality, ensure flexibility, and reduce the processing time. The study will see the integration between all activities based on the method and technology correlation within the risk categories medium-medium, medium-high, and high-high. This shows that not all of the activities will have a complete correlation.

3. Research Methodology

The research uses the qualitative method by combining and validating the results from the experts on the variables and risk factors used to analyze using the Delphi method [39] as a systematic and comprehensive risk identification, designed solely for application in the construction industry. The Delphi method is useful to structure the communication process in a group that requires interaction between a group of experts and researchers regarding specific topics to help build the present and future scenarios. Therefore, the interaction they projected will happen within the next five to ten years [40]. During the application of the Delphi method, the direction of the idea starts to materialize. The experts are also starting to form a consensus that will direct the decisions to make more strategic, focused, and well-informed steps. The researchers collect and compile the required data using questionnaires; they start from content and construct variables, pilot surveys, respondents' surveys, focus group discussions, and expert validation. The research methodology employed was in accordance with the steps shown in Figure 4. The first stage was observing the ongoing production process in the spun pile production line. The observation results would then map the factors related to the production methods and technologies used in each activity.

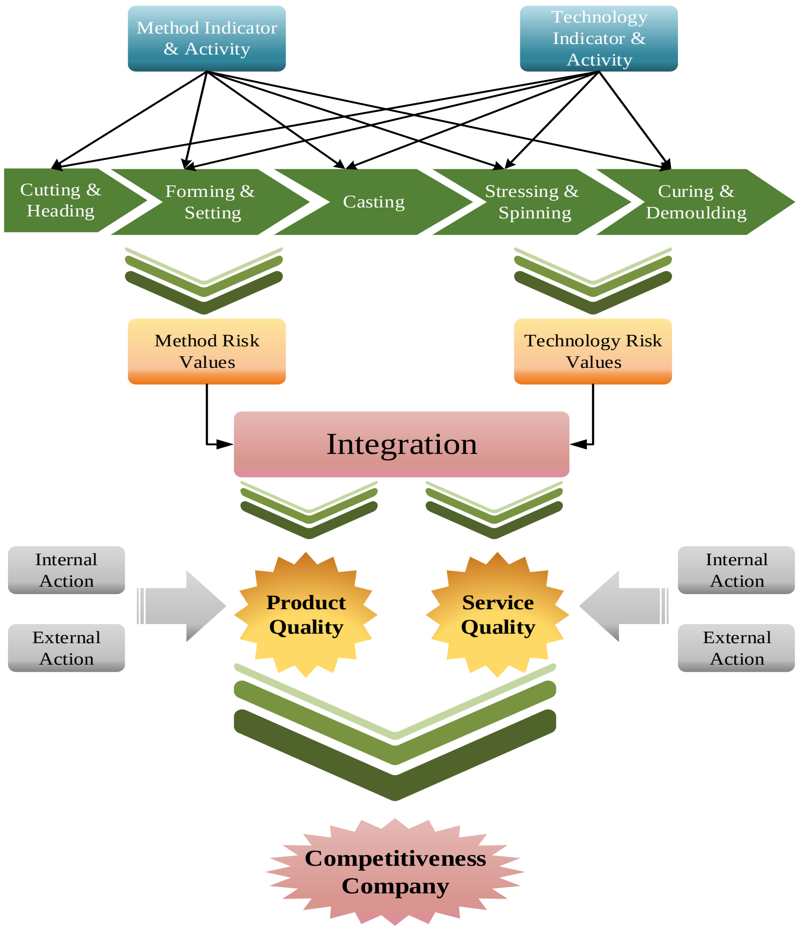

Figure 4. Flowchart of the research methodology

Each activity would undergo risk assessment through questionnaires involving all workers engaged in the spun pile production line.

3.1. Activities and Risk of Spun Pile Production Technology Method

The spun pile production methods and technologies are generally depicted in Figures 2 and 3. The risk activity values of the spun pile production method in the initial stage were calculated based on Equations 1 to 7. In stage 2, the risk value correction by eliminating the proportion of dimensions was calculated using Equations 8 and 9.

After using Equations 8 and 9 in Figure 5, there was an increase in the risk activity ranking, meaning that if the ranking value of each spun pile production method activity became larger, the value generally moved towards the low-risk classification. Whereas in Figure 6, after using Equations 8 and 9, there was an increase in the risk activity ranking, meaning that if the ranking value of each spun pile production technology activity became larger, the value generally moved towards the low-risk classification.

