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Material FLOW Analysis and Optimisation Using Simulation and Milk RUN System: A Case Study of an Automotive Wiring Industry

Abdelaziz Mrabti [1]* , Sana Bouajaja [2], Khaled Nouri [3]

[1] *Advanced System Laboratory (LSA), National Engineering School of Carthage, Tunisia*
[1]abdelaziz.mrabti@enicar.ucar.tn

[2] *OASIS-ENIT, National Engineering School of Bizerte, Tunisia*

[2]sana.bouajaja@enit.utm.tn

[3] *Advanced System Laboratory (LSA), National Engineering School of Carthage, Tunisia*
[3]khaled.nouri@enicar.ucar.tn

ABSTRACT

This paper presents a case study on material flow optimization within the automotive wiring harness industry, a sector characterized by complex product configurations, high variability in production requirements, and diverse task sequences. Efficient material flow management is crucial in this industry to ensure smooth operations, minimize delays, and enhance overall productivity. From the early planning phase, it is essential to identify potential transportation bottlenecks, particularly along production routes and at warehouse entry points. Addressing these inefficiencies proactively allows for better resource allocation and improved workflow continuity. To support this process, the proposed system provides a graphical analysis of material flows, offering a clear and structured visualization of logistical operations. Such diagrammatic representations play a pivotal role in simplifying material flow planning, enhancing logistics coordination, and focusing on the most critical transportation routes. By leveraging these insights, companies can effectively align their logistics objectives with broader operational goals, transforming material and inventory flow management into a strategic discipline. The study utilizes visTABLE® software, which enhances the planning process by harnessing the capabilities of the digital factory. This tool enables a more dynamic and creative approach to optimizing material flows, making complex logistics scenarios easier to comprehend. Its advanced visualization and evaluation functions, such as interactive diagrams, provide a structured and user-friendly way to identify inefficiencies and improve material handling strategies. These features allow decision-makers to precisely analyze and refine logistics operations, ultimately leading to more efficient workflows. The findings of this case study underscore the advantages of simulation-based approaches in achieving material flow optimization. The results demonstrate that by employing digital simulation tools, companies can effectively pinpoint bottlenecks, reduce logistical effort, and enhance overall operational efficiency. Furthermore, the implementation of these simulation techniques has significant practical implications, not only for the automotive wiring harness industry but also for other manufacturing sectors facing similar challenges. By adopting a simulation-driven methodology, companies can make data-informed decisions that lead to more streamlined logistics, reduced waste, and improved productivity.

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

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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 (Halčinová et al., 2014 [10]). 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. (Lekan et al., 2017 [15]). Thereby, before making costly investments, enterprises are able to 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 (Dupláková et al., 2021[5]). Various industries, are exploring multiple design iterations using simulation, particularly in manufacturing (Duplakova et al., 2020), logistics (Eduardo & Tseng, 2024; Siderska, 2016 [20])), and healthcare (Hejazi, 2021 [11]), 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 (Pérez-Gosende et al., 2021; Lekan et al., 2017 [15]; Karagoz & Karagoz, 2025; Vakharia & Wemmerlov, 1990). It consists on defining the optimum structure and facilities 'design incorporating workstations, storage AREAS, material handling systems, personnel… (Saira et al., 2019) consider facility's design as a strategic issue since it has interesting impact on the production line performance. It leads to material handling costs reduction, idle time minimization and maximize the use of labour, equipment and space.

Thus, material flow analysis is a key tool for improving industrial processes, since it focuses on two fundamental aspects: flow intensity, which refers to the amount of materials circulating in the system, and travel distance, which represents the distance materials cover throughout the production process. To optimize these flows, the goal is to minimize the quantity of materials in circulation and reduce transport distances as much as possible. Ideally, each piece or batch should move directly from one workstation to another, preventing accumulation and unnecessary handling. However, implementing these principles in real-world manufacturing environments is challenging. Factors such as warehouse organization, machine layout, and internal transport management significantly impact the efficiency of material flows. This is why a structured, data-driven approach is essential 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 softwares to produce computer models of production systems. These models are utilized to estimate the future behaviour 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 highlited in (Duplakova et al., 2020), we can list some of them Tecnomatix Plant Simulation, Arena, Simul8, AutoMod, Witness, VisTABLE…In (Halčinová et al., 2014 [12]), a comparative study was conducted between Plant Simulation and VisTABLE.

In this context, visTABLE® software provides an advanced solution for optimizing logistics flows in the automotive industry. This tool enables simulation and visualization of material flows, helping to identify bottlenecks, inefficiencies, and areas for improvement.

The case study presented in this research explores 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 (Tellini et al., 2019[24]).

