Improving Material Handling System Performance of a Toy Manufacturer Using Simulation

O.D.B. Mallawa Arachchige
Department of Manufacturing and Industrial Engineering
University of Peradeniya
Sri Lanka.
ovindidanuddara@gmail.com

S.P. Malliyawadu
Department of Manufacturing and Industrial Engineering
University of Peradeniya
Sri Lanka.
praveenasachini@gmail.com

C.D. Senanayake
Department of Manufacturing and Industrial Engineering
University of Peradeniya
Sri Lanka.
cds@eng.pdn.ac.lk

***Abstract* — This paper presents a discrete event simulation-based analysis to optimize trolley management at a leading toy manufacturer in South Asia. We address one of the many challenges faced by the toy industry, i.e., efficiently managing material handling equipment (trolleys). The paper explores an optimization approach for trolley management through the identification of critical items, clustering of sub-articles, and standardization of stacking methods. We develop simulation models to evaluate the performance of these optimized trolley management strategies. Comparison of the proposed methods with current strategies show that significant improvements can be realized in production efficiency and trolley utilization, reducing congestion and enhancing overall operational performance. The findings underscore the importance of simulation-based approaches in refining material handling processes and achieving long-term sustainability in manufacturing operations.**

Keywords— Material handling, Optimizing, Simulation, Trolleys

I. Introduction

Toy manufacturers commonly use batch manufacturing techniques. Most wooden educational toys are assembled from various components and require processes such as woodworking, painting, drying, and finishing. In this process, batches of materials are transported between different sections of the factory using material handling equipment. In the factory being examined, trolleys are employed for this purpose. These trolleys not only transport materials but also serve as temporary storage after painting, allowing the painted parts to dry. Given the toy industry's complex production processes and wide range of products, managing material handling trolleys effectively presents a challenge. Poor management of these trolleys can lead to operational inefficiencies and quality issues for the company.

The use of trolleys for material transport is commonplace in manufacturing settings, yet the optimal utilization and management of these resources often pose complex challenges. In the context of the company, the inefficiencies in trolley management have been identified as a bottleneck affecting their production flow and product quality. The company encounters difficulties in managing their trolleys during manufacturing operations due to a combination of a diverse product mix and constraints on available space for additional trolleys.

Inefficient management of trolleys primarily leads to high lead times, since final assembly/packing areas do not receive all the sub-articles for assembly on time. In addition, there was also frequently observed to be a lack of trolleys available. When there's a shortage of trolleys, employees' resort to manual handling, potentially causing defects in products as they touch them before the paint is fully dry. This manual handling poses additional risks, such as products falling and resulting in defects. Moreover, in the rush to quickly retrieve trolleys, workers may pass products without allowing sufficient drying time, introducing quality concerns. The lack of trolleys also intensifies employee workload, as they must actively search for them, contributing to a disorganized and busy workflow.

The inefficient trolley management problem stems from several factors. Firstly, there is a lack of standardized procedures for arranging articles in trolley trays, and there's uncertainty about the optimal capacity of each trolley for different products. Additionally, there is a deficiency in scheduling for the production of sub-articles, leading to unnecessary long waiting times for certain sub-articles as they linger in the trolley until the final assembly. Notably, in the packaging area, there is an accumulation of trolleys waiting at the inbound stock point.

The scope of this project encompasses the optimization of trolley management within the company's manufacturing processes. It includes the identification of critical items, classification of sub-articles into families, development of standardized procedures for arranging articles in trolley trays based on process behavior.

To enhance the material handling process, critical items were identified and a standardized stacking method was developed. Next, the number of trays per trolley was optimized. Simulation models were then created after studying the production process. Our results show that the improved strategies can significantly reduce the lead time and trolly utilization over existing ones. The implementation of optimized trolley management practices at the company promises a multitude of advantages across various facets of its operations. This enhancement will result in smoother workflows, minimized disruptions and improve performance.

II. Review of the Literature

The need for advanced material handling in manufacturing systems, noting that while the demand for sophisticated handling solutions has increased, universally applicable designs for material handling systems remain elusive [4]. This gap highlights the necessity for innovative approaches that are tailored to specific operational challenges.

Another study further emphasized the critical role of effective material handling in factory operations [6]. They highlight how efficient handling solutions impact several key areas, including production cycle times, inventory management, capacity utilization, and customer satisfaction. Effective material handling tools not only help minimize the risk of injuries but also streamline material movement, reduce product damage, and enhance overall product quality.

