Analysis and Optimization of Material Flow Employing Simulation and Milk Run System: An Automotive Wiring Industry Case Study

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ABSTRACT

This paper introduces a case study focused on optimizing material flow in the automotive wiring harness industry, known for its complex product configurations, high variability in production requirements, and diverse task sequences. Management of material flow is vital for smooth Operations, reduced delays, and enhanced productivity. Early identification of potential transportation bottlenecks, especially along production routes and at warehouse entries, is essential. A proactive approach to tackle these inefficiencies can improve resource allocation and maintain workflow continuity. The proposed system offers a graphical analysis of the material flow, providing a clear visualization of the logistical operations. These diagrammatic representations have a vital role in simplifying material flow planning, enhancing logistics coordination, and highlighting key transportation routes. By utilizing these insights, companies can align their logistics goals with broader operational objectives, turning material and inventory flow management into a strategic practice. The study employs visTABLE® software, which enhances planning by utilizing digital factory capabilities. This tool promotes a dynamic and innovative approach to optimizing material flows, making it easier to understand complex logistics scenarios. Its advanced visualization and evaluation features, such as interactive diagrams, offer a structured and user-friendly way to identify inefficiencies and enhance material handling strategies. These capabilities enable decision-makers to analyze and refine logistics operations accurately, resulting in more efficient workflows. The findings from this case study highlight the benefits of simulation-based strategies for achieving material flow optimization. The results show that using digital simulation tools allows companies to effectively identify bottlenecks, reduce logistical efforts, and improve overall operational efficiency. Furthermore, implementing these simulation techniques has considerable practical implications, not only for the automotive wiring harness sector but also for other manufacturing industries facing similar challenges. By adopting a simulation-driven approach, companies can make data-informed decisions that lead to streamlined logistics, less waste, and enhanced productivity.

Keywords: **Layout Optimization, Material flow improvement, Simulation, visTABLE, Milk run system**

I. INTRODUCTION

To remain competitive and maintain financial success, companies must consistently improve performance and efficiency, in the fast-evolving market and today’s competitive manufacturing sector. By achieving a market edge, enterprises can optimize production processes, reduce costs, and accelerate product development. In this endeavor, simulation has become critical tool allowing manufacturers to simulate and analyze their operations, identify inefficiencies, and explore different scenarios to enhance decision-making without the risks associated with physical experimentation [13]. In fact, Simulation plays a crucial role in manufacturing processes by enabling the modeling and analysis of complex systems before real-world implementation. This approach leads to improve efficiency and productivity as it provides a comprehensive view of manufacturing workflows and valuable insights into system behavior and performance [17]. Thereby, before making costly investments, enterprises are able to

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evaluate financial implications. Due to this proactive approach, waste minimization and resource allocation optimization become achievable, and leads to better process and more cost-effective operations [6]. Various industries, are exploring multiple design iterations using simulation, particularly in manufacturing ([5], [7], [22]), and healthcare [12], where engineers can test novel ideas and assess their feasibility using performance metrics. Through scenario-based evaluations, companies are able to anticipate potential challenges and develop efficient strategies.

One of the most significant current issues in production and operations management is material flow optimization and plant layout design ([18]; [17]; [15]; [27]).

It is about deploying the optimum structure and facilities design incorporating workstations, storage areas, material handling systems, personnel… ([3]) consider facility’s layout as a strategic issue since it has interesting impact on the production line performance. It leads to material handling costs reduction, lead time optimization and maximize the use of equipment, labour and space.

Thus, material flow analysis is mandatory for industrial processes improvement, since it focuses on two fundamental aspects: flow intensity, which refers to the amount of materials circulating in the system, and travel distance, which is the distance covered by materials throughout the production process. The optimization of these flows, comes down to reducing the quantity of materials in circulation and transport distances as much as possible. Ideally, each piece or batch should move directly from one workstation to another, preventing bottlenecks and unnecessary handling. Yet, implementing these principles in real-world manufacturing environments is challenging. Factors such as warehouse organization, machine layout, and internal transport management has a great impact on the efficiency of material flows. This is why a structured, data-driven approach is important for analyzing, planning, optimizing, and managing material flows at a system-wide level.

The simulation of production systems and processes is based on using commercial software to produce computer models of production systems. These models are utilized to estimate the future behavior of the production process and material flows and extract crucial information and valuable perspectives. In literature, several simulation tools are presented and used to optimize logistic systems and resource allocation. As highlighted in ([5]), we can list some of them Tecnomatix Plant Simulation, Arena, Simul8, AutoMod, Witness, VisTABLE…In ([13]), a comparative study was led between Plant Simulation and VisTABLE.

In this context, visTABLE® software introduces an advanced solution for optimizing logistics flows in the automotive industry. This tool leverages simulation and visualization of material flows, to identify bottlenecks, inefficiencies, and any potential of improvement.

The case study presented in this research provides a deep analysis the application of visTABLE® in an automotive wiring harness production facility, a sector characterized by high production variability and complex material flow management. We use the simulation tool VisTABLE as a problem-solving approach combined with Milk Run system which is a transportation and logistics concept applied to enhance the efficiency of materials flow within a supply chain [26].

In literature, the Milk Run system is defined as a logistics strategy that deals with material pickups and makes deliveries more efficient and optimized.

Following a scheduled in delivery of goods and materials, time is saved and costs are considerably minimized ([1]; [8]; [23]; [10]). Therefore, this concept is used far and wide as an efficient supply model that enhances processes in various serial production fields, including the automotive, mechanical, military industries, electronic,…[21].Based on their application Milk Run systems can be classified into two main types: intra-logistics (internal) and external Milk Run systems. External Milk Run is designed to reduce transportation cost, number of trucks on road, minimize travelling path and fuel consumption and CO_2 emission as discussed in ([25]; [1]). [19] introduces a milk-run system of some Japanese automotive companies in Indonesia. It was put in place in urban area to lower transportation costs and number of trucks circulating in order to minimize carbon dioxide (CO_2) emissions and promote green logistics. Before operating milk-run, it seems to be essential to prepare a Transportation Value Stream Mapping (TVSM) in order to optimize supply chain logistics and ensure just-in-time delivery. FlexSim simulation software was leveraged by [16] to design, analyze and develop Milk Run logistics systems. The proposed simulation model was based on hybrid modelling approach, combining discrete-event (DES) and agent-based simulations (ABS). Intra- logistics Milk run are also called in-plant Milk Runs, or mizusumashi as described and used in [4]. In this paper, a new approach for processes was introduced, in the context of automotive industry, for logistics planners to gain time in material provision for