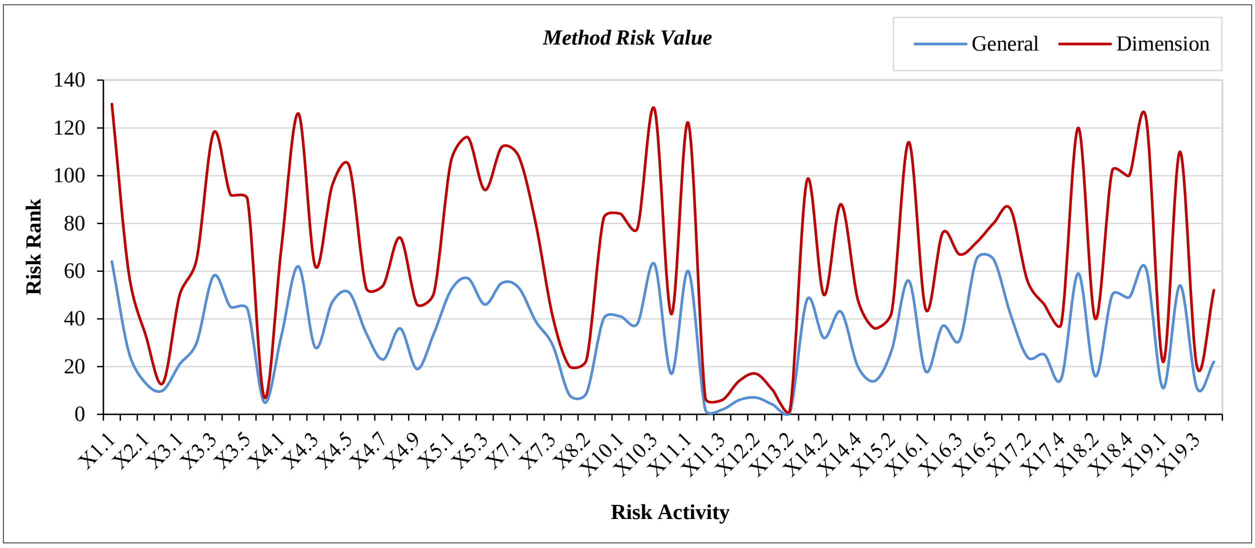

Figure 5. Method Risk Value of Spun Pile Production

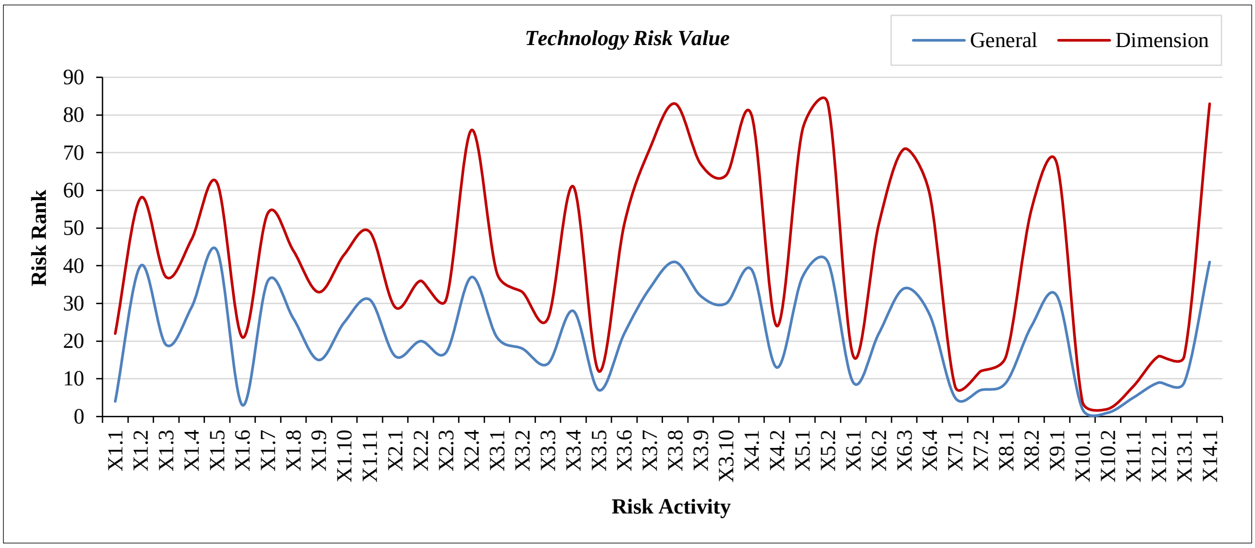

Figure 6. Technology Risk Value of Spun Pile Production

3.2. Method and Technology Integration

Integration is an essential element in mixed methods analysis and conceptualization. It has three main purposes: illustration, convergent validation (triangulation), and analytic weighting development or conceptual enrichment [41]. Based on the risk value mapping results in Table 1, this study had a total of 5 dimensions, 33 indicators, and 109 potential integrated activities. Each activity in this method connects to each activity in the technology within the same dimension, which leads to identifying the SOP that needs fixing and improving. The discussion would be conducted by observing the medium- and high-risk categories.