In 2021 discrete event simulation models were developed to understand the system, and identify inefficiencies [1]. Key data collected include the date, time, and location of pickups and drop-offs, as well as the type of cart carried by AGVs. A significant aspect of the study is the analysis of AGV movements along various routes, with the majority of movements concentrated only on two critical routes. These routes are scrutinized because they are major contributors to traffic congestion. By focusing on these critical paths, the study aims to optimize the selection of routes for AGVs, ensuring that critical items are delivered efficiently and congestion is minimized. This targeted approach helps streamline the material handling process, reduce delays, and enhance the overall efficiency of the system.

A novel approach was proposed in 2016 to optimize material handling through parts clustering [2]. Their research demonstrates that grouping frequently ordered parts closely within the storage area can significantly reduce travel distances for workers and minimize picking times. By considering total order frequency and strategically placing highly related part families together, their approach enhances efficiency. This principle of parts clustering can be adapted to optimize trolley management processes in manufacturing environments.

[5] explores how Simio simulation software can validate data models within automotive supply chains. It emphasizes the importance of accurate modeling and simulation for optimizing supply chain processes, including material handling and production scheduling. By demonstrating the use of Simio to create and validate detailed simulation models, the study highlights how such models can identify inefficiencies and bottlenecks, supporting data-driven decisions for process improvements. This approach is directly relevant to optimizing material handling, such as improving trolley management, by providing a framework to test and refine strategies before implementation.

III. METHODOLOGY

The optimization of material handling was achieved through a multi-faceted approach involving the identification of critical items via a Pareto chart, clustering sub-articles into families, standardizing stacking methods, optimizing the number of trays per trolley and validating results using simulation models.

A. *Identifying critical items*

To identify critical items, factors such as the number of sub-articles, the number of orders per period, volume of sub articles and the quantity of product per order were initially considered. Then a Pareto chart was constructed to prioritize critical items.

Considering the 80-20 rule, 21 articles were selected from a total of 2500 articles. From these selected articles, two major articles were chosen for modeling purpose and to illustrate further improvements, based on the quality level of the product and company requirements. Selected items are named as article A and article B which each contains 10 sub-articles and 40 sub-articles, respectively.

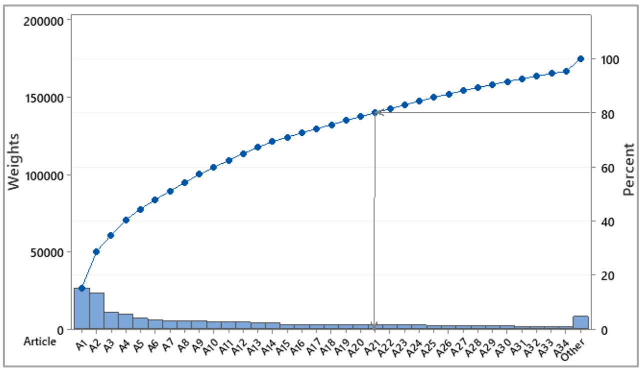


Fig. 1. Pareto chart for selecting critical items.

B. *Clustering sub-articles in to families*

The sub-articles within an article were systematically clustered into families based on their production behavior and the product characteristics. This categorization approach was aimed at simplifying material handling by grouping sub-articles.

Article A is classified into three families based on their processing paths, while Article B, having no difference in processing paths, is classified according to the colors of sub-articles. In the existing factory method, sub-articles are packed into trolleys one after the other, causing trolleys to accumulate in the packaging area. However, packaging cannot begin until all sub-articles belonging to the main article are present.

C. *Standardized stacking method*

Each trolley has several trays to stack the sub-articles. Measurements of both trolleys and trays were obtained to establish an understanding of the spatial constraints. Subsequently, a methodical approach was devised for stacking sub-articles onto trays. This method was based on maintaining minimum gaps between sub-articles (for drying purposes) while ensuring a minimum size for the border. By adhering to these criteria, space utilization was optimized, and ease of handling was facilitated, safeguarding the integrity of the sub-articles throughout the manufacturing process.

