AUTONOMIZATION OF NON-ADDED VALUE PROCESS IN LOGISTICS – CASE STUDY

Mariusz KMIECIK[1*], Anna HORZELA-MIŚ[2]

[1] Silesian University of Technology, Department of Management; mariusz.kmiecik@polsl.pl, ORCID: 0000-0003-2015-1132

[2] Silesian University of Technology, Department of Management; anna.horzela-mis@polsl.pl, ORCID: 0000-0003-2345-9861

* Correspondence author

Introduction/background: This research elucidates the tangible benefits and operational patterns of incorporating AMR (Autonomous Mobile Robots) in warehouse management, particularly for non-value-added processes. It offers insights to logistics providers on optimizing their use of AMR and understanding the cost-benefit dynamics when juxtaposed against traditional human-operated systems.

Aim of the paper: The primary objective of the study was to present the justification for the operation of AMR using the example of a selected warehouse process implemented by a 3PL company The selected process is handling of empty pallets in the warehousing management of a 3PL company.

Materials and methods: The research utilizes a case study approach targeting a leading global 3PL provider known for comprehensive warehousing solutions and value-added services (VAS). The case specifically addresses the deployment of two AMR to manage non-value-added processes related to empty pallet handling in the warehouse. The data for analysis was sourced from a system synchronized with a warehouse management system (WMS) covering a span of six months.

Results and conclusions: Upon extensive analysis, it was discerned that the AMRs, while operational, spent about 30% (AMR1) and 35% (AMR2) of their time ready but without tasks. Such statistics suggest an underutilization of the robots, yet also indicate a robust warehouse management system ready to accommodate unexpected surges in demand. Detailed examination further revealed that AMR1's main activity (57% of tasks) was retrieving empty pallets from the AS/RS output modules, whereas AMR2 was predominantly (70%) involved in moving empty pallets to the transit area. Notably, even with AMRs being underutilized, the operational cost savings compared to human-operated forklifts was evident. The study is restricted to the autonomization of a single process in one 3PL company, and the results might not be universally applicable to all logistics service providers or other processes. Further, the research only spans a period of six months.

Keywords: Autonomous mobile robots, Logistics, Planning and control, Value-added services.

1. Introduction

In the realm of industrial settings, spanning multiple decades, both AGV (automated guided vehicle) and AMR have played pivotal roles in enhancing the efficiency of intralogistics and material handling operations. Nevertheless, for system integrators, the selection and successful implementation of enhanced, appropriate, and dependable communication and control technologies for these unmanned vehicles continue to present a formidable challenge (Hercik et al., 2022). The unique communication demands of AGV and AMR place rigorous performance expectations on communication links in terms of both latency and reliability, criteria that many existing wireless technologies often struggle to meet (Oyekanlu et al., 2020).

AMR are now finding their way into various intralogistics domains, including manufacturing, warehousing, cross-docks, terminals, and hospitals. With their advanced hardware and control software, AMR are capable of carrying out tasks independently in dynamic settings. In contrast to AGV systems, where a central unit manages scheduling, routing, and dispatching for all AGV, AMR have the ability to communicate and negotiate autonomously with other resources such as machines and systems, thus distributing decision-making across the system. This decentralized approach enables the system to adapt dynamically to changes in both the system's state and the environment. These advancements are reshaping the conventional methods and decision-making processes for planning and control. The integration of automation and autonomy themes with third-party logistics is a topic that frequently appears in publications (Helmke, 2022; Amiri et al., 2022). The authors decided to review the SCOPUS database to examine how the automation theme, mainly using AMR, is connected with third-party logistics. Sources were searched with titles, keywords, or abstracts containing both AMR and third-party logistics terms. The query used was as follows: (*TITLE-ABS-KEY ("autonomous mobile robots") AND TITLE-ABS-KEY ("3PL" OR "third-party logistics" OR "third-party logistic" OR "logistics service provider" OR "LSP"))*. Two publications were found. In one, the AMR theme is described technically, and a tool for positioning these robots is developed (Tanaka et al., 1998). In the second publication, the emphasis is on the navigation of such robots in the internal logistics space, suggesting that AMR can positively impact the efficiency of logistics processes (Chen et al., 2023). Of course, the literature extensively describes the concept of using AGV-type solutions, mainly because these solutions have been on the market for a much longer time. The relatively low number of publications related to the use of AMR in the realm of third-party logistics and in non-value-generating processes led to the formulation of the main goal and the research question.