Table 1. Integration of Methods and Technology

No.	Dimension	Method		Technology	
		Indicator	Activities	Indicator	Activities
1.	Cutting & Heading	X1	2	X1	10
		X2	2	X2	4
2.	Forming & Setting	X3	6	X3	10
		X4	10	X4	2
		X5	3		
3.	Casting	X6	1	X5	2
		X7	3	X6	4
		X8	2		
		X9	1		
		X10	4		
4.	Stressing & Spinning	X11	3	X7	2
		X12	2	X8	2
		X13	2	X9	1
				X10	2
5.	Curing & Demolding	X14	4	X11	1
		X15	3	X12	1
		X16	5	X13	1
		X17	4	X14	1
		X18	5		
		X19	4		

Table 1 showed that the risk activities to be measured and integrated were 18 activities in the Cutting & Heading dimension, 31 activities in Forming & Setting, 19 activities in Casting, 14 activities in Stressing & Spinning, and 29 activities in Curing & Demolding.

3.2.1. Method and Technology Integration

Based on equations (10) - (14), the LR = 11%, MR = 84%, and HR = 5% category ratios were obtained.

In the Cutting and Heading production sub-line dimension (Figure 7), the discussion revolved around handling PC bars using a cutting machine (X1) and heading machine (X2) for technology. The production method perspective in cutting had a low risk value. However, it could have a high risk in technology handling because if an error occurred, it could result in failure in the stressing process and potentially cause additional costs.

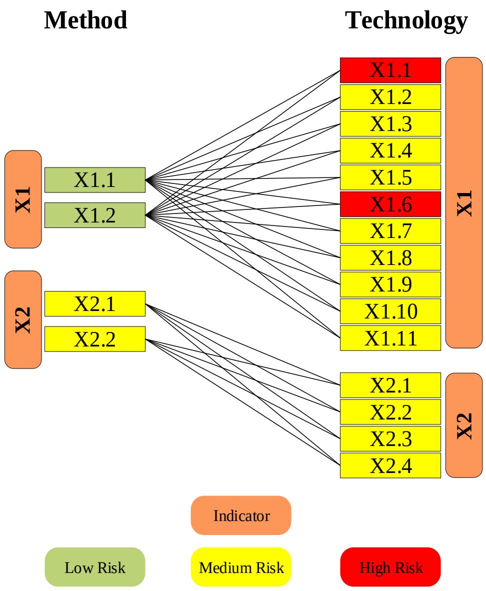

Figure 7. Cutting & Heading Activity Integration

From the perspective of handling methods and technology, heading machines had a similar medium risk. It was necessary to analyze the relationship between method activities X1.1, X1.2 → X1.1, X1.6 technology activities and the relationship between method activities X2.1, X2.2 → X2.1-X2.4 technology activities. The risk relation between low-high and low-medium as well as medium-medium as pictured in Figure 7 then identifies the number as the one needing to have a fix and develop SOP for the detailed activities.

3.2.2. Forming and Setting Integration

Based on Equations 10 to 14, the LR = 58%, MR = 39%, and HR = 3% category ratios were obtained. In the Forming and Setting production sub-line dimension (Figure 8), the discussion revolved around handling using forming machines (X3) and spreader beams (X4). The production method perspective in forming had a low risk value except for X3.6. However, it had a medium risk value in technology handling.

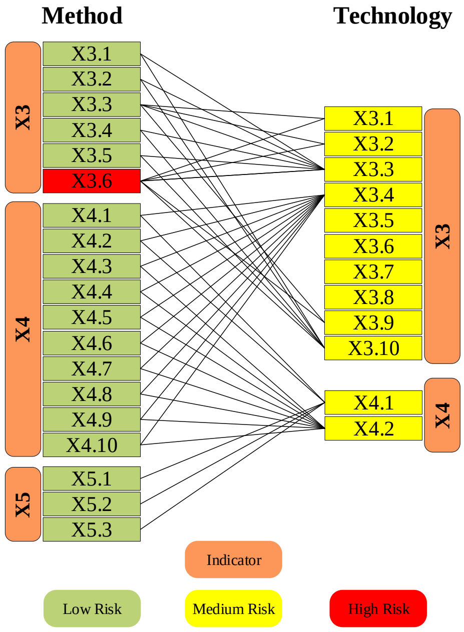

Figure 8. Forming and Setting Activity Integration

It was necessary to analyze the relationship between method activity X3.6 → X3.1-X3.3 technology activities. The risk relation between low-medium and high-medium as pictured in Figure 8 then identifies the number as the one needing to have a fix and develop SOP for the detailed activities.

3.2.3. Casting Integration

Based on equations (10) - (14), the LR = 65%, MR = 35%, and HR = 0% category ratios were obtained. In the Casting production sub-line dimension (Figure 9), the discussion revolved around handling using the Batching Plant (X5) and Truck Mixer (X4) from the technology perspective.

