Fly Ash Packaging Plant Downtime Assessment to Maintain Product Supply: A Case Study

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ABSTRACT

Fly ash is used as one of raw materials in cement and concrete industries. A fly ash packaging plant experienced downtime for two consecutive months due to automated fly ash transfer system failure. Pareto chart was used to map the failures from production log sheet. Simulation modelling approach through Arena software was used assess the feasibility of maintaining product supply by using a bulk tanker truck in 24-hour period. It was revealed that eight bulk tanker transfers can be completed which amounted to 256 tonnes production per day. Under this arrangement, the achievable production volumes were estimated at 5,888.00 tonnes for October and 5,632.00 tonnes for November. These figures represent 80.43% and 91.08% of typical monthly output, and 94.62% and 107.15% relative to the typical just-in-time production requirements. This equates to an additional cost of ZAR 1,166.46 per transfer. On a per-tonne basis, the intervention added ZAR 36.45 to the production cost of bulk bagged fly ash, compared with only ZAR 11.83 per tonne when using the automated transfer system. It was advised that the plant implement a new process control system incorporating artificial intelligence for enhanced early fault detection. Such a system supported by diagnostics and historical trend analysis would help prevent future instances of severe unplanned downtime.

OPSOMMING

Vliegas word as een van die grondstowwe in die sement- en betonbedrywe gebruik. 'n Vliegasverpakkingsaanleg het vir twee agtereenvolgende maande stilstand ervaar as gevolg van 'n outomatiese vliegas-oordragstelselfout. 'n Pareto-kaart is gebruik om die mislukkings vanaf die produksielogblad te karteer. ‘n Simulasiemodellerings-benadering deur middel van Arena-sagteware is gebruik om die haalbaarheid te bepaal om produkvoorraad te handhaaf deur 'n grootmaat-tenkwa binne 'n 24-uur-periode te gebruik. Daar is aan die lig gebring dat agt grootmaat-tenkwa-oordragte voltooi kan word, wat neerkom op 256 ton produksie per dag. Onder hierdie reëling is die haalbare produksievolumes geraam op 5 888,00 ton vir Oktober en 5 632,00 ton vir November. Hierdie syfers verteenwoordig 80,43% en 91,08% van die tipiese maandelikse produksie, en 94,62% en 107,15% relatief tot die tipiese net-betyds-produksievereistes. Dit is gelykstaande aan 'n bykomende koste van ZAR 1 166,46 per oordrag. Op 'n per-ton basis het die intervensie ZAR 36.45 by die produksiekoste van in grootmaat verpakte vliegas gevoeg, vergeleke met slegs ZAR 11.83 per ton wanneer die outomatiese oordragstelsel gebruik word. Daar is aangeraai dat die aanleg 'n nuwe prosesbeheerstelsel implementeer wat kunsmatige intelligensie insluit vir verbeterde vroeë foutopsporing. So 'n stelsel, ondersteun deur diagnostiek en historiese tendensanalise, sal help om toekomstige gevalle van ernstige onbeplande stilstand te voorkom.

1. INTRODUCTION

1.1. Background

Reducing the carbon footprint of construction materials such as cement and concrete has been gaining global attention for many years. The manufacture of cement is associated with the most carbon dioxide being emitted during the calcination process. Meanwhile, the footprint of carbon in concrete is accounted by the raw materials that have been used to produce concrete as one of the contributing factors.

Fly ash, as one of the coal combustion solid materials released in high quantities from coal-fired power station operations, has been used as a key ingredient to improve the technical performance properties of construction materials such as concrete. However, the amount of cement used in concrete is reduced when fly ash is also used, thus contributing to lower cement consumption at the same percentage of fly ash usage. Khalil and AbouZeid [1] indicated that concrete is one of the largest emitters of carbon dioxide (CO_2) worldwide owing to its use of cement as its main component.

This is because concrete is the world's most widely used construction material. Bonnet *et al.* [2] indicated that the total annual concrete consumption worldwide is 10 billion tonnes.

South Africa relies mainly on coal to generate electricity and produces over two million tonnes of ash per annum [3]. Fly ash has been beneficiated for use in cement, concrete, brick, and block. Thus, the availability of fly ash to the construction materials industry is not just for its technical benefits such as the improved workability of concrete but also offers other benefits such as reduced cement content in the concrete mix while maintaining the desired performance of concrete. However, there is a strategic need to reduce the carbon footprint in the finished goods.

The South African cement industry regulator has been initiating various ways in which the cement and concrete industry's carbon footprint could be reduced to achieve its commitment to reduced greenhouse gases by the year 2025 in accordance with the Paris Agreement. One of the South African National Treasury policies is the carbon tax, which works on the principle that the producer of carbon pays a certain tax fee set by the Carbon Tax Act of 2019 [4]. The South African carbon tax began at a base rate of ZAR 120/tonne CO_2 emitted, then increased by 5.2% in 2020, then from ZAR 127/tonne CO_2 to ZAR 134/tonne CO_2 in 2021. This base rate also depends on the type of cement produced by each manufacturer in South Africa [5].

The Act is propelling cement manufacturers to find innovative ways in which carbon dioxide emissions could be reduced, and cement consumers to make better product choices for green cement owing to the increased cost of non-green cement.

In the South African market, fly ash is supplied in bulk and in bags, depending on the specification of use, destination, and the operations set up of the users. The bagged fly ash has the advantage of also being sold to export markets. Thus, the availability of bagged fly ash is of great importance for both the South African and the export markets. A packaging plant is one of the operations in a fly ash processing plant to service the market of users of the fly ash to produce concrete with reduced cement content, which is replaced by fly ash, thereby contributing to lower cement usage, which is associated with CO_2 emissions.

Like other industrial manufacturing operations, such a plant needs to be properly managed to meet the demand and to be sustainable for market growth.

Tau *et al.* [6] indicated how continual improvement through lean tools in such operations could be deployed to debottleneck operations and to increase product availability.

1.2. Problem statement

In a fly ash processing plant, the bulk product manufacturing line feeds the finished product to a packaging plant where it is packaged in 1.25-tonne bulk bags, using an automated transfer system that uses air as a conveying medium. Figure 1 shows a simplified process flow in the production line.