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As defined in literature, the Milk Run system is a logistics strategy that optimizes material pickups and makes deliveries more efficient. Following a fixed schedule in collecting or delivering materials, time is saved and costs are reduced (Brar & Saini, 2011; Facchini et al., 2024 [7], Sipahioglu et al., 2024[21]; Grzegorz et al., 2021[9]). Thereby, this concept is widely used as an efficient logistics model that enhances operations in various serial production fields, including the automotive, mechanical, military industries, electronic,… (Simić et al., 2021[19]).
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 CO2 emission as discussed in (Suebsangin et al., 2013 [23] ; Brar & Saini, 2011). (Purba et al., 2019[17]) presents a milk-run system of Japanese automotive companies in Indonesia. It was implemented in urban area to decrease transportation costs and number of trucks used in order to reduce emission of carbondioxide (CO2) and support green logistics. Before operating milk-run, a Transportation Value Stream Mapping (TVSM) was prepared to optimize supply chain logistics and ensure just-in-time delivery. FlexSim simulation software was used by (Kluska & Pawlewski, 2018) 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 mentioned and used in (Droste & Deuse, 2012). In this paper, a new approach for planning and optimizing in-plant milk run processes was proposed, in the context of automotive industry, for logistics planners to gain time in material provision for assembly systems. It was combined with the Kanban system in (Simić et al. 2021[19]) for modelling material flow using particle swarm optimization (PSO), in automotive industry too. The objective was finding the optimal numbers of trailers and containers in for a train system in a defined route time period. In (Raposo et al., 2009[18]), a simulation model in Arena was developed to identify sources of waste and potential improvements by testing different system configurations, in semiconductors industry, a Milk Run system was also implemented.
Using SIMIO, a 3D microsimulation model was developed in (Vieira et al., 2014[26]), to model the Mil runs and picking systems of Bosch Car Multimedia Portugal, utilized to satisfy production lines needs by collecting containers of products, from a warehouse. To analyze in-plant milk-run systems, (Staab et al., 2016 [22])) presents a study applied to a large automotive supplier plant and focusing on typical traffic situations. The experimental study demonstrates delays are caused by frequent blockages, and schedules and system stability are also disrupted. Therefore, to improve system stability and enhance traffic flow, implementing streamlined handling processes for critical materials and optimizing routes are necessary. For efficient transport processes, (Fedorko et al., 2018) discusses the importance of Automated Guided Vehicle (AGV) systems in internal logistics. It proposes a simulation model identify failure points in a Milk Run delivery process. It was developed using Tecnomatix Plant Simulation. The obtained results show that material delivery process was improved and production process becomes more efficient, without any interruptions.
Through visTABLE® simulations, 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 the production park, ensuring a more responsive and streamlined material flow.
By integrating these simulation-based optimization strategies, this study demonstrates how visTABLE® can transform material flow management into a key driver of industrial performance, directly impacting 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

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This chapter presents 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 assessment of the existing material flows and workplace layout was conducted, followed by a proposed reorganization, both of which are detailed through calculations and logistic analyses in Chapter 4 of the case study. The selected company was chosen based on its alignment with the research objectives and the feasibility of collaboration. Data collection involved on-site observations, interviews, and document analysis to gather insights into workplace layout, material flow patterns, and production processes.

To validate the proposed solution, visTABLE software was employed 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 conducted to assess the impact of the proposed layout modifications. Key performance indicators, such as production time and worker productivity, were measured before and after implementation. Data visualization and statistical analysis were utilized to interpret results and identify trends.

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 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.

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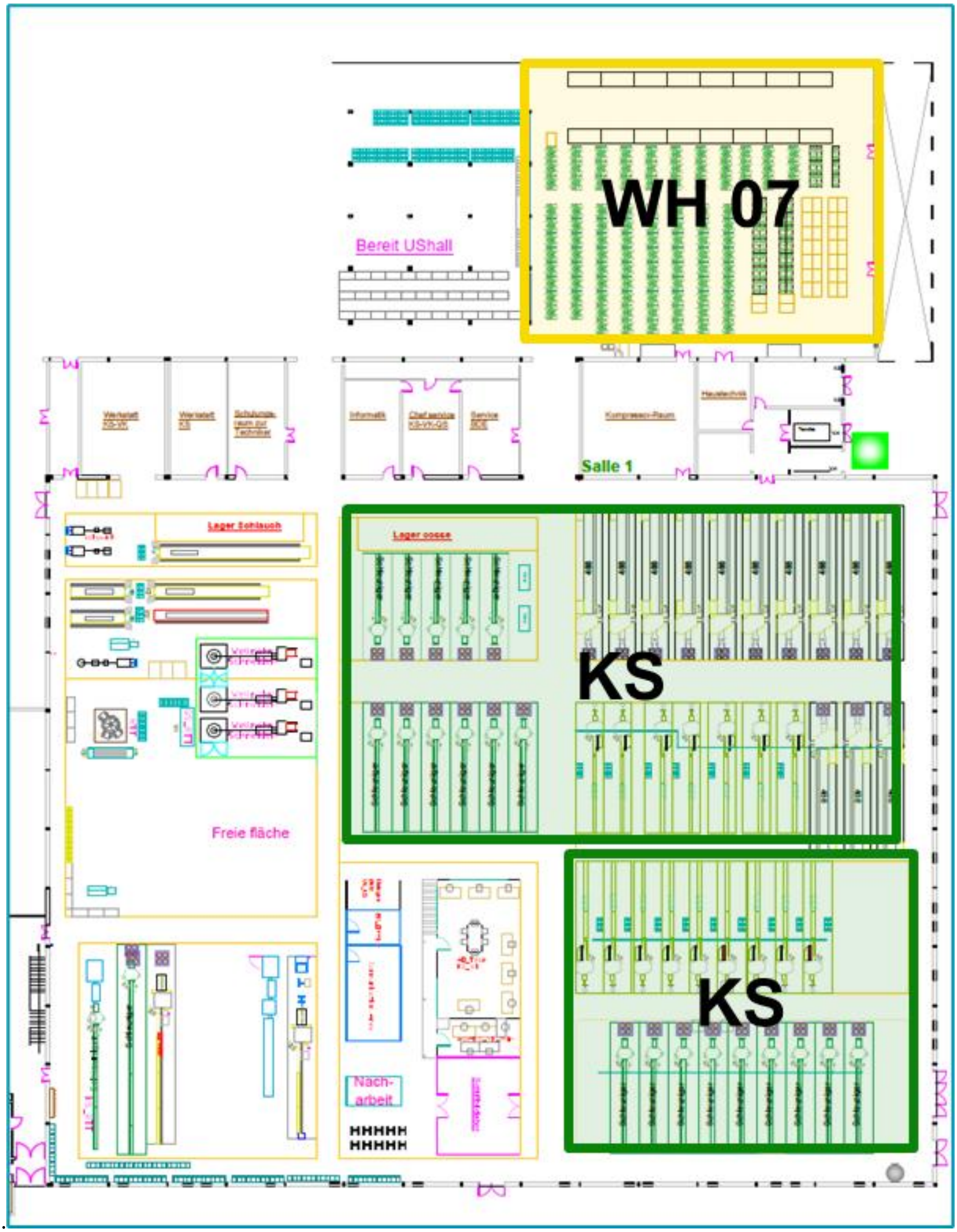

