Management Science and Information Technology

MSIT

2024, Volume 1, Issue 2, pp. 112-120
ISSN-Print: 3079-1006
ISSN-Online: 3079-1014
https://msit.refconf.com

Selecting the Optimal Resolution Strategy for Sizing a Job-Shop Manufacturing System using Simulation Approach

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Abstract

One of the critical optimization challenges in production logistics is the manufacturing system (MS) sizing problem, which involves determining the optimal configuration and capacity for each type of resource within a manufacturing system. This encompasses the selection of an adequate number of machines, labor, and material handling systems (MHS) to efficiently meet production targets while minimizing costs and ensuring flexibility. As manufacturing environments become increasingly complex and dynamic, addressing this problem has gained significant importance for improving the efficiency and responsiveness of production systems.
This paper proposes an investigation to further improve the MS sizing problem by evaluating and comparing five alternative resolution orders for addressing the three key issues: machine selection, labor selection, and MHS fleet sizing. To validate these alternatives, a discrete-event simulation model is developed and applied to a job shop MS. The model captures the intricate interactions between resources production and transfer process providing valuable insights into the performance of each alternative.
Through simulation-based analysis, this work aims to offer practical guidance on selecting the most suitable order for resource optimization, contributing to enhanced decision-making in production logistics and manufacturing system design.

Keywords: Resource Selection; Production Logistics; Manufacturing System; Material Handling; Fleet Size; Resolution Order; Simulation; Performance.

1. Introduction

One of the optimization problems in production logistics is the MS sizing. In fact, determining the appropriate number of resources is critical for ensuring efficient and flexible production flows. Under-sizing MS can lead to inefficiencies, such as bottlenecks, idle resources. This increases the cost per unit produced. Over-sizing MS can lead to unnecessary investment and congestion in the system. It is necessary to make the right decisions, from sizing, to meet customer needs and delivery times. (Masmoudi et al., 2007) developed a simulation optimization approach to resolve the manufacturing system sizing problem. However, the application domain of this approach is limited in sizing only the production resources (machines and labor) and neglects the MHS fleet sizing problem. (Lajmi et al., 2017) investigated the importance of incorporating MHS in this approach. Therefore, the objective of this paper is to identify the optimal order for solving the three key issues: machine selection, labor selection, and MHS fleet sizing, to enhance the optimization process of the approach. The Arena simulation tool is used to determine the optimal order. The remainder of this paper is organized as follows: Section 2 provides a literature review on MS sizing problems. Section

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DOI: 10.22034/ISS.2025.8330.1021

3 outlines the research methodology. Section 4 introduces the developed approach. Section 5 presents the alternative resolution orders. Section 6 details the case study. Finally, Section 7 discusses the results before concluding the study.

2. Literature review on the MS sizing problem

2.1. Used methods

The resource selection problem has been extensively studied in the literature using a wide range of methodologies. Various approaches have been proposed to address this issue, each with its own advantages and limitations. These methods can be broadly classified into three main categories:

Analytical methods, which rely on mathematical modeling and optimization techniques to determine optimal resource selection. While these methods provide precise solutions, they may become computationally infeasible for complex and dynamic systems.

Simulation-based methods, which allow for a more flexible and detailed representation of real-world manufacturing processes. These methods enable the evaluation of different resource configurations under varying conditions, capturing system variability and stochastic effects.

Hybrid simulation-optimization approaches, which combine simulation with optimization techniques (e.g., metaheuristics, heuristic search) to improve decision-making efficiency. Although these approaches can enhance solution search capabilities, they often require extensive parameter tuning and computational resources.