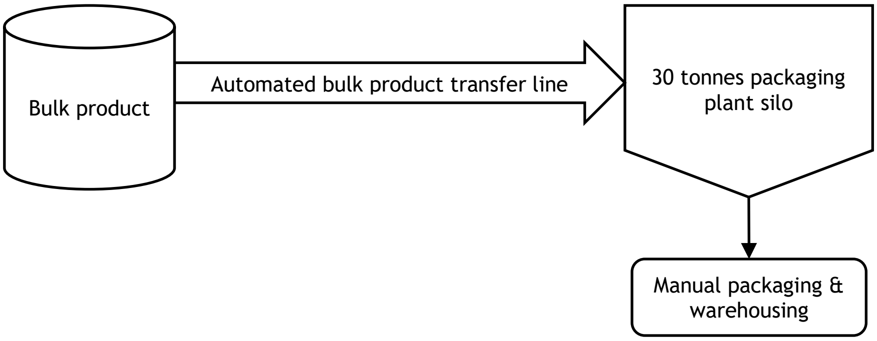

Figure 1: Simplified fly ash packaging production line

The transfer system is in breakdown because of process control failure, software failure, and fly ash blockages in the transfer system's pipeline that do not allow the product to be transferred. In a 24-hour production shift, eight transfers are completed, thereby producing packaged products. The lead time to resolve the breakdown is about eight months owing to the transfer system components that need to be procured. The demand for packaged products is such that it exceeds the currently available stock, and the plant will run out of stock to supply customers. An assessment of alternative options to transfer the product from the bulk production line to the packing plant needs to be explored to service customers. The available option is to use a dry bulk tanker with a maximum carrying capacity of 34 tonnes to be loaded at the bulk product production line and offloaded at the packing plant silo. This option needs to be assessed in relation to its feasibility for adoption.

1.3. Objectives

1.3.1. Overall objective

The purpose of the study was to evaluate the use of a transfer truck to transfer bulk product from the bulk production line to the packaging line to minimise the impact of the automated transfer system's downtime on supply and demand.

1.3.2. Specific objective

1.3.2.1 To characterise the typical daily and monthly production output at the packaging plant using the automated transfer system;
1.3.2.2 To conduct a downtime analysis of the fly ash transfer system;
1.3.2.3 To evaluate the effects of bulk tanker transfers on inventory levels and associated cost optimisation opportunities;
1.3.2.4 To estimate the impact of minimisation based on stock availability and new cost incurrence associated with the bulk tanker transfer scenario;
1.3.2.5 To determine the revenue impact of the bulk tanker truck transfer scenario.

2. LITERATURE REVIEW

Manufacturing companies are traditionally the largest source of growth in the economy, providers of employment, and contributors to gross domestic product [7]. Thus, the maintenance of efficient operations in manufacturing facilities is a matter of great concern, given their contribution to any country's economy. This also results in offering a higher-value product to customers and gaining their satisfaction. The manufacturing environment plays an important role in maintaining machines and equipment for production and plays a significant role in the service life of equipment and its efficiency in production [7]. Machine failures in manufacturing facilities are undesirable, as they contribute to low rates of production and lead to inferior quality. In addition, they pose a risk to manufacturers' ability to fulfil their commitment to customers [8], which is to supply the right product, quantity, quality, place, time, and price.

Lower production costs contribute to productivity and allow companies to decrease their prices as a lever for competitive advantage. This increases sales further, gains a share of the marketplace, brings in new customers, and gains customers' loyalty [9].

Badenhorst-Weiss et al. [10] noted that many suppliers determine their selling prices using cost-based pricing methods. The cost of production considers all direct and indirect costs that a company incurs production so that goods or services can be sold [11]. For a company's financial reporting, the calculation of the cost of goods is important, and it is done before the selling price can be determined. This helps management to compare the costs and the revenue generated in its income statements. The comparison also assists companies to have greater control if they know the cost of goods.

Calculating the cost of production can help to set the selling price and the profit margin, as it is important for management to decide on the product's selling price and other variables [12]. The full costing method and the variable costing method are the techniques that companies use most often to monitor the costs associated with production.

Different approaches can be used to estimate the markup applied to manufacturing costs to determine a selling price. These approaches include markups based on a percentage of the production costs, a percentage of the sales, or a target return on investment [10].

Rachman and Rachmat [11] and Elisa et al. [12] indicated that the product selling price using markup on production cost can be calculated using the following formula:

$$\text{Product selling price} = \text{Cost of product} + (\text{cost of product} \times \text{markup})$$

The product selling price is one element in the marketing mix that helps companies to generate revenue. Methods for fixing the selling price include cost plus pricing, value-based pricing, and competitive-based pricing [11].

Barbero and Zofio [13] indicated that the profit generated by a business is defined as the generated revenue less the observed cost, indicated by the formula:

$$\text{Profit} = \text{revenue - cost}$$

Managing revenue in business is of great importance for the enterprise to monitor its performance. Revenue management is defined as selling the right product to the right customer at the right time and at the right price [14]. Setting prices for various customer segments is important in-service industries, such as in an airline, where profit margins are narrow [14]. Elmaghraby and Keskinocak [15] indicated that, in the manufacturing and service industries in the past two decades, most companies have used pricing policies. Updating prices has been completed using technologically enhanced tools, which assist further with decision support to ensure fast and accurate decisions. Akbay and Çavdaroğlu [14] noted that human intervention and judgement will continue to play a crucial role in management practices relating to revenue in most companies in the future. This was indicated because of pricing policies, as they have an enormous impact on most firms' operations and profitability. This places attention on the need to investigate how human decision-makers finalise prices to achieve high profit margins.

In manufacturing, machines can fail, whether they are automated or not; and breakdowns have an impact on cost, adding to the cost of manufacturing. Automation in the manufacturing sector has been propelled mostly by changes in the marketplace, where manufacturers strive to compete with their product offerings. In general, automation is associated with reduced participation of humans in the production systems [16, 17]. The introduction of machines helps with repetitive and complex actions and transforms the production process to make it continuous [16]. Battini et al. [18] noted that, with the customisation of products, the variability of mix, a shorter lead time to market, and a reduced risk of product obsolescence, continuous flow and Just-In-Time (JIT) solutions push the industry to make constant improvements to the quality of their product, the efficiency of their operations, and their use of production capacity.