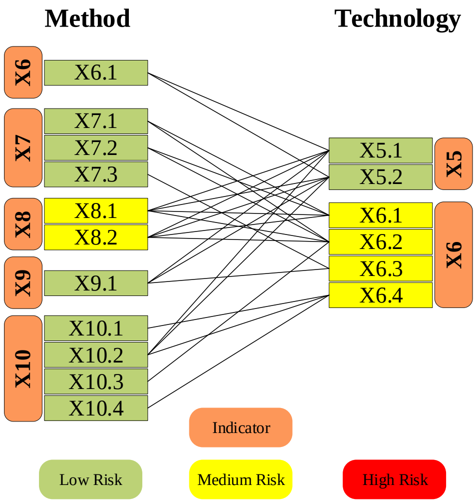

Figure 9. Casting Activity Integration

The production method perspective in casting had a low-risk value except for medium risk in X8.1 and X8.2. However, it had a medium risk value in technology handling on indicator X6. It was necessary to analyze the relationship between method activities X8.1, X8.2 → X6.1-X6.2 technology activities. The risk relation between low-medium and medium-medium as well as medium-low as pictured in Figure 9 then identifies the number as the one needing to have a fix and develop SOP for the detailed activities.

3.2.4. Stressing and Spinning

Based on Equations 10 to 14, the LR = 7%, MR = 59%, and HR = 18% category ratios were obtained. In the Stressing and Spinning production sub-line dimension (Figure 10), the discussion revolved around handling using the Overhead Crane (X7), Impact Wrench (X8), Stressing Machine (X9), and Spinning Machine (X10) from the technology perspective. The production method perspective in Stressing and Spinning had a low risk value at activity X11.1 and medium risk at X11.2, X11.3, X12.1, X12.2 and X13.1 and High Risk at X13.3. It had a medium risk value at indicators X7, X8, and X9, but a high risk at indicator X10 in technology handling.

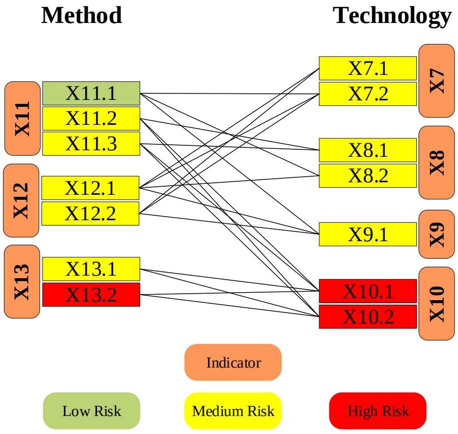

Figure 10. Stressing and Spinning Integration

It was necessary to analyze the relationship between method activities X11.2, X11.3 → X8.1, X10.2, X10.2 technology activities, method activities X12.1, X12.2 → X7.1, X7.2, X8.2, X9.1 technology activities, and method activities X13.1, X13.2 → X10.1, X10.2 technology activities. The risk relation between low-medium, medium-medium, medium-high as well as high-high as pictured in Figure 10 then identifies the number as the one needing to have a fix and develop SOP for the detailed activities.

3.2.5. Curing and Demolding Integration

Based on Equations 10 to 14, the LR = 79%, MR = 21%, and HR = 0% category ratios were obtained. In the Curing and Demolding production sub-line dimension (Figure. 11), the discussion revolved around handling using the Boiler Machine (X11), OHC (X12), Impact Wrench (X13), and Truck Trailer (X14) from the technology perspective.

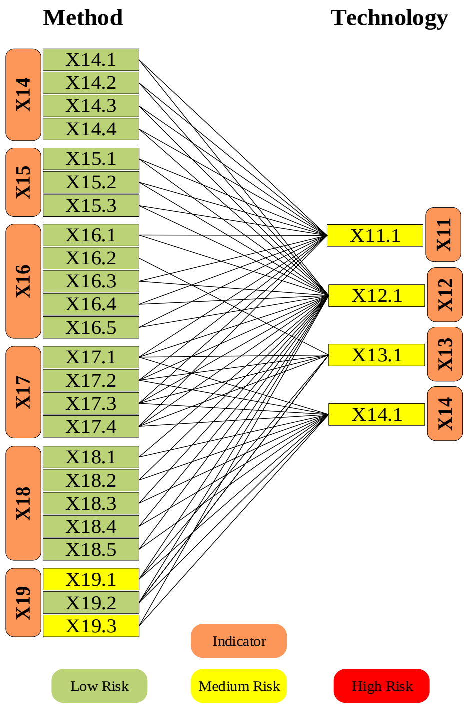

Figure 11. Curing and Demolding Integration

The production method perspective in Curing and Demolding had a low risk value except for medium risk at X19.1 and X19.3. However, it had a medium risk value in technology handling on indicators X11-X14. It was necessary to analyze the relationship between method activities X19.1, X19.3 → X11-X14 technology indicators. The risk relation between low-medium or medium-medium as pictured in Figure 11 then identifies the number as the one needing to have a fix and develop SOP for the detailed activities.

4. Result and Discussion

4.1. Innovation Process

The innovation process for the integration of spun pile production methods and technologies at the company was carried out in reference to ISO 56002:2019, as shown in Figure. 1. Implementing the integration between method and technology must consider the relative risk profile in each dimension. This is necessary since the production process that integrates method and technology in the same dimension must have a close-range risk value among its activity. The process is shown in Figures 5 and 6.

