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SIMULATION METHODS AND SENSITIVITY TESTING ON NPK FERTILIZER PRODUCTION IN WAREHOUSE STACKAGE MANAGEMENT (CASE STUDY AT PT PUPUK KUJANG)

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Abstract

PT Pupuk Kujang, as one of Indonesia's national fertilizer producers, faces inventory accumulation problems of NPK fertilizer in warehouses due to an imbalance between production capacity, storage capacity, and seasonal market demand. Excessive stockpiling exceeding standard storage limits, reaching up to 40 stacks, leads to increased operational costs and product damage risks of up to 20–30 percent, thereby reducing operational efficiency. This study aims to analyze the management of NPK fertilizer accumulation in warehouses and to determine optimal production scheduling and storage capacity policies through simulation methods and sensitivity analysis. The research applies a system dynamics approach using Causal Loop Diagram (CLD) and Stock Flow Diagram (SFD) models developed with AnyLogic software, complemented by supply chain simulation using SCM Globe. The study utilizes secondary data on NPK fertilizer production and distribution at PT Pupuk Kujang from 2015 to 2017. Simulation results indicate that inventory accumulation is primarily caused by inflexible production schedules that do not adequately adjust to seasonal demand fluctuations influenced by planting cycles and weather conditions. Sensitivity analysis results show that the scenario with a warehouse capacity of 25 stacks represents the most optimal condition, as it significantly reduces inventory buildup without disrupting distribution activities. This study recommends implementing more adaptive production scheduling and optimizing warehouse capacity and distribution systems to enhance operational efficiency and minimize the risk of product damage.

Keyword: Warehouse Management; Product Stacking; Inventory Management; Production Systems

A. INTRODUCTION

The agricultural sector plays a strategic role in supporting Indonesia's national food security, given that the majority of the population still relies on agriculture for its livelihood. To maintain agricultural productivity, fertilizer availability is crucial, particularly inorganic fertilizers such as NPK, which provide essential plant nutrients (Integrasi, 2025). The high demand for NPK fertilizer in Indonesia requires fertilizer manufacturers to effectively manage production and distribution to ensure timely supply and in quantities appropriate to farmers' needs (Riyantori, 2024). PT Pupuk Kujang, a State-Owned Enterprise (BUMN) under the auspices of PT Pupuk Indonesia (Persero), plays a crucial role in meeting national fertilizer demand, particularly in West Java. The company produces both subsidized and non-subsidized NPK fertilizers with a large production capacity and an extensive distribution network.

However, in practice, the high annual production targets set by the government are often not matched by adequate warehouse storage capacity. This situation leads to a buildup of NPK fertilizer products in warehouses, particularly in PT Pupuk Kujang's line II warehouse. The problem of fertilizer stockpiling is increasingly complex because fertilizer demand is seasonal and heavily influenced by farmers' planting cycles and unpredictable weather factors. Mismatches between production schedules and market absorption result in product stockpiling exceeding safe storage standards. Under certain conditions, NPK fertilizer stockpiles can reach up to 40 stacks, while the ideal warehouse capacity is only 18–25 stacks. Consequently, the company experiences product damage of up to 20–30% and increased production costs due to the need for rework (Saputra et al., 2024). Various efforts have been made by the company, including the implementation of forecasting methods such as the Simple Moving Average (SMA) to align production volumes with demand. While these methods can reduce forecasting errors, sudden changes in demand cannot be optimally anticipated. Therefore, a more comprehensive approach is needed to fully understand the dynamics of the production system, inventory, and warehouse capacity (Ezrah et al., 2024).

System dynamics simulation and sensitivity testing are considered appropriate approaches to analyze this problem. Through Causal Loop Diagram (CLD) and Stock Flow Diagram (SFD) modeling, the company can evaluate the causal relationships between production variables, warehouse capacity, and distribution, and test various possible policy scenarios. Therefore, this research is expected to provide a more optimal solution for managing NPK fertilizer stockpiles in warehouses, reducing the risk of product damage, and sustainably improving PT Pupuk Kujang's operational efficiency (Okta & Revi, 2021).