2.2. Studied resources

Research on resource selection has explored various perspectives. Some studies have specifically addressed **machine selection**, aiming to determine the optimal number of machines. The objective is to balance efficiency and cost and to ensure optimal machine utilization while avoiding bottlenecks or idle times in the manufacturing system. Among the recent works, there is the study by (Abdelsalam et al., 2023) that developed a Mixed Integer Programming to determine the number of machine required in a production line. The aim is to minimize worker and machine idle time, unused machine capacity and increase productivity and meet demand. Moreover, (Yang et al., 2023) developed a multi-stage hybrid algorithm based on a backtracking searching algorithm to find the number of machines and process sequence in a production line. The aim is to minimize equipment cost and improve line efficiency. Further, (Jabarzadeh et al., 2017) They developed a fuzzy stochastic programming model with uncertain processing times, where both deterioration and learning effects are simultaneously evaluated. The goal was to determine the optimal number of machines and the production scheduling in MSs. The approach consists of two stages. The first focuses on selecting the type and number of machines to minimize acquisition costs. Based on these decisions, the second stage involves scheduling orders to minimize delay costs while considering uncertain operation durations. The model's defuzzification was performed using Dependent-Chance Programming (DCP). A Branch and Bound (B&B) method was employed to establish effective lower bounds, while a genetic algorithm was developed to assign task priorities and optimize scheduling accordingly. Also, (Hajej et al., 2018) used the branch-and-bound algorithm and Random exploration methods to determine the optimal number of machines to lease and the production quantities for each period. Developing a production plan that accounts for the preventive maintenance schedule of each machine, with the goal of minimizing total maintenance costs.

Moreover, others research works have focused on **labor selection**, considering workforce allocation, skill levels, and availability to optimize production performance. The goal is to balance productivity and minimize costs and idle time. Among the recent works, there is the study by (Wahyulistiani et al., 2022) that used the Full Time Equivalent method to determine the optimal number of workers in soap production system. The aim is to improve the effectiveness and efficiency of the system. Also, (Bolsi et al., 2021) developed a multi-start random constructive heuristic to determine the optimal number of workers, their assignment to machines, and the scheduling of activities in a food industry. Besides, (Iriani et al, 2021) used the work sampling method to find the number of workers required to balance the workload of operators and increase productivity. Further, (Samant et al., 2018) used the ARENA simulation software in conjunction with the CPLEX optimization software, which is based on a constraint programming approach, to determine the optimal number of operators to assign to each workstation in an automotive chassis production line. Simulation provides valuable insights into the production line, offering a dynamic view of the system to minimize waste, while optimization ensures efficient resource planning. This approach identifies the optimal number of operators while considering their skill levels and fatigue.

Additionally, some works have been interested to determine the required number of machines and labors simultaneously, highlighting the interdependencies between these resources and their combined impact on system performance. (Masmoudi et al., 2007) Integrated simulation and expert system approaches to determine the optimal number of machines and labor in a job-shop environment, aiming to minimize **mean tardiness** and **earliness**. Additionally, key operational factors of material handling systems, such a**s travel time**, are incorporated into the analysis. Further, (Azadeh et al., 2016) used Taguchi method, Data Envelopment Analysis and computer simulation to determine the optimal number of machines and workers in order to find the best configuration. Moreover, (Hazza et al., 2018) developed a mathematical model to determine the minimum number of work centers, machines, and labor in a production line.

Another stream of research has investigated **material handling system (MHS)**, optimizing material handling operations to minimize transfer times and congestion. The aim is to determine the optimal number of MHS (such as carts, forklifts, or automated guided vehicles) required to efficiently handling materials within a manufacturing or distribution system. Among the recent studies, there is the study by (Zhou et al., 2024) that developed a semi-open queuing network (SOQN) and simulation model to determine the AGV fleet size and analyze their effect on production efficiency and cost. Moreover, (Amjath et al., 2022) used the analytical method based on sequential quadratic programming, mean value analysis algorithm and discrete event simulation to determine the required number of trucks in steel manufacturing system. The aim is to minimize transportation and handling costs. Further, (Fu et al., 2021) used the simulation fractional factorial design and response surface methodology to determine the required number of AGV in a manufacturing system that ameliorate the system performance. Also, (Zhou et al., 2024) They address the AGV fleet sizing problem in flexible manufacturing systems (FMS) by considering the interaction between processing and transportation. A semi-open queuing network (SOQN) model is developed to assess the impact of resource utilization and waiting times on production efficiency. Additionally, an optimization model is formulated to balance efficiency and cost, with its accuracy validated through FlexSim simulation.

2.3. Problem resolution strategy

Despite the significant impact of material transfer on production (Lajmi et al., 2017), previous research has not simultaneously considered the MHS fleet sizing problem in conjunction with machine and labor selection. In response, (Imen et al., 2019) examined the importance of incorporating MHS into the optimization simulation approach developed by (Masmoudi et al., 2007), suggesting several improvements, including addressing the MHS fleet sizing problem. Basing on this work, this paper aims to expand the application domain of this approach by selecting the optimal order for solving the three selection problems: machine selection, labor selection, and MHS selection (see Fig. 1). To achieve this, a purely simulation-based methodology is adopted.