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assembly systems. It was combined with the Kanban system in [21] for modelling material flow taking advantage of particle swarm optimization (PSO), in the automotive industry. The objective was optimizing trailers and containers in for a train system in a defined route time period. [20], a simulation model in Arena was developed to track sources of waste and identify improvements by examining different system configurations, in semiconductors industry, a Milk Run system was also implemented.
Using SIMIO, a 3D microsimulation model was settled in [28], to model the Milk runs and picking systems of Bosch Car Multimedia Portugal, leveraged to comply with production lines needs by bringing together containers of products, from a warehouse. To explore in-plant milk-run systems, [24] introduces a study applied to a wide range of automotive supplier plants and focusing on typical traffic situations. The experimental study reveals delays are caused by frequent blockages, and production schedules and system stability are also disrupted. Thereby, to enhance system stability and enhance traffic flow, implementing streamlined handling processes for critical materials and optimizing routes are necessary. For efficient transport processes, [9] discusses the importance of Automated Guided Vehicle (AGV) systems in on-site logistics. It introduces a simulation model to detect failure points in a Milk Run delivery process. It was developed using Tecnomatix Plant Simulation. The obtained results prove that material delivery was enhanced and the production process becomes more and more efficient, without any breaks.
Through visTABLE®, this study aims to:

- Reduce logistical effort by optimizing operator and material movements.
- Improve operational efficiency by minimizing transport distances and ensuring a smooth supply chain.
- Decrease downtime by ensuring better availability of raw materials at workstations.
- Enhance communication and coordination between the raw material warehouse and internal production areas, ensuring a more responsive and structured material flow.

By taking advantage of these optimization strategies based primarily on simulation tools, this study demonstrates how visTABLE® can change material flow management into a key factor of industrial performance, directly moving forward with productivity and overall competitiveness.
The structure of our paper is as follows. In Section 2, we introduce our studied problem. Section 3 focuses on the resolution and improvements achieved through simulation and Milk run concept. Finally, we conclude with a summary of our findings and discuss potential future perspectives.

II. PROBLEM STATEMENT AND CURRENT STATE ANALYSIS

This chapter explains the methodology used to design a workplace within a digital factory, with the objective of optimizing material flows and enhancing productivity. The study integrates data collection, analysis, software-based simulation, and experimental validation.
An initial evaluation of the existing material flows and workplace layout was led, followed by reorganization proposals, both of which are detailed through calculus and supply chain analysis in Chapter 4 of the case study. The company object of our study was selected based on its alignment with the research goals and the feasibility of collaboration. Data collection included on-site observations, interviews, and document analysis to bring insights into workplace layout, material flow patterns, and production processes.
To validate the proposed solution, visTABLE software was leveraged to design and evaluate different workplace configurations. The software enabled virtual simulations of material flows, focusing on minimizing handling distances to streamline logistics. Additionally, real-world testing was led to assess the impact of the proposed layout modifications. Key performance indicators, such as production time and worker productivity, were tracked and measured before and after implementation. Data visualization and statistical analysis were utilized to interpret results and identify patterns.
The findings of this study demonstrated a significant reduction in production time, confirming the effectiveness of the proposed layout improvements.
Figure 1 illustrates the layout of the Production Area (KS), which includes more than 60 cutting machines along with the raw material storage warehouse (WH07). The production process within this area is heavily dependent on logistical operations, as the supply of raw materials to the machines is carried out manually by logistics operators. This method of material handling requires a significant logistical effort, leading to frequent production stoppages, inefficiencies, and delays. The lack of an

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optimized material flow increases the time required for replenishment, further impacting overall productivity. Consequently, improving the efficiency of the material supply process is critical to reducing logistical bottlenecks and ensuring a more streamlined production flow.

