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DESIGN OF A FEEDING SYSTEM WITH A CAPACITY OF 3 TONS/HOUR AT THE NPK PLANT TO IMPROVE FEEDING EFFICIENCY AND AUTOMATION

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ABSTRACT

An NPK plant is a facility that produces NPK fertilizer through a manufacturing process specifically designed to create fertilizer with a special formulation. However, in the production process, the feeding of raw materials is still done manually, resulting in low productivity and high operational costs. Based on production performance tests conducted on September 15, 2024, the manual system only achieved an average of 1.34 tons/hour, or 47% of the production target of 3 tons/hour. Therefore, a transportation system is needed to transport the materials, given the limitations of human labor capacity in terms of material handling and employee safety. This study aims to design an automatic feeding system to maximize production capacity up to 3 tons per hour. The system design begins with analyzing losses due to low productivity of the manual system, analyzing factory requirements, designing the main components of the feeding system, such as the hopper, weigher, and conveyor belt, equipped with an on-off control-based system to ensure consistent raw material flow. Technical design was carried out through visualization using AutoCAD and Visio software, solid flow simulation using Altair EDEM software, and economic feasibility analysis by calculating the Return on Investment (ROI) and Payback Period (POT). The calculation results show that this feeding system has a ROI of 40.8% and a POT of 2.05 years, indicating that the designed system is economically viable for implementation.

Keyword: *Altair EDEM, Feeding System, NPK Plant, Pay Out Time (POT), dan Return On Investment (ROI).*

1. INTRODUCTION

The NPK fertilizer company is one of the fertilizer producers in Indonesia that operates an NPK Plant with a production capacity of 3 tons per hour, designed to produce NPK fertilizers with formulations tailored to the specific needs of soil and crops. However, the actual production output remains low, averaging only 1.34 tons per hour (47%) due to the use of a manual feeding system for raw materials. This manual operation has led to several operational issues such as inconsistent material flow, formulation deviations, prolonged downtime, and increased safety risks for workers.

These issues reflect a gap between the plant's operational efficiency requirements and the technology currently in use. Although automated feeding systems have been widely adopted in large-scale industries due to their ability to enhance process consistency and efficiency, their implementation in small-scale facilities like the NPK Plant remains limited. The main constraints include high initial investment costs, and the absence of automation systems specifically designed for small-scale production capacities [1].

This study aims to design an automated feeding system suitable for small-scale operations, particularly with a capacity of 3 tons per hour. The proposed system integrates hoppers, weighers, and conveyors belt controlled through an automated mechanism to improve both the efficiency and accuracy of the feeding process. The implementation quality andem is expected to reduce downtime, ensure consistent product quality, and deliver technical as well as economic benefits for the NPK Plant operated.