Garner et al. [19] defined JIT as a management philosophy that is part of Lean, which entails producing goods to meet the exact demand of customers, in time, and in the right quantity, whether the customer is the final purchaser of the product or there is another process further along the production line. Thus, finished goods are produced and delivered just-in-time to be purchased. The JIT principle is that production is pulled through rather than pushed through. Thus the production is for specific customer orders, so that the cycle of production only begins once a customer has placed an order with the intention to purchase.

Szedlak et al. [20] indicated that different solutions for automation are used in production plants. Industrial automation uses computer-based software to control processes for manufacturing, which is associated with less human intervention. This production software uses historical data by analysing the trends in the production process control. Nemeth et al. [21] indicated that data in the industrial area is collected and generated at several levels of operations control. Process control is mostly implemented by deploying systems of control in a hierarchical structure.

Supervisory control and data acquisition (SCADA) was developed to improve industrial control systems. SCADA has been deployed in systems that are used to monitor and regulate a plant or equipment in many industries. For example, a SCADA system gathers information to report where there is a leak in a pipeline. This information is then transferred to a central site where the home station is alerted to the leak, and the necessary analysis and controls are carried out. This includes determining the criticality of the leak and displaying the information in a way that is logical and organised [22].

SCADA systems have undergone considerable changes in their capabilities, structures, functionality, and general perception, and in their functional contribution in the overall industrial control system. The evaluation of SCADA in association with digital transformation in industrial automation under Industry 4.0 (I4.0) has shown the potential of SCADA systems in the conception of smart factory designs [23]. This aids in merging the physical and virtual worlds of interconnectedness and integration throughout the entire chain, which leverages the new emerging technologies of the Internet of Things (IoT), big data, artificial intelligence, cloud computing, service-oriented architecture, and cyber-physical systems as core Industry 4.0 enabling technologies [23]. The use of these technologies is to increase the level of flexibility, autonomy, interoperability, equipment efficiency, quality of products or services, and overall productivity of manufacturing processes [24].

The SCADA system is a software tool that provides automation software to control a process in real time. Its main tasks are to collect data from sensors and to present it in a way that is convenient by using graphs of the changing parameters as a function of time. It also helps with the remote control of actuators and the insertion of tasks for automatic control algorithms [25].

Sverko et al. [26] conducted a survey of architectures, standards, challenges, and Industry 5.0 on SCADA systems with a focus on continuous manufacturing and the steel industry. SCADA systems have a monitoring capability that allows the reading of transducer measurements to be evaluated and reports critical changes promptly to the operator. Furthermore, it was reported that the SCADA system has disadvantages with respect to efficiency and high functionality – for example, the lack of basic methods to check the system, or to evaluate the errors and results being reported. Epifancev and Mishura [25] also investigated the problems and benefits of using SCADA systems when measurements in hazardous production technologies are performed. Some studies have investigated the application of automation in a production line using robots to enhance production rates and overall factory efficiencies [27], while Sin et al. [28] identified typical breakdowns in automated manufacturing lines and devised a mathematical analysis to address such issues.

Todmal et al. [29] analysed breakdowns and implemented a way to maintain engine cylinder block machines that would be optimal in improving their operational availability. The analysis of breakdowns was achieved through analysis of failure modes and effects, and through root cause analysis and why-why analysis. A customised maintenance plan that helped to reduce breakdowns and to shift maintenance from reactive behaviour to proactive behaviour was implemented. The analysis and interpretation of information associated with operations in the database of a computerised maintenance management system should assist with monitoring machine or system reliability in production and thus contribute to profitability [30].

Tools such as fishbone and Pareto diagrams are used mainly to assess causes and effects in operations, thereby deriving solutions, as described in various studies [31, 32].

3. METHODOLOGY

First, an understanding of the fly ash packing operation was established through the manufacturing process flow. This was followed by characterising the daily and monthly production output. This was derived by obtaining the dispatch dataset from the dispatch software over a full year, month on month. The dispatch data was then assumed to be equivalent to the production data; however, it was found that 60% of the monthly product supply was produced/dispatched using just-in-time production. This was to avoid having dead stock and holding an unnecessary overstock of inventory, which would create a financial burden. Calculations were made to convert the actual product dispatch data over the 12-month period, month on month, to a dataset that represented the 60% just-in-time production on daily and monthly bases. The formulas below are some of the equations used to calculate factors such as quantity supplied, potential of transfers via bulk tanker truck, cost incurred per bulk fly ash transfer, revenue, and profit margin in the bulk tanker transfer system.

$$\text{Quantity supplied} = \frac{\text{Actual monthly supplied}}{\text{Production days}}$$

$$\text{Potential of transfers via bulk tanker truck} = \frac{\text{Actual allocated time of transfers}}{\text{Total time for completion of loading} + \text{total time for completion of unloading} + \text{time spent packaging one transfer}}$$

$$\text{Cost incurred per bulk fly ash transfer} = \frac{\text{Daily cost fly ash transfer via bulk truck}}{\text{Potential number of transfers via bulk tanker truck}}$$

$$\text{Profit} = \text{revenue} - \text{cost}$$

$$\text{Profit margin at the bulk tanker transfer system} = \text{Selling price} - \text{production cost at the bulk tanker transfer system}$$

A downtime analysis was then conducted over the full months of October and November by using the downtime log sheet, in which all the reasons for downtime, together with their number of occurrences, were noted. A Pareto chart was then used to present the downtime data for October and November.

Next, it was determined how many transfers could be carried out in a 24-hour production shift using a bulk tanker truck to minimise the impact of the automated system downtime. This determination was conducted by using Arena simulation software to quantify how many transfers could be completed in an allocated 24-hour production time. To achieve this, the whole proposed transfer process using a bulk tanker was defined to understand the sequence of the truck's activities for simulation purposes.

Finally, the new cost incurred in the bulk tanker transfer scenario in an allocated 24-hour production time was calculated using the price of ZAR 9,331.70 per day, excluding value-added tax.

Figure 2 summarises this procedure.