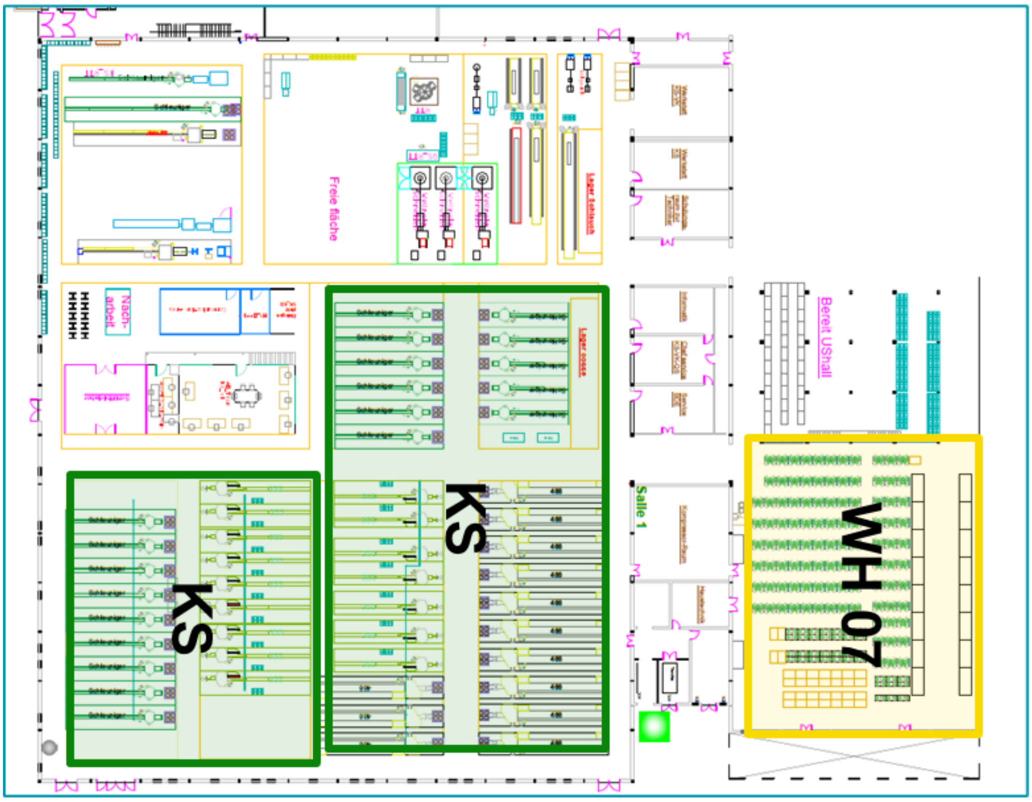

Fig. 1: Production layout

In the production area, the machines are organized into five distinct groups based on their physical location. This grouping aims to streamline operations and facilitate material handling. Similarly, in the raw material storage area, materials are systematically divided into sections labelled from A to J. This classification is based on the type and cross-sectional dimensions of the cables, ensuring a structured and efficient storage system. As illustrated in Figure 2, this division optimizes the retrieval and distribution of raw materials.

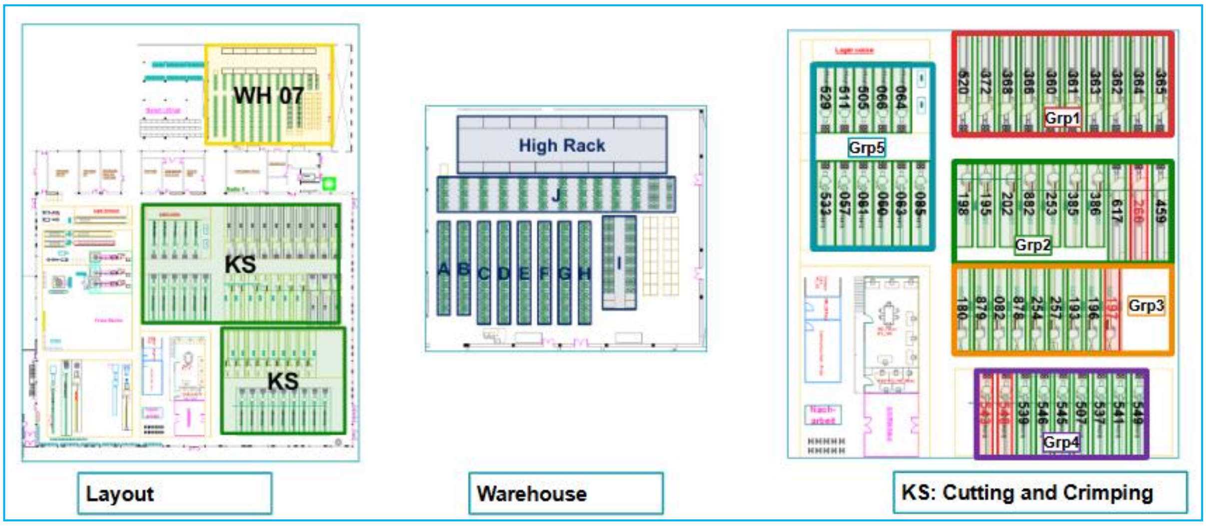

Fig. 2: Workplace layout of the current state details

Figure 3 illustrates the flow diagram between the different storage areas and the five machine groups. For example, storage zones A and B are linked to a specific machine group for the supply of raw

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materials (cable reels) used in production. Once production is completed, the remaining cable reels are returned to the storage area.

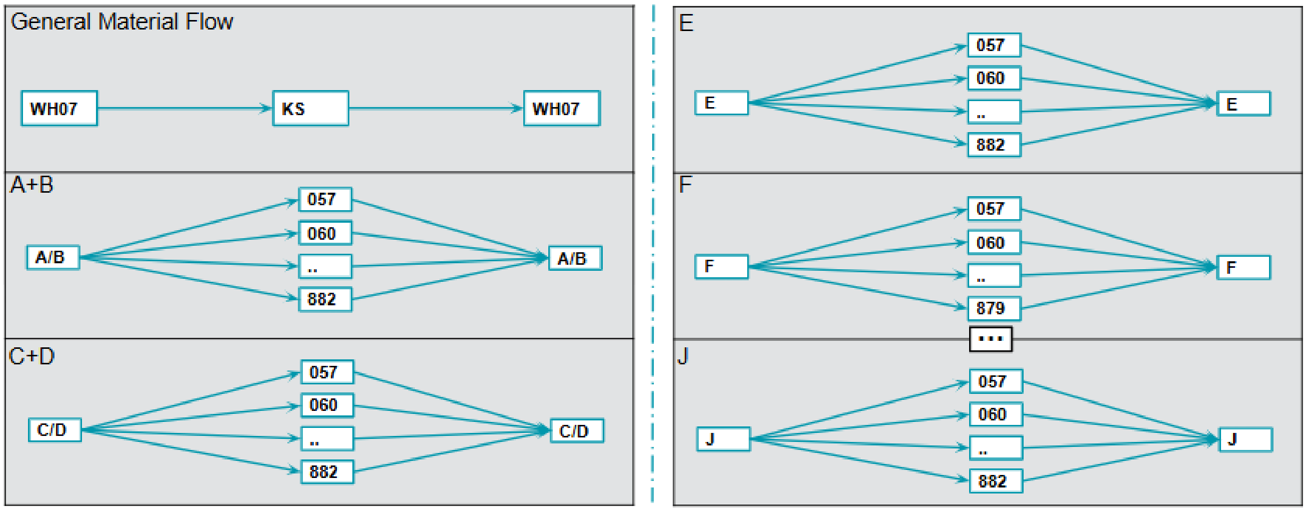

Fig. 3: General Material Flow

The simulation of the current state, illustrated in Figure 4, is designed to visualize and analyze the material flow between the raw material storage area and the production park. By utilizing visTABLE software, all movements, including the transportation of materials and the displacement of operators, are accurately tracked and quantified. This allows for a detailed assessment of the logistical effort required in the current setup.

As shown in Figure 4, operators collectively travel a total distance of 307,433.67 km annually to transport materials within the production area. This significant logistical workload highlights inefficiencies in the current layout and material handling processes. The primary objective of this study is to optimize these movements by reducing unnecessary transportation, streamlining workflows, and enhancing the overall work organization. By minimizing travel distances, the company can achieve substantial time savings, lower operational costs, and improve overall efficiency, leading to a more productive and lean manufacturing environment.