B. LITERATURE REVIEW

NPK Fertilizer and Its Role in Agriculture

NPK fertilizer is a type of inorganic fertilizer containing three main macronutrients: nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth and development. Nitrogen plays a role in leaf and chlorophyll formation, which supports photosynthesis; phosphorus plays a role in root, flower, and seed formation; and potassium plays a role in increasing plant resistance to disease and improving crop quality. The combination of these three elements makes NPK fertilizer an effective compound fertilizer widely used by farmers (Method & Carlo, 2021).

In the context of Indonesian agriculture, which is dominated by food crops such as rice, corn, and soybeans, NPK fertilizer plays a strategic role in increasing productivity and maintaining national food security. The need for NPK fertilizer tends to be high and seasonal, as it is highly dependent on farmers' cropping cycles (Habibah et al., 2025). Therefore, the availability of NPK fertilizer in sufficient quantities, on time, and well-distributed is a crucial factor in supporting the success of the agricultural sector. This condition requires fertilizer producers to be able to manage production and inventory effectively to adapt to fluctuations in demand (Nurshihah et al., 2026).

Inventory Management in the Fertilizer Industry

Inventory management is the activity of managing goods aimed at ensuring optimal product availability to meet consumer needs without creating excess or shortages. In the fertilizer industry, inventory plays a crucial role because products must be available at specific times according to the planting season, but it must still be controlled to prevent excessive stockpiling (Hermawan et al., 2024).

Excess inventory can have various negative impacts, such as increased storage costs, the risk of product damage, and wasted resources. NPK fertilizers, in particular, are sensitive to humidity and stacking pressure, so prolonged stockpiling can reduce product quality.

Conversely, too little inventory also risks hampering fertilizer distribution to farmers and impacting agricultural productivity (Imisbah et al., 2025).

Therefore, inventory management in the fertilizer industry must balance production capacity, storage capacity, and dynamic market demand. Production planning that is not aligned with seasonal demand patterns can lead to operational inefficiencies, such as the accumulation of NPK fertilizer products in warehouses. This condition shows the importance of implementing an inventory control system that is integrated with demand forecasting and warehouse management (Hendra & Hendri, 2022).

Warehousing Systems and Storage Capacity

A warehouse is a crucial component of a logistics and supply chain system, serving as a temporary storage location for products before distribution to consumers. A warehousing system encompasses not only the physical storage of goods but also the layout, storage capacity, and control of incoming and outgoing goods to ensure efficient operation.

Warehouse storage capacity must be aligned with production volume and inventory turnover. A mismatch between warehouse capacity and the number of stored products can lead to excessive inventory accumulation. In the fertilizer industry, product accumulation in warehouses is particularly risky because NPK fertilizers are hygroscopic, readily absorbing moisture, potentially causing clumping or damage if stored in suboptimal conditions or exceeding recommended stacking limits.

Warehouse accumulation also increases operational costs, such as rework, stock reordering, and potential distribution delays. Therefore, optimal warehouse capacity management is key to maintaining product quality and operational efficiency. A good warehousing system must support smooth distribution by ensuring that products are stored within safe limits and distributed according to market needs.

C. RESEARCH METHODOLOGY

Design Penelitian

Penelitian ini menggunakan pendekatan simulasi sistem dinamis yang dipadukan dengan uji sensitivitas untuk menganalisis permasalahan penumpukan produk pupuk NPK di gudang PT Pupuk Kujang. Metodologi ini dipilih karena mampu menggambarkan sistem yang kompleks, dinamis, serta melibatkan banyak variabel yang saling memengaruhi, seperti produksi, permintaan, kapasitas gudang, dan distribusi (Sugiyono, 2020).

Jenis dan Pendekatan Penelitian

Penelitian ini merupakan penelitian studi kasus dengan pendekatan kuantitatif berbasis simulasi. Studi kasus dipilih karena penelitian berfokus pada satu objek tertentu, yaitu pengelolaan persediaan pupuk NPK di PT Pupuk Kujang, khususnya pada gudang lini II yang mengalami penumpukan melebihi kapasitas ideal. Pendekatan simulasi digunakan untuk mengevaluasi perilaku sistem produksi dan persediaan dalam jangka waktu tertentu tanpa harus melakukan perubahan langsung pada sistem nyata (Sugiyono, 2020).

