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Evaluation of Performance Improvement Rate of Plastic Production System Using ARENA: A Case Study of Phoenix Plastic Services

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Production improvement has become essential to all industrial activity because of the fierce competition among today's production systems and organizations and the unquenchable customer demand. The shorter product life cycle has significantly increased the demand for prompt reactions to increase the productivity and efficiency of these industrial systems. This study examined the evaluation of performance improvement rate of plastic production system using ARENA. The report

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provided by the plastics industry was used in the study to analyze and assess the rate of performance improvement of the plastic manufacturing system. The location of the bottleneck was determined by the research following a thorough analysis of the plastic company's data, which included information on all manufacturing lines and procedures. The research employed Arena to assess and compute the rate of improvement in system performance while accounting for the material transporting process throughout the production line. The conveyor velocity maintains a lock at 75m/min, despite the company's report stating that the transports run at 30m/min. The optimized and unoptimized processes when obtained from a finished recycling process running for 1000 working hours, indicate that the conveyor process had 1045 and 1027 entity input and output, respectively, and the transporter process had 953 and 929 entities input and output respectively. The remaining number left when considering the number that enters the system with the number that leaves the system went to waste, resulting from the sorting and demagnetization process. The introduction of the conveyor brings 10.549% in the production rate and 50% decrease on expenses spent in labor. Through the conveyor system's speed control factor, which is an automated procedure, the system's percentage increment may be further raised. By raising the conveyor system's speed, more items will be produced. Conveyor system installation free up more space for additional production-related equipment, increasing products formed and the company's profit. The cost of purchasing and installing the conveyor will be covered by the excess profit.

Keywords: Arena; plastic production; conveyor; transporter; entity; optimization; plant design.

ABBREVIATION

RMA	*: Raw Material Arrival*
OSS	*: Offloading & Sorting Station*
DMSP	*: De-sanding & Magnetic Separation Process*
RMSP	*: Raw Material Storage Process*
CP	*: Crushing Process*
WP	*: Washing Process*
SFP	*: Separation by Floating Process*
DP	*: Drying Process*
MP	*: Melting Process*
FCRP	*: Floating & Contaminant Removal Process*
MoP	*: Molding Process*
FPPS	*: Finished Plastic Product Store*
WIP	*: Work in Progress*
VA	*: Value Added*
NVA	*: Non-Value Added*

1. INTRODUCTION

Production improvement has become essential to every industrial operation because of the fierce competition amongst today's production systems or companies and the unquenchable customer demand (Roos 2016, Soosay et al. 2016). The rising need for quick responses to boost the productivity and efficiency of the industrial systems has been greatly exacerbated by the shorter product life cycle (Javaid et al. 2021, Zhong et al. 2017). The outdated production processes need constant upgrading due to technological advancements and the desire to enhance the products and services these companies provide to satisfy the current demand of humans, and this is true even though significant efforts are dedicated to research and practice improvement strategies, methods, technologies, and implementations (Fu 2022, Pascucci et al. 2023, Shabalov et al. 2021).

Material handling is still crucial and significant since the smooth and successful flow of materials determines a plant's peak level of system performance, and improper management halts the perfect flow of the material along the production line (Caggiano 2014). A significant disruption can cost an organization more than thirty percent of its revenue (Katsaliaki et al. 2022). Material handling, a crucial aspect of manufacturing, takes up between 80% and 95% of the time between receiving an order and transportation to the client (Rosenblatt 2013).
One of the main objectives of material handling is to guarantee that products are easily and affordably available at the right time and place (Rosenblatt 2013, Hama Kareem et al. 2022).

Enhancing the material handling procedure within the company to guarantee a free-flowing supply of production materials is one way to lessen or eliminate limitations, thereby maintaining or raising the product quality within the allotted production time (Hama Kareem et al. 2022, Hosseinzadeh Lotfi et al. 2023, Zhang and Li 2020). The improvement in material handling will result in less waste when various goods generate more leftover material (Ajayi and Oyedele 2018, Ayilara et al. 2020, Sadh et al.

2018, Ugwu et al. 2021). Additionally, to handle the variety of these items, it's necessary to alter the present assembly lines to integrate model assembly lines with the right equipment and designs to manage customers' varying product preferences (Boysen et al. 2022, Dwivedi et al. 2021).

Manufacturing systems are becoming more and more expensive these days. On the one hand, manufacturers are looking for practical ways to reduce typical production line issues including bottlenecks and wait times (Dieste et al. 2021, Lal Bhaskar 2020, Oluwagbemiga et al. 2014, Rounaghi et al. 2021). However, businesses are working to maintain their competitiveness by reducing bottlenecks, lowering overall costs, and boosting productivity [21]. Various approaches can be used to address various industrial issues that impact the productivity of the production system in order to accomplish these aims. Computer simulation is a useful method that has been used to evaluate different industrial performance improvement procedures in an attempt to boost productivity and eliminate bottlenecks (Mourtzis 2020, Thomas et al. 2022, Xu et al. 2016). Moreover, computer simulation has several advantages in a number of fields, such as robotic and electromagnetic systems, forming processes, building projects, manufacturing systems, and more (Ebrahimi 2019a, 2019b). These include shorter cycle times for processes, higher throughput, better use of resources, and lower costs (Mourtzis et al. 2014, Muratore et al. 2022). Since the 1950s, a variety of business issues have been addressed by computer simulation, which has improved productivity, decreased expenses, and raised profitability (Beese et al. 2019, Borrelli and Wellmann 2019). The public sector, manufacturing, and service industries are among the business sectors where simulation studies have been conducted (Loblay et al. 2023, Tlapa et al. 2022). Business games and flight simulators are two well-known examples of simulations, which are models that replicate reality (Hsu and Wu 2023, Ross and Gilbey 2023).

The ARENA program, a computer modeling tool, determines and evaluates the bottleneck and then suggests strategies to decrease it and boost output (Zahraee et al. 2014). The efficiency of the color industry production line depends on a number of elements, and the relative importance of each is assessed using computer modeling and experiment design (Zahraee et al. 2014). Through the use of arena simulation software, industrial companies may boost productivity, locate bottlenecks in their processes, enhance logistics, and assess possible process modifications (Dias et al. 2022). Warehouse, distribution, task routing, inventory control, process flow, packaging systems, and personnel needs may all be modeled and examined with Arena (Nur Aizat Ahmad et al. 2022). Coordinating several process processes to operate as efficiently as possible is necessary for a plant to operate successfully. Reduced plant throughput, greater off-grade material, and increased work-in-progress are all possible outcomes of an uneven production line (Rashidifar 2021, Said and Ismail 2013). Inefficient logistics can also raise expenses when production has to halt because of storage space or resource limitations (Katsaliaki et al. 2022, Paul et al. 2019). Throughput may be increased and expenses can be decreased by using simulation to optimize plant processes (Chen and Bollas 2018). There are numerous features that make using Arena software appealing to researchers, such as the ability to quickly, easily, and intuitively build a manufacturing process flow, drag and drop elements and structures to create simulations, and visualize results (Allen 2011). The integrated dynamic dashboards of Arena offer the necessary model analysis to support industrial optimization, and the engaging 2D and 3D animation features don't require programming help (Allen 2011). Researchers can gain a better understanding of the process by utilizing Arena to create customized model information presentations (Allen 2011). Arena software is a suitable tool for simulating the production line of a plastics industry in this project. The main objective is to use Arena software to create a simulation of the whole manufacturing line and calculate the rate of performance improvement.

2. MATERIALS AND METHODS

2.1 Materials

The plant system is optimized in this study using the company's report, and data analysis for the plant system's performance enhancement was done using Arena software.