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2. RESEARCH METHODOLOGY

2.1 Research Stage

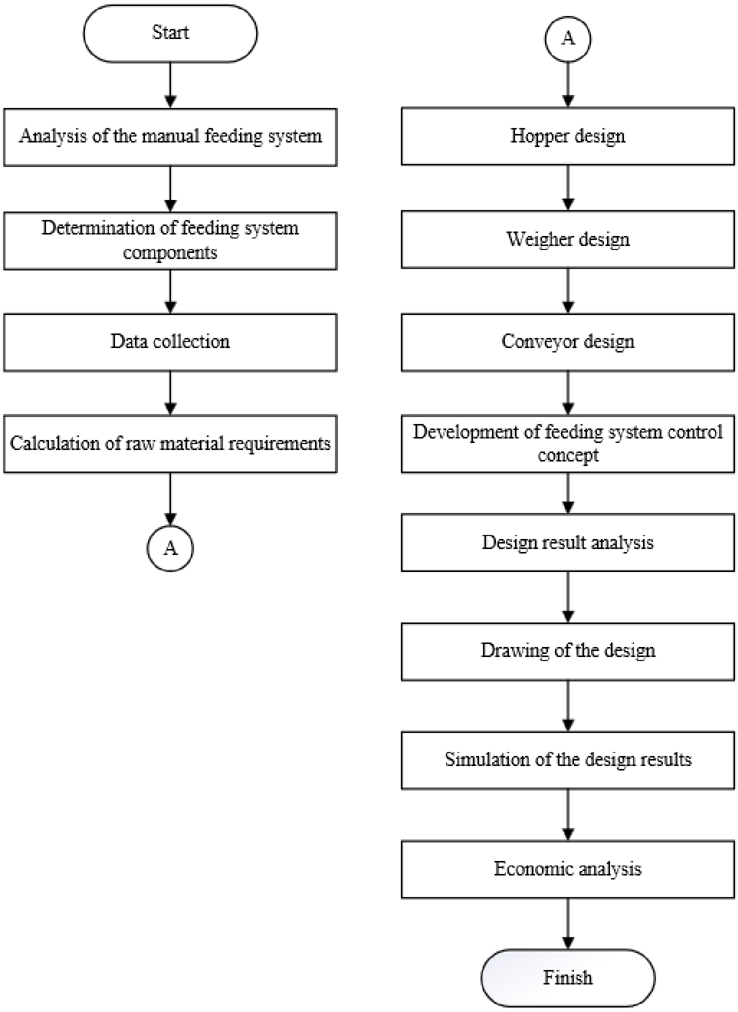

Figure 1. Flowchart for the Design of the Feeding System for the NPK Plant

The feeding system design process begins with an analysis of the existing manual system, followed by the identification of key components such as hoppers, weighers, and conveyors. Once the data and raw material requirements are calculated, each component is designed. Subsequently, a system control concept is developed, followed by analysis and design drawings, and then simulation to test the design's feasibility. The final step involves an economic analysis to evaluate the financial viability of the investment.

2.2 Research Equipment and Facilities

The research conducted to design the feeding system required the equipment and facilities shown in the following table.

Table-1. Research Equipment and Facilities

No	Equipment and Facilities
1	Camera
2	Roll meter
3	Microsoft Excel & Visio Software
4	AUTOCAD Software
5	Altair EDEM Software

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3. ANALYSIS AND RESULT

3.1 Design of a 3 Ton/Hour Automatic Feeding System Equipment at the NPK Plant

3.1.1 Hopper Design

Hoppers, bins, and silos are widely used to store various types of granular materials, such as raw materials, intermediate materials, and final products [2]. A conical-shaped hopper was selected due to its ability to provide stable material flow and prevent common flow obstructions such as bridging and rat-holing [3], making it highly suitable for granular raw materials such as DAP, urea, KCl, and clay. The capacity and dimensions of each hopper were designed based on the NPK 15-15-15 fertilizer formulation and the nutrient content of each raw material, resulting in hoppers of different sizes corresponding to the mass and density of each component. The hopper material selected is SA-299 carbon steel, known for its high tensile strength and corrosion resistance, making it ideal for storing chemical raw materials in the fertilizer industry [4].