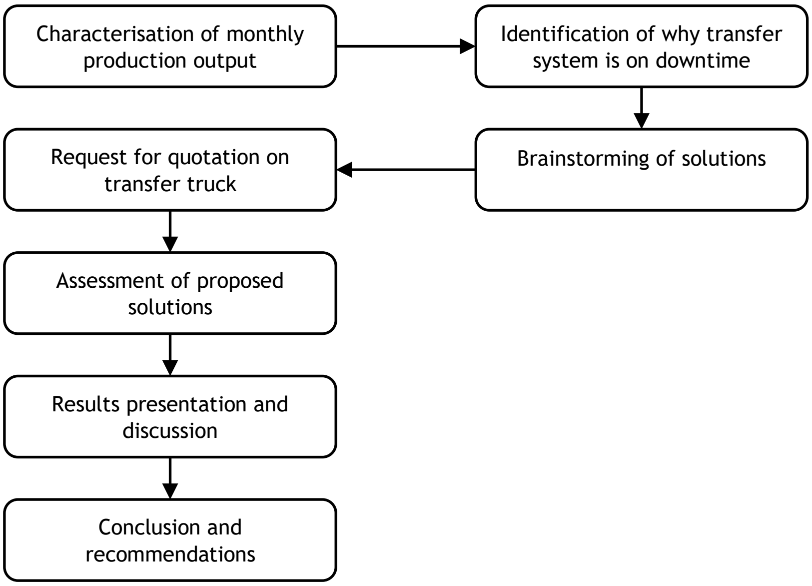

Figure 2: Research procedure

4. RESULTS AND DISCUSSION

4.1. Characterisation of the typical daily and monthly production output at the packaging plant using the automated transfer system

Figure 3 indicates the monthly production output as recorded on the computer dispatch system. It can be noted that August is the anticipated peak month, while January has the slowest start to the year because most users of fly ash are closed for the holidays and work for fewer days in January.

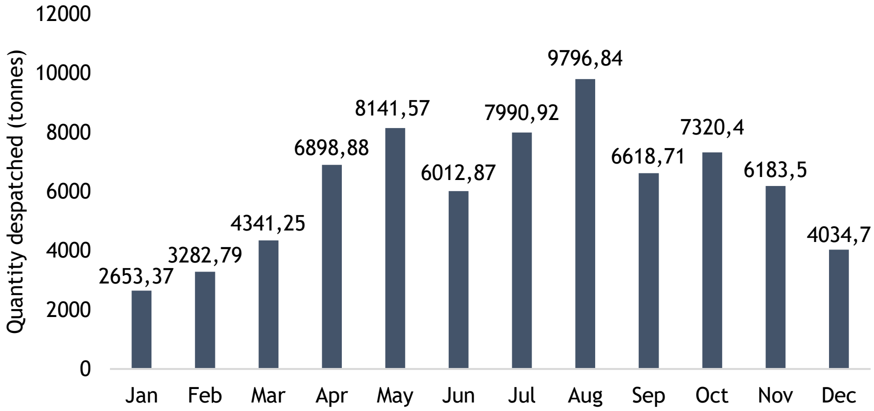

Figure 3: Actual monthly supply

The daily production output per month, based on the actual quantity produced, was calculated, as highlighted in Figure 4.

For example, in January, $\text{Quantity supplied}=\frac{\text{Actual monthly supplied}}{\text{Production days}}$

$$\text{Quantity supplied} = \frac{2{,}653.37 \text{ tonnes}}{31 \text{ days}}$$

$$\text{Quantity supplied} = 85.59 \text{ tonnes/day}$$

Similar calculations were made for the months from February to December by using production days, as indicated in Table 1.

Table 1: Production days per month

Month	Number of production days
February	28
March	31
April	30
May	31
June	30
July	31
August	31
September	31
October	31
November	30
December	31

It was assumed that the actual quantities supplied each month, as indicated in Figure 3, were produced daily on the available days in each month, since the plant operated around the clock each week from Monday to Friday for both production and dispatch activities. Figure 4 indicates the daily production output per month.

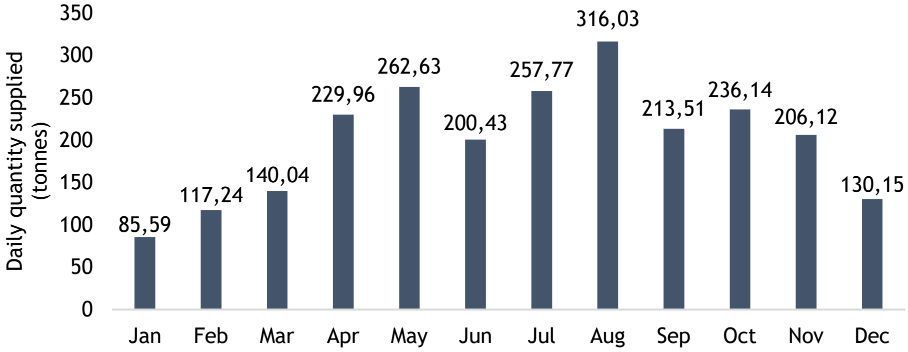

Figure 4: Daily production output based on the monthly quantities given in Figure 3

About 85% of the product's total actual quantity supplied each month was based on JIT production, based on historical production and sales trends; thus, the calculation below indicates how the monthly production output indicated in Figure 3 was converted to cater for the JIT output.

For example, in January, $\text{quantity supplied} = \text{Actual monthly supply} \times \%\ \text{JIT output}$

$$\text{Quantity supplied} = 2{,}653.37 \text{ tonnes} \times 85\%$$

$$\text{Quantity supplied} = 2{,}255.36 \text{ tonnes}$$

Similar calculations were made for the months from February to December. Figure 5 indicates the monthly supply, considering the 85% JIT supply.

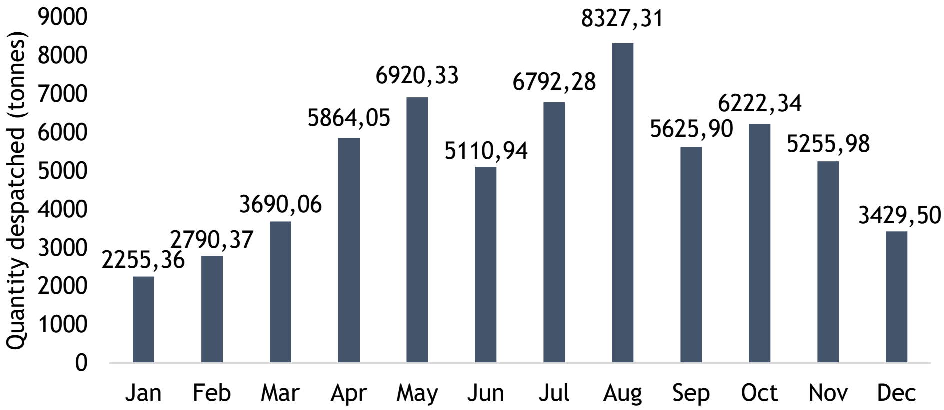

Figure 5: Actual monthly supply from just-in-time production

Figure 6 indicates the daily quantity of just-in-time production each month, considering the 85% JIT production outlined in Figure 5 and based on the following calculation:

For example, in January, $\textit{quantity supplied} = \dfrac{\text{Actual monthly supplied}}{\text{Production days}}$

$$\text{Quantity supplied} = \frac{2{,}255.36 \text{ tonnes}}{31 \text{ days}}$$

$\text{Quantity supplied} = 72.75 \text{ tonnes/day}$

Similar calculations were made for the months from February to December by using the production days given in Table 1.