2.2 Methods

The primary objective of this research project is to increase the plastic manufacturing system's efficiency. The study evaluated the writings of numerous writers to offer further details and explanations about the use of plastic manufacturing systems and the various challenges that arise during the plastic production process. According to the research, several issues have prevented plastic production equipment from operating at maximum efficiency. Optimizing the plastic production system's performance is the study's primary goal.

The study utilized the report provided by a plastic industry to perform the analysis. This report covers the performance aspect of the plastic manufacturing workflow procedures, including installed capacity, actual capacity, labor force, type of material handling equipment, material feeding mode, number of machines used, number of products produced, storage location, and many other details. The research was aware of the location and activities of the plant since it updated its report and operational point where constraint variables impact plastic manufacturing performance optimization. The study identified the material dispatching pattern along the production line as the bottleneck after carefully examining the plastic company's report and observing the production activities and processes. The transporter as a material dispatching process was found to be delaying productions rate as demand increase. The study utilized Arena Free to analyze and determine the level at which the system's performance improved.

2.2.1 Plastic recycling production process

The plant system's procedure diagram for recycling plastic is displayed in Fig. 1. The methods are linked to the strategic approach utilized to accomplish the objective. In the plant system recycling process, raw materials are delivered, loaded, sorted, de-sanded, and separated by magnetic means, stored, dried, separated by floating, cleaned, chopped, and crushed, melted under pressure and heat, filtered, impurities removed, molded, and final plastic products. After plastic chips are melted and processed, two techniques are used in the plant system to generate the necessary shape for plastic production: injection molding and extrusion molding. A transporter is a machine that transfers goods from one place to another. Because of the material movement bottleneck, conveyors were considered for best performance in the optimization process. from one stage of the manufacturing process to the next.

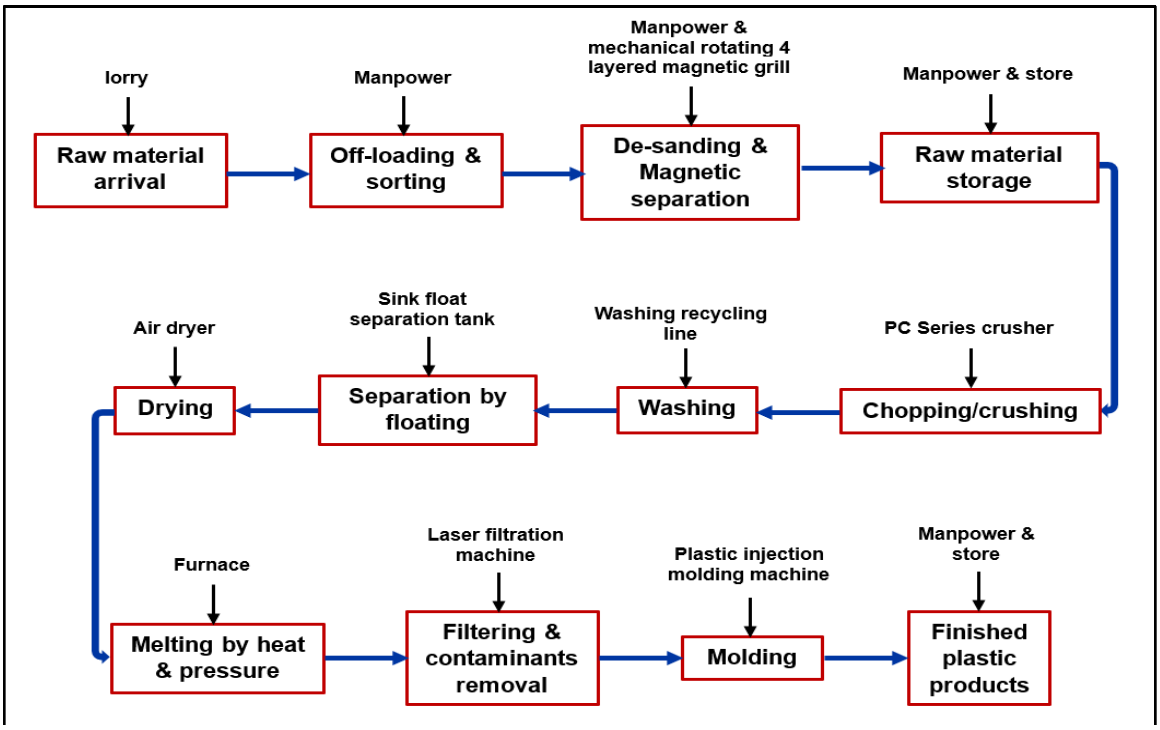

Fig. 1. Plastic recycling production process flow chart (Conceptual design)

2.2.2 Modeling framework

The modeling framework uses five key processes to develop simulation models for plastic recycling in ARENA-Free. The model architecture follows the steps shown in Fig. 2.

2.2.3 Plant layout DESIGN

Fig. 3 dissipates the plant layout design of the plastic recycling company. The layout design houses all the production processes sections as seen in the Fig. 3. The company's principal products include spoons, chairs, plates, and tables. The developed, optimized plant layout operates on an automated conveyor system instead of the conventional transporter system (hand trolley).

2.2.4 Company's report and proposed factors for optimization process

The company's report describes the plant mode activities in Table 1. The table reveals the number of workers, material conveying equipment, material handling effectiveness, storing material transporting equipment, feeding material, in-between process distance, transporting equipment velocity, and in-between process distance time coverage.