Alur Penelitian

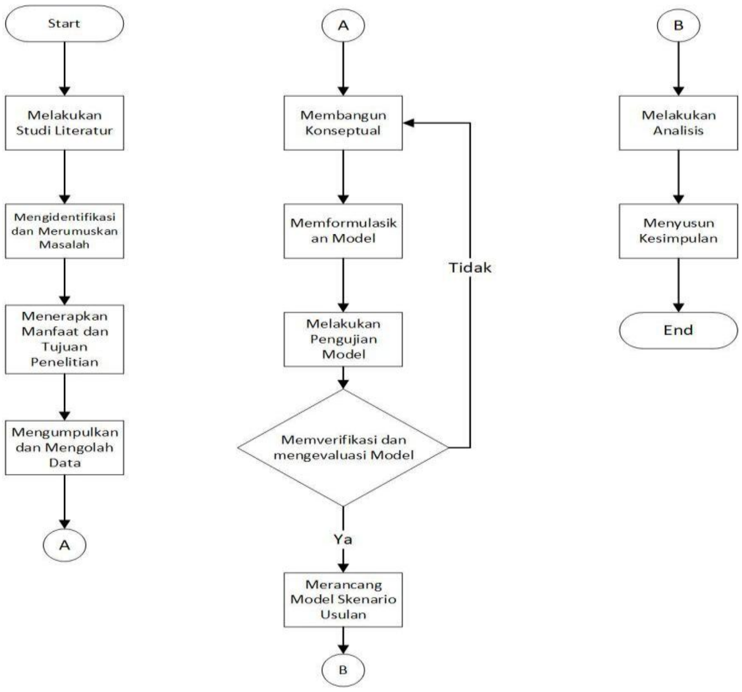

Figure 1. Research Flowchart

Based on the research flowchart in the figure, the research methodology is systematically structured and visualized in the form of a flowchart, encompassing several main stages as follows:

Literature Study: This research began with a literature review to understand the topic under study and relevant theories related to the research topic. This study focused on the journal "Simulation Method and Sensitivity Test for NPK Fertilizer Production in Warehouse Stacking Management: A Case Study at PT Pupuk Kujang."

Problem Identification and Problem Formulation: Based on the literature review, the main problem was identified and clearly formulated to ensure the research has a precise focus, namely, to reduce the stacking of finished products in the Line II warehouse.

Determining Research Benefits and Objectives: Once the problem has been defined, the next step is to determine the benefits and objectives of the research to provide a more focused direction.

Data Collection and Processing: This section discusses the data collection process, specifically secondary data. Secondary data is obtained from various reliable sources to support the analysis and improve the accuracy of the results. Relevant data is collected and processed to support the analysis and model design process that will be carried out in the next stage.

Conceptual Model: This stage aims to design an initial outline of a model that can solve problems within a system.

Formulating the Model: The model formulation stage focuses on translating system concepts into Causal Loop Diagrams (CLDs) and Stock Flow Diagrams (SFDs). CLDs are used to illustrate interrelated cause-and-effect relationships within a system, while SFDs are flowcharts that explain the system in more detail based on the CLD structure.

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Model Verification and Evaluation: Model testing involves verification and validation processes. Internal verification or validation is conducted to ensure that the CLD and SFD models have been created logically and systematically, for example by checking the appropriateness of variable units and the accuracy of calculation formulas. Meanwhile, external validation aims to assess whether the model adequately represents real-world conditions. If the model does not meet the verification and validation criteria, revisions and repetition of the system conceptualization stage are necessary.

Designing Proposed Scenarios: This stage aims to develop scenarios that can be used as alternative solutions. The model was tested against various different policies to evaluate its effectiveness in addressing existing issues, resulting in a more optimal model.

Analysis: The analysis phase was conducted to assess the suitability of the model scenario output generated from the data processing process. This analysis included a comparison of the initial model simulation results with the designed scenarios. The evaluation was conducted by examining the advantages and disadvantages of each scenario compared to the initial model.