The main objective of the paper is to present the justification for the operation of AMR using the example of a selected warehouse process implemented by a 3PL company. The paper adopts a single research question, with the following content: What are the benefits of autonomizing the process of handling of empty pallets in the area of warehouse management of a 3PL company? We contribute to the literature to guide managers in the decision-making process, thus supporting them in achieving optimal performance using AMR and AGV. Finally, we propose an agenda for future research in this area.

2. Theoretical background

2.1. Non-added value processes in logistics

While the traditional Taylor-Ford model primarily aimed at cost reduction through volume-based strategies, the contemporary business landscape demands a more comprehensive approach. In today's dynamic environment, companies must prioritize their sustainability and competitiveness. To achieve this, firms need to reevaluate their production processes, distinguishing between "Added Value" (AV) and "Non-Added Value" (NAV) tasks. To assess and optimize these actions, companies employ a process known as value-added analysis. This systematic examination dissects each step within their processes to determine if each activity contributes value to their products or services. When a process or activity is found to lack value, the company's objective is to either transform or eliminate it. Some NAV tasks should be systematically eliminated to align with the modern industrial vision and the focus should shift toward enhancing management practices (Azzemou, Noureddine, 2021).

An effective point of intervention for improving competitiveness is within the logistics chain, a pivotal component of current production and distribution systems. The logistics chain encompasses physical operations such as transportation, warehousing, handling, and packaging, all of which significantly contribute to the overall value of the end products. In essence, logistics represents a complex system comprising both product flows and information flows, necessitating adept management to ensure quality, reliability, and responsiveness while minimizing operational costs (Min, 2019). It is recognized as a strategic function that generates added value for the company, making it an ideal area for strategic enhancement in the pursuit of sustainability and competitive advantage.

Appreciating the significance of value-added activities hinges on a deep comprehension of the requirements of businesses. These activities present substantial opportunities to manufacturing firms, particularly when their impact on business performance has been thoroughly grasped (Yang et al., 2013). In this context, value-added activities provided by suppliers can be defined as any proactive measures taken by suppliers to enhance the value of the delivered products or services, with a notable emphasis on contributions from key suppliers (O'Brian, 2014). This research area is attention on four key value-added activities that exert a notable influence on the performance of manufacturing firms: supplier-customized services, collaborative logistics, the sharing of information, and the realms of innovation and development. These facets collectively underscore the multifaceted nature of value enhancement within the manufacturing domain, with the potential to yield substantial gains in overall business performance (Jum'a, 2020).

Elevating business performance hinges on the optimization of flow management, a domain mastered by the logistics function. In essence, this optimization entails the reduction of production or transportation time, ultimately leading to substantial financial benefits. It is imperative to recognize that logistics has evolved into a strategic imperative, with Added Value (AV) serving as a pivotal factor in a company's competitiveness, regardless of its size or specific industry.

In this context, the elimination of non-AV activities is a central objective, and this aspiration is realized through the Lean concept (Ikechukwu, 2019). At its core, Lean thinking revolves around the eradication of waste, known as "Muda" in Japanese. Waste is defined as any action or circumstance that fails to create value for the customer (Womack, Jones, 2015). Any action that ceases to contribute value or has never done so is categorized as non-value-added, often referred to as waste. Waste encompasses anything that surpasses the minimal essential resources required to produce a product or service. Depending on the context, waste can manifest as surplus materials, superfluous equipment, unnecessary expenditures, time squandered, surplus personnel, or excess parts. Another perspective on waste is any activity or process that fails to bring about a physical alteration in the product or bolster its profitability by fulfilling the customer's prerequisites.