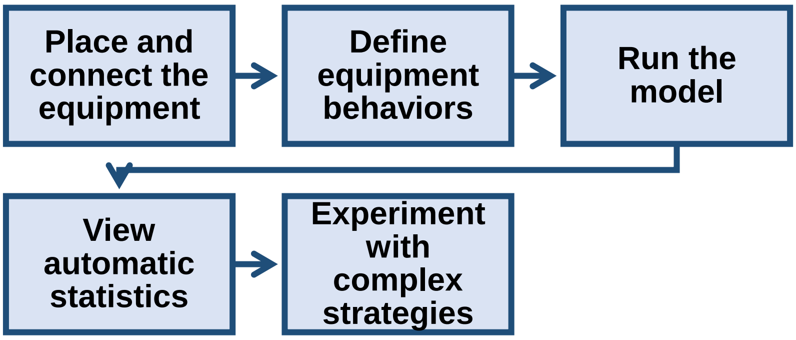

Fig. 2. Modeling framework

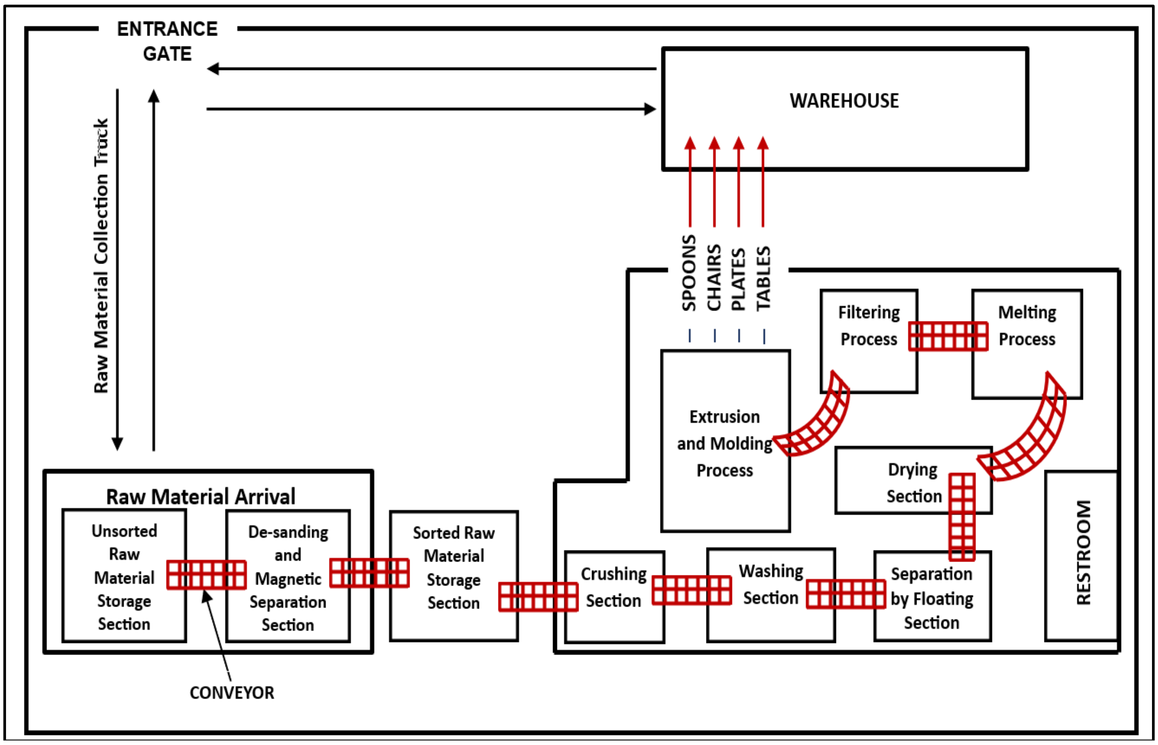

Fig. 3. Plant layout design

Table 1. Company's report and proposed factors for optimization process

Category	Description	Proposed factor for optimization
Number of workers	60	Maximum of 30
Materials conveying equipment	Hand trolley	Conveyor
Material handling effectiveness	Not optimized	Requires optimization
Store material conveying equipment	Hand trolley	Forklift
Feeding material	Manual	Automatic
In-between process distance	15m	7m
Conveying equipment velocity	Hand trolley (35m/mins)	Conveyor (50m/mins)
In-between process distance time coverage	0.428mins	0.14mins

Table 2. Processing time data from the company's report

Process	OSS	DMSP	RMSP	CP	WP	SFP	DP	MP	FCRP	MoP
Time (sec)	300	720	240	180	180	119	180	180	180	360

After being optimized for performance improvement, the evaluation for the report projects the best category that will affect others positively, thereby achieving optimal performance at a moderate cost. Therefore, conveying equipment was selected for optimization, which will reduce the number of workers, optimize the system, minimize the manual handling process, and reduce the distance, time & velocity between processes. Table 2 shows the processing time data from the company's data while Table 3 shows the assigned time and distance for each process for conveyor and transporter.

3. RESULTS AND DISCUSSION

The results were obtained by duplicating and constructing two production systems that used conveyors and haulage. ARENA Free modeled the proposed plastic recycling company system, taking conveyors and transporters into account, and the results were generated and analyzed. The study conducted on the company's report indicates that the transports run at a 35m/min velocity. The optimization procedure employs an automatic conveyor whose speed rate can be increased or decreased based on the operational process and strategies considered in the system's restrictions. The conveyor velocity is fixed constantly at 50m/min. The ARENA simulation runs at 1000hrs, which conforms with the work of (Oljira et al. 2020).

The simulation performed utilizing the conveyor and transporter system indicates that the queue formed is significantly higher in the transporter than in the conveyor, and this results in higher processing time in the transporter than in the conveyor, which conforms with the work of Lorou et al. (2021).

3.1 Plant System Design

ARENA mimics and develops the system for optimal simulation using the plant layout design, production process paths, equipment, and time and distance, and this conforms with the work of John & Joseph (2013), stating that only the properly laid out plant can ensure the smooth and rapid movement of material, from the raw material stage to the end product stage. Constraining the Arena design utilizing the appropriate input variables, including time, space, and velocity, helps to increase the performance of the working process by obtaining a steady flow with minimum waiting time, which conforms with the work of John & Joseph (2013). Fig. 4 shows the plant system design utilizing ARENA.

Table 3. Assigned time and distance for each process for conveyor and transporter

Processes	Transporter					Conveyor				
	Dist. (m)	Time (hrs.)				Dist. (m)	Time (hrs.)			
		Process in-between distance time	Entity discharging time	Entity processing time	Total time		Process in-between distance time	Entity discharging time	Entity processing time	Total time
OSS Leave 1	0	0	0	0.0833	0.0833	0	0	0	0.0833	0.0833
DMSP Enter 1	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
DMSP Leave 2	0	0	0	0.2	0.2	0	0	0	0.2	0.2
RMSP Enter 2	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
RMSP Leave 3	0	0	0	0.0667	0.0667	0	0	0	0.0667	0.0667
CP Enter 3	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
CP Leave 4	0	0	0	0.05	0.05	0	0	0	0.05	0.05
WP Enter 4	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
WP Leave 5	0	0	0	0.05	0.05	0	0	0	0.05	0.05
SFP Enter 5	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
SFP Leave 6	0	0	0	0.033	0.033	0	0	0	0.033	0.033
DP Enter 6	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
DP Leave 7	0	0	0	0.05	0.05	0	0	0	0.05	0.05
MP Enter 7	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
MP Leave 8	0	0	0	0.05	0.05	0	0	0	0.05	0.05
FCRP Enter 8	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
FCRP Leave 9	0	0	0	0.05	0.05	0	0	0	0.05	0.05
MoP Enter 9	15	0.0071	0.0011	0	0.0082	7	0.0023	0.0011	0	0.0034
MoP Leave 10	0	0	0	0.1	0.1	0	0	0	0.1	0.1

N/B:

1. *The entity processing time for the processes as populated are data gotten from the company’s Process Supervisor during an interview carried out.*
2. *The uniform process in-between distance time for the transporter is measured from the company’s plant machine layout diagram.*
3. *The uniform process in-between distance time for the conveyor is part of the optimization process innovation.*