Fig. 1: Production layout

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

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efficient storage system. As illustrated in Figure 2, this division optimizes the retrieval and distribution of raw materials.

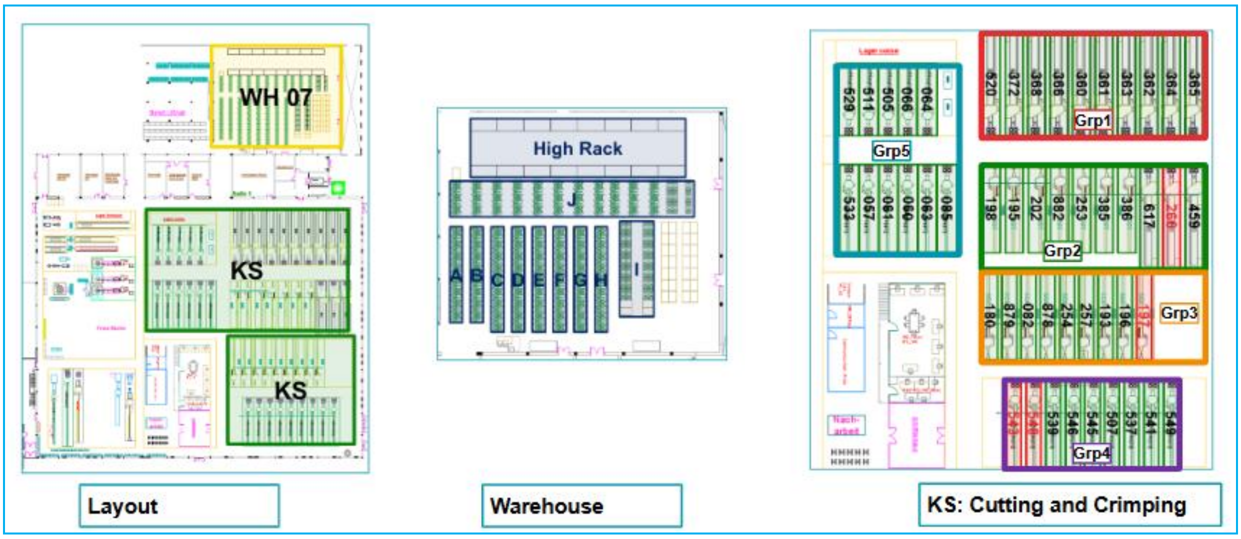

Fig. 2: Workplace layout of the current state details

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

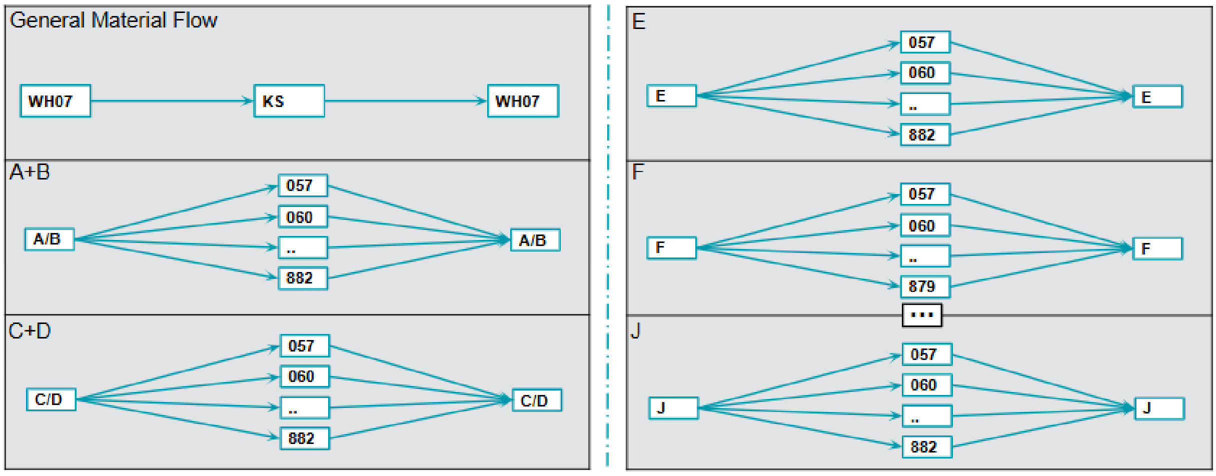

Fig. 3: General Material Flow

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.