D. *Optimized number of trays per trolley*

The number of trays in a trolley was optimized considering specific conditions and constraints. These constraints included the height of the trolley, the maximum number of trays allowed per trolley, and the maximum and minimum number of sub-articles permitted on a trolley. Each trolley was designated to a single family of sub-articles, ensuring uniformity in the number of sub-articles carried in each trolley. This uniformity facilitated the assembly process, making it more organized and efficient.

IV. SIMULATION MODEL

The main steps conducted to develop the current simulation model are addressed here. The model was developed in Simio Simulation software, Academic Version R15. The first step consisted of developing the main production stages of the company. The Simio standard objects library was used to achieve this (Figure 02).

According to the above methodology, the data is provided to the Simio model to implement the proposed method. To compare the results, another Simio model was created to represent the existing method.

and the remaining total product count within the relevant label was updated for each family.

After the sub-articles had been loaded, the trolley had followed the production path specific to the sub-articles stacked on it according to a given add-on process and given actual data.

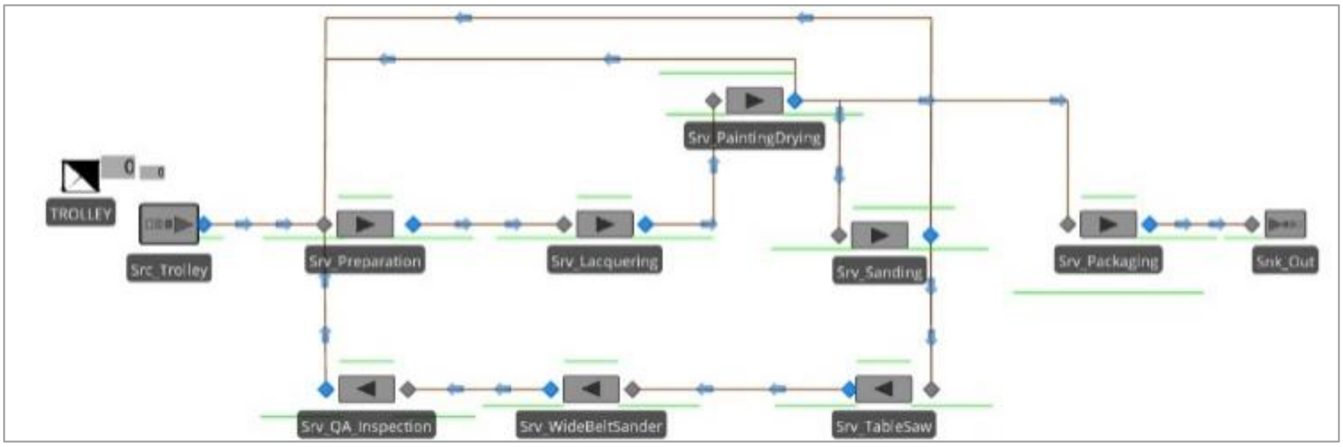
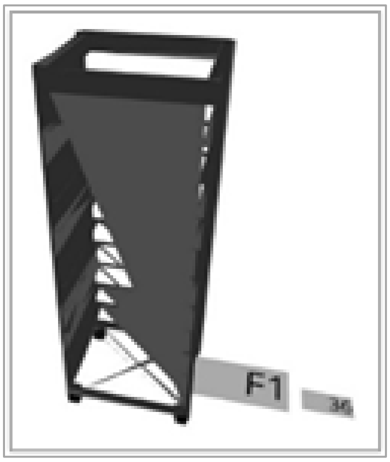


Fig. 2. Simio standard objects used to model the behavior of the system.



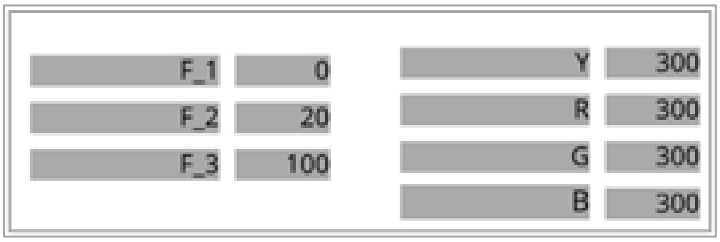


Fig. 3. Model entity & Labels for each family.

The trolley has been represented by a “Model Entity,” accompanied by two labels indicating the product family and the quantity of products present in the trolley at a time.

Additionally, state variables had been incorporated to track the remaining product count in the system for each family as shown in Figure 3.