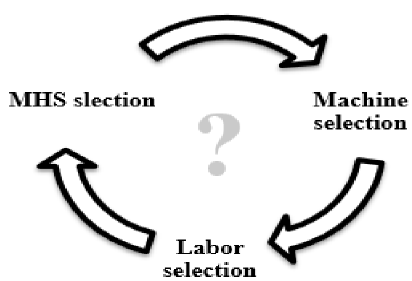

Figure 1. What is the best order for solving the MS sizing problems?

3. Research Methodology

This study improves the approach developed by (Masmoudi et al., 2007) to determine the optimal number of machines, labor, and MHS in a job shop manufacturing system. The research methodology follows a structured three-step approach (see Fig.2). First, a discrete-event simulation model is developed to represent the manufacturing system, integrating both production resources (machines and operators) and transfer resources. This model provides a dynamic and realistic representation of job flow, resource interactions, and overall system performance. Second, to determine the most effective resource selection strategy, five alternative resolution orders are proposed. Each alternative represents a different order in which the three resource selection problems (machine selection, labor selection, and MH fleet sizing) are addressed. These alternatives aim to explore how different decision orders impact system efficiency, cost, and workload distribution.

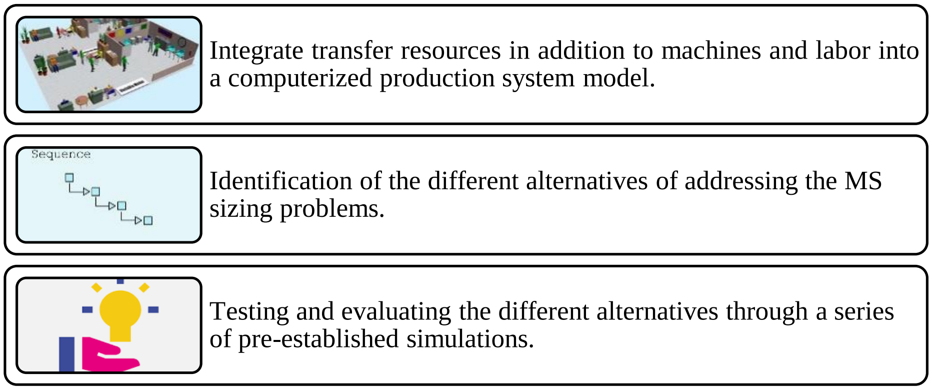

Figure 2. Research methodology

Finally, the proposed alternatives are simulated and analyzed to compare their performance based on key evaluation criteria such as throughput, resource utilization, and mean tardiness. By analyzing the simulation results, the most effective order is identified, ensuring an optimal balance between production efficiency and cost-effectiveness.

4. Developed approach

To address the challenge of selecting the optimal resolution order, a simulation-based approach is proposed (see Fig.3). This method enables the evaluation of different resolution orders by analyzing their impact on key performance indicators. The approach takes specific input parameters and generates detailed output metrics. The inputs to the approach include the MS data and the initial quantities of each resource type. Using these inputs, the simulator models the system over a specified time horizon. The simulation outputs serve as performance indicators. Based on the results and the identified performance limits, the decision-maker determines whether the system may be improved. If an improvement is possible, a recommendation for system reconfiguration is made, and a new cycle is started. Otherwise, the current results are accepted, marking the end of the cycle. The primary objective is to ensure that job due dates (DD) are met while optimizing resource utilization. To achieve this, two types of performance indicators are used:

Global Performance Indicators: These metrics assess the overall efficiency of the system. The Mean Tardiness (MT) is the key objective, measuring the average delay of jobs beyond their due dates. A lower MT value indicates better system performance.