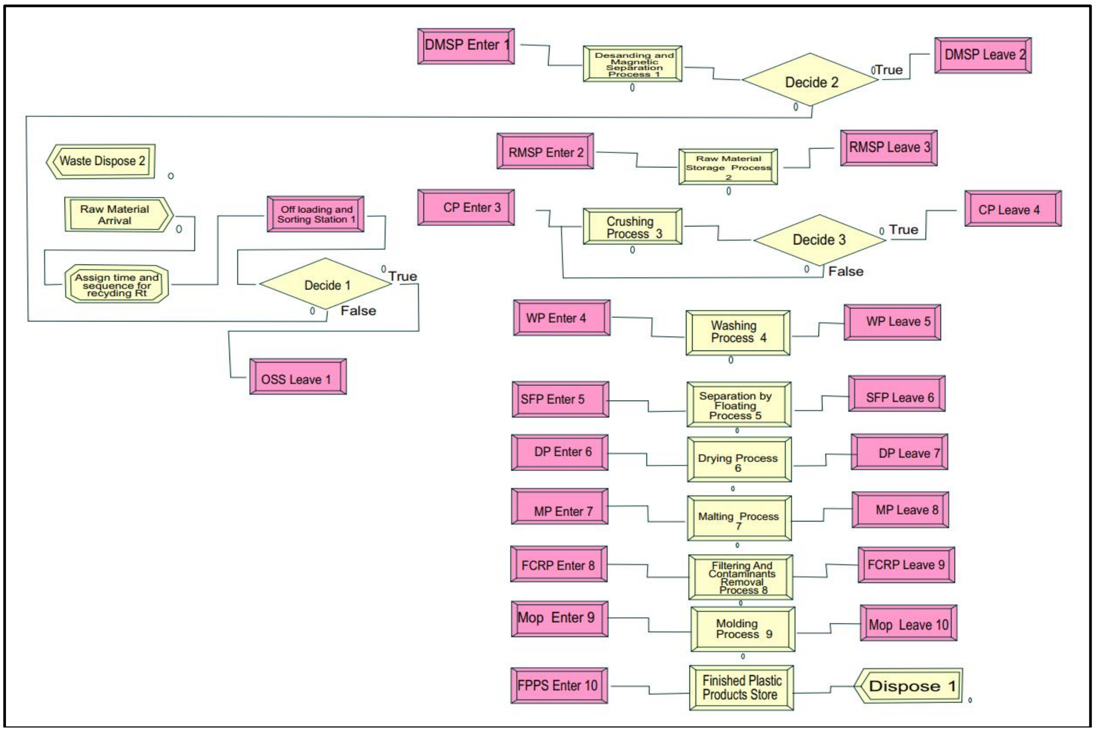

Fig. 4. ARENA plant system design

The modified plant system design involves the introduction of a conveyor system as a means of transportation of materials under the production stage from one process to another. Introducing the conveyor system in the new plant production processes will reduce distances between each process because there will be no human transporting materials under the production process from one point of the production process to another. The distance reduction significantly impacts the system, including reducing the time products are being formed and the cost reduction of acquiring unnecessary lengthy conveyor trains. Reducing the production line distance between processes increases the number of products created by increasing production speed and reducing unnecessary costs generated by installing conveyor trains that convey materials from one production process to another in the production system, which conforms with Adinarayanan et al., (2021) stating that distance traveled by the parts increases which in turn increase the time of production for each product. Hence, reduced productivity and the flow of components will not be smooth. Conveyor systems streamline production by efficiently transporting materials between different stages of the manufacturing process. This reduces the physical distance that materials need to travel, which in turn minimizes the time and effort required for manual handling. By automating the movement of goods, conveyor systems enhance productivity, reduce labor costs, and decrease the risk of damage or loss during transit. This efficiency is crucial because it leads to faster production cycles, lower operational costs, and improved overall workflow. In a competitive market, these advantages can significantly impact a company's ability to meet demand and maintain profitability. Plus, reducing manual handling also enhances workplace safety, which is always a win. Conveyor systems can sustain the required consistent output rate since they are automated machines rather than human-driven transporters that may become tired while in use.

3.2 Work in Progress & Entity (In & Out)

Fig. 5 and Table 4 show the detailed explanation and chart of the number of entities still under production in the system considering the conveyor and transporter. The figure shows that work-in-progress for the transporter is slightly higher than for the conveyor because utilizing the conveyor in production doesn't take time, considering the constant process and velocity at which it moves material in the production channel (Ji et al. 2021). Due to the conveyor's minimum WIP due to high constant speed and operation, the entity in and out for the conveyor increases more than the transporter, as represented in Fig. 5.

Table 4. Work in progress and Entity (in & out) representation for conveyor and transporter

Category	Work In Progress (WIP)		Entity	
	Average	Maximum	Entity In	Entity Out
Conveyor	14.1364	26	1045	1027
Transporter	14.2476	32	953	929

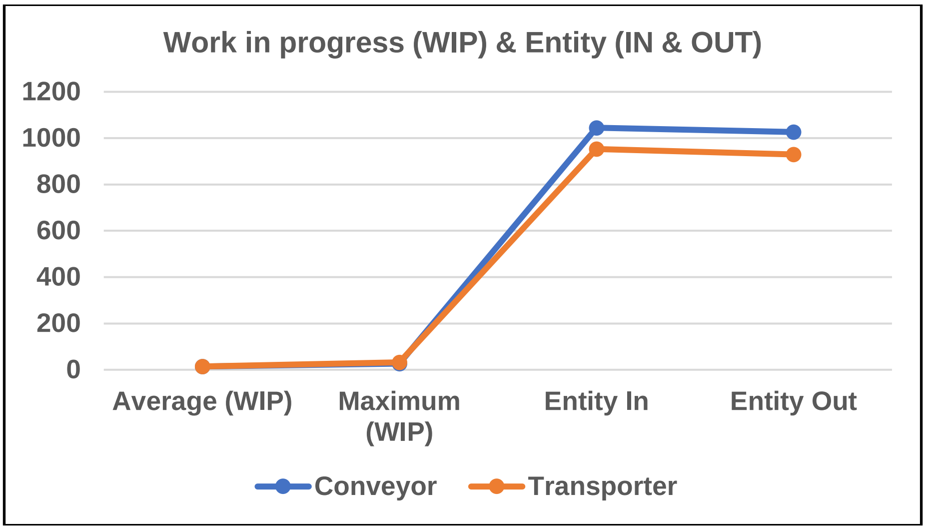

Fig. 5. Work in progress & entity (in & out)

3.3 Material in and Out Evaluation (Result Validation)

Fig. 6 and Table 5 show the entity in and out chats and production process values. The material that enters, processed, and leaves during the production process using a conveyor as a source of movement is much higher than that of a transporter. This process shows that the system was well-optimized. Utilizing a conveyor to transport materials in the production processes will increase performance by improving the quality and quantity of products formed, which conforms with the work of Kawalec et al. (2020) and Bashir et al. (2022), stating that conveyors can improve the quality and quantity of recycled materials. There will be a reduction in human resources and costs invested in laborers. The validation of the results shows that the system is running at its optimal performance with the aid of a conveyor as a source of material movement along the production processes formed, which conforms with the work of Kovalchuk & Poddubniy (2019), stating that the most optimal solution to these problems is the use of long conveyor lines for transportation because Traditional motor vehicles (transporter) is quite expensive, have issues with reliability and leads to extensive gas pollution of the atmosphere, as well as the associated necessary stoppages, which in turn leads to high economic costs. The conveyor process, which runs at a higher velocity than the transporter, contributes to the high yield of the entity in and out. During production, the conveyor system can run continuously for days without causing disruption or interference in the production system. When a conveyor system processes more materials in a given time frame, it showcases system optimization in several ways. First, it indicates that the system is operating efficiently, with minimal downtime and maximum throughput. This means that the conveyor is effectively moving materials from one stage of production to the next without unnecessary delays or bottlenecks. Second, increased processing capacity often results from improved coordination between different parts of the production line. This synchronization ensures that each stage of the process is ready to receive materials as soon as they arrive, reducing idle time and enhancing overall productivity. Regular maintenance keeps the conveyor system in optimal condition, preventing breakdowns and ensuring smooth operation. Effective management practices, such as monitoring performance metrics and making data-driven adjustments, further contribute to the system's efficiency. The increased quantity of processed materials demonstrates that the conveyor system is well-optimized, leading to faster production cycles, reduced operational costs, and improved overall efficiency.

3.4 Throughput Time Evaluation

At a constant entity input production rate without considering the time utilized in moving the materials along the production process, the transporter is higher than the conveyor in the value-added, waiting, and transfer time. In contrast, the conveyor is higher than the transporter during the process of non-value-added time. Considering the total time of value-added, non-value-added, wait time, and transfer time, the transporter is much higher, as shown in Fig. 7 and Table 6.

3.5 Whole System Queue Waiting Time

Fig. 8 shows the whole system queue waiting time comparative analysis for the conveyor and transporter. The system shows that waiting time is higher in transporters than in conveyors due to the minimum speed in transporting materials non-uniformly from one production channel to another. The effect of waiting time is significantly affected by the material leaving each production stage. The conveyor has more queues from DP to MoPL and SFPL to WPL. In the transporter, the total waiting time is 40.1497, while that of the conveyor is 31.9082.

3.6 Accumulated Value-Added Time

Fig. 9 and Table 7 depict the dissipation of cumulative value-added time. Accumulated value-added time is the accumulated time of an entity in processes and delays. The speed variation at which both transporter and conveyors move the materials from the input to the output shows that the conveyor has more significant accumulated value-added time than the transporter. The conveyor runs at a constant higher speed than the transporter, processing more materials at every process than the transporter. The amount of human strength necessary to power transporter movement limits the transporter's speed rate; as a result, the value-added time suffers due to this constraint. Considering the conveyor, which runs at a constant speed, powered by the machine, it yields a higher accumulated value-added time. However, some restrictions like machine breakdown, power supply, and many more can negatively alter its performance, but its efficiency is higher than that of the transporter.