Seven distinct types of waste have been identified, and among them, overproduction stands out as the most pernicious, as it begets and conceals other forms of waste (Cortes et al., 2016). Overproduction invariably leads to surplus inventories, which, in turn, obstruct the path to continuous improvement (Dossou et al., 2022). Just as Lean Manufacturing principles have been successfully applied to production, they are equally adaptable to the realm of logistics. Lean Logistics sets its sights on eliminating waste throughout the supply chain (Morgan, 2006). This endeavor translates into heightened productivity, diminished inventories, reduced floor space requirements, decreased overall logistics expenses, and enhanced service levels, notably in terms of on-time deliveries (Christopher, 2013). Within the logistics domain, it's evident that seven areas of waste have been identified:

- Handling disproportionate quantities, involving unnecessary movements or the handling of larger quantities than required.
- Empty transportation, signifying the transport of underutilized or empty loads.
- Superfluous operations, such as unnecessary or redundant transportation, repackaging, and more.
- Unwarranted human movements and motion.
- Accumulation of stock and outstanding inventory.
- Non-conforming goods, encompassing deterioration, picking errors, and quality issues.
- Machine underutilization and inactivity.

Recognizing and systematically addressing these areas of waste is instrumental in achieving streamlined and cost-efficient logistics operations On the flip side, In the fast-paced world of logistics, the efficiency of operations is paramount. To ensure that products and goods reach their destination in a timely and cost-effective manner, companies must continually seek ways to optimize their processes (Azzemou, Noureddine, 2021). One key aspect of this optimization is the identification and elimination of non-added value processes. Non-added value processes are activities within the logistics chain that do not directly contribute to the quality or functionality of the product but consume valuable resources, including time, labor, and capital. Identifying and minimizing these processes is essential for improving overall efficiency and cost-effectiveness. Several strategies can be employed to address non-added value processes in logistics: Process Mapping, Value Stream Analysis, Lean Principles, Technology Integration, Continuous Improvement, Collaborative Partnerships. By recognizing and addressing non-added value processes, logistics companies can enhance their competitiveness, reduce costs, and provide better service to their customers. This ongoing commitment to process improvement is essential in a world where every minute and resource count in the quest for operational excellence.

2.2. AMR and AGV

Within the industrial sector, the evolution of robots has seen them progress from being robust but stationary machines to becoming highly advanced mobile platforms, catering to a more extensive array of automation requirements (Liaqat et al., 2019). The inception of AGV dates back to 1953, when Barret Electronics, located in Northbrook, Illinois, USA, introduced the first known AGV (Muller, 1983). Since that milestone, AGV have found extensive use in streamlining intralogistics and material handling operations within industrial settings (Ullrich, 2014). In recent decades, the adoption and integration of AMR have continued to flourish in these same environments. AMR typically refer to material handling vehicles with the ability to autonomously traverse from one location to another to fulfill specific tasks. They are often equipped with robotic arms and actuators mounted on mobile platforms (Shneier, Bostelman, 2015). AGV, on the other hand, are predominantly employed in industrial applications for the purpose of moving materials within manufacturing facilities or warehouses (Iwasa, 2017).

Over the past few decades, there has been rapid progress in materials handling technology. Notably, one significant advancement has been the transformation of AGV into AMR. The guidance systems that are at the core of AGV-based material handling systems have undergone a remarkable evolution, progressing through various stages, including mechanical, optical, inductive, inertial, and laser guidance, culminating in the present-day vision-based system (see Fig. 1). This contemporary vision-based system relies on a plethora of sensors, robust on-board computers, artificial intelligence (AI), and simultaneous location and mapping (SLAM) technology. These components empower the device to comprehend its operational environment and navigate within facilities without the need for pre-defined reference points. This breakthrough has ushered in a new era of navigational flexibility.

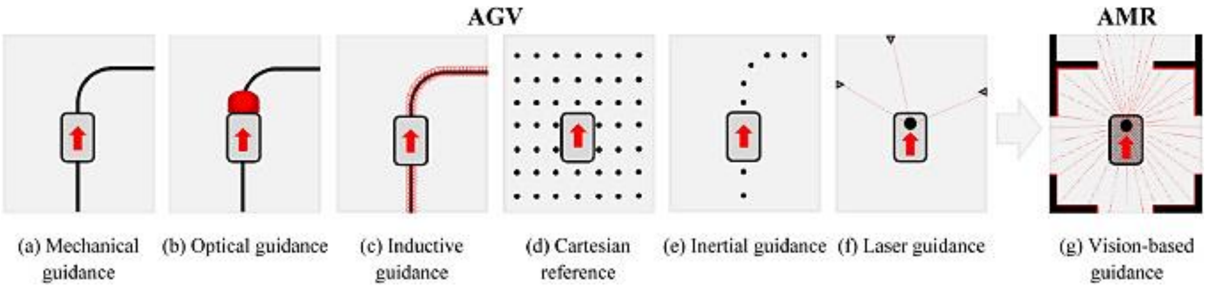

Figure 1. General workflow of AMR1.