In this simulation model, the flow of entities begins at the "Src-Trolley," which was responsible for releasing trolleys to the preparation area. Once a trolley had been created at the source, it moved to the "Srv-Preparation" stage, where sub-articles had been stacked onto the trolley trays. In the Srv_Preparation phase, utilizing an add-on process as shown in Figure 4, the sub-articles were classified based on their respective families. Subsequently, the number of sub-articles were assigned to the corresponding label in the model entity,

A. *Model vaidation*

To validate the model presented here, first, a statistical comparison of the current system with the developed simulation model had been conducted based on production times. The purpose of this comparison was to ensure that the model accurately reflected the logic and business rules of the current system.

Initially, by doing a normality test, it was ensured that all data were normally distributed. Then the production times of the model with actual data was tested, using a t-test at a 95% confidence level, to determine whether they were significantly different. Figure 5 and 6 summarize the results of the t-test. The obtained p-values were 0.968 for article A and 0.598 for article B. Therefore, it was concluded that the difference between average travel times was not statistically significant, confirming the validity of the simulation model presented.

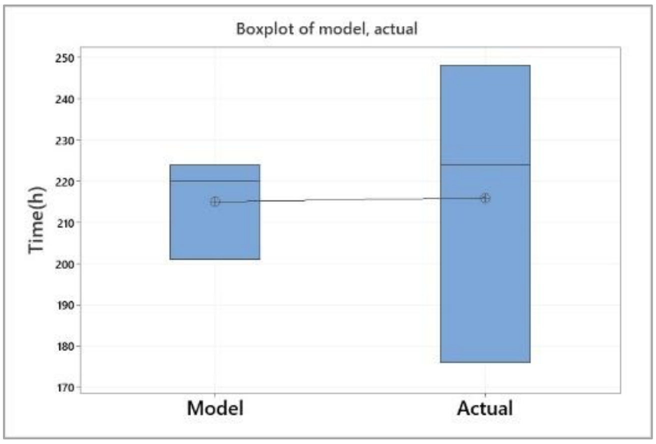


Fig. 5. Box plot for task completion time of actual data and simulation model for article A.

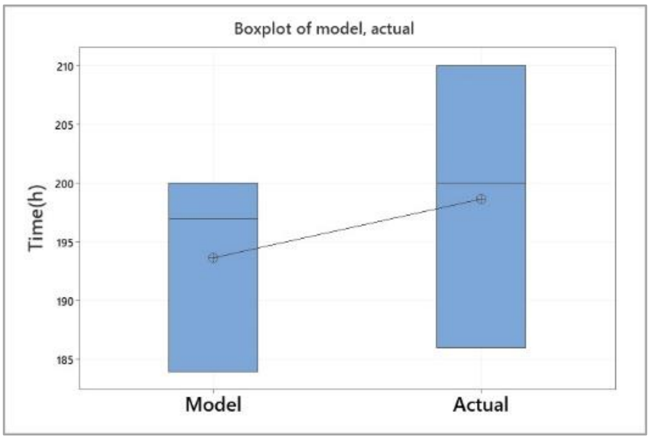


Fig. 6. Box plot for task completion time of actual data and simulation model for article B.

B. Results

Using the simulation models developed for both the proposed and existing methods, results were obtained for total production time and average trolley utilization in the system. Ten data points representing ten combinations of product quantity, were randomly generated within the usual range of order quantities. The results, depicted in Figures 7 and 8, shows the total production time and average trolley utilization in the system for both proposed and existing methods.

Figure 7 illustrates the trolley utilization throughout total production period for the proposed method compared to the existing method, with data shown for 100 units of Article A and 300 units of Article B. Table 1 summarizes the results for other product combinations, which were randomly selected for analysis. These results show that the average number of trolleys used is significantly reduced through the proposed strategies. Figure 8 shows that the total production time for each of the selected product mix combinations is significantly lower than that of the existing methods. Therefore, the proposed method is shown to be more efficient, exhibiting lower congestion levels compared to the existing method.

