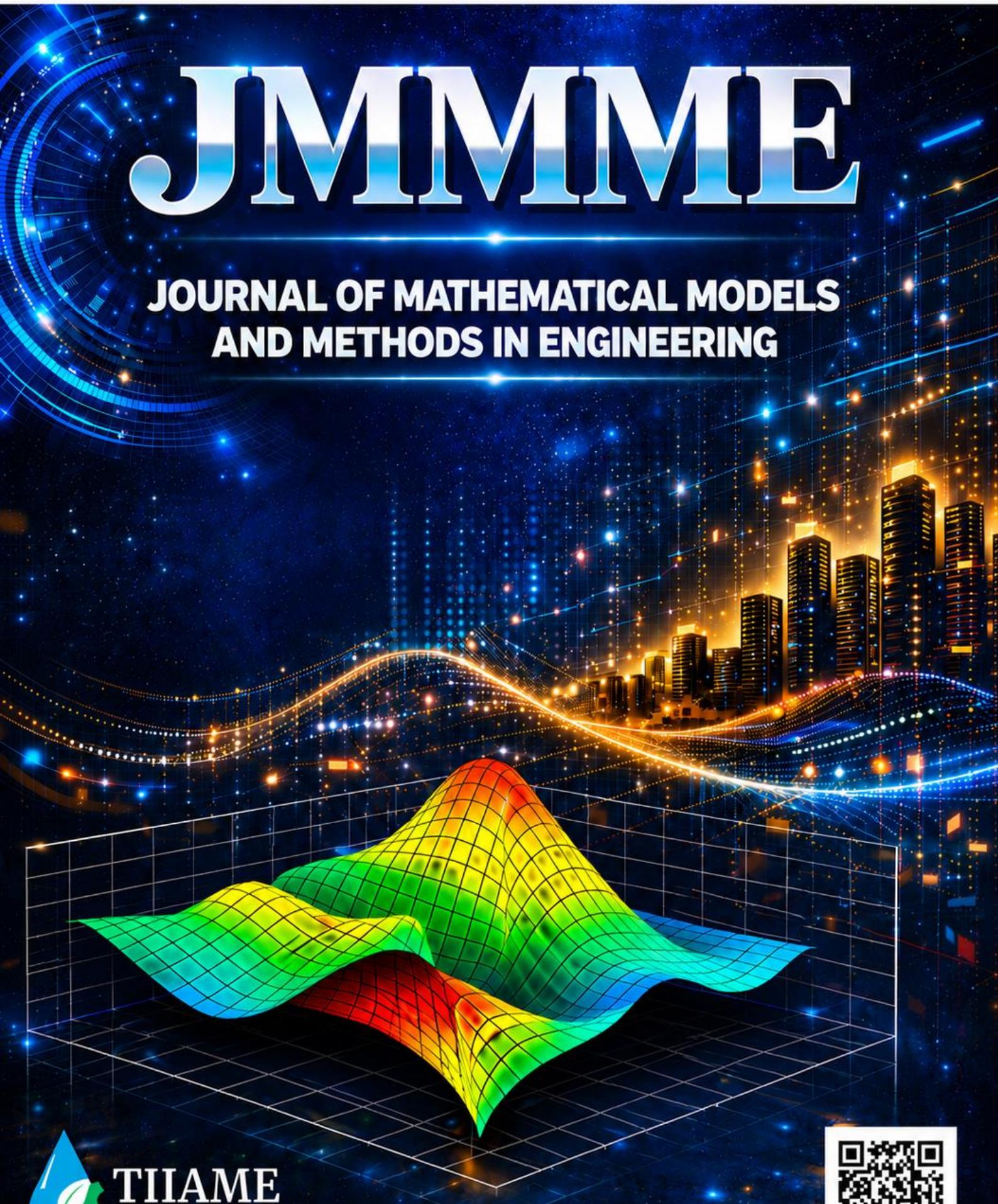
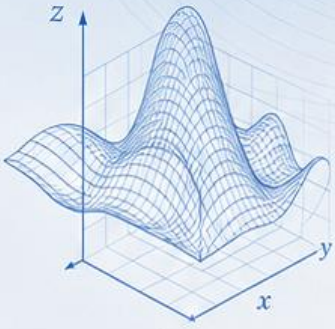
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$$\frac{dx}{dt} = Ax + b(t)$$