Table 5. Material in & out using conveyor and transporter

Entity		**Material In & Out**								
Category		**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**SFP**	**WP**	**RMSP**
Conveyor	**In**	873	917	854	851	852	850	859	855	856
	Out	872	910	852	850	851	849	858	854	855
Transporter	**In**	865	846	811	808	810	806	821	813	814
	Out	860	840	810	806	808	804	819	811	813

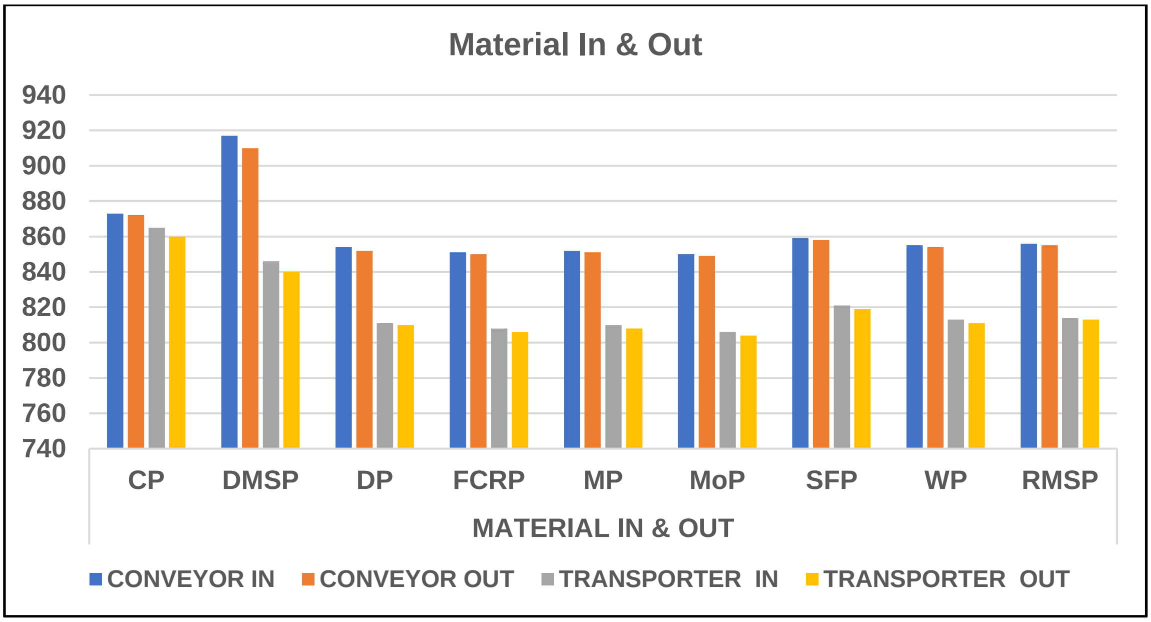

Fig. 6. Material in & out using conveyor and transporter

Table 6. Time evaluation for conveyor and transporter

Category	VA Time		NVA Time		Wait Time		Transfer Time		Total Time	
	Average	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Conveyor	7.3370	11.3411	0.8297	1.4780	5.3987	16.6340	0.04253625	0.3363	13.6079	26.9266
Transporter	8.8725	12.8335	0	0	6.1605	28.5775	0.07229099	0.08333333	15.1053	39.6621