Source: Adapted from: Fragapane et al., 2021, p. 406.

Traditional AGV are restricted to adhering to predetermined routes and navigating exclusively to predefined locations along those routes, as illustrated in Figure 1(a) through 1(f). In contrast, AMR possess the capability to maneuver to any reachable point within a designated area without encountering collisions, as depicted in Figure 1(g). Minor alterations, such as modifications to machine layouts, would typically entail significant time and potential periods of inactivity when employing most AGV guidance systems, posing economic risks and productivity setbacks. In contrast, AMR exhibit a remarkable ability to swiftly adjust to changes in the operational environment (Fragapane et al., 2021, pp. 405-407).

The demand for increased flexibility has been a driving force behind the evolution of AMR, expanding their role far beyond basic navigation capabilities. While AGV are often characterized as computer-controlled, wheel-based load carriers primarily designed for repetitive transportation tasks, devoid of onboard operators or drivers (Le-Anh, De Koster, 2006), AMR offer a wide array of services beyond mere transportation and material handling operations. They can engage in tasks like patrolling and collaborative activities with human operators. Coupled with their autonomous decision-making capabilities, these mobile platforms present highly adaptable solutions.

The autonomy of AMR implies a constant need for decision-making, taking into account the prevailing rules and constraints within their operating environment. A significant challenge arises from the absence of a human supervisor who possesses an intimate understanding of the system's limits. Consequently, AMR must autonomously monitor their own state, identify potential system faults, and respond appropriately.

The hardware and control software of AMR enable not only advanced navigation and object recognition but also object manipulation within unstructured and dynamic environments (Hernández et al., 2018). These advancements have ushered in a shift toward decentralized decision-making processes. In contrast to AGV systems, where a central unit governs key decisions such as routing and dispatching for all AGV, AMR can independently communicate and negotiate with other resources, including machines and systems such as enterprise resource planning or material handling assessment and control software, allowing them to make decisions autonomously. This shift reduces the reliance on centralized, external control (Furmans, Gue, 2018). Industrial robots have undergone a transformation, shifting from robust but immobile machines to advanced mobile platforms that can cater to a wider spectrum of automation requirements. These mobile platforms, known as AMR, rely on sensor feedback to navigate their surroundings (Siegwart, 2011). This stands in stark contrast to the traditional AGV, which are constrained to predefined paths employing methods such as magnetic/electrical wires, inertial navigation, optical sensors, or infrared sensors (Lasi et al., 2014).

What sets AMR apart is their heightened level of built-in intelligence, enabling them to identify obstacles in their path and autonomously recalibrate their route to reach their destination (Loganathan, Ahmad, 2023). The overarching goal of decentralized decision-making in AMR is to enable dynamic responsiveness to changes in demand and environmental conditions while allowing each vehicle to continuously optimize its operations. Due to their impressive efficiency and cost-effectiveness, AMR have found applications across various industries. They are now considered a pivotal component of the 'Industry 4.0' concept, contributing to the realization of smart factories and self-organizing systems.

3. Methods

The choice of a case study as a research method was motivated by the desire to empirically test the functionality of AMR in a real business environment that has implemented such a solution. The subject of this case study is a selected 3PL (third-party logistics) provider. The chosen 3PL company is one of the leading logistics service providers in the world, specializing in offering comprehensive warehousing solutions and VAS. With its many years of experience in the global market, the company is renowned for delivering high-quality services that assist clients in optimizing their supply chains. The firm provides warehousing solutions tailored to the needs of each client, regardless of size or industry sector. Its modern warehouses are equipped with advanced technologies, ensuring efficient goods management and rapid product flow. Besides standard warehousing services, the 3PL company also offers a broad range of VAS that add value to a client's products at various stages of the supply chain. These services include, among others, assembly, labeling, packaging, and other specialized solutions tailored to the individual needs of clients. Collaborating with such a logistics service provider allows businesses to focus on their core operations, while all logistics-related matters are entrusted to experts with years of experience in the industry.