$$\frac{\partial u}{\partial t} = \alpha \nabla^2 u + f$$

$$\sum_{i=1}^{n} a_i x_i + b$$

$$f(x) = \int_a^b f(x)\,dx$$

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

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$$\sum_{i=1}^{n} w_i x_i$$

The journal specializes in publishing scientific research on mathematical modeling, numerical methods, computational algorithms, optimization, and analytical approaches across various fields of engineering — including civil engineering, mechanical engineering, energy, hydraulic engineering, materials science, robotics, and environmental protection. It serves as a scientific platform for scholars, engineers, educators, and doctoral researchers to exchange theoretical and applied knowledge.



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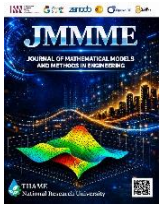
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Evaluation of Cement Production for Continuous and Discrete Flow Systems by Applying a Discrete Event Simulation Approach

Wan Laailatul Hanim Mat Desa[1], Mohd Kamal Mohd Nawawi[2*], Nur Anis Hannan Md Shahid[3]

[1,2,3] *School of Quantitative Sciences, UUM College of Arts & Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah Darul Aman, Malaysia*

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ABSTRACT

The purpose of this study is to model and simulate the operations of the cement manufacturing industry using the Discrete Event Simulation (DES) approach. The study focuses on improving operational efficiency and supporting decision-making through systematic process analysis and modeling. Although cement manufacturing consists of three main stages, including raw material preparation, pyro processing, and cement grinding and distribution, this study adopts a tank-flow approach to analyze material flow behavior during the critical cement grinding process. A simulation model was developed using Arena Software version 16.2 to represent both continuous and discrete flow characteristics of the system. Four alternative scenarios were evaluated against the basic model. According to the results, Scenario 2 reduced the mixing time of Mixing Tank 2 by almost 22%, while Scenario 3 obtained the lowest average total mixing time for Mixing Tank 1 (2.194 hours), which is a decrease of roughly 32% when compared to the basic model. Scenario 4 significantly increased the accumulation in Mixing Tank 2 (4046.9 tons) in terms of tank levels, suggesting possible bottlenecks downstream. These results emphasize the difference between higher inventory levels and shorter processing times. Preventive maintenance techniques are suggested, considering the simulation results, in order to reduce delays and manage excessive material accumulation, which will enhance system dependability and overall operating performance.

1. Introduction

Manufacturing has been crucial to Malaysia's industrial growth and economic transition. As an important contributor to national gross domestic product (GDP), the manufacturing sector promotes job creation, technological advancement and value-added output across a wide range of industries. Manufacturing is the systematic conversion of raw materials into finished or semi-finished products using machinery, technology and human effort, which is generally organized into a structured division of labor. In Malaysia, the industry is classified into three sectors which are light industry, medium industry and heavy industry.

[2] Corresponding author: *School of Quantitative Sciences, UUM College of Arts & Sciences, University Utara Malaysia, 06010 Sintok, Kedah Darul Aman, Malaysia*

Cement manufacturing was categorized as a heavy industry that relies on heavy raw materials such as coal, clay and limestone, as well as large-scale machinery and high energy consumption. Cement manufacturing requires significant thermal and electrical energy, making it one of the most resource-intensive industries. Despite these difficulties, the cement sector is essential to infrastructure expansion and economic development, especially in developing and emerging nations like Malaysia. Cement is one of the primary raw materials used in the production of concrete along with water and aggregate. In the heavy industry sector, it plays a crucial role in the development of infrastructure, including buildings, bridges, and roads. The availability and reliability of cement supply directly influence the pace and scale of construction activities, thereby affecting national development objectives and economic growth.

In general, cement refers to a wide range of adhesive substances that are capable of binding materials together but in a more specific context, it refers to the binding materials utilized in the construction of buildings and civil engineering projects. The raw materials used to make cement are heated to high temperatures, creating a rock-like substance that is then ground into a fine powder. Besides that, professionals made cement by combining raw materials with metals and minerals like silicon, calcium, iron and aluminium, then heating the mixture to high temperatures to create clinker. After that, the clinker is ground into a powder and sold to ready-mix concrete companies as cement.