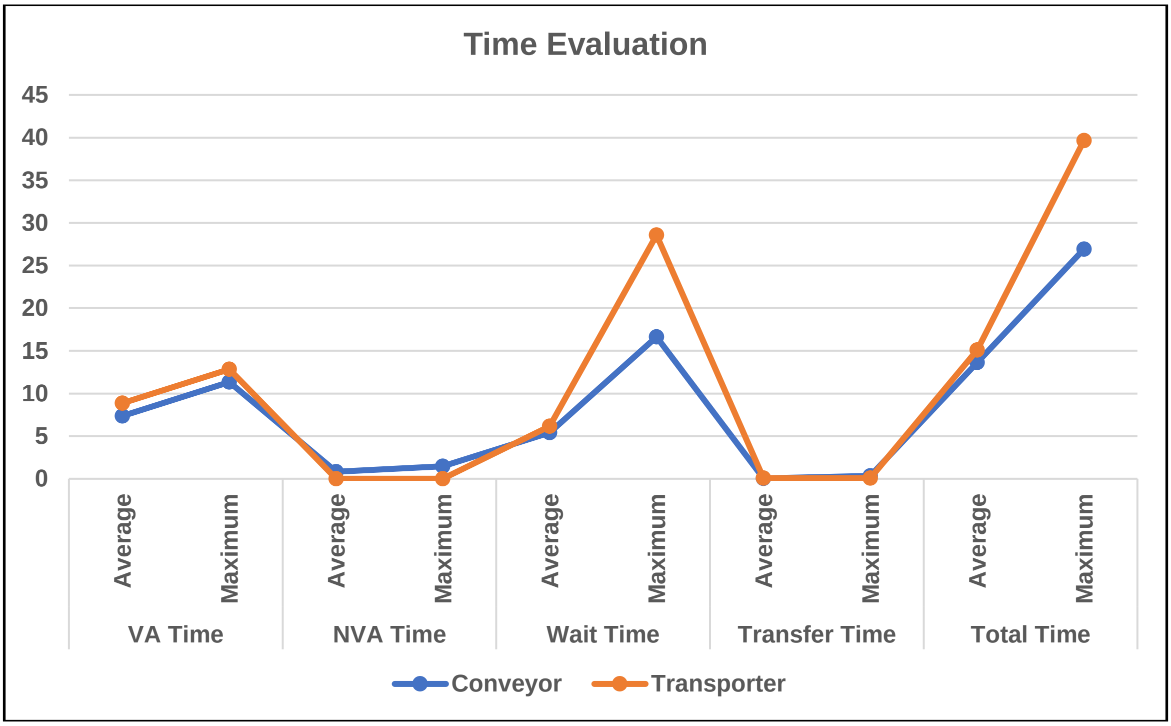

Fig. 7. Time evaluation for conveyor and transporter

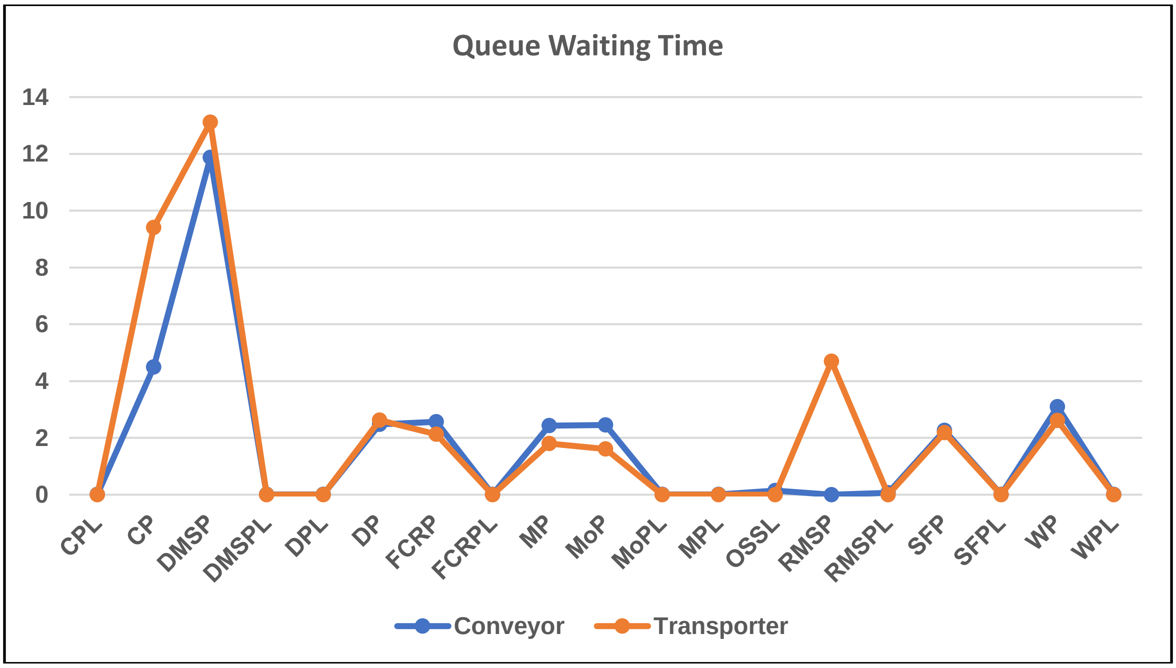

Fig. 8. Queue waiting time

Table 7. Accumulated value-added time

Entity	**Accumulated Value-Added Time**								
CATEGORY	**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**SFP**	**WP**	**RMSP**
Conveyor	865.52	903.20	850.42	852.74	848.96	852.58	839.12	865.35	860.54
Transporter	852.67	833.54	807.73	815.32	801.53	790.44	811.97	813.78	819.83

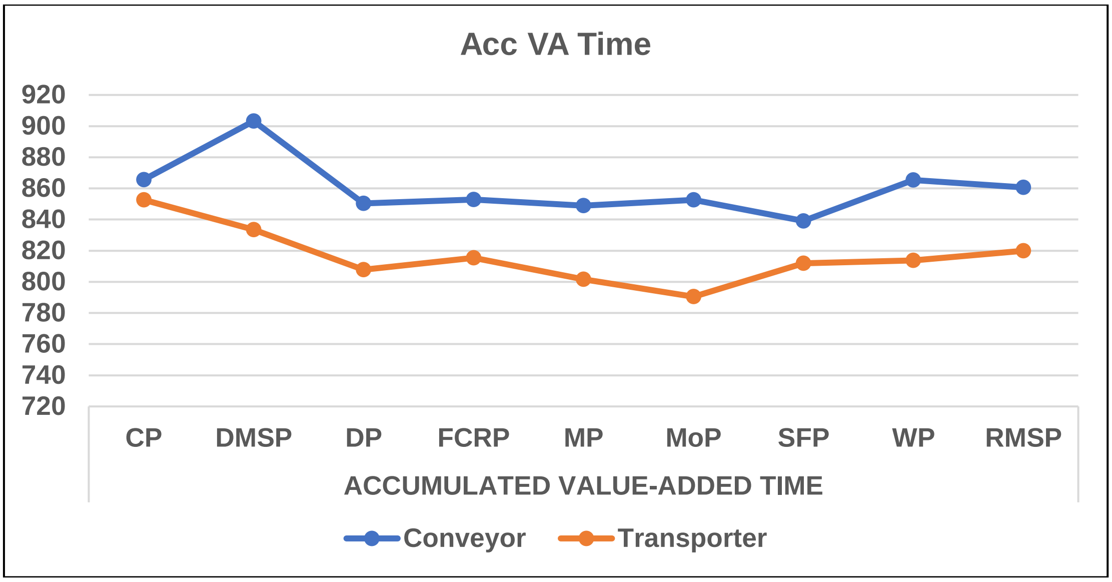

Fig. 9. Accumulated value-added time

Table 8. Accumulated wait time

Entity	**Accumulated Wait Time**								
CATEGORY	**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**RMSP**	**SFP**	**WP**
Conveyor	655.47	3244.12	330.15	235.70	275.66	240.32	0	226.22	409.04
Transporter	1626.93	2316.71	302.58	216.78	178.96	134.33	505.60	227.77	308.25

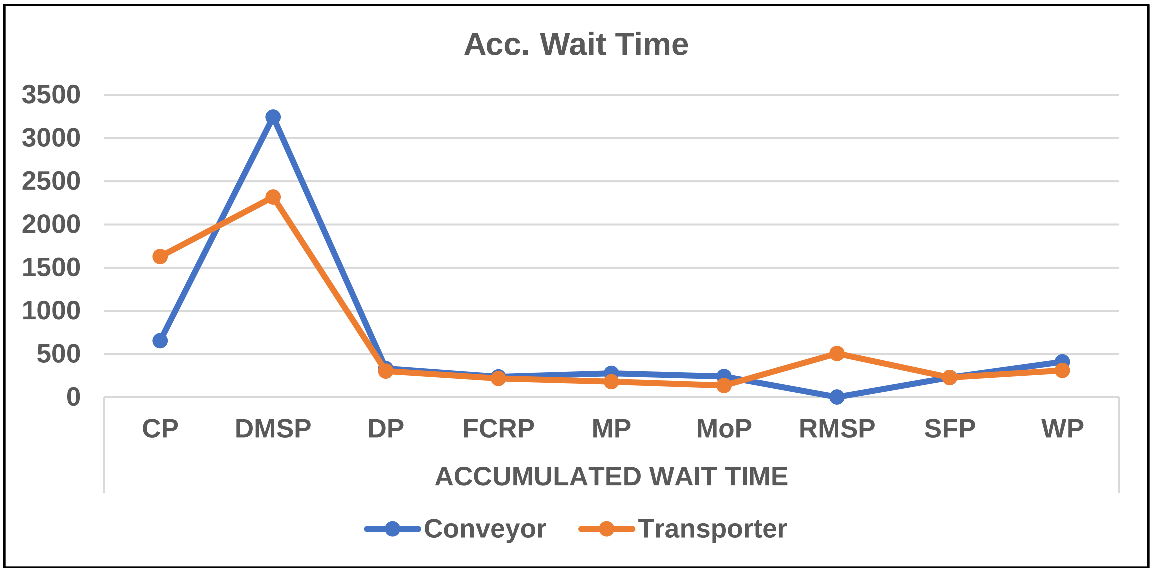

Fig. 10. Accumulated wait time

3.7 Accumulated Wait Time

Fig. 10 and Table 8 show the accumulated wait time for all production processes for both conveyor and transporter. The accumulated wait time for the conveyor system of each production process is higher than that of the transporter except in CP and RMSP, and this is because of the high speed and shorter distance at which the conveyor conveys materials to the processing machines. The conveyor moves more materials than the transporter, resulting in a higher accumulated wait time than the transporter. The accumulated wait time shows that the conveyor system produces more products than the transporter system.

3.8 Entity Value-Added Time for Conveyor and Transporter

Fig. 11 and Table 9 clearly explain entity value-added time for the conveyor and transporter system. The variation in the value-added time of the two systems is similar because the value-added time does not consider the mode of transporting the material up to the processing point. The entity value-added time only examines the activities happening in the machine, of which both the conveyor and transporter system utilize the same production machine during production. Therefore, the value-added time will remain relatively higher with the transporter than the conveyor, even when considered average. The entity value-added time does not consider the entrance and the leaving process. Moreover, it only examines what happens inside the process per input, and the transporter tends to have more materials per input than the conveyor.

3.9 Wait Time Per Entity of Conveyor and Transporter

Table 10 and Fig. 12 dissipate a distinct clarity on the wait time per entity. Considering the wait time per entity, the transporter system is slightly higher due to its extensive material inserted in the production machine for processing, unlike conveyors that do not insert up to that quantity compared to the transporter in the production machine. In not considering the entering and leaving medium, the transporter system has a longer wait time than the conveyor, considering only the quantity of the material inserted in the production machine. Moreover, the conveyor is an automated system that can be structured to carry a particular amount, and it is that quantity that enters the machine, considering its placement and positioning on the conveyor tray. The amount that enters the manufacturing machine for each input, rather than the quantity queued up on the conveyor tray or the move, is typically utilized to estimate the wait time per entity. Therefore, the transporter inserts slightly more material per entity, which results in a higher wait time.