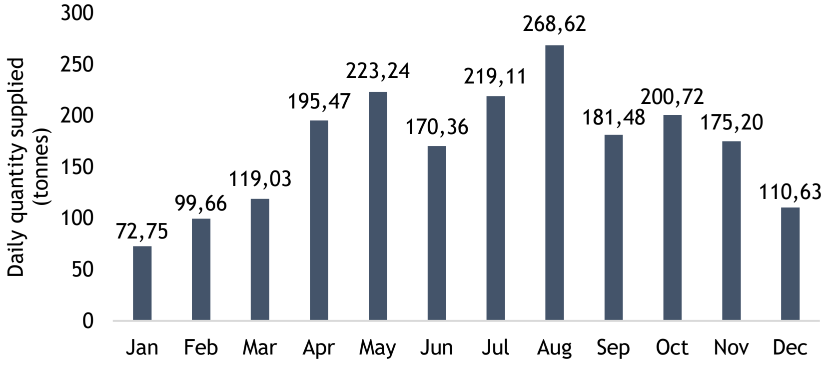

Figure 6: Daily quantity of just-in-time production per month, from Figure 5

4.2. Downtime analysis of the fly ash transfer system

4.2.1. Downtime for month of October

The highest amount of downtime occurred in the month of October – a result of no ash being delivered from the power station to the processing plant, as noted in Table 2. The Pareto chart outlined in Figure 7 shows that no ash flowed from the power station, as 20% of issues caused 80% of the plant downtime during the month of October. This was mainly because the fly ash extraction equipment performed well below the set targets for parameters such as flow rate, which was attributed to low aeration in the equipment because of worn aeration pads.

Table 2: Downtime log sheet data for the month of October

Causes of downtime	Total number of occurrences causing downtime	Total percentage (%)	Cumulative percentage
No ash flow from the power station	17	57	57
Line leaks	13	43	100

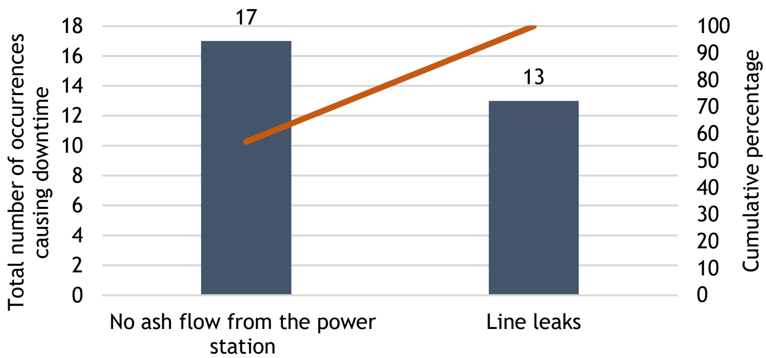

Figure 7: Pareto chart for downtime mapping, month of October

4.2.2. Downtime for month of November

Table 3 indicates that blockages caused by high fly ash humidity contributed to 46% of the total number of downtimes caused by occurrences, as noted in the Pareto chart in Figure 8. The downtime from blockages because of high fly ash humidity was linked to the rainy season in this period, which resulted in fly ash agglomeration, generating a lumpy fly ash which was difficult to transfer at times, putting pressure on the transfer system.

Table 3: Downtime log sheet data for the month of November

Causes of downtime	Total number of occurrences causing downtime	Total percentage (%)	Cumulative percentage
No ash flow from the power station	16	35	35
Line leaks	9	20	54
Blockages caused by high fly ash humidity	21	46	100

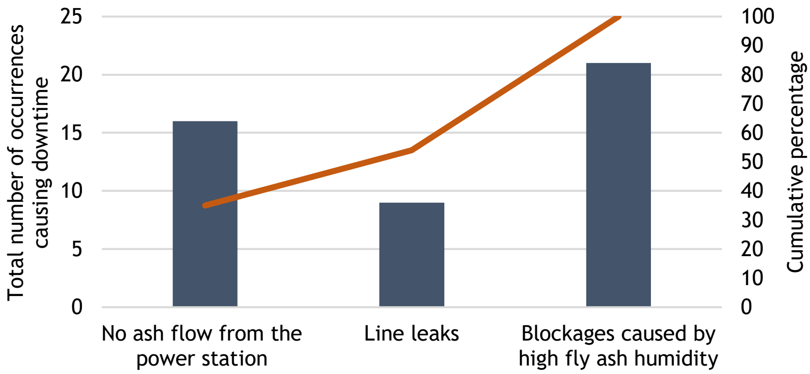

Figure 8: Pareto chart for downtime mapping in month of November

4.3. Determination of the number of transfers in a 24-hour production shift using a bulk tanker truck

4.3.1. Modelling and simulation, using Arena software, of product transfer, from bulk production line to packaging plant

A bulk tanker truck with a maximum carrying capacity of 34 tonnes arrives at the bulk product loading bay every 51 minutes, based on historical dispatch trends; it queues for 43 minutes, and then moves on to the scale for loading. The loading process for 32 tonnes takes between 21 and 24 minutes. As soon as the truck has been loaded with 30 tonnes of product, it travels about 100 metres to the packaging plant, taking two minutes to do so, as the plant allows vehicles to travel at a speed of only 30 km/hour. When the truck arrives at the packaging plant, it offloads the product into a 30-tonne silo. The offloading takes about 43 minutes, and, as soon as that has been done, it leaves to join the queue for the next load. Figure 9 simplifies the sequence of activities followed by the truck in the form of a flow diagram.