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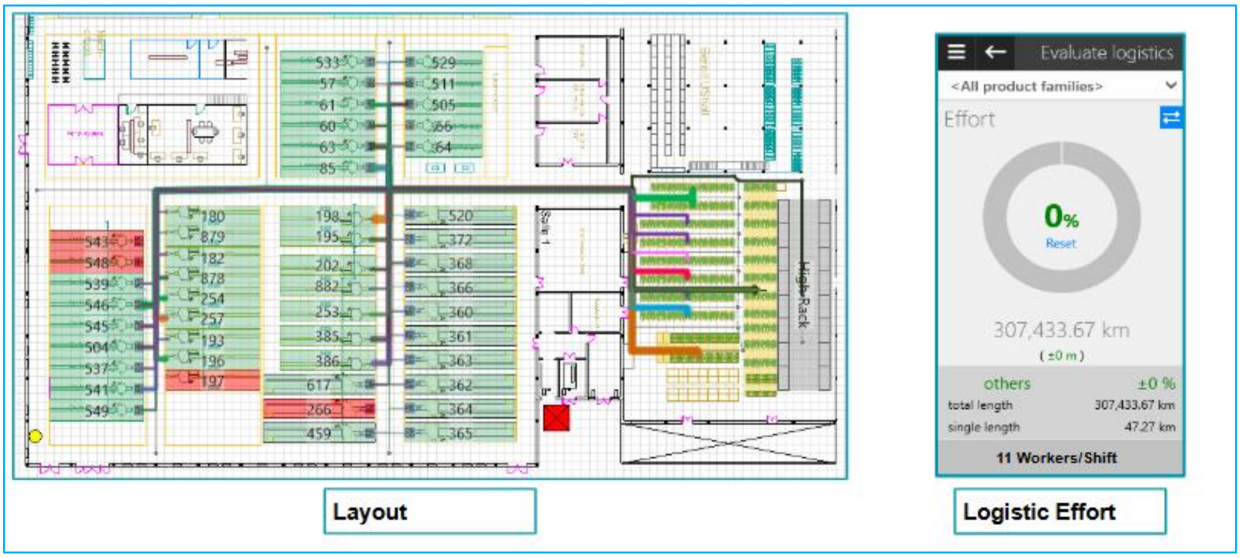

Fig. 4: Logistic Effort Current State

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.

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.

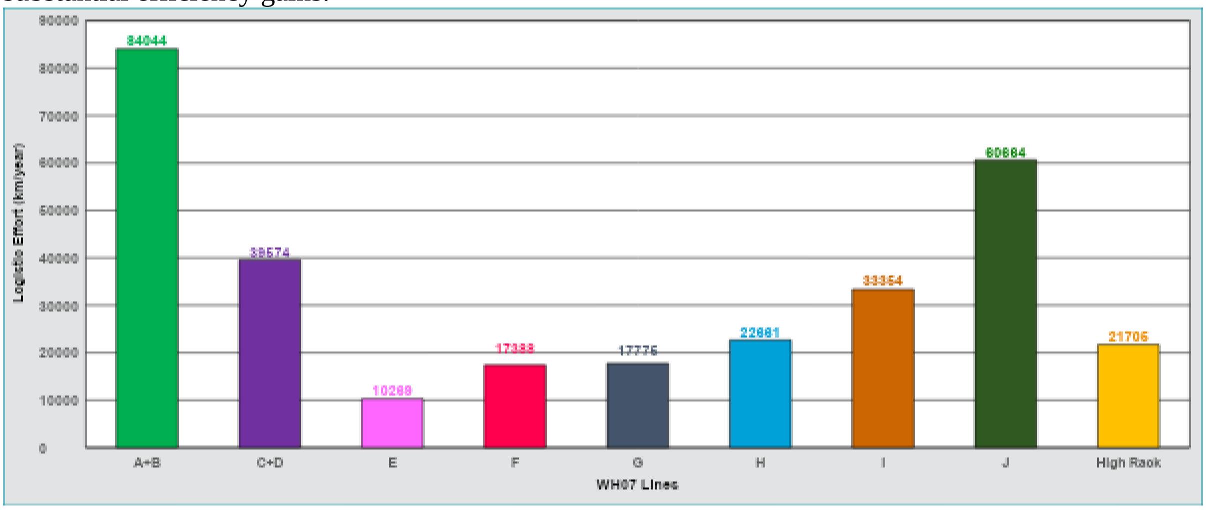

Fig. 5: Logistic Effort Ranking Warehouse

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

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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.