Malaysia's cement demand is still strong because of the continuous large-scale infrastructure projects. These initiatives support the cement industry's medium to long-term growth by boosting market sentiment and indicating a possible rise in building activity in Peninsular Malaysia. The cement industry plays a crucial role in the country's building sector by providing necessary materials for development and infrastructure projects. These projects represent important pillars for the cement industry's medium- to long-term growth, suggesting a possible rise in building activity throughout Peninsular Malaysia.

In the face of pressures like global competition and the need to maintain the quality of the increasing consumer demand, all industries are constantly looking to improve their efficiency and minimize their expenses. Internal process inefficiencies can have a major impact on overall performance as production systems grow more complex. There are few issues found in the manufacturing industry such as unintended machine downtimes and high maintenance costs (Nganga et al., 2023), assembly process (Dalle Mura & Dini, 2022; Kolny et al., 2023; Scrivano et al., 2023), identification of the bottlenecks in manufacturing systems (Rocha & Lopes, 2022; Javadi et al., 2023) and challenges and inefficiencies associated with traditional mass production systems (Katsigiannis et al., 2024).

One of the most common and critical challenges that happens in every industry is bottleneck mitigation strategies. Effective identification and management of such restrictions are critical to maintaining competitiveness and operational excellence. The identification of the bottleneck is an important tool for ongoing production line optimization (Rocha & Lopes, 2022) and the bottleneck problem can be solved by completely understanding the manufacturing process and making efficient use of the resources to improve productivity. Bottlenecks are phases in the production process that restrict the manufacturing process's overall capacity and efficiency. They frequently result in longer lead times, higher work-in-progress (WIP), and lower overall productivity.

In the cement manufacturing industry, the cement grinding stage is an important step because it transforms raw materials into finished cement products. Material is usually moved through tanks and processing machines during this stage before the final product is produced. The flow of material through these tanks must be carefully controlled to ensure consistent production and minimize excessive delays. However, material flow can be disrupted by differences in processing time, tank capacity and operational parameters, leading to accumulation, long waiting times or idle equipment. These circumstances point to inefficiencies in system configuration and resource allocation, which could have a negative effect on overall production.

In order to address the problem mentioned above, this study created a discrete event simulation model of a cement manufacturing system, assessed its performance, and made recommendations for how to make the system better. Many fields use a discrete event simulation model to solve the problem such as manufacturing (Javadi et al., 2023) (Katsigiannis et al., 2024), healthcare (Abideen & Mohamad, 2021; Sala et al., 2023), parcel centre (Hawari et al., 2021), restaurant (Sakamoto, 2019), traffic light control (Abd Jalal et al., 2017) and gas station (Hawari et al., 2025).

2. System description and process flow of the study

The cement manufacturing process is a highly complex industrial activity that converts raw materials into a finely ground hydraulic binder commonly used in construction. The preparation of raw materials, pyro processing and cement grinding and distribution are the three primary stages of this process. Every stage is essential to guarantee the final cement product's strength, performance and quality. The process flow chart of the cement manufacturing process is illustrated in Figure 1.