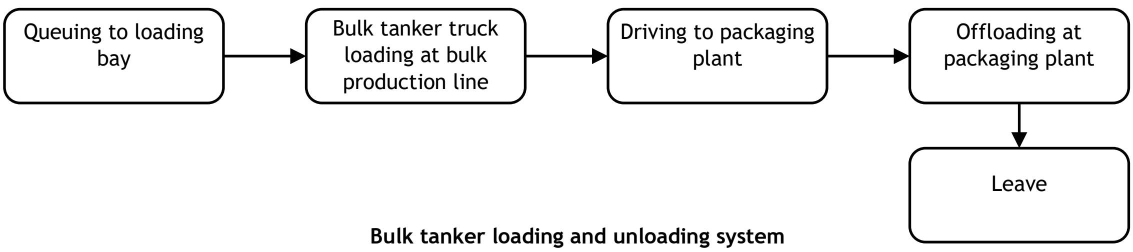

Figure 9: Sequence of activities for bulk tanker loading and offloading

Figure 10 shows the model developed in the Arena software, while Table 4 shows the modelling and simulation results for selected key performance indicators.

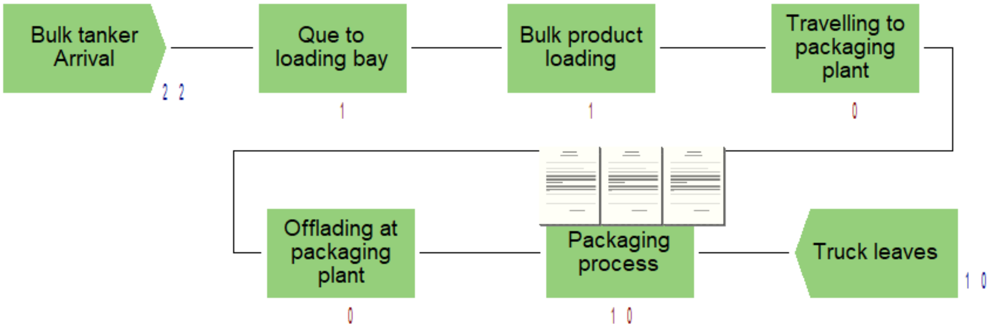

Figure 10: Simulation model for packaging operations

Table 4: Arena simulation results

Key performance indicators	*Model result*		*% system efficiency*
	Number in	*Number out*	*(number out/number in)*
Bulk product loading	21.00	20.00	95.24
Offloading at the packaging plant	20.00	19.60	98.00
Packaging process	19.60	10.00	51.20
Queue at loading bay	22.00	21.00	95.45
Travelling to the packaging plant	20.00	20.00	100.00

4.3.2. Verification and validation of simulation and modelling results

The following calculations were made to validate the modelling results for the number of transfers that could be completed in the allocated 24-hours.

$$\text{Potential of transfers via bulk tanker truck} = \frac{\text{Actual allocated time of transfers}}{\text{Total time for completion of loading} + \text{total time for completion of unloading} + \text{time spent packaging one transfer}}$$

$$\text{Actual allocated time of transfers} = \text{Total available time - non-productive time}$$

$$\text{Non-productive time} = \text{Drivers' allocated time for resting}$$

There would be two drivers to complete the 24-hour shift, and there would be two shifts. Each driver would be given 90 minutes of rest.

$$\text{Non-productive time} = 90 \text{ minutes} \times 2 = 180 \text{ minutes}$$

$$\therefore \text{ Actual allocated time of transfers} = 1\,440 \text{ minutes - } 180 \text{ minutes} = 1{,}260 \text{ minutes}$$

In most cases, owing to high demand for bulk fly ash products, bulk tankers are loaded JIT when the product is produced. It is known that the classifier that produces the bulk fly ash product where the transfer truck will be loading has a production rate of 43 tonnes, according to the study of [35].

$$\therefore \text{ Loading time for 32-tonne product while the truck on the scale} = (43 \text{ tonnes}/60 \text{ minutes}) \times 32 \text{ tonnes} = 22.93\ minutes$$

Unloading time for 32 tonnes of product at the packaging plant = 47 minutes (measured with a stopwatch)

Time spent packaging one transfer = 83 minutes (measured with a stopwatch)

$$\therefore \text{Potential number of transfers via bulk tanker truck} = \frac{1\ 260}{(22.93 + 47 + 83)}$$

$$\text{Potential number of transfers via bulk tanker truck} = 8.24 \sim 8$$

Thus, the potential total quantity that can be packaged in 24 hours is:

$$\text{Potential quantity to be packaged in 24 hours} = \text{Potential number of transfers via bulk tanker truck} \times \text{quantity carried per truck}$$

$$= 8 \times 32 = 256 \text{ tonnes}$$

Using 256 tonnes as the daily production rate, Monday to Friday, Table 5 shows the potential monthly production output, calculated as follows:

For example, in January, $\text{potential monthly production output through bulk tanker transfers} = \text{Potential quantity to be packaged in 24 hours} \times \text{Number of production days excluding weekends}$

$$\text{Potential monthly production output through bulk tanker transfers} = 256 \text{ tonnes} \times 22$$

Table 5: Potential monthly fly ash packaging quantity based on transfers

Month	Number of production days excluding weekends	Potential monthly production output through bulk tanker transfers (tonnes)
January	22	5,632.00
February	20	5,120.00
March	21	5,376.00
April	22	5,632.00
May	22	5,632.00
June	20	5,120.00
July	22	5,632.00
August	22	5,632.00
September	22	5,632.00
October	23	5,888.00
November	22	5,632.00
December	19	4,864.00

4.4. Estimation of impact on stock availability and incurring of new costs associated with the bulk tanker transfer scenario

4.4.1. Estimation of impact on stock availability

Table 6 estimates the impact of reduced stock availability by comparing the typical monthly production, outlined in Figure 6, with the potential monthly production output through bulk tanker transfers, indicated in Table 5. The calculation of the impact assessment monthly is calculated as:

Impact (%) = $\frac{\text{PMP}}{\text{TMP}}$ ×100 ; PMP is the potential monthly production output through bulk tanker transfers and TMP is the typical monthly reduction measured in tonnes and

For example, for January, impact (%) = $\frac{5,632.00}{2,653.37} \times 100$

Similar calculations were made for months of February until December by using production days as indicated on Table 6 and Table 7 for 85% just-in-time monthly supply.