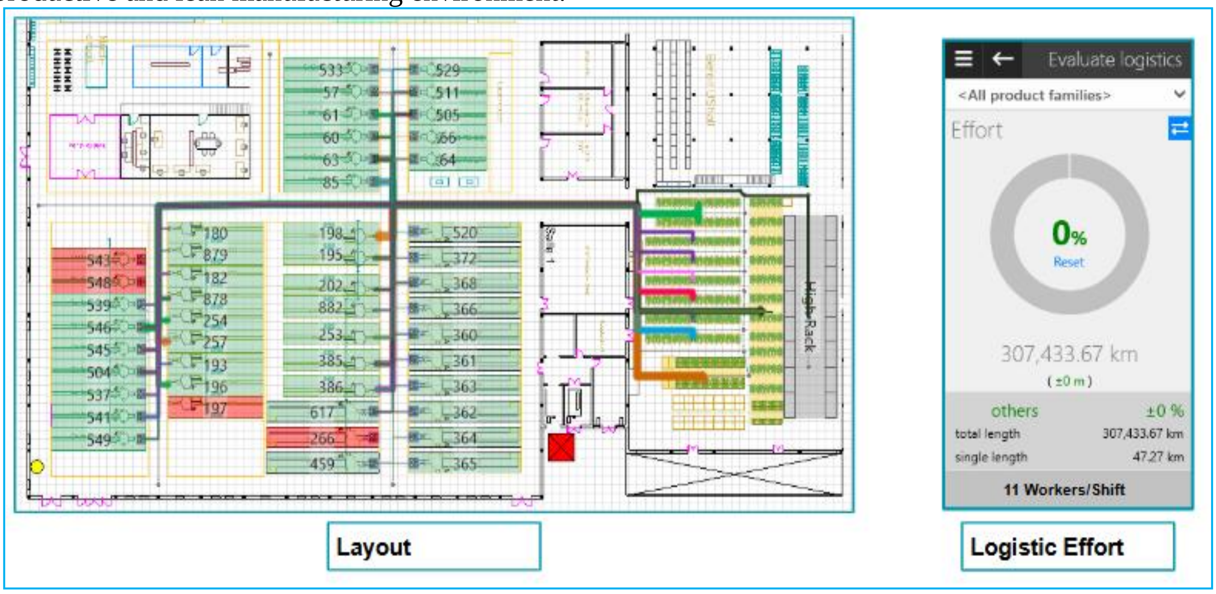

Fig. 4: Logistic Effort Current State

Figure 5 illustrates the distribution of logistical effort across different storage areas within the raw material warehouse. Each zone contributes differently to the overall transportation workload, with some areas requiring significantly more operator movement than others.

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Among these, storage zones A and B collectively account for a logistical effort of 84044 km per year, representing more than 27% of the total annual logistical distance traveled by operators. This high percentage indicates a considerable concentration of material handling activities in these zones, which may be due to their strategic importance in supplying production lines or their suboptimal layout.
Similarly, storage zone J records an annual logistical effort of 60884 km, contributing nearly 20% of the total effort. This highlights another critical area where material flow optimization could lead to substantial efficiency gains.

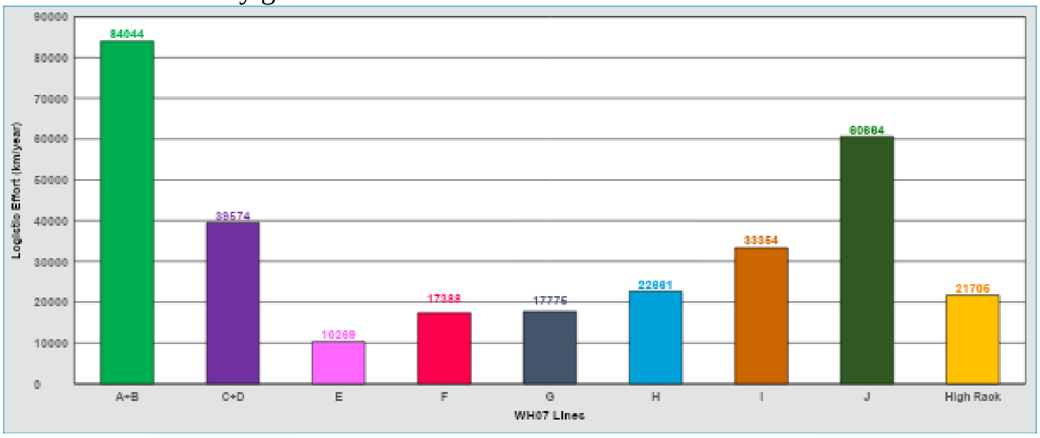

Fig. 5: Logistic Effort Ranking Warehouse

Figure 6 provides an in-depth analysis of the distribution of logistical effort across different machines and machine groups within the production area. Using visTABLE software, the logistics effort for each individual machine within its respective group is accurately calculated. This analysis helps to identify inefficiencies and areas where material flow improvements can be made to reduce unnecessary movement and enhance productivity.
Each machine group contributes differently to the overall transportation workload, with some requiring significantly more operator travel than others. Among these, machine group 4 accounts for 29% of the total annual logistics distance travelled by operators. This high percentage suggests an intensive flow of materials between the storage areas and the machines in this group, likely due to their critical role in supplying the production lines or an inefficient layout that increases transportation distances.
Similarly, machine group 3 represents 27% of the total logistics effort, making it another key area where improvements in material flow organization could yield substantial efficiency gains. The high logistical demands in these groups indicate potential bottlenecks in the production process, emphasizing the need for a more optimized layout and better coordination of material handling activities.
By analysing and addressing these inefficiencies, the company can reduce operator travel distances, lower logistical workload, and improve overall production efficiency. Optimizing machine placement, refining material handling procedures, and implementing smarter storage strategies could lead to significant time and cost savings, contributing to a leaner and more effective production system.