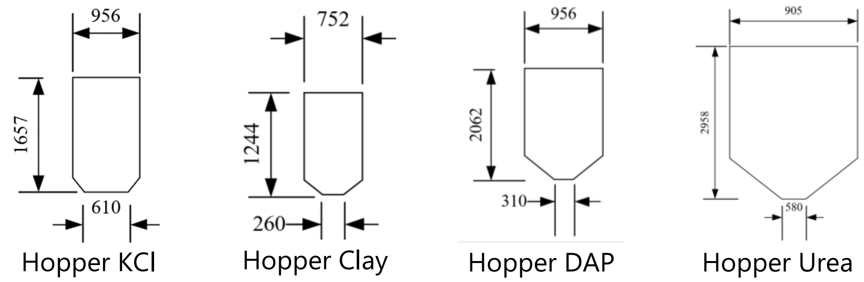

Figure-2. Hopper Design Result for the Feeding System of the NPK Plant

3.1.2 Weigher Design

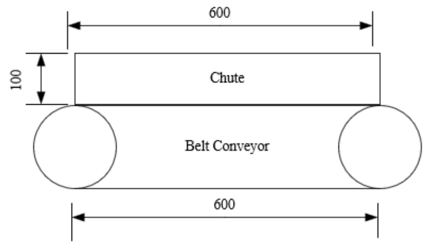

Figure-3. Weigher Design Result for the Feeding System of the NPK Plant

The four weighers were designed using a weight belt system with uniform dimensions: 600 mm in both conveyor width and length, chute width of 600 mm, chute height of 100 mm, and constructed from carbon steel. Each weigher requires a power input of 0.18 kW. The DAP weigher operates at a normal flow rate of 3.45 kg/s with a belt speed of 0.198 m/s; the urea weigher at 2.24 kg/s and 0.168 m/s; the KCl weigher at 2.71 kg/s and 0.09 m/s; and the clay weigher at 2.14 kg/s and 0.096 m/s. Although the weigher structures are identical, each unit was calibrated based on the specific material properties. All weighers are equipped with load cells to ensure high-precision and accurate weight measurement. A load cell is attached to the weigher. Load cells on all weighers function to ensure accurate and precise measurements. Load cell sensors integrate material weight with belt speed to obtain real-time material flow values [5].

3.1.3 Conveyor Design

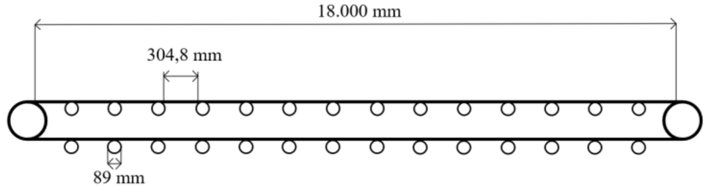

Figure-4. Belt Weigher Design Result for the Feeding System of the NPK Plant

In the design of the material transfer system for the NPK Plant, a belt conveyor was selected as the primary transport equipment to deliver materials from the weighing units to the mixer. This choice was

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based on its efficiency, stable material flow, ease of maintenance, and compatibility with the properties of the raw materials DAP, urea, KCl, and clay which are abrasive and hygroscopic. The conveyor is designed with an abrasion-resistant rubber belt, smooth surface, and a width of 600 mm to provide sufficient capacity flexibility and ease of maintenance.

Technical analysis indicates that, at a belt speed of 0.177 m/s, the system is capable of transferring 3,600 kg of material in less than 600 seconds, aligning with the allocated feeding time. This speed is well below the maximum recommended velocity for granular materials, ensuring stable flow without material slipping. In terms of power requirements, calculations show an actual demand of 0.97 kW. After applying a safety factor and correcting for system efficiency, the total motor power required is 1.75 kW. For safety and availability considerations, a 2.2 kW drive motor was selected.

3.2 Implementation of a Control System to Regulate Material Flow Rate in the Feeding System at the NPK Plant

The manual handling system at NPK Plant unit causes various production challenges, such as inconsistent formulations, low time efficiency, and workplace safety risks. This manual handling directly impacts production quality and quantity, as evidenced by cases of product composition deviations and low daily output, which only reaches 32 tons out of the target of 72 tons per day. Additionally, the absence of digital recording makes process corrections difficult to implement.

To address these needs, an automatic feeding system capable of batch processing, precision, and flexibility in handling formulation variations is required. This system must be able to synchronize raw material flow and record process parameters in real-time. Control recommendations include a combination of on-off control, PLC-based logic control, and load cell-based feedback control. This system involves automatically adjusting material flow based on actual weight, coordinating the sequence of operations between equipment, recording deviations, and systematically implementing corrective actions. With this approach, the feeding system not only improves formulation accuracy and time efficiency but also reduces workplace safety risks and supports reliable production at a small industrial scale [6]. The following control mechanisms will be implemented.