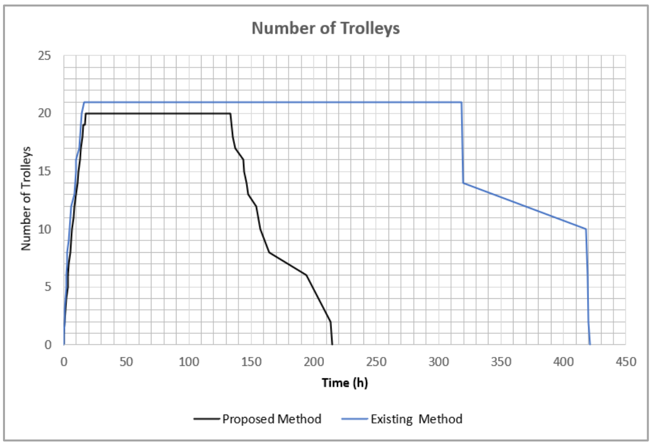


Fig. 7. Results of trolley utilization for product combination - 100 of article A and 300 of article B

TABLE I. AVERAGE TROLLEY UTILIZATION FOR DIFFERENT PRODUCT COMBINATIONS

Product Combinations (Article A, Article B)	Average Trolley Utilization	
	Existing Method	Proposed Method
"100,300"	19	15
"115,300"	20	16
"100,255'"	18	15
"150,285"	20	16
"90,280"	19	15
"120,275"	20	16
"115,250"	19	15
"130,275"	20	16
"85,290"	20	14
"75,265"	20	14

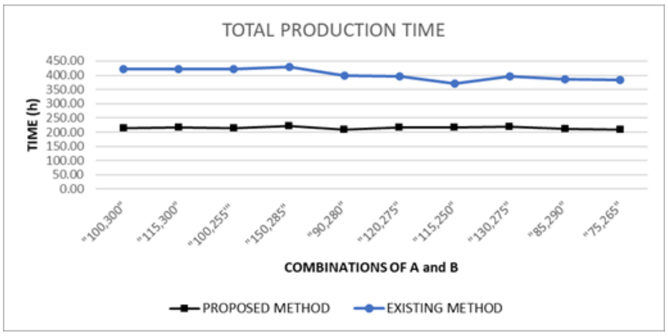


Fig. 8. Results of total production times for different product combinations

V. CONCLUSION

Efficiently managing a material handling system with a high product mix is a very complex task. Modeling such systems with simulation can be very useful for testing different scenarios, quantifying various performance measures, and adopting a preemptive approach rather than a reactive one. In this regard, this paper presented a methods, including grouping of sub-articles into families and optimized stacking processes to improve the efficiency of operations at a toy manufacturer, especially through efficient management of its material handling equipment. The developed methods were evaluated using a simulation model. created using Simio software. The validation of these methods employed in optimizing trolley management has yielded promising results. Through rigorous testing and experimentation, the effectiveness of the standardized stacking methods, efficient packing techniques for sub-articles, and systematic trolley management systems have been demonstrated. These methods will also help to reduce defects and improved product quality. Future work includes implementation, continued monitoring and refinement of these methods which will be essential to ensure sustained improvements in operational efficiency, customer satisfaction, and the long-term sustainability of the company within the competitive toy manufacturing industry.

VI. References

[1] Bhosekar, A., Işık, T., Ekşioğlu, S., Gilstrap, K., & Allen, R. (2021). Simulation-optimization of automated material handling systems in a healthcare facility. IISE Transactions on Healthcare Systems Engineering, 11(4), 316–337. https://doi.org/10.1080/24725579.2021.1882622

[2] Moshref-Javadi, M., & Lehto, M. R. (2016). Material handling improvement in warehouses by parts clustering. International Journal of Production Research, 54(14), 4256–4271. https://doi.org/10.1080/00207543.2016.1140916

[3] Joines, Jeffrey A., and Stephen D. Roberts. (2015). Simulation modeling with SIMIO: a workbook. Pittsburgh: Simio LLC.

[4] Telek, P. (2018). Process-based planning of material handling in manufacturing systems. IOP Conference Series: Materials Science and Engineering, 448(1). https://doi.org/10.1088/1757-899X/448/1/012018

[5] Vieira, A.C., Dias, L.S., Santos, M.Y., Pereira, G.B., Oliveira, J.A., (2018). Simulation of an Automotive Supply Chain in Simio: Data Model Validation. 30th European Modeling and Simulation Symposium, EMSS; 294–301.

[6] Yaacob, Mohd Asmedi, Baharuddin Mohd Zanggi, and Nurul Asyikin Yusri. "Storage Equipment for Woodstock Assembly Line. (2023). " Borneo Engineering & Advanced Multidisciplinary International Journal 2.Special Issue (TECHON 2023): 140-147