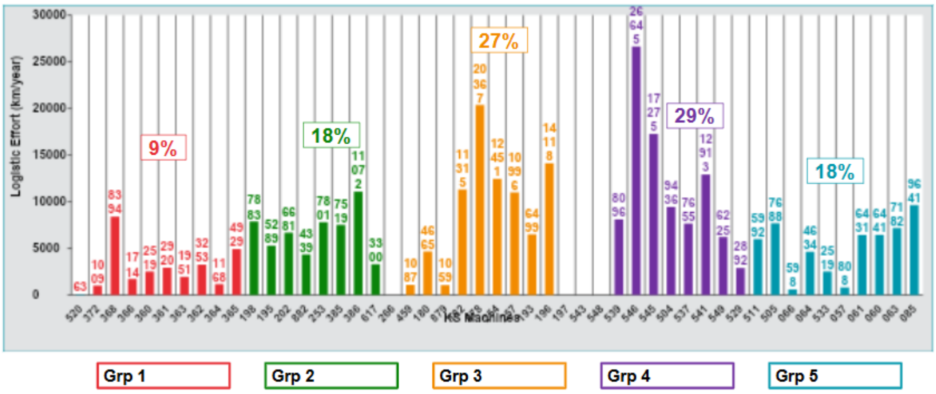

Fig. 6: Logistic Effort Ranking machines

Figure 6 highlights the stock occupancy in the current state. The inventory charts visually represent the status of stock over a 10-day period. It highlights the stock state, indicating recurring instances where

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specific Work-in-Progress (WIP) items positioned between the chain and the "Electrical test" station, as well as those between the «Pre-assembly» and the chain, reaches their maximum capacities. These occurrences can be attributed to bottlenecks in the process, particularly in the "Takt1" and "Electrical Test" stages, which require a significant amount of time to complete their respective processing tasks.

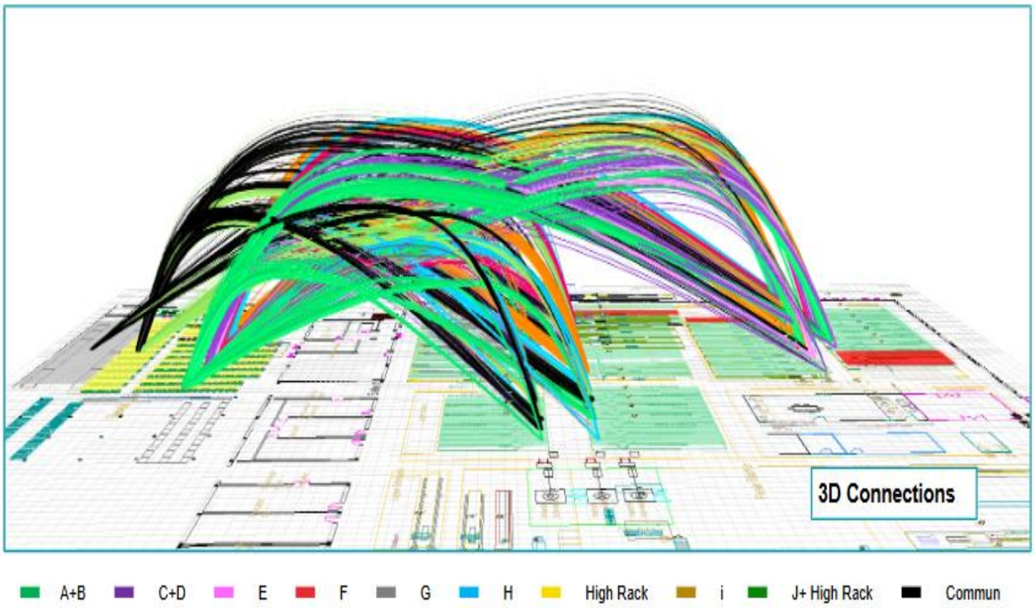

Fig. 7: Material Flow 3D

Figure 7 presents a 3D simulation of material flow connections between the warehouse and the production park, providing a graphical analysis of material movements within the facility. This visual representation offers a comprehensive overview of the entire logistics network, enabling a clearer understanding of material flow patterns, transport routes, and areas of inefficiency. The simulation results highlight a high volume of material movement across the production facility, indicating a significant logistical effort. The analysis reveals that several transport routes are highly congested, leading to increased material handling complexity, inefficiencies, and excessive travel distances. Additionally, the presence of heating flow issues—where certain areas experience excessive transportation density—suggests an imbalance in the distribution of material handling efforts. Moreover, the study identifies numerous unnecessary movements, which contribute to operational slowdowns, higher energy consumption, and increased workload for logistics personnel. These inefficiencies highlight the need for strategic optimization measures to streamline material flows and reduce logistical effort. To address these challenges, potential improvements could include:

- Optimizing warehouse layout to minimize travel distances and enhance accessibility to materials.
- Implementing lean logistics principles to eliminate unnecessary movements and reduce bottlenecks.
- Enhancing coordination between warehouse and production teams to ensure smoother material flow and better synchronization.
- Utilizing automated material handling solutions to further improve efficiency and reduce manual transport efforts.

By leveraging 3D simulations for logistics analysis, manufacturers can identify inefficiencies, test alternative flow configurations, and implement data-driven improvements to enhance overall production efficiency and reduce operational costs.

III. SIMULATION IMPROVEMENT

To reduce logistical effort and improve material flow efficiency, we incorporate the Milk run concept, designed to reduce logistical effort and improve material flow efficiency. This concept revolves around the use of a specialized tractor equipped with a two-story storage cabin, facilitating the seamless

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transportation of materials between the warehouse and production area. Figure 8 presents the optimized logistics solution.