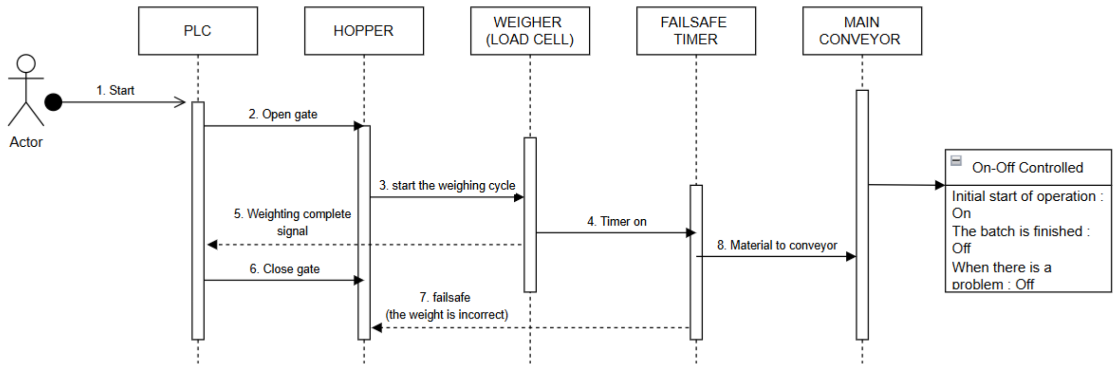

Figure 5. Control Sequence Diagram

The on-off control process in the batch feeding system aims to ensure the accuracy and efficiency of automatic material weighing. The process begins with a PLC command to open the hopper gate, allowing material to flow into the weigher equipped with a load cell. The material weight is read in real-time and compared with the target. If the target is achieved, the gate is closed, and the material is sent to the mixer via the main belt conveyor. If the target is not achieved within a certain time limit, the gate is automatically closed as a failsafe measure [7]. The main belt conveyor operates automatically based on the process status, i.e., it is active when the process starts, when the material is transferred to the mixer, and stops in the event of a malfunction. All weigher lines are connected to an interlock system to maintain consistency in composition. The feeding process is considered complete when all material has exited the weigher and the main belt is empty.

3.3 Operational Analysis of the Batch Feeding System

3.3.1 Process Time Allocation

The operational analysis of the batch feeding system at the NPK Plant was conducted to ensure coordination between the hopper, weigher, conveyor, and mixer within the defined process cycle time

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of 960 seconds per batch. This duration includes 350 seconds for material weighing, 100 seconds for transfer to the conveyor, 150 seconds for system response and interlock actions, and 360 seconds for mixing. In this batch-based system, each raw material DAP, urea, KCl, and clay has a different number of weighing cycles depending on its target composition and weight per cycle. However, the weighing processes for all materials are executed in parallel to optimize efficiency and maintain synchronization.

3.3.2 Weighing Cycle

Each raw material requires a different batch mass, resulting in varying numbers of weighing cycles. The weighing process is calculated based on the formulation ratio and the effective volume of the belt weigher. The weight per cycle ranges from 28 to 63 kg, with the highest number of cycles recorded for DAP at 33 cycles, and the lowest for clay at 20 cycles. The system is configured to complete all weighing operations within a 350-second time window in parallel mode. The PLC-based control logic ensures that the opening time of each hopper aligns with the material's flow rate and required number of cycles, without interference between units. For instance, clay has a lower flow rate and thus requires a longer opening time compared to KCl, which flows more easily. This highlights that hopper opening time is influenced not only by the target mass but also by the material's flow properties. Therefore, the control system must be adaptable to each material type to maintain process efficiency. The detailed operational parameters of each weigher are presented in the following section.

Table-2. Weighing Cycle Parameters

Material		Ratio (3000kg)	Weight per cycle (kg)	Rounded cycle (kali)	Time per cycle (s)	Material Flow Rate (kg/s)	Belt Weigher Speed (m/s)
DAP	Min	1159,83	36,64	32	10,94	3,35	0,19
	Normal	1173,91	36,64	33	10,61	3,45	0,20
	Max	1191,52	36,64	33	10,61	3,45	0,20
Urea	Min	696,93	28,04	25	14,00	2,00	0,15
	Normal	791,12	28,04	28	12,50	2,24	0,17
	Max	732,15	28,04	27	12,96	2,16	0,16
KCl	Min	886,5	63,24	15	23,33	2,71	0,09
	Normal	900,00	63,24	15	23,33	2,71	0,09
	Max	913,5	63,24	15	23,33	2,71	0,09
Clay	Min	432	46,72	10	35,00	1,33	0,06
	Normal	734,97	46,72	16	21,88	2,14	0,10
	Max	900	46,72	20	17,50	2,67	0,12