After the process is completed, then the innovation process continues. The process conducted in this study is described in Table 2.

Table 2. Innovation Process for Integration of Methods and Technology

Innovation Process	Explanation	Input	Process	Output
Identify Opportunities	Conducting gap analysis and identifying opportunities.	Identifying risks in current precast concrete manufacturing methods, tools, technologies, and production stages.	Analyzing archives, conducting interviews, and making observations.	Methods and technologies currently applied in the spun pile production line activities.
Create Concepts	Efforts to fill the identified gaps and capitalize on opportunities.	Output identifies opportunities (current Methods and Technologies for Spun Pile Manufacturing).	Risk-based analysis of precast concrete manufacturing methods and technologies.	Designing recommendations for integrated method and technology adoption by the company based on the highest potential risks.
Validate Concepts	Validating the innovation ideas and concepts created.	Output creates concepts (Proposed method & technology implementation design).	Presentation and focus group discussion on the recommended design.	Recommendations for potential implementation based on the validated methods and technologies from the FGD.
Develop Solutions	Developing the validated innovation ideas and concepts.	Output validates concepts (Recommendations for the Application of Method Analysis & Technologies that had been validated by FGD).	Refining and supplementing the recommended technology innovation based on FGD discussion.	Reviewing the revised and adjusted recommendation proposal based on FGD results
Deploy Solutions	Actualizing the value of the innovation idea.	Output develops solutions (Review of revised and adjusted recommendation proposal).	Proposing the issuance of a Board of Directors Decree (*Surat Keterangan/SK*) or authorized SOP to implement the innovation recommendations.	- A Board of Directors Decree (*Surat Keterangan/ SK*) for implementing the innovation and SOP for Methods & Technology Innovation. - Monitoring and control evaluation

Table 2 illustrates the innovation process carried out to integrate Spun Pile production methods and technologies. Each input for each innovation process step was a sequential process from the first step. Most process activities had to be discussed in Focus Group Discussions to strengthen management policies. Each output from the innovation process in this study would follow a continuous cycle that is part of the company's innovation policy.

4.2. Innovation Recommendation for Integration

The recommended innovations for integrating spun pile production methods and technologies analyzed would be proposed in Focus Group Discussion activities as referred to in Table 2. SOP fixing is part of the internal process, which means the product quality depends on how the manufacturer starts the production process. Specifically, it is an indispensable part of improving the SOP for a sustainable innovation process. The recommendations were based on the analysis of each dimension's activities, as follow:

4.2.1. Cutting and Heading

Table 3 shows that the largest percentage ratio was in the Medium Risk category at 84%, with recommended integration between methods and technologies as follows:

Service Quality (Internal), target: Handling PC bar production by improving SOPs, requiring tools to aid in precise PC bar quality measurements, and increasing worker competency.

Service Quality (External), target: -

Product Quality (Internal), target: Producing PC bars that are part of the spun pile in accordance with product qualifications.

Product Quality (External), target: If the production of PC bars that are part of the spun pile meets market product qualifications, the potential for PC bar part orders is very high.

Recommendation: Adding monitoring technology for production quality and internal and customer documentation to monitor and increase customer satisfaction

Table 3. Cutting & Heading Recommendation

Risk Dimension (%)			Activity Integration	
Low Risk	Med Risk	High Risk	Method	Technology
11	84	5	X1.1, X1.2 X2.1, X2.2	X1.1, X1.6 X2.1-X2.4

Table 4 shows that the largest percentage ratio was in the Low Risk category at 58%, with recommended integration between methods and technologies as follows:

Service Quality (Internal), target: Carefulness and perspicacity in assembling and moving the constructed frames are required. Handling must adhere to new SOPs.

Table 4. Forming and Setting Recommendation

Risk Dimension (%)			Activity Integration	
Low Risk	Med Risk	High Risk	Method	Technology
58	39	3	X3.6	X3.1-X3.3

Service Quality (External), target: Monitoring the production process.

Product Quality (Internal), target: Manufacturing in accordance with SOPs and a high level of precision results in good frame products.

Product Quality (External), target: If the frame production that is a part of the spun pile meets market product qualifications, the potential for frame orders is very high.

Recommendation: Adding monitoring technology for production quality and internal and customer documentation to monitor and increase customer satisfaction.

4.2.3. Casting

Table 5 shows that the largest percentage ratio was in the Low Risk category at 65%, with recommended integration between methods and technologies as follows:

Service Quality (Internal), target: Handling casting for improved good aggregate quality.

Service Quality (External), target: -

Product Quality (Internal), target: Producing stable and good aggregate mixtures according to machine operation capabilities.

Product Quality (External), target: Good aggregates and handling processes using Batching Plant machines and delivery by truck mixers to ensure the maintained ready-mix quality.