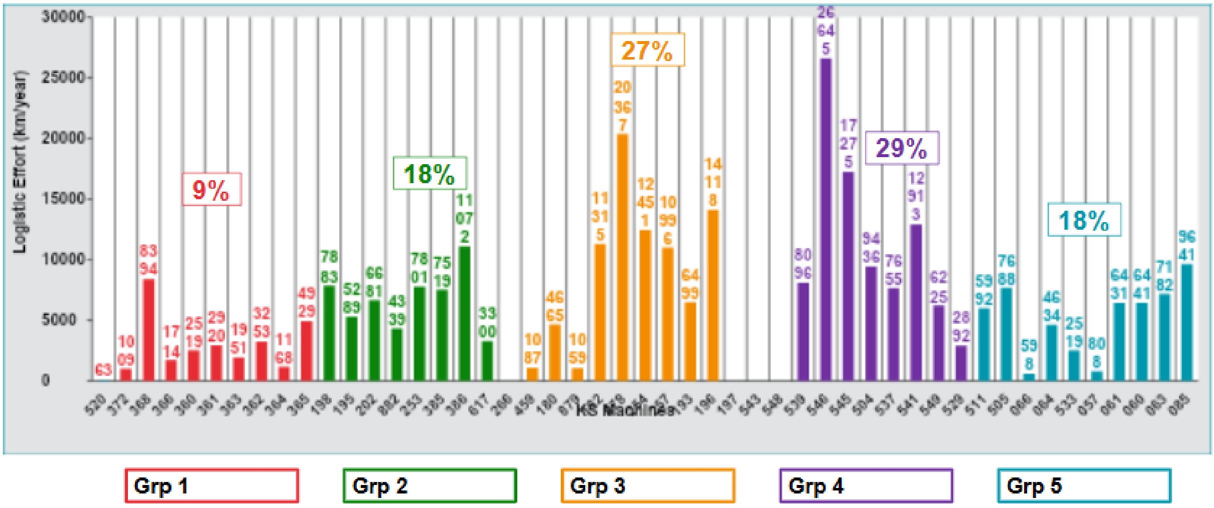

Fig. 6: Logistic Effort Ranking machines

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 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.