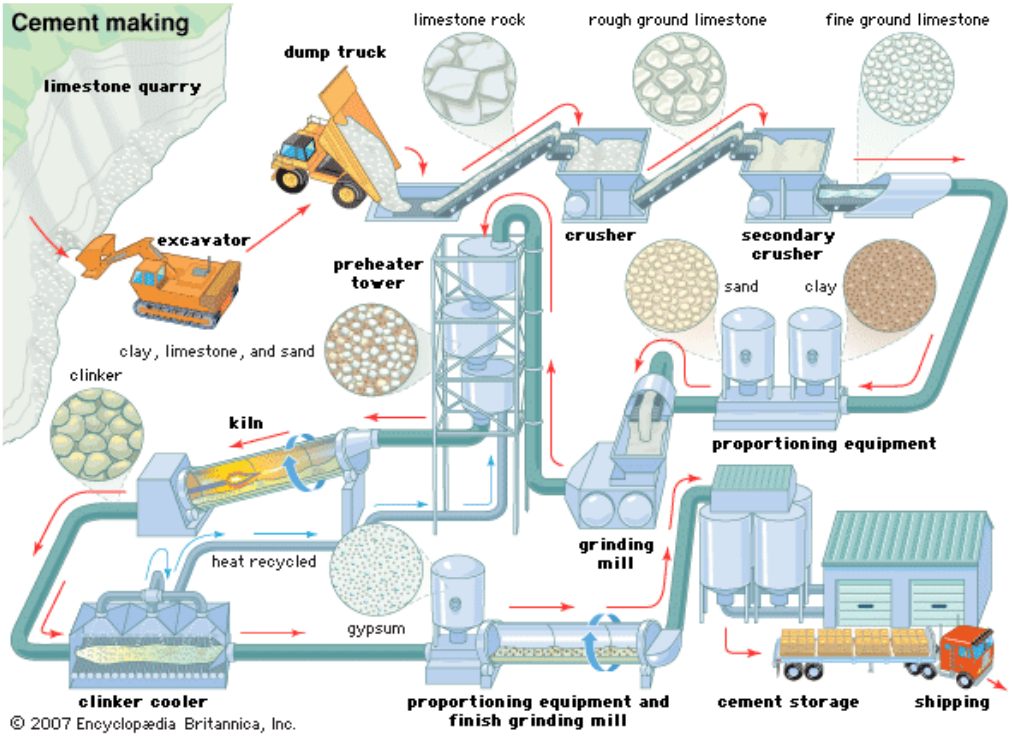


Fig. 1. Cement manufacturing process.

3. Model development

The primary goal is to evaluate system performance metrics and suggest alternatives for preventive maintenance in the cement manufacturing industry. DES provides a visual representation of the system's operations, facilitating an in-depth analysis of crucial metrics like waiting times and resource use. The data for this simulation model were collected through primary and secondary data. Primary data were gathered directly by observing the cement manufacturing process and conducting semi-structured interviews with the operations executive in the cement manufacturing company, and secondary data involved in this study were websites, journals, and articles. The data gathered consists of machine capacity, the proportion of raw materials needed in every mixing process, and daily output of finished cement products.

In order to capture realistic system behaviour and operational unpredictability, the observations were carried out continuously for 24 hours a day to capture realistic operational conditions. The Arena Input Analyzer was used to process raw data and fit it into a statistical distribution. The model was developed based on several assumptions, which were:

• All materials are available without supply shortages.
• No tanks experience breakdowns during the study period.
• No rework or remixing is required.

Table 1. Expression Value for Each Tank.

Process name	Distribution type	Value
Amount from Tank 1	Uniform	UNIF(4.32e+03, 5.06e+03)
Amount from Tank 2	Beta	240 + 42 * BETA(1.18, 1.13)
Amount from Tank 3	Beta	240 + 42 * BETA(1.18, 1.13)