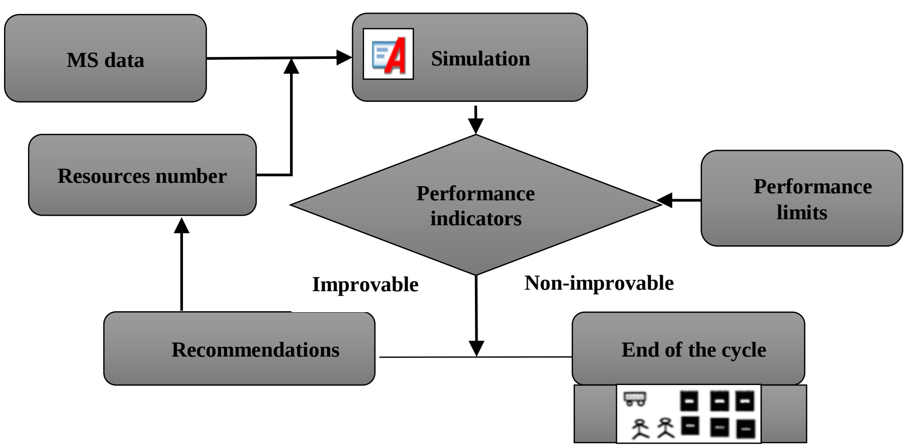

Figure 3. Developed approach

The Mean Earliness (ME) is considered as a secondary objective, representing how early jobs are completed before their due dates.

Diagnostic Indicators: These indicators provide insights into resource utilization and potential inefficiencies. The Utilization Rate (RU) is analyzed for each resource type, machines, labor, and MHSs, to detect imbalances. A high RU suggests potential bottlenecks and overutilization, which may lead to delays, while a low RU may indicate underutilized resources, leading to inefficiencies and increased operational costs. By identifying these imbalances, adjustments can be made to improve system performance. This dual approach ensures a balance between meeting due dates and maintaining efficient resource management.

Accounting for uncertainties such as resource breakdowns, labor delays, and power outages is crucial for ensuring the reliability and robustness of the manufacturing system. To define performance limits and maintain operational efficiency, two key utilization thresholds are established:

Maximum Utilization Rate (UR max), that represents the upper threshold of resource usage, beyond which the system is at risk of overload. Exceeding this limit can lead to accelerated equipment degradation, increased failure rates, and longer job processing times due to congestion and bottlenecks.

Minimum Utilization Rate (UR min), that defines the lower threshold, below which resources are underutilized, leading to inefficiencies and unnecessary operational costs. A low utilization rate may indicate excessive idle time for machines, labor, or MHSs, suggesting that resources are not optimally allocated.

By maintaining resource utilization within these predefined limits, the system can operate efficiently while minimizing disruptions caused by unexpected events. This approach enhances overall system reliability and ensures a balanced workload distribution across all resources.

5. Different alternative resolution orders

To identify the best order, five alternatives are proposed, each offering a different order for tackling these selection problems. Table 1 outlines the various alternatives.

Table 1. Different alternatives

Alternatives	**Resolution orders**
Alternative 1	**Machine selection→ labor selection→ MHS fleet size**
Alternative 2	**Machine selection → MHS fleet size → labor selection**
Alternative 3	**Machine & labor selection → MHS fleet size**
Alternative 4	**Machine selection → MHS fleet size & labor selection**
Alternative 5	**Machine & MHS fleet size → labor selection**

Alternative 1: The first phase addresses the machine selection problem (machine shortage/surplus) without considering labor and MHS constraints (assuming a sufficient number of both resources). The second phase addresses the labor selection problem. It starts with a balanced number of machines, a number of labors equal to the number of machines in each department and a sufficient number of MHS. Finally, the third phase deals with the MHS selection problem.

Alternative 2: The first phase addresses the machine selection problem without considering labor and MHS constraints (assuming a sufficient number of both resources). The second phase then handles the **MHS fleet size** problem with a balanced number of machines and a number of labors equal to the number of machines in each department. Finally, the third phase deals with the labor selection problem.

Alternative 3: The first phase addresses both the machine selection problem and the labors' selection problem, without considering MHS constraints (assuming a sufficient number of MHS). The second phase then handles the **MHS fleet size** problem with a balanced number of machines and labor.

Alternative 4: The first phase addresses the machine selection problem without considering operator and cart constraints (assuming a sufficient number of both resources). The second phase then handles both the labor selection problem and the **MHS fleet size** problem simultaneously.

Alternative 5: The first phase addresses both the machine selection problem and the MHS selection problem without considering labor constraints (assuming a sufficient number of labor). The second phase then handles the labor selection problem.