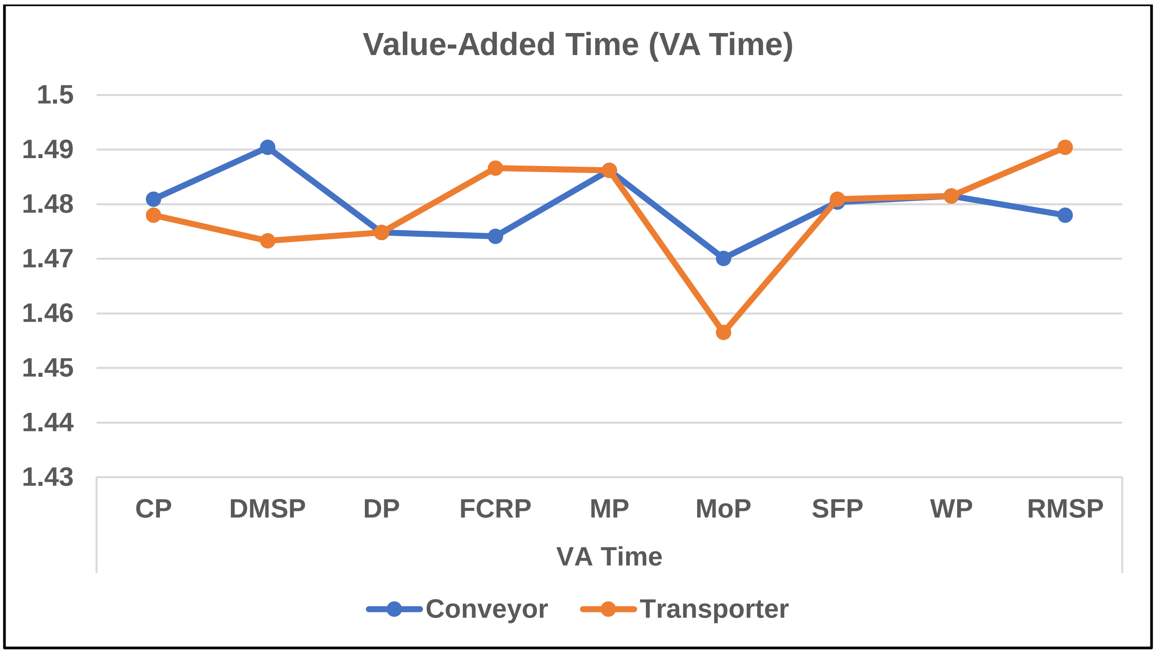

Fig. 11. Entity value-added time

Table 9. Entity value-added time for conveyor and transporter

Entity	Value-Added Time								
CATEGORY	**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**SFP**	**WP**	**RMSP**
Conveyor	1.4809	1.4904	1.4748	1.4741	1.4862	1.4701	1.4804	1.4815	1.4780
Transporter	1.4780	1.4733	1.4748	1.4866	1.4862	1.4565	1.4809	1.4815	1.4904

Table 10. Wait time per entity of conveyor and transporter

Entity	Wait Time								
CATEGORY	**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**SFP**	**WP**	**RMSP**
Conveyor	4.4936	11.8697	2.4808	2.5630	2.4313	2.4516	2.2570	3.0904	0
Transporter	9.4024	13.1087	2.6230	2.1245	1.8016	1.6070	2.1789	2.6097	4.6939

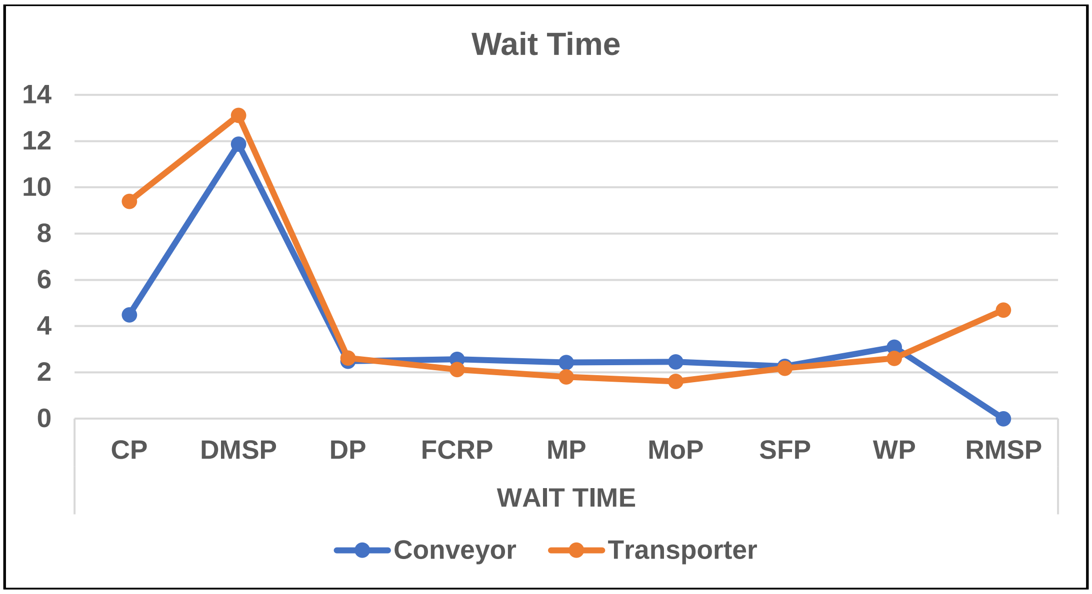

Fig. 12. Entity wait time

Table 11. Entity total time

Entity	Total Time								
CATEGORY	**CP**	**DMSP**	**DP**	**FCRP**	**MP**	**MoP**	**SFP**	**WP**	**RMSP**
Conveyor	5.4287	12.5159	3.3637	3.7118	3.4026	3.7101	3.2396	4.1455	1.4780
Transporter	10.3453	14.0096	3.6695	3.2779	2.6982	2.8296	3.3160	3.7325	5.6922