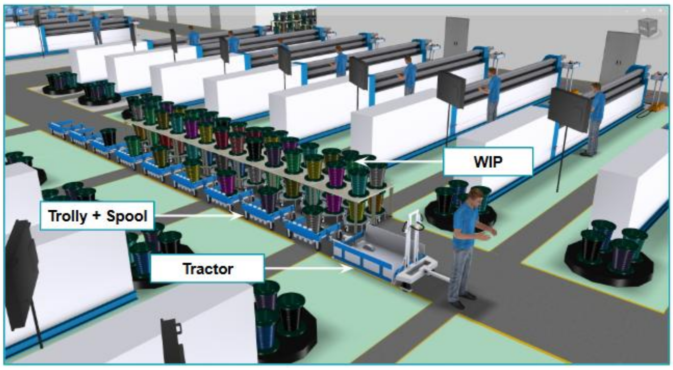

Fig. 8: 3D Display Solution

In the Milk Run system, the first level of the storage cabin is dedicated to the transportation of raw materials, ensuring a continuous and timely supply to the production machines. This structured approach minimizes delays and interruptions in the manufacturing process by streamlining material replenishment. Meanwhile, the second level is designated for returning the remaining cable reels from the machines back to the warehouse. This dual-purpose design enhances logistical efficiency by consolidating material movements, thereby reducing unnecessary trips and optimizing resource utilization. By implementing the Milk run concept, the company can achieve several key benefits, including a significant reduction in operator travel distances, lower transportation workload, and improved organization of material handling activities. Additionally, this system minimizes congestion within the production area, leading to smoother workflow execution and increased overall productivity. The integration of this innovative approach contributes to a leaner and more efficient logistics strategy, reinforcing the company’s commitment to operational excellence.
Figure 9 presents a simulation of the newly implemented Milk run concept, demonstrating its impact on optimizing logistics operations.

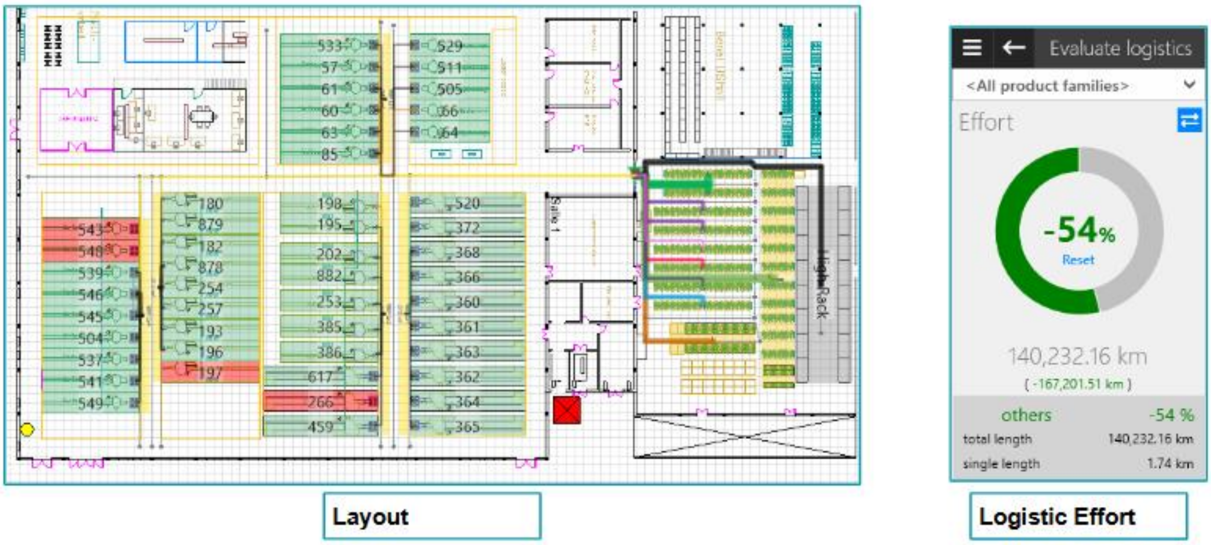

Fig. 9: Logistic Effort Current State

The simulation results presented in Figure 9, indicate a significant reduction in logistical effort, with the total annual distance travelled by operators decreasing to 140232 km. This represents an impressive 54% reduction compared to the current state, highlighting the effectiveness of the proposed solution. This implies an improved overall efficiency by 3% from 71% to reach 74% and reduced downtime by

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39%. The drastic decrease in logistical effort is primarily attributed to the improved material flow efficiency enabled by the Milk run concept. By integrating a two-story storage cabin system, the transport of raw materials to production machines and the return of unused cables to the warehouse have been streamlined. This optimization has led to a reduction in unnecessary movements, minimized transportation bottlenecks, and enhanced overall workflow organization. Beyond the numerical improvements, this reduction in logistical effort has several operational benefits. It decreases operator fatigue, reduces transportation time, and enhances the overall efficiency of material handling activities. Furthermore, fewer internal transport movements lead to lower energy consumption and maintenance costs for handling equipment, contributing to a more sustainable and cost-effective supply strategy. The simulation results confirm that implementing such an advanced logistics system can bring substantial improvements in productivity, resource utilization, and operational efficiency. These findings reinforce the importance of simulation-based planning in identifying and implementing effective solutions for material flow optimization.

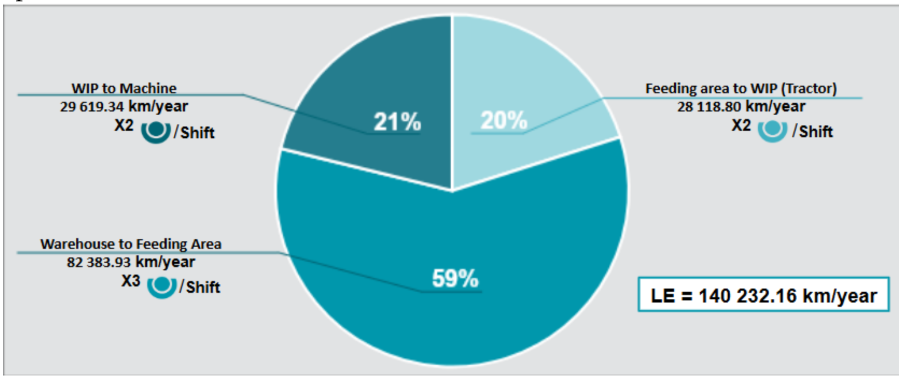

Fig. 10: Logistic Flow Statistics

We can know how the logistical effort is spread out in our new system, dividing the total distance travelled into three main parts (Figure 10). This breakdown helped us see how much more efficient our optimized material flow strategy is. The biggest chunk of the effort, 59% (82,383 km annually), goes towards moving raw materials from the warehouse to the feeding areas. This is still the most demanding part because it involves transporting large volumes to keep production running. The next segment, accounting for 20% (28,118 km annually), covers moving materials from the feeding area to the Work In Progress (WIP) tractor. This step plays a crucial role in ensuring a smooth transition of materials from storage to production, allowing for better synchronization between supply and demand. The reduction in distance compared to the first segment highlights the effectiveness of integrating an intermediate staging area, which helps in optimizing the overall workflow.