In this study, all alternatives start with the machine selection problem, as machines are the critical resources in a manufacturing system (MS). This paper aims to select the optimal alternatives that respects due dates, improves efficiency and meets production requirements.

6. Studied MS model

The data for this case study is obtained from (Masmoudi et al., 2007). The MS studied is a job shop MS (see Fig.4), comprising **five departments** (D1–D5) and **two storage areas**, and it produces **three types of products** (P1, P2, and P3). Each production department is equipped with **computer numerical control (CNC) machines**, which are functionally identical and dedicated to the same type of operations. Additionally, each department has a team of **functionally equivalent operators**, whose primary role is to adjust the machines whenever a product type change occurs. The movement of the products between departments and storage areas is handled by **MHS**s, which are defined by their **speed, capacity, and dispatching rules** to ensure efficient material flow within the system.

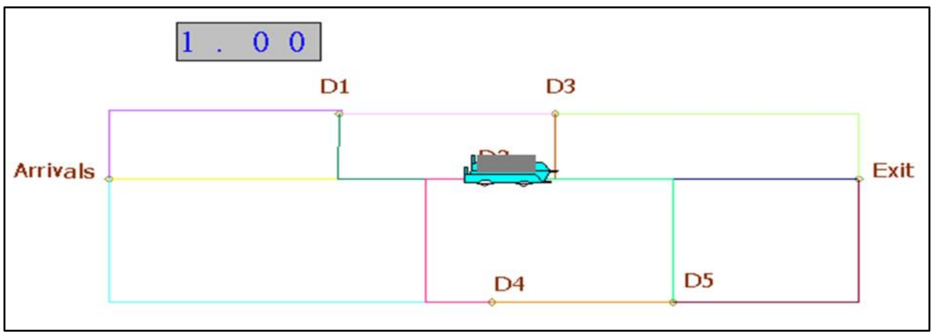

Figure 4. Studied MS model using Arena simulation tool

The simulation is executed as a single long replication of **130,000 minutes**, with a **warm-up period of 20,000 minutes** applied once to allow the system to reach a steady state before data collection, ensuring reliable results while minimizing computational time. The MS data required for the simulation model is, inter-arrival times, sequences, due date and batch size of each product type, processing times and setup times of each product type on different machines, distances between work centers and MHS velocity. A First-In, First-Out (FIFO) policy is applied, ensuring that the first job arriving in the queue is the first to be processed.

In the MS, three types of products will be manufactured. The launched products will be grouped into batches, with batch sizes varying depending on the product type. Once an MHS becomes available, the batch will be loaded and transported to the processing phase. Following its predefined sequence, upon arriving at the designated department, a product batch selects a machine from the set of available machines. It is then divided into individual parts for processing. Once all parts have completed their transformation on the machine, the batch is reassembled and waits for an available MHS to transport it to its next destination. When a batch completes its final processing stage, it is once again fragmented into individual pieces before exiting the system.

7. Results and discussion

The proposed approach is applied to evaluate the performance of each resolution order, with key performance indicators collected for every sequence tested. This iterative process aims to identify the most effective order by assessing its impact on system efficiency. A series of planned simulations is conducted to determine the optimal order for addressing the three selection problems, focusing on meeting DD while minimizing tardiness and earliness. The

DD for each product type is fixed, calculated by multiplying the Total Work Content (TWK) by a factor K, set to 10 in this study. The primary goal is to meet this due date while minimizing mean tardiness as the first priority and mean earliness as the second. Furthermore, the utilization rate is constrained between a minimum of 40% and a maximum of 80%. Each alternative begins by determining the optimal number of machines. The initial solution assumes two machines per department. The number of labor is set equal to the number of machines, ensuring a balanced workforce allocation. As for MHS, an initially high number is considered, providing full system coverage to avoid transportation bottlenecks. This simulation series shows that when the number of MHS is undersized, for instance with only one handling unit, product batches fail to reach their designated machines. As a result, machine utilization rates remain extremely low (see Fig.5). However, as the number of forklifts increases, utilization rates improve until they stabilize at an optimal level. This highlights the critical role of MHS fleet sizing in the overall production system design. It also explains why, during the machine selection phase, an initially high number of handling units was considered necessary.