Table 6: Estimate of minimised impact, based on stock availability through bulk tanker transfers versus typical monthly production

Month	Typical monthly production (tonnes)	Potential monthly production output through bulk tanker transfers (tonnes)	Impact (%)
January	2,653.37	5,632.00	212.26
February	3,282.79	5,120.00	155.96
March	4,341.25	5,376.00	123.84
April	6,898.88	5,632.00	81.63
May	8,141.57	5,632.00	69.18
June	6,012.87	5,120.00	85.15
July	7,990.92	5,632.00	70.48
August	9,796.84	5,632.00	57.49
September	6,618.71	5,632.00	85.09
October	7,320.40	5,888.00	80.43
November	6,183.50	5,632.00	91.08
December	4,034.70	4,864.00	120.55

Table 7: Estimate of minimised impact, based on stock availability through bulk tanker transfers versus typical monthly production with 85% just-in-time.

Month	Typical monthly production with 85% JIT (tonnes)	Potential monthly production output through bulk tanker transfers (tonnes)	Impact (%)
January	2,255.36	5,632.00	249.72
February	2,790.37	5,120.00	183.49
March	3,690.06	5,376.00	145.69
April	5,864.04	5,632.00	96.04
May	6,920.33	5,632.00	81.38
June	5,110.94	5,120.00	100.18
July	6,792.28	5,632.00	82.92
August	8,327.31	5,632.00	67.63
September	5,625.90	5,632.00	100.11
October	6,222.34	5,888.00	94.62
November	5,255.98	5,632.00	107.15
December	3,429.50	4,864.00	141.83

4.4.2. *Estimate of new cost insurance*

Cost assessment

The third-party logistics company that was appointed to carry the bulk fly ash transfer to packaging quoted a price of ZAR 9,331.70 per day, excluding value-added tax.

$$\text{Cost incurred per bulk fly ash transfer } = \frac{\text{Daily cost fly ash transfer via bulk truck}}{\text{Potential number of transfers via bulk tanker truck}}$$

$$\text{Cost incurred per bulk fly ash transfer } = \frac{\text{ZAR 9,331.70}}{\text{8 transfers}} = \text{ZAR 1,166.46/transfer}$$

$$\therefore \text{ Cost incurred per tonne bulk bag } = \frac{\text{Cost incurred per bulk fly ash transfer}}{\text{Total product quantity per transfer}} = \frac{1{,}166.46}{32} = \text{ZAR36.45 excl. vat}$$

The eight transfers of bulk product to the packaging facility incurred a cost of ZAR 1,166.46 on every completed transfer. This meant that each bulk bagged fly ash product packaged at the packaging plant incurred a cost of ZAR 36.45 compared with the ZAR 11.83 contributed by the automated transfer system to the cost of manufacturing a tonne bulk bag fly ash product, excluding value-added tax. Thus indicated a cost increase for the bulk bagged fly ash product of ZAR 24.62, excluding value-added tax.

Profit margin assessment

In a case study, Pelser *et al.* [33] indicated that the average selling price of coal in South Africa, in the analysis of the energy consumption and cost distribution in a South African cement plant, is ZAR 728.91, excluding value-added tax. Most qualities of coal in South Africa are split into 85% fly ash and 15% coarse ash [3, 34] during the combustion process in power station operations. The assumption of this study was that the average selling price of fly ash was about 85% of the average selling price of coal.

$$\therefore \textit{ Fly ash average selling assumption } = \textit{ Coal average selling price } \times 85\% = \text{ ZAR 728.91 } \times 85\%$$

$$= \text{ ZAR 619.57 excl. vat}$$

The profit margin could be based on the production cost plus a 30% markup, which is common; this would signify the following:

$$\text{Average selling price } = (\text{\% markup } \times \text{ Production cost}) + \text{ Production cost}$$

$$ZAR\ 619.57 = (30\% \times \text{ Production cost}) + \text{ Production cost}$$

$$\therefore \text{ Production cost } = ZAR\ 476.59\text{/tonne fly ash bulk bag excl. value-added tax}$$

$$\text{Profit margin at the automated transfer system } = \text{ Selling price } - \text{ production cost} = ZAR\ 619.57 - ZAR\ 476.59$$

$$= ZAR\ 142.98\text{/tonne fly ash bulk bag excl. value-added tax}$$

$$\text{Profit margin for the bulk tanker transfer system } = \text{ Selling price } - \text{ production cost for the bulk tanker transfer system}$$

$$\text{Production cost at bulk tanker transfer system} = \text{Total production cost - cost contribution to total cost by automated transfer system} + \text{cost contribution to total cost by bulk tanker truck transfer}$$

$$\text{Production cost at bulk tanker transfer system } = ZAR\ 476.59 - ZAR\ 11.83 + ZAR\ 36.45$$

$$\text{Production cost at bulk tanker transfer system } = \text{ ZAR 501.21/tonne fly ash bulk bag excl. value-added tax}$$

$$\therefore \text{Profit margin at bulk tanker transfer system} = \text{ZAR 619.57 - ZAR 501.21}$$

$$\text{Profit margin at bulk tanker transfer system} = \text{ZAR 118.36/tonne fly ash bulk bag excl. value-added tax}$$

$\therefore$ Margin of loss $=$ Profit margin for the automated transfer system $-$ Profit margin for the bulk tanker transfer system

$= \text{ZAR } 142.98 - \text{ZAR } 118.36 = \text{ZAR } 24.54\text{/tonne fly ash bulk bag}$

$$\therefore \text{ New \% margin } = \frac{\text{ZAR margin value}}{\text{New production cost}} = \frac{ZAR\ 11.36}{ZAR\ 501.21} = 23.61$$

Table 8 summarises the costs and profit margin analysis calculated.

Table 8: Summary of costs and profit margin analysis

Factor	Result
Average selling price	ZAR 619.57/tonne fly ash bulk bag
Production cost	ZAR 476.59/tonne fly ash bulk bag
Profit margin at the automated transfer system @ 30% markup of the production cost	ZAR 142.98/tonne fly ash bulk bag
Production cost at bulk tanker transfer system	ZAR 501.21/tonne fly ash bulk
Profit margin at bulk tanker transfer system	ZAR 118.36/tonne fly ash bulk bag
New % margin at bulk tanker transfer system	23.61%
Margin of loss	ZAR 24.54/tonne fly ash bulk bag

Table 8 indicates that the production cost increased from ZAR 476.59/tonne fly ash bulk bag in the automated transfer system to ZAR 501.21/tonne fly ash bulk in the case of the bulk tanker transfer system, which meant a 3.97% (ZAR 24.62/tonne fly ash bulk) increase in the selling price without customers incurring this increase.