Although each material has a different weighing cycle duration, all materials are transferred to a continuously running central belt for 600 seconds at a speed of 2.09 m/s to prevent accumulation. The belt speed at each weigher varies according to the required number of cycles, with DAP requiring the highest speed due to having the most cycles. The estimated hopper usage time ranges from 7.75 to 8.24 minutes depending on the material properties and its flow rate, ensuring synchronization between discharge rate and system throughput. This design ensures efficient batch feeding and optimal timing between weighing, conveying, and mixing stages.

3.3.3 Hopper Pressure and Hopper Refill Time

The pressure at the bottom of the hopper is influenced by the height of the material column; the higher the content, the greater the pressure. As the material decreases, the pressure and flow rate decrease, which can cause weighing errors. To overcome this, control logic is used to regulate the gate opening or give a refill signal when the hopper content is 20–30%, in order to keep the material flow stable and accurate.

Table-3. Estimated Filling Time Data for Raw Materials into the Hopper

Material	Total Volume (m^3)	Volume 70% (m^3)	Mass 70% (kg)	Flow rate (kg/s)	Time (s)	Time (min)
DAP	2,31	1,61	1643,48	3,45	476,37	7,94
Urea	2,03	1,42	1107,56	2,24	494,45	8,24
KCl	2,05	1,43	1260,00	2,71	464,94	7,75
Clay	1,13	0,79	1028,96	2,13	483,08	8,05

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The hopper usage time is calculated up to a refill limit of 30% of the material volume in the hopper, based on 70% of the total volume divided by the material flow rate (kg/s) after conversion to mass using density. The results obtained are: DAP 7.94 minutes, Urea 8.24 minutes, Clay 8.05 minutes, and KCl 7.75 minutes. These time differences are influenced by the flow rate and mass of the material, and affect the logic of hopper refill scheduling in the PLC control system to prevent process overlap.

3.4 Latest Visualization at the NPK Plant

3.4.1 PFD Feeding System of the NPK Plant

The following shows the Process Flow Diagram (PFD) at the NPK Plant after integration with the feeding system.

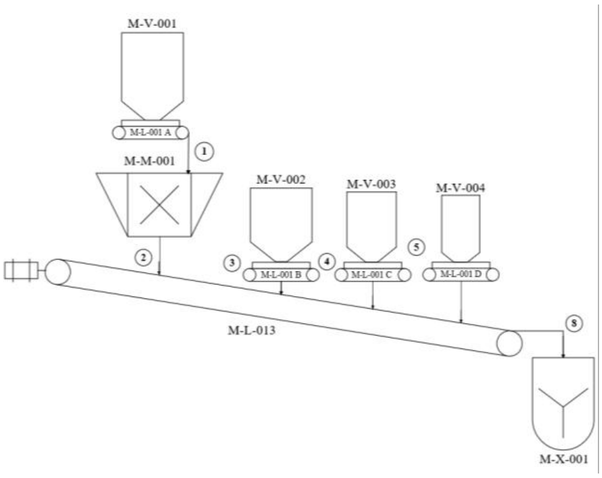
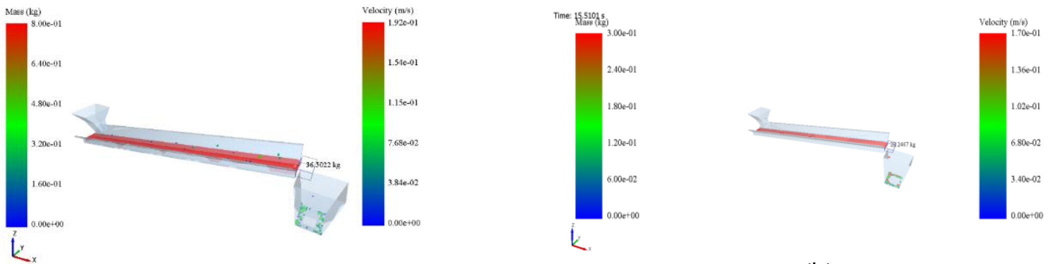