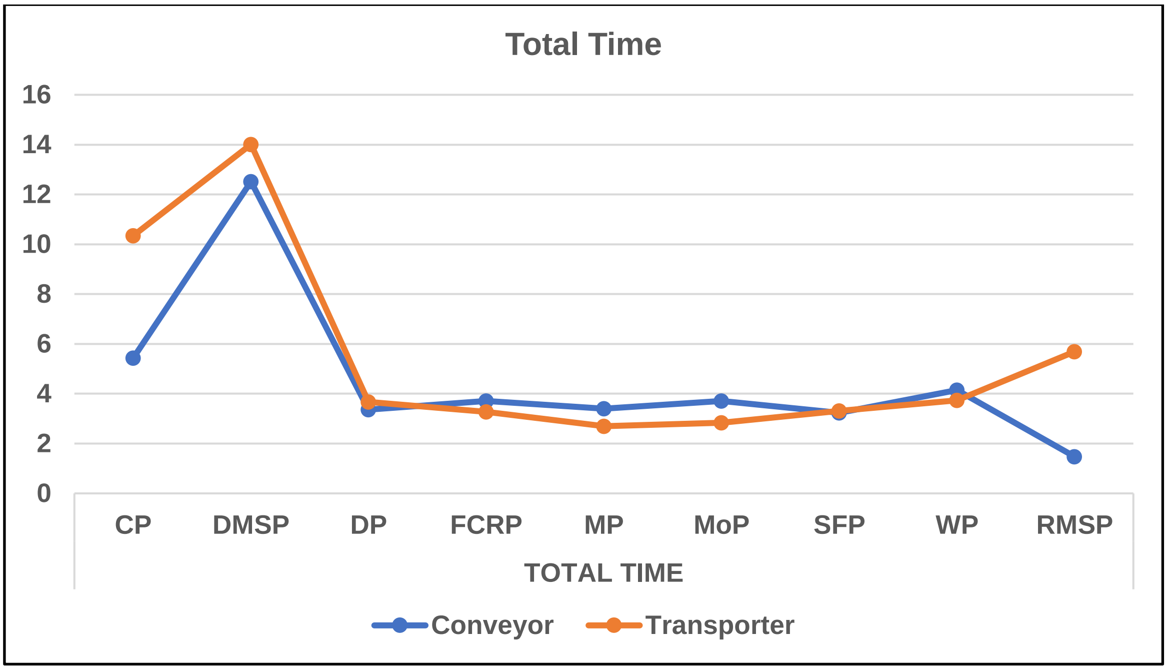

Fig. 13. Entity total time

3.10 Entity Total Time

Table 11 and Fig. 13 clearly understand the entity's total time. As shown in Fig. 13, the entity's real-time includes VA, NVA, wait time and transfer time. In terms of overall time per entity, the transporter system is slightly faster due to the amount of material placed in the manufacturing machine for processing, as opposed to conveyors, which do not insert as much material as the transporter. The transporter system has a longer total time than the conveyor when only considering the quantity of material inserted in the producing machine. Furthermore, the conveyor is an automated configured system that carries a specific amount, and it is the quantity that enters the machine, considering materials placement and positioning on the conveyor tray. The quantity entering the manufacturing machine for each input, rather than the amount queued up on the conveyor tray or the move, is frequently utilized to measure wait time per entity. As a result, the transporter inserts slightly more material into each entity, increasing overall duration.

3.11 Cost analysis

Output

After completing a recycling process that lasted 1000 working hours, the optimized and unoptimized processes revealed that the conveyor process had 1045 and 1027 entity input and output, respectively, and the transporter process had 953 and 929 entities input and output. Upon comparing the number that entered the system with the number that exited, the system discarded the residual number that remained after the sorting and demagnetization procedure.

Cost percentage implication on production in the optimized system over 1000 hours is gotten as:

$$\frac{Total\ number\ of\ conveyor\ over\ 1000hrs - \ Total\ number\ of\ output\ of\ transporter\ over\ 1000hrs}{Total\ number\ of\ output\ of\ transporter\ over\ 1000hrs} \times 100$$

$$\%\ product\ increament\ was\ gotten\ from\ the\ optimized\ process$$

$$\frac{1027 - \ 929}{929} \times 100\% = 10.549\%$$

The introduction of the conveyor brings 10.549%. increase in the production rate The percentage increment of the system can further be increased due to the speed control factor of the conveyor system as an automatic process by increasing the speed of the conveyor system, which will increase the number of the output of the products formed.

N/B: Because some input materials in-process went to disposal, utilizing the input factors will not produce the desired outcome. Furthermore, the availability of sufficient raw resources contributed to the limitation of using input factors.

Labor

$$\frac{Total\ number\ of\ labor\ in\ transporter - Total\ number\ of\ labor\ in\ coveyor}{Total\ number\ of\ labor\ in\ transporter} \times 100\%$$

$$Labor\ of\ Transporter = 60$$

$$Labor\ of\ Conveyor = 30$$

$$Reduction\ in\ Labor = 60 - 30 = 30$$

$$\frac{30}{60} \times 100\% = 50\%$$

$$Therefore\ we\ have\ 50\%\ decrease\ on\ expenses\ spent\ in\ labor$$

Plant layout space reduction

Conveyor system installation will free up more space for additional production-related equipment, increasing output and, consequently, the company's profit. The surplus profit will pay the cost of the conveyor.

Percentage improvement in production rate achieved by optimizing the conveyor speed

Percentage improvement in production rate achieved by optimizing the conveyor speed was conducted from Table 6.

Total average time of production for conveyor (t_1)

$$t_1 = 13.6079\, mins$$

Total average time of production for transporter (t_2)

$$t_2 = 15.1052\, mins$$

$$\%\, improvement\ in\ production\ rate\ = \frac{t_2 - t_1}{t_2} \times 100\%$$

$$\%\, improvement\ in\ production\ rate\ = \frac{15.1053 - 13.6079}{15.1053} \times 100\%$$

$$\%\, improvement\ in\ production\ rate\ = 9.913\%$$

Factors that can affect production speed include increase in conveyor speed, increase in the number of workers and decreasing the distance between processes.

Adjusting any of the following factors mentioned above will affect the production rate of the plant. The optimal manufacturing process must be preserved when increasing the conveyor speed, which requires consideration of other factors including production cost and safety. It is important for production organizations to realize that the faster a process is performed, the less safe it is, and the higher the risk (He et al. 2018, Ji et al. 2020). Furthermore, a quicker manufacturing process would need more supervisors and thorough maintenance protocols, both of which would inevitably raise production costs (Ji et al. 2021, Kupkovits et al. 2017, Zhou et al. 2023). Finally, it is necessary to raise the conveyor speed in a way that maintains the plant's maximum output.

4. CONCLUSION

This research investigates performance improvement of the plastic recycling process. The performed optimization of the production system considered the mode of moving materials from one point in the production process to another. The materials transporting system introduces a conveyor as a new form of transporting material from one point in the production process to another instead of using a transporter (hand trolleys).

The results and discussion of the analyses draw the following conclusions:

1. The plastic recycling process's production structure has improved and eliminated constraints restricting the efficiency of the material transport system. The conveyor system increases system flexibility and efficiency for optimum production.
2. The simulation using the conveyor and transporter system shows that the queue formed in the transporter is significantly higher than in the conveyor, resulting in a longer processing time in the transporter than in the conveyor.
3. The optimization approach uses an automatic conveyor whose speed rate can be increased or decreased based on the operational process and strategies considered in the system's constraints. The conveyor velocity maintains a lock at 75m/min, despite the company's report stating that the transports run at 30m/min.
4. The optimized and unoptimized processes when obtained from a finished recycling process running for 1000 working hours, indicate that the conveyor process had 1045 and 1027 entity input and output, respectively, and the transporter process had 953 and 929 entities input and output respectively. The remaining number left when considering the number that enters the system with the number that leaves the system went to waste, resulting from the sorting and demagnetization process.
5. The data validation shows that the system is performing optimally with the help of a conveyor as a source of material movement along the production processes. The amount of material that enters

production processes and exits during manufacturing when using a conveyor as a source of material transporting is substantially more significant than that of a transporter. This procedure demonstrates that the system was well-optimized. Using a conveyor to carry materials in manufacturing improves performance by increasing the quality and quantity of products formed, which conforms with the work of Kovalchuk and Poddubniy (2019), stating that the most optimal solution to these problems is the use of long conveyor lines for transportation because Traditional motor vehicles (transporter) is quite expensive, have issues with reliability and leads to extensive gas pollution of the atmosphere, as well as the associated necessary stoppages, which in turn leads to high economic costs.

6. There will be a significant reduction in human resources, which will invariably lead to a decrease in labor expenditures and overall run cost of the recycling process over a long period, according to Taneepanichskul et al. (2022) and Pati & Majumdar (2020), who state that Conveyors can reduce labor costs by up to 50% when compared to transporters, and low labor and low energy requirements are fundamental with belt conveyors when compared to other.
7. Optimization involves reducing space, which can lead to space availability to develop more plants and install more equipment and warehouse space.
8. Conveyors are a very safe process that supports goal zero (zero-incident) as a safety yardstick for measuring the safety of a production process due to a reduction in human labor conveying material from one production process to another, and this aligns with Mahajan et al. (2020) who state that conveyors can improve the safety and efficiency of recycling operations by minimizing human exposure to hazards and optimizing material flow.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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