The profit margin reduced from ZAR 142.98/tonne fly ash bulk bag to ZAR 118.36/tonne fly ash bulk bag – that is, a ZAR 24.54/tonne fly ash bulk bag had a loss in margin because of the manual transfer of the product by bulk tankers. Furthermore, this meant a 23.61% margin with the bulk tanker transfer system instead of the 30% achieved by the automated transfer system. To maintain this percentage profit margin, it means the customers need to incur a 5.16% price increase per on-fly ash bulk bag, calculated as follows:

$\text{New average selling price} = (\text{\% markup} \times \text{production cost}) + \text{Production cost}$

$= (30\% \times \text{ZAR } 501.21\text{/tonne fly ash bulk}) + \text{ZAR } 501.21\text{/tonne fly ash bulk}$

$= ZAR\ 651.57\text{/tonne fly ash bulk}$

The percentage price increase on selling to achieve a 30% margin on the new cost of packaging fly ash =

$$= \frac{\text{New average selling price} - \text{Old average selling price}}{\text{Old average selling price}} \times 100$$

$$= \frac{\text{ZAR } 651.57 - \text{ZAR } 619.57}{\text{ZAR } 619.57} \times 100$$

$= 5.16\%$

4.5. Determination of impact on revenue and profit

Table 9 indicates the revenue and gross profit margins for the months of October and November, which were the months of the automated transfer system's downtime. The revenue and gross profit margins are compared for the two months for the scenarios of automated transfer and of transfer via a bulk tanker truck, calculated as follows:

For example, for January at automated transfer,

$$\text{Revenue} = \text{Monthly volume} \times \text{Average selling}$$

$$= 7{,}320.40 \times 619.57$$

$$= \text{ZAR } 4{,}535{,}500.23$$

$$\text{Gross margin} = \text{Revenue} - \text{Cost}$$

$$= ZAR\ 4{,}535{,}500.23 - ZAR\ 3{,}488{,}829.44$$

$$= ZAR\ 1{,}046{,}670.79$$

Table 9 indicates that what is typically produced in the month of October using the automated transfer system to transfer the bulk product to the packaging plant is 7,320.40 tonnes, which generates a gross profit of ZAR 1.04 million, compared with 5,888.0 tonnes that is potentially produced but using bulk tanker truck transfers, which generates a gross profit of ZAR 0.70 million. This means a reduction in the bulk bag fly ash quantity of 1,432.40 tonnes at a loss of ZAR 0.34 million when the bulk tanker transfer is used. During the month of November, the expected quantity to be sold is 6,183.50 tonnes that is produced using the automated system, which then generates a profit of ZAR 0.88 million; compare this with the production of 5,632.00 tonnes for ZAR 0.67 million using transfers via bulk tanker truck. This means a profit margin loss of ZAR 0.21 million.

Table 9: Revenue and gross profit with automated transfers versus bulk tanker truck transfers during the downtime of the automated transfer system

Month	**Factor**	**Under normal production circumstances**		**Production at 85% just-in-time**	
		Automated transfer	**Transfer via bulk tanker**	**Automated transfer**	**Transfer via bulk tanker**
October	Monthly volume (tonnes)	7,320.40	5,888.0	6,222.34	5,888.0
	Average selling price (ZAR/tonne bulk bag fly ash)	619.57	619.57	619.57	619.57
	Production cost (ZAR/tonne bulk bag)	476.59	501.21	476.59	501.21
	Revenue (ZAR)	4,535 500.23	3,648,028.16	3,855,175.19	3,648,028.16
	Cost (ZAR)	3,488,829.44	2,951,124.48	2,965,505.02	2,951,124.48
	Gross profit ZAR/tonne bulk bag fly ash)	1,046,670.79	696,903.68	889,670.17	696,903.68
November	Monthly volume (tonnes)	6,183.50	5,632.00	5,255.98	5,632.00
	Average selling price (ZAR/tonne bulk bag fly ash)	619.57	619.57	619.57	619.57
	Production cost (ZAR/tonne bulk bag)	476.59	501.21	476.59	501.21
	Revenue (ZAR)	3,831,111.10	3,489,418.24	3,256,447.53	3,489,418.24
	Cost (ZAR)	2,946,994.27	2,822,814.72	2,504,947.51	2,822,814.72
	Gross profit (ZAR/tonne bulk bag fly ash)	884,116.84	666,603.52	751,500.02	666,603.52

In the case of production at 85% just-in-time, Table 9 indicates that, in October, the automated system produces 6,222.34 tonnes, which is sold to generate a gross profit of ZAR 0.89 million, compared with the production potential via the bulk truck transfer system of 5,888.0 tonnes, which generates a gross profit of ZAR 0.70 million, which means a loss of ZAR 0.19 million. Table 9 also shows that, during the month of November, the expected sales is 5,255.98 tonnes produced via the automated system with JIT, with an expected gross profit of ZAR 0.75 million, compared with ZAR 0.67 million associated with 5,632.00 tonnes if it is all sold – although the production cost is the main reducer of the gross profit.

5. CONCLUSION

Based on this assessment, it was noted that, during the two-month period of downtime (October and November 2023), the required production quantity in October was not met by 19.57% in the case of normal production (and by 5.37% with 85% just-in-time) when comparing bulk product transfer via trucks with the automated system. This also had an impact on gross profit of a reduction of 33.42% in the case of normal production and of 21.67% in the case of 85% just-in-time.

In the month of November, the production quantity reduced by 8.92% with normal automated transfer compared with transfer via bulk tanker truck, which meant a reduced gross profit by 24.60%. In the case of production at 85% just-in-time, the production quantity reduced by 7.15%, with an 11.30% reduction of gross profit in the case of automated transfer and transfer via bulk tanker truck.

6. RECOMMENDATIONS

Dependence on automated systems in the manufacturing process has been part of the industrial sector for decades. To avoid downtime from software recurring, an artificial intelligence process control system was recommended to avoid the software failing without an early warning.

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