Figure 6. PFD of the feeding system at the NPK Plant

The initial design of the PFD at the NPK Plant showed that the feeding system was still operated manually. In the latest revision, an automatic feeding system consisting of a hopper, weigher, and belt conveyor has been added and integrated into the control system, resulting in a more stable and measurable flow of raw materials. Figure 6 illustrates the PFD details of the feeding system, which includes four hoppers and weighers for each raw material, as well as the main conveyor leading to the mixer unit.

3.4.2 Simulation Results of the Feeding System Design Experiment

Altair EDEM simulation is used to evaluate the performance of the feeding system in a single cycle of weighing and material transfer. The simulation process will use Altair EDEM software, which is software for material flow and granular simulation. This software is supported by the Discrete Element Method (DEM) methodology, enabling EDEM to quickly and accurately simulate and analyze the behavior of solid materials [8]. Due to configuration limitations, the simulation is simplified to a direct flow from the hopper to the belt, which represents the weigher. The time and speed in the simulation are adjusted to actual conditions to maintain the accuracy of the weighing process.



(a) (b)

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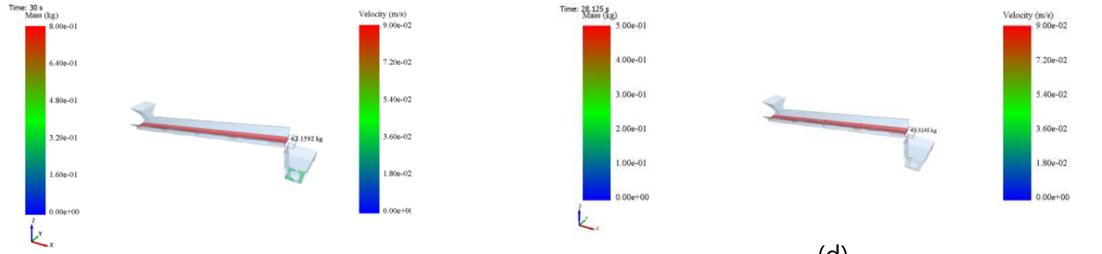

(c) (d)

Figure 7. Simulation Results of Raw Material Flow Per Cycle From Hopper to Weigher (a) DAP, (b) Urea, (c) KCl, and (d) Clay

Based on the simulation results for DAP material, within 14.06 seconds, a mass of 36.5022 kg was recorded with a target of 36.64 kg, a difference of <0.4% still within the tolerance limit. Urea material flows for 15.5101 seconds at a speed of 0.174 m/s, resulting in a mass of 28.2467 kg with a target of 28.044 kg and a difference of ±0.72%. KCl material flowed for 30 seconds at a speed of 0.09 m/s, with a recorded mass of 63.1592 kg from a target of 63.24 kg and a difference of ±0.08 kg. Meanwhile, clay required 28.125 seconds at a speed of 0.092 m/s, with a recorded mass of 45.9248 kg from a target of 46.7226 kg and a deviation of ±1.7%. All simulation results indicate that the feeding system is capable of handling all four materials stably, accurately, and within design tolerance limits.