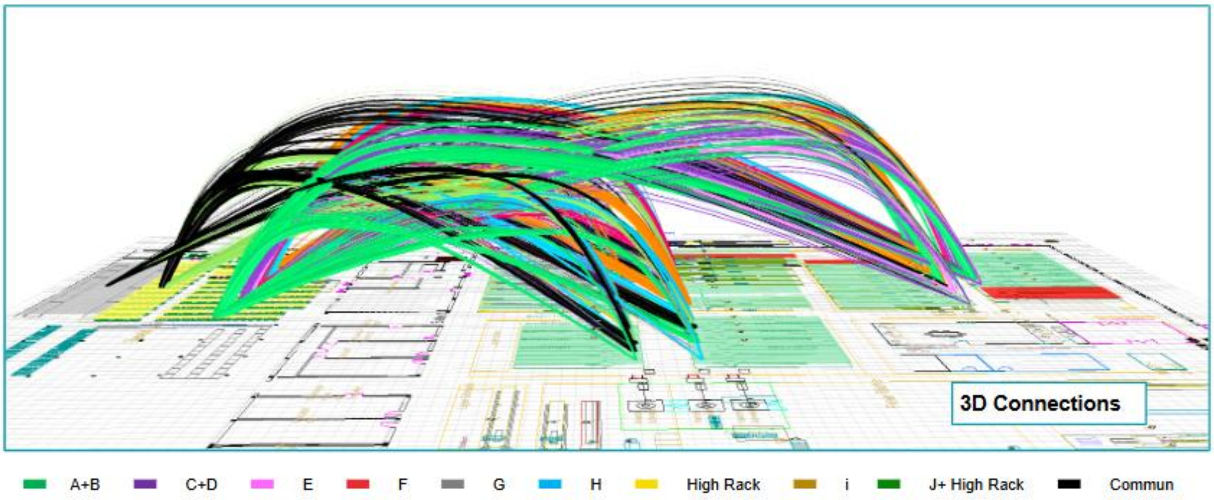

Fig. 7: Material Flow 3D

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

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

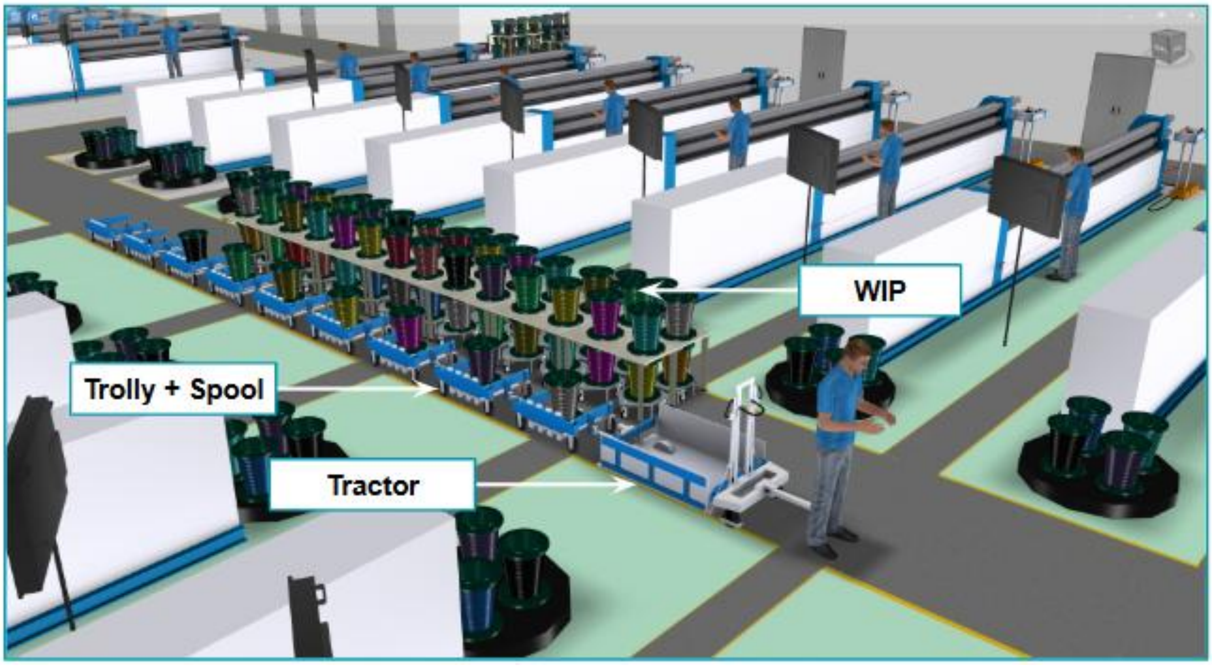

Fig. 8: 3D Display Solution

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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.

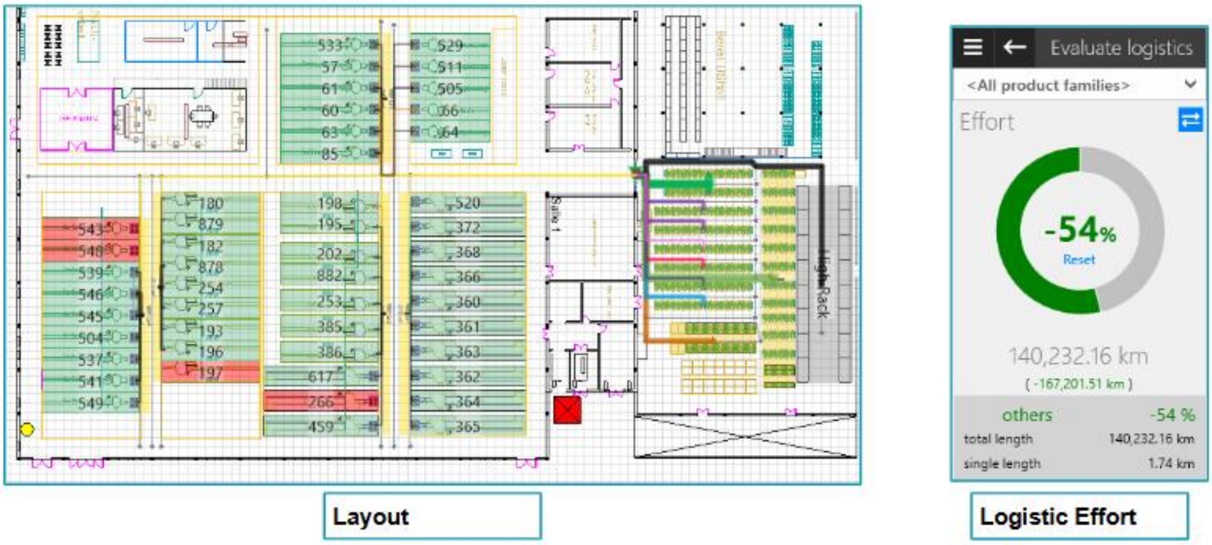

Fig. 9: Logistic Effort Current State

The simulation results presented in Figure 9, indicate a significant reduction in logistical effort, with the total annual distance travelled by operators decreasing to 140,232 km. This represents an impressive 54% reduction compared to the current state, highlighting the effectiveness of the proposed solution. 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 logistics 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.

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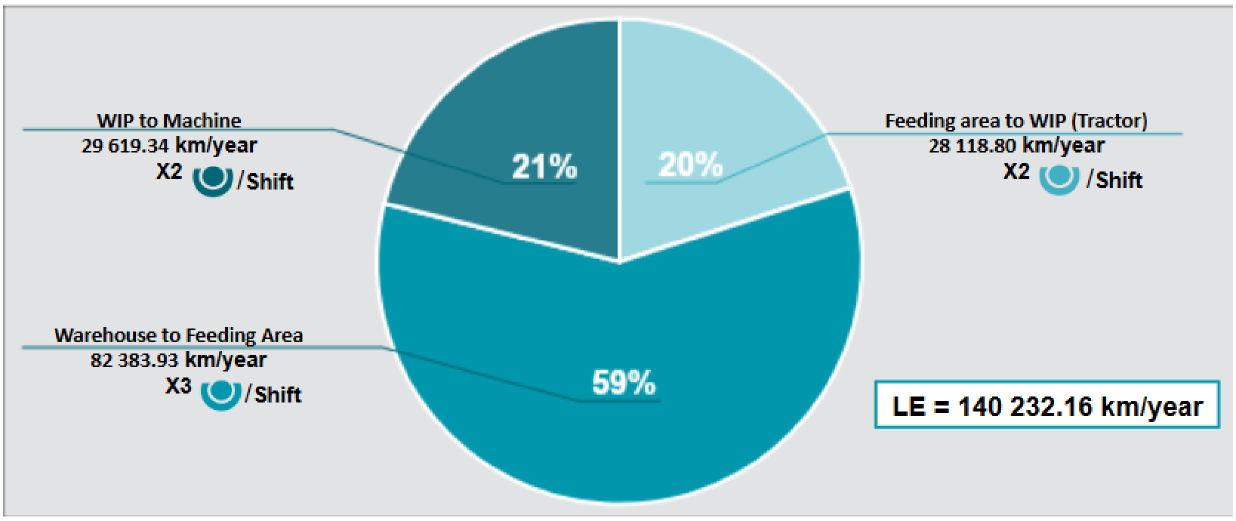