Conclusion: The conclusions drawn based on the analysis results aimed to determine the best scenario for use in the NPK fertilizer product stacking system that occurred at Pupuk Kujang's Line II warehouse in 2017. Furthermore, recommendations were provided to relevant parties to improve the effectiveness of the NPK fertilizer product stacking system in the future, thus ensuring a more optimal aid distribution process.

D. RESULT AND DISCUSSION

Result

Sensitivity Testing of PT Pupuk Kujang Parameters

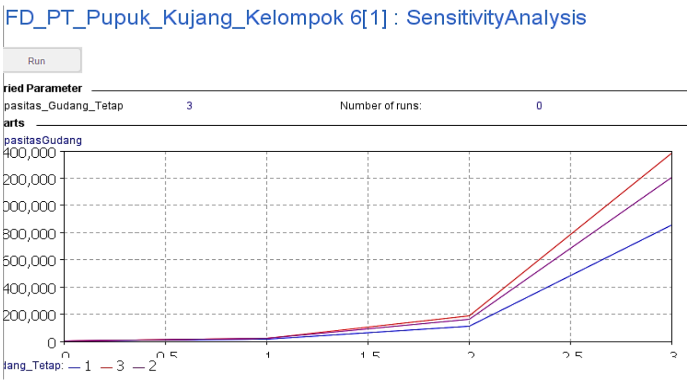

Figure 2. Sensitivity Analysis Graph

Based on the sensitivity test of the number of workers parameter to the percentage of profit using Anylogic software, it produces a graph as in the image above, the results of the graph obtained are, Where the red graph is a scenario that produces 40 stacks of NPK fertilizer capacity, it can be seen in the image that the highest graph where this indicates an increase in capacity that continues to accumulate, and the purple graph is a scenario that produces 35 stacks of NPK fertilizer capacity, it can be seen in the image that the graph in the middle is still experiencing accumulation in the warehouse capacity and is still not optimal, and the dark blue graph is a scenario that produces 25 stacks of NPK fertilizer capacity, it can be seen in the image that the graph is at the bottom between the purple and red graphs, so it indicates that the accumulation of warehouse capacity is no longer piled up and is optimal.

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Parameter Sensitivity Test

kapasitas gudang tetap 3

Data 2				
Perubahan Nilai		ersentase Perubahar		Kesimpulan
Input	Output	Input	Output	
1	14	0.67	0.98	Sensitif
2	114	0.33	0.87	Sensitif
3	855.77	0	0	Tidak Sensitif

1	
0	64.175
1	13,699.95
2	114,254.37
3	855,774.12

Figure 3. Warehouse Capacity Table 3

In the image, after entering the formula and testing the sensitivity in Microsoft Excel, warehouse 3 produces "Not Sensitive", this indicates that there is still accumulation in warehouse 3 and it is not optimal.

kapasitas gudang tetap 2

Data 2				
Perubahan Nilai		Persentase Perubahan		Kesimpulan
Input	Output	Input	Output	
1	19	0.50	0.88	Sensitif
2	161	0.00	0.00	Tidak Sensitif
3	1.21	0.50	0.99	Sensitif

2	
0	89.845
1	19,291.47
2	160,890.28
3	1,205,084.09

Figure 4. Warehouse Capacity Table 2

In the image, after entering the formula and testing the sensitivity in Microsoft Excel, warehouse 2 still produces "Not Sensitive", this indicates that there is still a buildup in warehouse 2.

kapasitas gudang tetap 1

Data 1				
Perubahan Nilai		Persentase Perubahan		Kesimpulan
Input	Output	Input	Output	
1	19	0,67	0,98	Sensitif
2	114	0,33	0,00	Tidak Sensitif
3	855,70	0	0	Tidak Sensitif

2	
0	89.845
1	19,291.473
2	160,890.277
3	1,205,084.089

Figure 5. Warehouse Capacity Table 1

In the image, after the formula was entered and the sensitivity test was carried out in Microsoft Excel, warehouse 1 produced "Sensitive". This indicates that there is no buildup in warehouse 1 and it is optimal.