Rounding out the logistical effort, 21% (29,619 km per year) is spent on moving materials from the Work In Progress (WIP) area to the individual production machines. This ensures timely delivery to each workstation, which in turn reduces delays and boosts overall production efficiency.

Analyzing these logistical distributions highlights how effectively the new solution optimizes transportation. Breaking down tasks this way helps cut down travel distances, minimize inefficiencies, and improve productivity. Ultimately, this approach lowers operational costs and reduces the workload for logistics staff, resulting in a more efficient and well-organized production system. Figure 11 presents a 3D simulation of the material flow connections between the warehouse and the production park.

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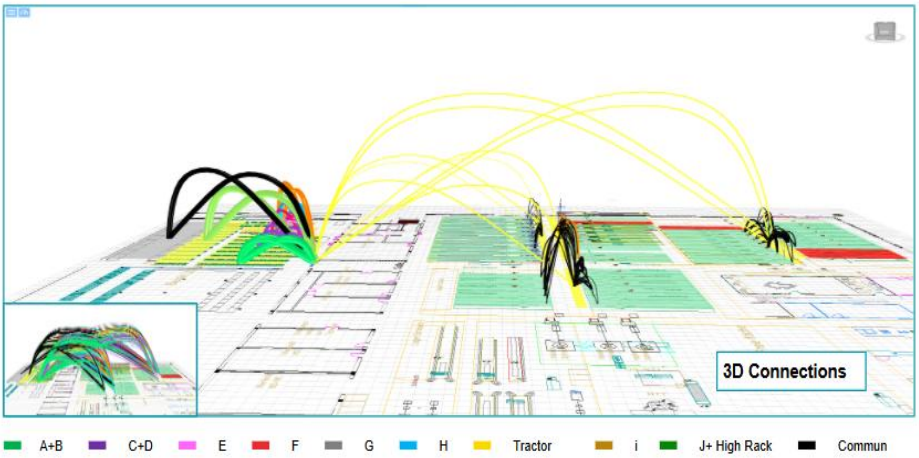

Fig. 11: Material Flow 3D Future State

This visual representation provides a comprehensive overview of the logistics network, enabling a clearer understanding of material movement patterns and transportation routes within the facility. The results from the simulation confirm that the integration of the Milk run concept has significantly optimized the flow of materials between the warehouse and the production park. This improvement has led to smoother, more efficient operations with fewer unnecessary movements, contributing to increased productivity and reduced operational strain on logistics personnel. However, despite the evident improvements in external logistics, the simulation also highlights a persistent logistical effort within the warehouse itself. This suggests that internal material handling operations such as the retrieval, sorting, and staging of raw materials before they are dispatched to production—still require optimization. Factors such as warehouse layout, storage zone organization, and internal transport routing may be contributing to these inefficiencies.

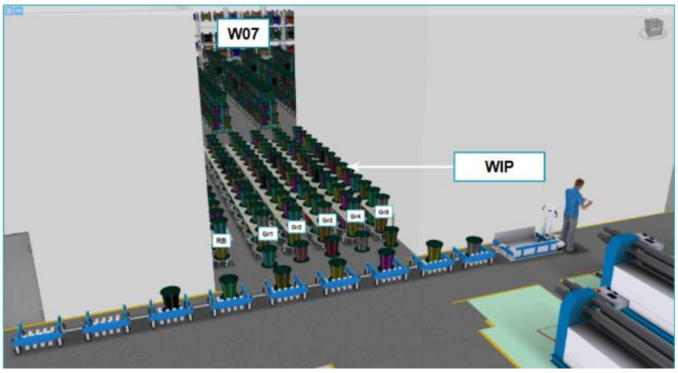

Fig. 12: 3D Display of Warehouse Solution

To improve warehouse efficiency, we should explore additional optimization strategies. As Figure 12 illustrates, this could involve reorganizing storage areas and sorting cabling reels by machine type. Such an approach would simplify tasks for both the logistics coordinator and the transporter, ensuring reels are moved to the yard precisely when production demands them. Furthermore, 3D factory modeling with visTABLE® (Figure 13) is a potent tool for streamlining material flows, cutting down on logistical effort, and boosting overall factory efficiency. By allowing businesses to visualize, simulate, and analyze factory operations, this technology empowers them to make smarter decisions, reduce inefficiencies, and enhance productivity. It plays a vital role in the digital transformation of manufacturing, aligns with Industry 4.0 goals, and helps create an agile and cost-effective production

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system.

Fig. 13: Factory Layout in 3D

IV. CONCLUSION

Our methodology includes an initial classification of storage areas within the warehouse aligned with the machine group based on its location. The data analysis and comparison using visTABLE® has permitted to select the best scenario of the future layout based on simulation results. The application of the milk run approach has allowed a better restructure of the information flow, thus a quicker identification of the storage area with the targeted machine group by the tractor.

A real-world automotive study showed that visTABLE® software is great for improving logistics. By digitally simulating their operations, the software helped them thoroughly analyze their existing system, pinpointing inefficiencies and bottlenecks. This simulation-based approach allowed for better decision-making, which significantly cut down on the effort needed for logistics and reorganized material handling from the raw material warehouse to the production park which resulted in:

- A drop in overall transport distances, reducing operator exhaustion and resource consumption, improved efficiency by minimizing unnecessary movements and ensuring timely material supply to production machines, a reduction in downtime, as better material availability prevented stoppages in the production process.
- Enhanced communication and coordination between warehouse staff and production teams, ensuring a smoother workflow and a more responsive supply chain.