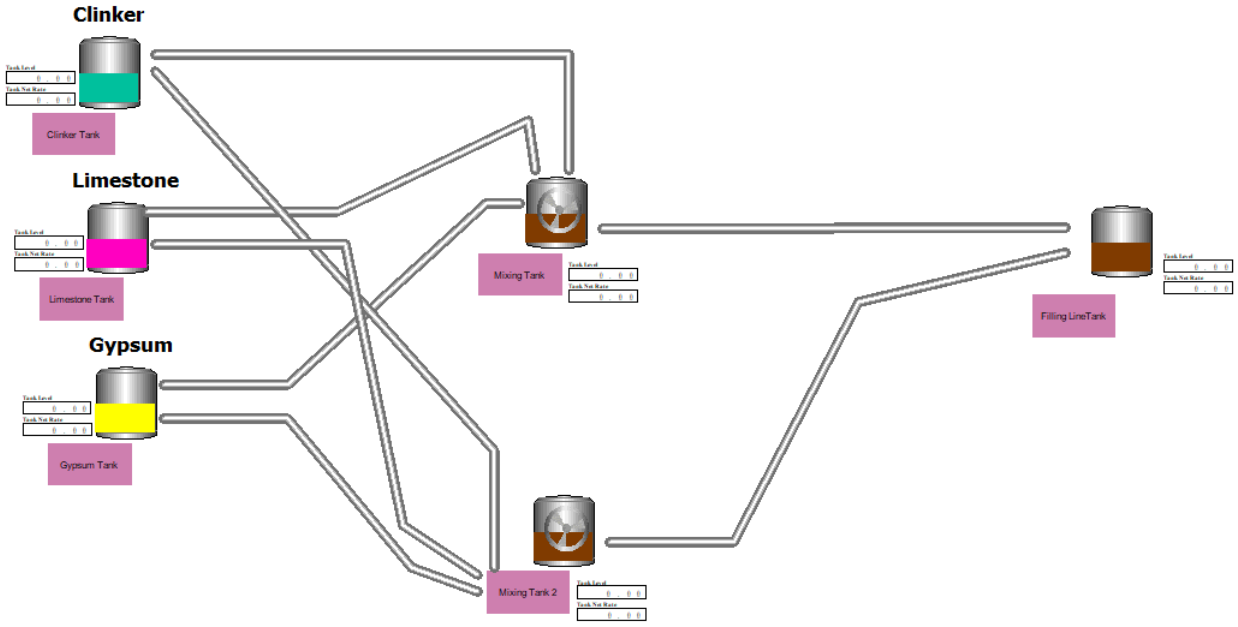


Fig. 2. Animation of the grinding process in cement manufacturing.

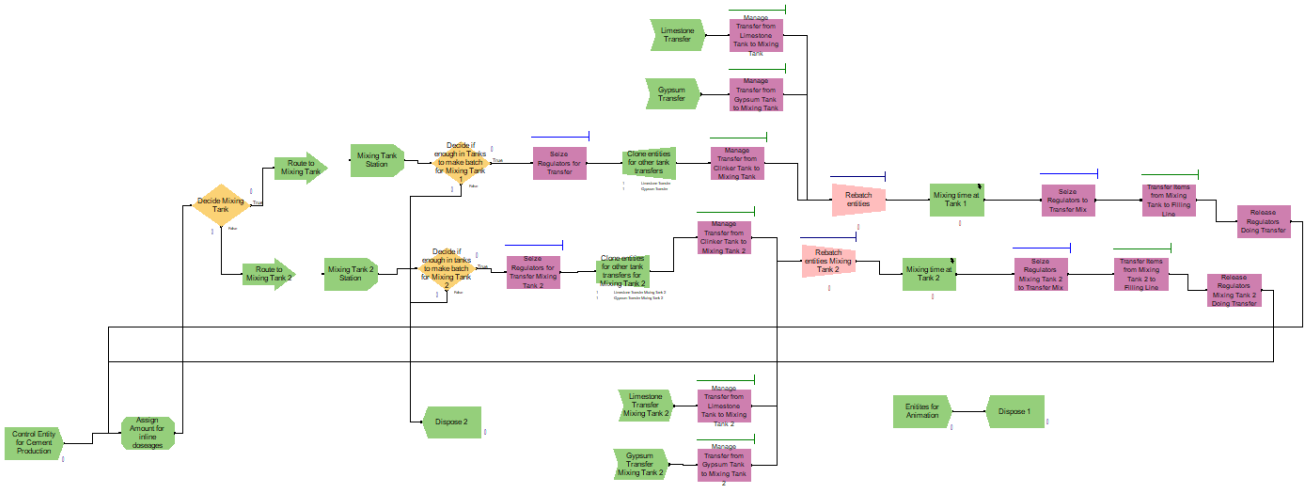


Fig. 3. Model logic used in the study.

4. Model verification and validation

The process of verifying that the model functions as expected usually involves analysing or animating the model. Validation requires more than just verification, as it involves a model that can be verified and yet be invalid. It determines whether the model complies with the requirements and conceptual design and behaves as intended. Validation ensures that the model accurately represents reality and that there are no significant variations between it and the actual system. Two validation techniques were performed in this study, which are statistical testing using the T-test and the validity level (Kelton et al., 2024; Hawari et al., 2025).

$$\text{Validity level} = \frac{\text{Actual data} - \text{simulation data}}{\text{Actual data}} \quad (1)$$

5. Model experimentation

The simulation's outcomes showed that the cement manufacturing system is performing as intended. The base case showed fewer significant bottlenecks or operational failures, indicating that the current process design is typically efficient. However, several potential scenarios were created and evaluated, with a focus on preventative maintenance techniques to further improve system performance and aid in decision-making. The purpose of these scenarios was to investigate the possible effects of various maintenance schedules and policies on equipment usage, system efficiency and overall operational performance.