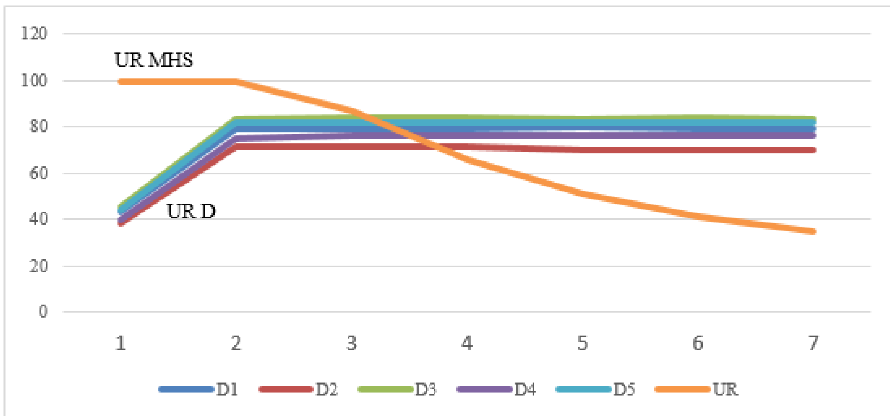

Figure 5. Impact of MHS number on Departments utilization rate

Based on the simulation results, Alternatives 1 and 4 emerge as the most optimal solutions (see Table 2). While the number of machines and operators remains consistent across all five alternatives, Alternatives 1 and 4 require fewer material handling resources. This reduction not only leads to lower operational costs but also enhances system flow efficiency, minimizing congestion and ensuring smoother production operations.

Table 2. Simulation results

Alternatives	**Machines number in each department**	**Labor's number in each department**	**MHS number in the system**
Alternative 1	6/5/6/9/6	1/1/1/2/1	**3**
Alternative 2	6/5/6/9/6	1/1/1/2/1	4
Alternative 3	6/5/6/9/6	1/1/1/2/1	4
Alternative 4	6/5/6/9/6	1/1/1/2/1	**3**
Alternative 5	6/5/6/9/6	1/1/1/2/1	4

In addition, an experimental study by (Masmoudi et al., 2004) suggests that addressing each selection problem individually is simpler and can yield more stable outcomes. Consequently, this paper adopts the first alternative as the preferred order for addressing the three selection problems: first determining the optimal number of machines, then identifying the required number of labor, and finally establishing the necessary quantity of material handling resources.

8. Conclusion

This paper tackles a crucial optimization challenge in manufacturing logistics: the efficient sizing of manufacturing systems (MS) by integrating machines, labor, and material handling systems (MHS). This holistic approach aligns with real-world complexities and practical decision-making. The primary objective is to determine the optimal order for selecting MS resources. To achieve this, five alternative strategies are explored. A simulation-based resource selection model is applied to a job shop MS, and the results indicate that the most effective order is the first alternative, beginning with machine selection, followed by labor selection, and concluding with MHS fleet sizing.

Future research can be suggested to develop an optimization module combined with the simulation, incorporating a reasoning mechanism, and to address the scheduling problem for MHSs.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

Abdelsalam, N., Mohammoud, F., Eder, H., Abuyousef, A., Kaya, O., Kilic, A. C., & Ulku, I. (2023). A PRODUCTION LINE ASSIGNMENT PROBLEM FOR A TEXTILE INDUSTRY. *Mühendislik Bilimleri ve Tasarım Dergisi*, *11*(1), 22–32. https://doi.org/10.21923/jesd.1101063

Amjath, M., Kerbache, L., Smith, J. M., & Elomri, A. (2022). Fleet sizing of trucks for an inter-facility material handling system using closed queueing networks. *Operations Research Perspectives*, *9*, 100245. https://doi.org/10.1016/j.orp.2022.100245

Azadeh, A., Kolaee, M. H., & Sheikhalishahi, M. (2016). An integrated approach for configuration optimization in a CBM system by considering fatigue effects. *The International Journal of Advanced Manufacturing Technology*, *86*(5), 1881–1893. https://doi.org/10.1007/s00170-015-8204-x