Fig. 10: Logistic Flow Statistics

We illustrate the distribution of the logistical effort in the newly implemented solution, breaking down the total transportation distances into three key segments (Figure 10). This detailed analysis provides insights into the efficiency improvements achieved through the optimized material flow strategy. The results show that the majority of the logistical effort, 59% (82,383 km per year), is dedicated to the transportation of raw materials from the warehouse to the designated feeding areas. This segment remains the most resource-intensive part of the logistics process, as it involves large quantities of materials being transported to ensure a continuous supply for production. The second segment, which accounts for 20% (28,118 km per year), covers the movement of 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.

The final segment, responsible for 21% (29,619 km per year) of the logistical effort, involves transporting materials from the WIP area to the individual production machines. This phase ensures that each workstation receives the necessary materials precisely when needed, reducing unnecessary waiting times and improving overall production efficiency.

By analyzing these logistics flow distributions, it becomes evident that the new solution significantly optimizes transportation efforts. The structured division of logistical tasks helps to reduce travel distances, minimize operational inefficiencies, and enhance productivity. Furthermore, this approach contributes to lowering operational costs and reducing the workload on logistics personnel, leading to a more streamlined and effective production system.

Figure 11 presents a 3D simulation of the material flow connections between the warehouse and the production park.

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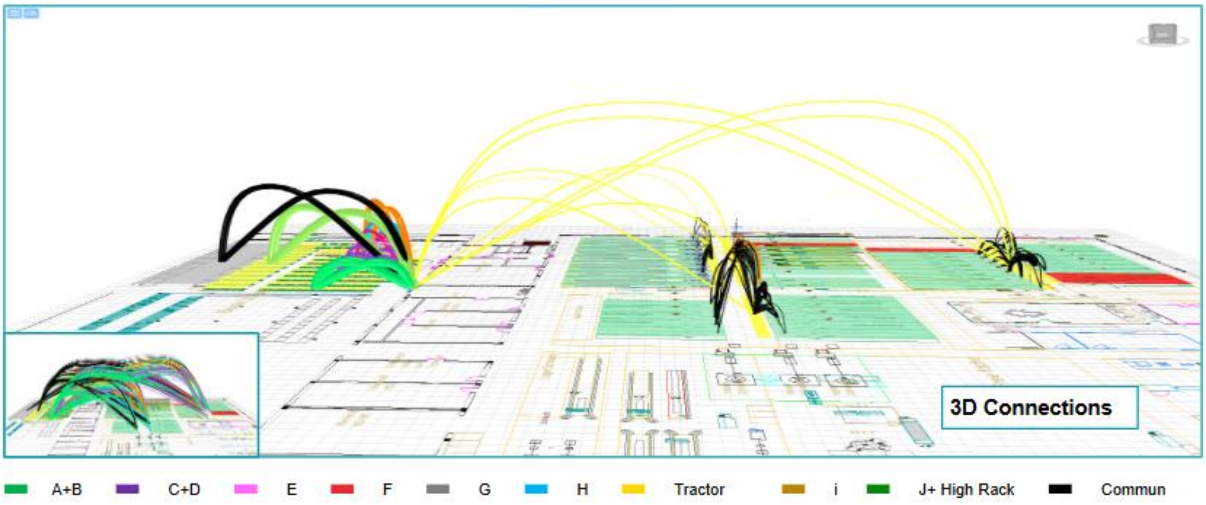

Fig. 11: Material Flow 3D Future State

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.