3.5 Economic Feasibility Analysis of the 3 Ton/Hour Automatic Feeding System at the NPK Plant

3.5.1 Initial Investment Analysis on the Handling System Before and After Using the Feeding System

Table-4. Comparison of Operational and Economic Performance Manual vs. Automated

Component (per month)	Manual System	Automated System
Operational Costs		
Labor Cost	IDR 49,500,000	IDR 19,800,000
Electricity	–	IDR 410,169
Maintenance	–	IDR 7,177,851
Total Operational Cost	IDR 49,500,000	IDR 27,388,020
Production Output		
Monthly Production (tons)	964.8	2,16
Revenue	IDR 1,755,936,000	IDR 3,931,200,000
Total Revenue	IDR 1,755,936,000	IDR 3,931,200,000
Net Profit		
Revenue	IDR 1,755,936,000	IDR 3,931,200,000
Operational Cost	IDR 49,500,000	IDR 27,388,020
Net Profit	IDR 1,706,436,000	IDR 3,903,811,980

The economic feasibility of the automated feeding system was evaluated by comparing the conditions before and after its implementation at the NPK Mini Plant. The manual system required no initial capital investment but exhibited significant limitations in terms of capacity, operational efficiency, and product consistency. In contrast, the automated system demanded an initial investment of IDR 17 billion but offered substantial improvements in productivity and product quality.

Operationally, the manual system incurred a monthly cost of IDR 49.5 million solely for labor. Meanwhile, the automated system significantly reduced labor costs while introducing additional electricity and maintenance expenses, resulting in a total monthly operating cost of IDR 27.3 million. Despite these added components, the total operational cost of the automated system remained 55% lower than that of the manual approach.

The implementation of the automated feeding system increased production output from 964.8 tons to 2,160 tons per month. Consequently, monthly revenue rose from IDR 1.75 billion to IDR 3.93 billion. The net profit of the automated system reached IDR 3.9 billion per month, substantially higher than the IDR 1.7 billion generated by the manual system. With its cost efficiency, enhanced production capacity,

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and improved product consistency, the automated feeding system is proven to be economically and operationally feasible.

3.5.2 Economic Analysis Comparing the Handling System Before and After Using the Feeding System in the Production Process at the NPK Plant

Economic analysis is a crucial component of designing systems or tools in factories to assess the feasibility of investments. This analysis includes estimates of initial capital, potential profits, return on investment (ROI) time, and break-even point [9]. The economic analysis reveals that the investment in the feeding system at the NPK Plant is both feasible and highly efficient. With a total investment of Rp17.49 billion and annual operational costs of approximately Rp2.08 billion, this system can generate annual revenue of Rp9.32 billion and a net profit of Rp7.24 billion. The Return on Investment (ROI) reaches 41.8%, and the Payback Time (POT) is only 2.05 years. A good ROI percentage generally ranges above 10%. An ROI of 10–20% is considered good and feasible for most industrial projects, while an ROI above 20% is highly profitable and reflects high investment efficiency [10]. The smaller the Payback Time value, the faster the investment capital is recovered, indicating efficient use of funds and accelerated investment returns [10].

4. CONCLUSION

Based on the results of the research and data analysis conducted, the following conclusions can be drawn:

1. An evaluation of the manual handling system (without a feeding system) in the production of NPK Plant revealed several major issues, including low productivity, inconsistent product formulations, and an increased risk of workplace accidents.
2. The feeding system at NPK Plant consists of four hoppers and four main weighers, each equipped with backup units for the hopper and weigher, as well as a conveyor belt to transfer material to the mixer. The equipment is designed in accordance with the specifications of the raw materials and product formulation.
3. The control system for the feeding system is designed using an on-off control approach, PLC logic, and load cell-based feedback to enhance weighing accuracy, synchronize raw material flow, and improve operational efficiency. This design demonstrates potential for application in batch production with variable formulations.
4. The Altair EDEM simulation results indicate that the feeding system design operates stably, efficiently, and accurately in handling DAP, urea, KCl, and clay materials. Particle flow is uniform, exhibiting laminar characteristics. The actual mass differences remain within the tolerance limit of <2%, and cycle number adjustments successfully maintain accuracy for each batch.
5. The implementation of the automatic feeding system at NPK Plant is economically viable and efficient. With an initial investment of Rp17 billion, the system reduces operational costs by up to 55%, increases production capacity by more than double, and boosts monthly net profit from Rp1.71 billion to Rp3.90 billion. With a ROI of 40.8% and a POT of only 2.05 years, the system demonstrates rapid capital return and high profitability.

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