Scenario 1: Only one mixing tank is available for the grinding process.
Scenario 2: Increased delay time to 30 seconds for mixing tank 1.
Scenario 3: Decrease the number of rotations of the mixing tank.
Scenario 4: Increased delay time to 30 seconds for both mixing tanks.

6. Simulation results and discussion

The average filling tank level from the seven replications of the DES model was identified and compared to the actual data which are shown in Table 2.

Table 2. Validity Level of the Filling Tank Level (tons)

Performance measure	Actual Data	Simulated Data	Validity Level (%)
Filling Tank Level	5632	5208.6	7.52

The value of the validity level is 7.52%. Therefore, it is highly considered that the developed DES model of this case study is valid and represents a real system.

6.1 Total time mixing tank

Table 3 shows the comparison of the total mixing time of Mixing Tank 1 and Mixing Tank 2 when compared to the other four scenarios. The basic model's average time for Mixing Tank 1 is 3.222 hours, which is slightly longer than Scenario 3 (2.194 hours) but shorter than Scenarios 1 (5.672 hours), 2 (12.260 hours), and 4 (12.410 hours). This shows that, in comparison to the basic model, Scenarios 2 and 4 greatly increase the mixing time, whereas Scenario 3 is the most effective for Mixing Tank 1.

Table 3. Average Total Time Mixing Tank (in Hours)

Performance Measure	Average of 7 Replications				
	Basic Model	S1	S2	S3	S4
Amount Total Time Mixing Tank 1	3.222	5.672	12.26	2.194	12.41
Amount Total Time Mixing Tank 2	3.481	-	2.698	3.62	8.265

The basic model's average mixing time for Mixing Tank 2 is 3.481 hours. While Scenario 3 (3.620 hours) is similar to the basic model with a minor rise, Scenario 2 shows a reduction to 2.698 hours, indicating increased efficiency. However, in Scenario 4, the mixing time increases significantly to 8.265 hours, suggesting a less effective setup. Overall, the comparison demonstrates the sensitivity of system performance to various scenario settings, as certain scenarios lead to significant increases in total mixing time while others enhance performance in contrast to the basic model.

6.2 Mixing tank level

Table 4 shows that the average mixing tank levels in the basic model are moderate in comparison to all four scenarios. The basic model records an average level of 4049 tons for Mixing Tank 1. This result is comparable to Scenario 3, which also shows 4049 tons, although it is lower than Scenario 2 (4344.8 tons), suggesting a greater material accumulation in Scenario 2. Scenario 1 (3075.8 tons) and Scenario 4 (2613.9 tons), on the other hand, show far lower tank levels than the basic model, indicating either a decrease in inventory or a quicker material flow.

Table 4. Average mixing tank level (tons)

Performance Measure	Average of 7 Replications				
	Basic Model	S1	S2	S3	S4
Average Mixing Tank 1	4049	3075.8	4344.8	4049	2613.9
Average Mixing Tank 2	3091.5	-	3011.3	3091.5	4046.9

The average level for Mixing Tank 2 in the basic model is 3091.5 tons. While Scenario 3 stays the same as the basic model at 3091.5 tons, suggesting no change in tank behavior, Scenario 2 exhibits a tiny decline to 3011.3 tons. However, in Scenario 4, the tank level rises significantly to 4046.9 tons, suggesting slower discharge rates or potential downstream restrictions. Overall, the comparison shows that variations from the basic model across scenarios can either increase or decrease inventory in the mixing tanks, reflecting different flow balances and operational efficiencies.

7. Conclusion

In conclusion, the material flow behaviour of the cement grinding process was effectively captured by the Discrete Event Simulation model, which also proved to be useful in assessing operational options. The findings demonstrate that certain scenarios, particularly Scenario 3, dramatically reduced mixing time while others increased material buildup, indicating apparent trade-offs between efficiency and inventory levels. These results validate that improved operational decision-making and system optimization can be facilitated by simulation-based analysis. Overall, the study shows that the suggested model is a useful tool for enhancing performance and directing the planning of preventive maintenance in the cement manufacturing sector.

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