Recommendation: Adding monitoring technology for production quality because time is a challenge affecting product quality. Additional information technology monitoring tools are needed.

Table 5. Casting Recommendation

Risk Dimension (%)			Activity Integration	
Low Risk	Med Risk	High Risk	Method	Technology
65	35	0	X8.1, X8.2	X6.1, X6.2

4.2.4. Stressing and Spinning

Table 6 shows that the largest percentage ratio was in the Medium Risk category at 59%, with recommended integration between methods and technologies as follows:

Service Quality (Internal), target: Internal Service Quality, target: Improving performance with better eye bolt handling processes. Stressing and spinning machine operators must carefully follow Standard Operating Procedures (SOPs).

Service Quality (External), target: -

Product Quality (Internal), target: Focusing on the product quality produced with better control of spinning and stressing machines.

Product Quality (External), target: The final product quality highly depends on this process.

Recommendation: This stage has a considerable degree for both medium and high-risk dimensions. Hence, the addition of precise information technology utilization for production monitoring is necessary.

Table 6. Stressing and Spinning Recommendation

Risk Dimension (%)			Activity Integration	
Low Risk	**Med Risk**	**High Risk**	**Method**	**Technology**
			X11.2, X11.3	X8.1, X10.1,X10.2
7	59	18	X12.1, X12.2	X7.1, X7.2, X8.2,X9.1
			X13.1, X13.2	X10.1, X10.2

4.2.5. Curing and Demolding

Table 7 shows that the largest percentage ratio was in the Low Risk category at 79%, with recommended integration between methods and technologies as follows:

Service Quality (Internal), target: Handling and maintaining product quality assurance until delivery to customers according to desired quality.

Service Quality (External), target: Third-party spun pile handling operations must be ensured to comply with SOPs.

Product Quality (Internal), target: Product quality must be ensured from the end of production, stockyard and shipping until the spun piles are received and installed.

Table 7. Curing and Demolding Recommendation

Risk Dimension (%)			Activity Integration	
Low Risk	**Med Risk**	**High Risk**	**Method**	**Technology**
79	21	0	X19.1, X19.3	X11-X14

Product Quality (external), target: Product quality is maintained according to customer requirements and can be tested as well as being equipped with facilities for handling defective goods.

Recommendation: IT utilization is needed to monitor quality and handle defective goods returned by customers.

5. Conclusion

Based on Figures 7 to 11, the technology side was mostly in the medium-risk and partially high-risk categories. This illustrates that technology utilization in production machines significantly influences service and product quality outcomes. Operators must possess adequate competency qualifications. What qualifies as competence is how the operator manages the building capacity and has the legal institution to declare the building proper in anticipation of any machine changes in the production line. Improving competence can reduce the risk level. The largest Medium Risk category was in the initial stage of Cutting & Heading at 84%, followed by the final Stressing and Spinning sub-process at 59%. These two processes should have their performance quality improved. The first-dimension process is the start of the manufacturing production, and the fourth dimension process is the final manufacturing process with potential medium risk. Integration will improve by involving information technology that can function internally and externally for the company. Internally, it relates to SOP quality improvement and human resource quality enhancement by utilizing technology.

The performance monitor perspective for the production (to reduce the risk value), especially the time allocation to produce the spun pile product, must be in line with the SOP with other spun pile products. It requires the information technology to monitor and ensure the quantity and quality, in which the customer also can monitor the information regarding the production order (traceability). The information technology can provide information in real time and send it to customers through external and internal links. This can begin by improving SOPs based on the integration relationships between activities with medium-medium, medium-high, and high-high risk categories. Increased product and production service quality can involve and influence customer satisfaction, increasing product or company competitive value and loyalty.

5.1. Future Research

Many factors influence product quality and service improvement, and many variables can also increase a company's competitive value, not only internal variables such as method and technology integration but also factors such as context organization of the organization, leadership, planning, support, operation, performance evaluation, improvement, and information systems. External factors regarding regulations, market conditions, etc., must also be considered. Research regarding the previously mentioned factors can be conducted and is highly recommended for the next stage.

6. Declarations

6.1. Author Contributions

Conceptualization, R.H. and Y.L.; methodology, V.G.; software, V.G.; validation, R.H., Y.L., and V.G.; formal analysis, Y.L.; investigation, R.H.; resources, Y.L.; data curation, V.G.; writing—original draft preparation, R.H.; writing—review and editing, R.H.; visualization, V.G.; supervision, Y.L. and V.G.; project administration, R.H.; funding acquisition, R.H. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data sharing is not applicable to this article.

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Orozco, F., Serpell, A., & Olenaar, K. (2011). Competitiveness factors and indexes for construction companies: Findings of Chile. Revista de La Construccion, 10(1), 91–107. doi:10.4067/s0718-915x2011000100009.

[2] Lomineishvili, K. (2021). How entrepreneurial management and continuous learning affect the innovation and competitiveness of companies? Economic Alternatives, 2021(3), 459–468. doi:10.37075/EA.2021.3.08.