Bolsi, B., de Lima, V. L., de Queiroz, T. A., & Iori, M. (2021). Integrated Workforce Scheduling and Flexible Flow Shop Problem in the Meat Industry. In A. Dolgui, A. Bernard, D. Lemoine, G. von Cieminski, & D. Romero (Eds.), *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems* (pp. 594–602). Springer International Publishing. https://doi.org/10.1007/978-3-030-85902-2_63

Fu, J., Zhang, J., Ding, G., Qin, S., & Jiang, H. (2021). Determination of vehicle requirements of AGV system based on discrete event simulation and response surface methodology. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 0954405421995602. https://doi.org/10.1177/0954405421995602

Hajej, Z., Rezg, N., & Askri, T. (2018). Joint optimization of capacity, production and maintenance planning of leased machines. *Journal of Intelligent Manufacturing*. https://doi.org/10.1007/s10845-018-1450-7

Hazza, M. H. F. A., Elbishari, E. M. Y., Ismail, M. Y. B., Adesta, E. Y. T., & Rahman, N. S. B. A. (2018). Productivity improvement using discrete events simulation. *IOP Conference Series: Materials Science and Engineering*, *290*, 012025. https://doi.org/10.1088/1757-899X/290/1/012025

Imen, L., Wassim, M., Mounir, E., & Hedi, C. (2019). Improvement opportunities of a Simulation/Expert System Approach for Manufacturing System Sizing: A review and proposal. *Advances in Science, Technology and Engineering Systems Journal*, *4*(5), 213–223. https://doi.org/10.25046/aj040527

Iriani, Y., & Al, E. (2021). Determination the Number of Packing Operators Using Work Sampling Method. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, *12*(8), Article 8. https://doi.org/10.17762/turcomat.v12i8.3024

Jabarzadeh, A., Rostami, M., Shahin, M., & Shahanaghi, K. (2017). Two-stage fuzzy-stochastic programming for parallel machine scheduling problem with machine deterioration and operator learning effect. *Journal of Industrial and Systems Engineering*, *No. 3*, 17.

Lajmi, I., Masmoudi, W., & Elleuch, M. (2017). Importance of Handling Resources' Incorporation Into Simulation Expert System Approach. *2017 6th IEEE International Conference on Advanced Logistics and Transport (ICALT)*, 139–143. https://doi.org/10.1109/ICAdLT.2017.8546999

Masmoudi, W., Chtourou, H., & Maalej, A. (2004). SIMULATION-BASED APPROACH FOR MACHINE SELECTION WITH LABOR CONSTRAINTS. *Proceedings of the International Industrial Engineering Conference IIEC, Riyadh, Kingdom of Saudi Arabia*, 11.

Masmoudi, W., Chtourou, H., & Maalej, A. Y. (2007). Labor and machine sizing through a Simulation-Expert-System-based Approach. *Simulation Modelling Practice and Theory*, *15*(1), 98–110. https://doi.org/10.1016/j.simpat.2006.10.001

Samant, S., Mittal, V. K., & Prakash, R. (2018). Resource optimisation for an automobile chassis manufacturer through value stream mapping enhanced with simulation technique and constraint programming. *International Journal of Industrial and Systems Engineering*, *28*(3), 379–401. https://doi.org/10.1504/IJISE.2018.089746

Wahyulistiani, A. F., Safirin, M. T., Tranggono, T., & Lantara, D. (2022). WORKLOAD ANALYSIS TO DETERMINE THE NUMBER OF LABOR IN SOAP PRODUCTION USING THE FULL TIME EQUIVALENT METHOD: A CASE STUDY OF PT. XY. *Journal of Industrial Engineering Management*, *7*(3), Article 3. https://doi.org/10.33536/jiem.v7i3.1322

Yang, M., Li, C., Tang, Y., Wu, W., & Lv, Y. (2023). Multi-stage hybrid algorithm-enabled optimization of sequence-dependent assembly line configuration for automotive engine. *Journal of Manufacturing Systems*, *66*, 13–26. https://doi.org/10.1016/j.jmsy.2022.11.014

Zhou, Q., Peng, C., Sun, J., Zhu, J., Lin, C., & Yang, B. (2024). An optimal AGV fleet sizing estimation method for flexible manufacturing systems. *2024 IEEE International Conference on Mechatronics and Automation (ICMA)*, 1147–1152. https://doi.org/10.1109/ICMA61710.2024.10633167