Simulation Scenarios and Results

Based on the results of processing the Causal Loop Diagram (CLD) and Stock Flow Diagram (SFD) from the PT Pupuk Kujang model, a scenario model can be created as follows:

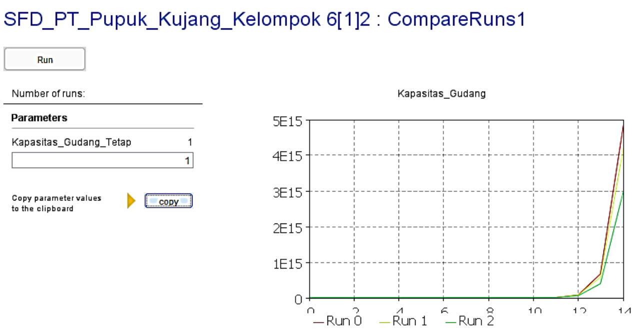

Figure 6. Warehouse Capacity Graph

The figure shows the graph showing warehouse capacity. The red graph indicates Warehouse 3's high capacity due to unresolved backlogs. Meanwhile, the yellow graph depicts Warehouse 2's high capacity due to ongoing backlogs. The green graph shows the lowest capacity, at around 25 stacks, as backlogs have been successfully addressed, optimizing warehouse capacity.

Discussion

Based on the results of a Stock Flow Diagram (SFD) scenario simulation using AnyLogic software, changes were made to one key parameter, namely warehouse capacity. Of the various scenarios tested, the simulation results indicated that scenario 1 was the closest to sustainable and optimal conditions for the proposed solution. By implementing scenario 1, warehouse capacity was maximized without experiencing excessive buildup, as expected. These results indicate that the scenario is capable of optimizing stock flow and distribution within the warehouse. However, although the simulation results demonstrated optimal performance, regular evaluation is still necessary to ensure the system remains stable and adaptable to changing operational needs. With ongoing evaluation, warehouse management strategies can be continuously refined to maintain the efficiency and effectiveness of inventory storage.

Analysis of warehouse capacity at PT Pupuk Kujang based on modeling results indicates that challenges remain in managing inventory buildup within the warehouse. In scenario 3, with a warehouse capacity of 40 stacks, significant inventory buildup occurs, potentially hampering the effectiveness of distribution flows and increasing the risk of delays in inventory management. A similar situation was also found in scenario 2, where, with a warehouse capacity of 35 stacks, stockpiling still occurred, albeit to a lesser extent than in scenario 3.

Conversely, in scenario 1, with a warehouse capacity of 25 stacks, the stockpiling rate was drastically reduced, indicating that this scenario provides more optimal sensitivity in stock management. With more controlled capacity, the warehousing system can operate more efficiently, reducing the risk of excessive stockpiling, and ensuring smoother distribution. Based on the results of this analysis, the implementation of scenario 1 is the most effective solution for PT Pupuk Kujang. With a warehouse capacity of 25%, the company can optimize inventory management, reduce the risk of late deliveries, and increase efficiency in the distribution flow. Furthermore, the implementation of this scenario is also expected to support more stable operational continuity and adaptability to changes in market demand. Therefore, regular evaluation and monitoring are still necessary to ensure the long-term effectiveness of this scenario.

E. CONCLUSION

Based on research conducted on the production and inventory management of subsidized NPK fertilizer at PT Pupuk Kujang, it can be concluded that: This study indicates that NPK fertilizer stockpiles at PT Pupuk Kujang are caused by limited warehouse capacity and production that is not aligned with seasonal demand. Implementation of scenario 1, which adjusts warehouse capacity to 25 stacks, proved to be the optimal solution for reducing stockpiles without hampering distribution. Furthermore, the forecasting method used, namely the Simple Moving Average, is quite helpful in predicting demand, but it is not fully capable of addressing fluctuations caused by crop cycles and weather factors. Therefore, a more complex forecasting method such as Winter's Exponential Smoothing is recommended to improve accuracy.

The results of the study indicate that a flexible production schedule adjusted to demand trends can reduce stockpiles in the warehouse. This requires better coordination between production, marketing, and distribution teams. Furthermore, fertilizer distribution can be optimized by expanding collaboration with more distributors, including utilizing e-commerce platforms, for more equitable distribution and reducing the risk of excess stock. Implementing technology-based solutions, such as Internet of Things (IoT) inventory monitoring and regular evaluation of warehouse and distribution capacity, can help companies manage production and storage more efficiently.

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