[3] Wang, Z., Wang, T., Hu, H., Gong, J., Ren, X., & Xiao, Q. (2020). Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. Automation in Construction, 111. doi:10.1016/j.autcon.2019.103063.

[4] Reichenbach, S., & Kromoser, B. (2021). State of practice of automation in precast concrete production. Journal of Building Engineering, 43. doi:10.1016/j.jobe.2021.102527.

[5] Hidayawanti, R., & Latief, Y. (2023). Raw Material Optimization With Neural Network Method in Concrete Production on Precast Industry. International Journal of GEOMATE, 24(102), 10–17. doi:10.21660/2023.102.g12146.

[6] Kosse, S., Vogt, O., Wolf, M., König, M., & Gerhard, D. (2022). Digital Twin Framework for Enabling Serial Construction. Frontiers in Built Environment, 8. doi:10.3389/fbuil.2022.864722.

[7] Hidayawanti, R., Latief, Y., & Gaspersz, V. (2024). Perceptron model application for traceability risk in spun pile manufacturing. Journal of Infrastructure, Policy and Development, 8(6), 4638. doi:10.24294/jipd.v8i6.4638.

[8] Nurjaman, H. N., Hariandja, B. H., & Sidjabat, H. R. (2008). The Use Of Precast Concrete Systems In The Construction Of Low-Cost Apartments In Indonesia. 14th World Conference on Earthquake Engineering (14WCEE), 22, 1–8. 12-17 October, 2008, Beijing, China.

[9] Noerpratomo, A. (2018). The influence of raw material inventory and production processes on product quality at CV. Banyu Biru Connection. Almana: Jurnal Manajemen dan Bisnis, 2(2), 20-30. (In Indonesian).

[10] Nurjaman, H., Faizal, L., Suaryana, N., Hariandja, B., Gambiro, Purnomo, & Wicaksono, S. (2017). Design, development, and application of precast and prestressed concrete system for rigid pavement in Indonesia. AIP Conference Proceedings, 1903, 030003. doi:10.1063/1.5011510.

[11] Gault, F. (2013). The Oslo Manual. Economics 2013: Handbook of Innovation Indicators and Measurement, 41–59. doi:10.4337/9780857933652.00010.

[12] Bateman, T., Snell, S., Konopaske, R. (2019). Management: Leading & Collaborating in a Competitive World (13th Ed). McGraw Hill, New York, United States.

[13] Putra, R. E., & Isvara, W. (2023). Qualitative Risk Analysis of Production Precast Spun Pile at Company-X. United International Journal for Research & Technology, 05(01), 51–60.

[14] Wiegmann, P. M., de Vries, H. J., & Blind, K. (2017). Multi-mode standardisation: A critical review and a research agenda. Research Policy, 46(8), 1370–1386. doi:10.1016/j.respol.2017.06.002.

[15] Velasquez Villagran, N., Estevez, E., Pesado, P., & De Juanes Marquez, J. (2019). Standardization: A Key Factor of Industry 4.0. Sixth International Conference on eDemocracy & eGovernment (ICEDEG), 350–354. doi:10.1109/icedeg.2019.8734339.

[16] Yang, J., Zhou, L., Qu, Y., Jin, X., & Fang, S. (2023). Mechanism of Innovation and Standardization Driving Company Competitiveness in the Digital Economy. Journal of Business Economics and Management, 24(1), 54–73. doi:10.3846/jbem.2023.17192.

[17] Hyland, J., & Karlsson, M. (2021). Towards a management system standard for innovation. Journal of Innovation Management, 9(1), XI–XIX. doi:10.24840/2183-0606_009.001_0002.

[18] Tidd, J. (2021). A Review and Critical Assessment of the ISO56002 Innovation Management Systems Standard: Evidence and Limitations. International Journal of Innovation Management, 25(1), 2150049. doi:10.1142/S1363919621500493.

[19] Hoonsopon, D. (2009). The empirical study of the impact of product innovation factors on performance of new products: Radical and incremental product innovation. Ph.D. Thesis, Chulalongkorn University, Bangkok, Thailand.

[20] Pan, M., & Pan, W. (2019). Determinants of Adoption of Robotics in Precast Concrete Production for Buildings. Journal of Management in Engineering, 35(5), 05019007. doi:10.1061/(asce)me.1943-5479.0000706.

[21] Fu, Y., Downey, A., Yuan, L., Pratt, A., & Balogun, Y. (2021). In situ monitoring for fused filament fabrication process: A review. Additive Manufacturing, 38. doi:10.1016/j.addma.2020.101749.

[22] O'g, B. O. N. (2021). The Role of Quality Management System in Increasing Product Quality in Enterprises. Web of Scientist: International Scientific Research Journal, 2(12), 228–233.

[23] Feng, C., & Ma, R. (2020). Identification of the factors that influence service innovation in manufacturing enterprises by using the fuzzy DEMATEL method. Journal of Cleaner Production, 253. doi:10.1016/j.jclepro.2020.120002.