The findings highlight the strategic value of using visTABLE® as a planning and simulation tool for optimizing logistics in manufacturing environments. By visualizing and analyzing different scenarios, companies can make data-driven decisions, improve work organization, and achieve a leaner, more efficient production system. The success of this case study reinforces the importance of simulation-based approaches in tackling logistical challenges and enhancing overall operational performance in the automotive industry.
This work could open the door for further improvements in the future. Safety wise, it is noteworthy that our layout solution using milk run system via the tractor has eliminated several security and ergonomics risks which have forced the operator to focus primarily on value-added tasks rather than the non-value added ones. A future perspective seems to be reachable which none other than the migration to industry 4.0 is.

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References

[1] Brar, G. S., & Saini, G. (2011, July). Milk run logistics: literature review and directions. In Proceedings of the world congress on engineering (Vol. 1, pp. 6-8). WCE.

[2] Bozer, Y. A. (1978). A minimum cost design for an automated warehouse (Master's thesis, Georgia Institute of Technology. Directed by John A. White.).

[3] Chacko Pearly Saira, Paul Gritty Maria, Hareesh Ramanathan. (2019), "FACILITY LAYOUT IMPROVEMENT FOR ENHANCING PRODUCTIVITY: AN APPLICATION OF SYSTEMATIC PLANT LAYOUT". Journal of Sustainable Development and Innovation, 2:5-19.

[4] Droste, M., & Deuse, J. (2012). A planning approach for in-plant milk run processes to optimize material provision in assembly systems. In Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2011), Montreal, Canada, 2-5 October 2011 (pp. 604-610). Springer Berlin Heidelberg.

[5] Dupláková, D., Duplák, J., Mital, D., Soltes, P., & Sukic, E. (2020). Analysis of approaches to the material flow in the production process with the use of simulation.

[6] Dupláková, D., Töröková, M., Duplák, J., & Török, J. (2021). An Alternative Approach to the Rationalization of the Production Process Using Simulation Methods.

[7] Eduardo, S. J., & Tseng, S. H. (2024). Design of experiment and simulation approach for analyzing automated guided vehicle performance indicators in a production line. Simulation, 100(3), 265-281.

[8] Facchini, F., Mossa, G., Sassanelli, C., & Digiesi, S. (2024). IoT-based milk-run routing for manufacturing system: an application case in an automotive company. International Journal of Production Research, 62(1-2), 536-555.

[9] Fedorko, G., Molnár, V., Honus, S., Neradilova, H., & Kampf, R. (2018). The application of simulation model of a milk run to identify the occurrence of failures. International Journal of Simulation Modelling, 17(3), 444-457.

[10] Grzegorz, B., Izabela, N., Arkadiusz, G., & Zbigniew, B. (2021). Reference model of milk-run traffic systems prototyping. International Journal of Production Research, 59(15), 4495-4512.

[11] Hausman, W. H., Schwarz, L. B., & Graves, S. C. (1976). Optimal storage assignment in automatic warehousing systems. Management science, 22(6), 629-638.

[12] Hejazi, T. H. (2021). State-dependent resource reallocation plan for health care systems: A simulation optimization approach. Computers & Industrial Engineering, 159, 107502.

[13] Jana Halčinová, Peter Trebuňa, Iveta Janeková (2014), The Comparison of Production Workplace Layouts Using Selected Software Tools Acta Mechanica Slovaca 18 (1): 26 - 30, 2014, DOI: 10.1515/mopa-2014-0003.

[14] Jewell, W. S. (1962). New methods in mathematical programming—optimal flow through networks with gains. Operations Research, 10(4), 476-499.

[15] Karagoz, S., & Karagoz, Y. (2025). Optimization of Material Flow and Product Allocation in Inter-Unit Operations: A Case Study of a Refrigerator Manufacturing Facility. Logistics, 9(1), 13.

[16] Kluska, K., & Pawlewski, P. (2018). The use of simulation in the design of Milk-Run intralogistics systems. IFAC-PapersOnLine, 51(11), 1428-1433.

[17] Lekan, O. K., Kayode, O. I., & Abdulrazaq Morenikeji, A. (2017). Analysis of plant layout design for operational efficiency with craft algorithms. Acta Universitatis Danubius. Œconomica, 13(4).

[18] Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. International Journal of Production Research, 59(12), 3777-3816.

[19] Purba, H. H., Fitra, A., & Nindiani, A. (2019). Control and integration of milk-run operation in Japanese automotive company in Indonesia. Management and Production Engineering Review, 10.

[20] Raposo, R., Pereira, G., & Dias, L. S. (2009). Simulation of a milk run material transportation system in the semiconductors industry.

[21] Simić, D., Svirčević, V., Corchado, E., Calvo-Rolle, J. L., Simić, S. D., & Simić, S. (2021). Modelling material flow using the Milk run and Kanban systems in the automotive industry. Expert Systems, 38(1), e12546.

[22] Siderska, J. (2016). Application of tecnomatix plant simulation for modeling production and logistics processes. Business, Management and Education, 14(1), 64-73.

[23] Sipahioglu, A., Acar, I., & Altin, I. (2024). A Metaheuristic Approach for In-Plant Milk-Run System with Autonomous Vehicles. Networks and Spatial Economics, 24(4), 1021-1041.

[24] Staab, T., Klenk, E., Galka, S., & Günthner, W. A. (2016). Efficiency in in-plant milk-run systems—The influence of routing strategies on system utilization and process stability. Journal of Simulation, 10(2), 137-143.

ISSN: 1737-9288

[25] Suebsangin, P., Ratanamalakul, N., & Dumrongsiri, A. (2013). Planning of production, inventory and logistics with direct shipment and milk run strategies: Numerical experiment. Journal of social and development sciences, 4(2), 39.

[26] T.Tellini, F.J.G. Silva, T. Pereira, L. Morgado, R. D.S.G. Campilho, L.P. Ferreira (2019), Improving-InPlant Logistics Flow by Physical and Digital Pathways, 29th International Conference on the Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28,2019, Limerick, Ireland.

[27] Vakharia, A. J., & Wemmerlov, U. (1990). Designing a cellular manufacturing system: a materials flow approach based on operation sequences. IIE transactions, 22(1), 84-97.

[28] Vieira, A. A. C., Dias, L., Pereira, G., Oliveira, J. A., Carvalho, M. S. F. B. S., & Martins, P. J. D. F. (2014). 3D microsimulation of milkruns and pickers in warehouses using SIMIO.

ISSN: 1737-9288