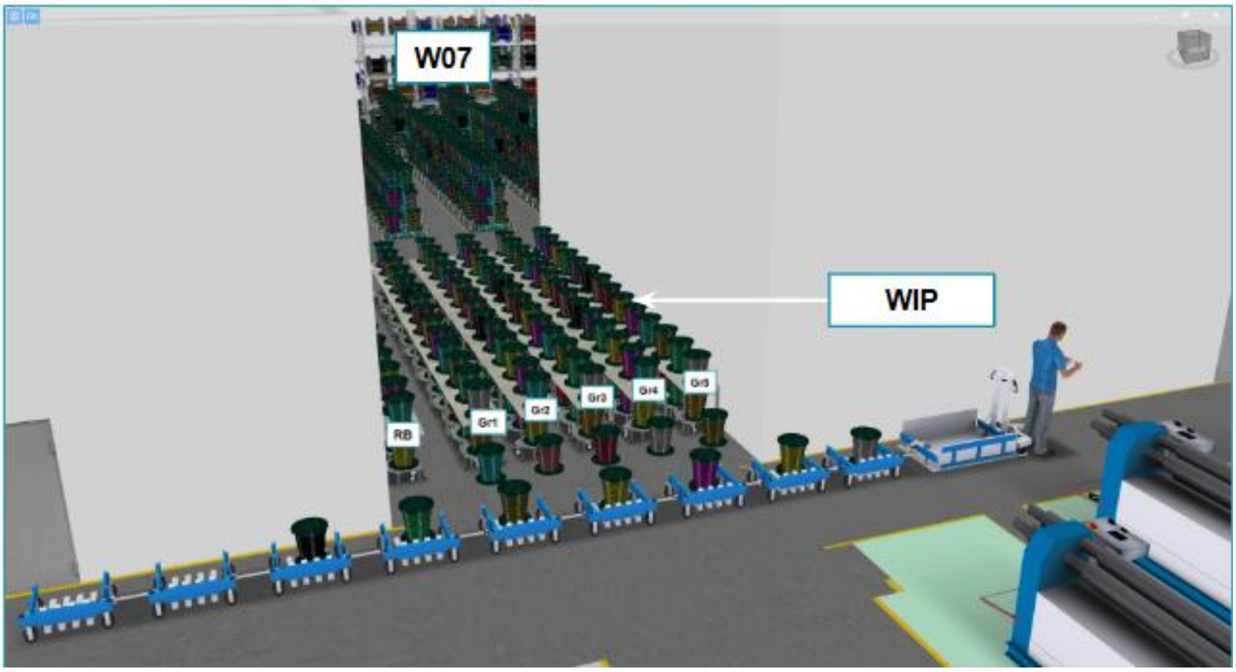

Fig. 12: 3D Display of Warehouse Solution

To further improve logistics efficiency, additional optimization strategies should be considered within the warehouse. Figure 12 illustrates potential improvements, which include restructuring storage areas and preparing cabling reels according to machine groups. This approach would facilitate the work of the

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logistics coordinator and the transporter by ensuring that reels are transferred to the yard in alignment with production demand.

The use of 3D factory modelling with visTABLE® (Figure 13) is a powerful tool for optimizing material flows, reducing logistics efforts, and enhancing factory efficiency. By visualizing, simulating, and analysing factory operations, companies can make better decisions, minimize inefficiencies, and improve productivity. This technology plays a crucial role in the digital transformation of manufacturing, aligning with Industry 4.0 objectives and ensuring a lean, agile, and cost-effective production system.

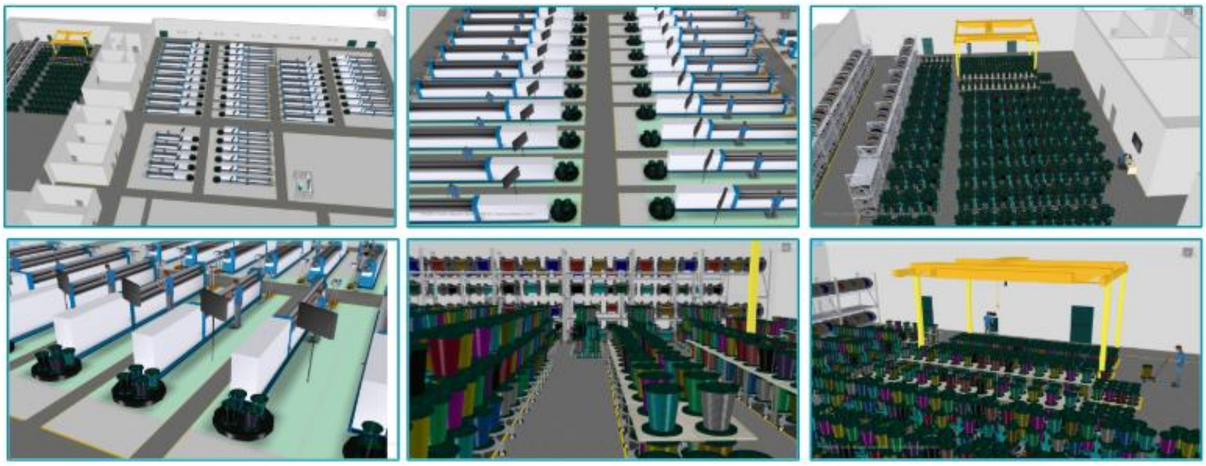

Fig. 13: Factory Layout in 3D

IV. CONCLUSION

The implementation of visTABLE® software in a real case study within the automotive sector has demonstrated its effectiveness in optimizing material flow and improving logistics efficiency. Through digital simulation, the software provided a comprehensive analysis of the current logistics system, identifying inefficiencies, bottlenecks, and areas for improvement. By integrating simulation-based decision-making, the study achieved significant reductions in logistic effort, leading to more efficient material handling processes. The optimized flow of materials between the raw material warehouse and the production park resulted in:

A decrease in overall transport distances, reducing operator fatigue 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 disruptions 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 analysing 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.

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