[24] Nyadzayo, M. W., Leckie, C., & Johnson, L. W. (2023). Customer participation, innovative aspects of services and outcomes. Marketing Intelligence and Planning, 41(1), 1–15. doi:10.1108/MIP-03-2022-0090.

[25] Truong, N. T., Dang-Pham, D., McClelland, R. J., & Nkhoma, M. (2020). Service innovation, customer satisfaction and behavioural intentions: a conceptual framework. Journal of Hospitality and Tourism Technology, 11(3), 529–542. doi:10.1108/JHTT-02-2019-0030.

[26] Nimfa, D. T., Uzir, M. U. H., Maimako, L. N., Eneizan, B., Latiff, A. S. A. L., & Wahab, S. A. (2021). The Impact of Innovation Competitive Advantage on Product Quality for Sustainable Growth among SMEs: An Empirical Analysis. International Journal of Business Science and Applied Management, 16(3), 39–62. doi:10.69864/ijbsam.16-3.152.

[27] Mohamed, H. A. E., & Eltohamy, A. I. (2022). Critical Success Factors for Competitiveness of Egyptian Construction Companies. Sustainability (Switzerland), 14(17). doi:10.3390/su141710460.

[28] Aboutorab, H., Hussain, O. K., Saberi, M., Hussain, F. K., & Chang, E. (2021). A survey on the suitability of risk identification techniques in the current networked environment. Journal of Network and Computer Applications, 178. doi:10.1016/j.jnca.2021.102984.

[29] Kasap, D., & Kaymak, M. (2007). Risk Identification Step of the Project Risk Management. PICMET '07 - 2007 Portland International Conference on Management of Engineering & Technology, 2116–2120. doi:10.1109/picmet.2007.4349543.

[30] Alfreahat, D., & Sebestyén, Z. (2022). A construction-specific extension to a standard project risk management process. Organization, Technology and Management in Construction, 14(1), 2666–2674. doi:10.2478/otmcj-2022-0011.

[31] PMI (2021). The Standard for Project Management and a Guide to the Project Management Body of Knowledge (7^{th} Ed.). PMBOK Guide, Project Management Institute (PMI), Upper Darby, United States.

[32] Satyadharma, W. R. (2022). Optimization of the spun pile production process using connector rings on the mold. Seminar Nasional Insinyur Profesional (SNIP), 2(1). doi:10.23960/snip.v2i1.39.

[33] Andika Okayana. (2023). Evaluation of Production Process Flow with Line Balancing Method to Increase Round Pile Production Capacity at PT. Adhi Persada Beton Plant Mojokerto-East Java. Jurnal Teknik Industri, 13(1), 90–97. doi:10.25105/jti.v13i1.17520.

[34] Naim, M. A., Rimawan, E., & Putri, A. (2020). Relayout Production Facility of PC. Spun Pile Using Systematic Layout Planning in ABC Factory. International Journal of Innovative Science and Research Technology, 5(8), 1620–1629. doi:10.38124/ijisrt20aug614.

[35] Pop, G. I., & Țîțu, A. M. (2021). Identifying the influence of technical resources knowledge on product quality requirements in a global engineering process. International Journal of Mechatronics and Applied Mechanics, 1(9), 225–231. doi:10.17683/ijomam/issue9.32.

[36] Moreira, B. M. D. N., Gouveia, R. M., Silva, F. J. G., & Campilho, R. D. S. G. (2017). A Novel Concept of Production and Assembly Processes Integration. Procedia Manufacturing, 11, 1385–1395. doi:10.1016/j.promfg.2017.07.268.

[37] Lager, T., Simms, C. D., & Frishammar, J. (2023). Managing Ideation and Concept Integration in the Product Innovation Work Process for Non-Assembled Products. International Journal of Innovation and Technology Management, 20(3), 2350016. doi:10.1142/S0219877023500165.

[38] Fattouh, A., Chirumalla, K., Ahlskog, M., Behnam, M., Hatvani, L., & Bruch, J. (2023). Remote integration of advanced manufacturing technologies into production systems: integration processes, key challenges and mitigation actions. Journal of Manufacturing Technology Management, 34(4), 557–579. doi:10.1108/JMTM-02-2022-0087.

[39] Kıral, I. A., Kural, Z., & Çomu, S. (2014). Risk identification in construction projects: Using the Delphi method. 11th International Congress on Advances in Civil Engineering, 21-25 October, 2014, Istanbul, Turkey.

[40] Renzi, A. B., & Freitas, S. (2015). The Delphi Method for Future Scenarios Construction. Procedia Manufacturing, 3, 5785–5791. doi:10.1016/j.promfg.2015.07.826.

[41] Fielding, N. G. (2012). Triangulation and Mixed Methods Designs: Data Integration with New Research Technologies. Journal of Mixed Methods Research, 6(2), 124–136. doi:10.1177/1558689812437101.