The described case pertains to the use of AMR in warehouse management for non-value-added processes, specifically processes associated with the handling of empty pallets in the warehousing sector. In this case, two AMR-type robots are used. The first AMR performs two types of operations. The first type involves picking up empty pallets from the drop-off area of the AS/RS (automated storage & retrieval system) module and transporting them to the pallet sorting area. The second type is associated with taking the empty pallets from the sorting area and transporting them to the pallet retrieval zone for the AS/RS module. The general flow logic is presented in figure 2.

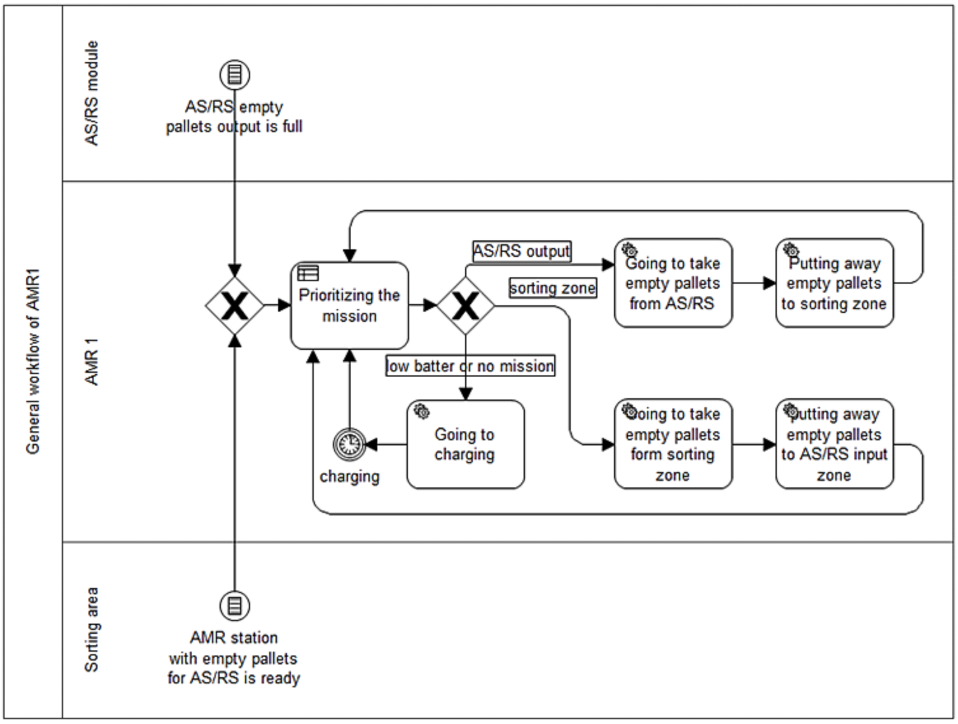

Figure 2. General workflow of AMR1.

Source: Own study.

Depending on the situation, following established business rules related to the cost-effectiveness of performing operations and the current location of the robot, it receives missions that have appropriate priorities in the action hierarchy. The second robot (AMR2) also operates on empty pallets, where empty pallets are allocated either to the transit module or to one of the two other modules available in the warehouse, or, when the robot receives such information, it also retrieves pallets post-regeneration and transports them to other warehouse modules. In this case, a hierarchy of actions is also established, similar to the previous case, and the robot's operation is interrupted in the event of a low battery level.

The data used for analysis came from data collected from a system integrated with a WMS (warehouse management system) that recorded the work of the AMR robots. The scope of the data adopted for analysis spans 6 months, and the displayed results are calculated over such a warehouse operating period.

4. Results

In the conducted case study, the performance of two AMR robots was measured. Data was collected from the last 6 months of the robots' activities in the warehouse management area. Initially, a calculation was made of the breakdown of individual activities generated by the robots (figure 3). The activities were divided into durations of:

- Productivity, when the robot is involved in moving empty pallets.
- Charging time, when the robot is charging its battery and cannot perform other tasks.
- Other, related to tasks such as setup or service work.
- Anomalies, when the data sent to the IT system by the AMR was incorrect, complications arose in the robot's operation, or when tasks assigned to the robot had to be abandoned.
- Not used – ready for action, when the robot's battery level was sufficient for a task, but none was available.

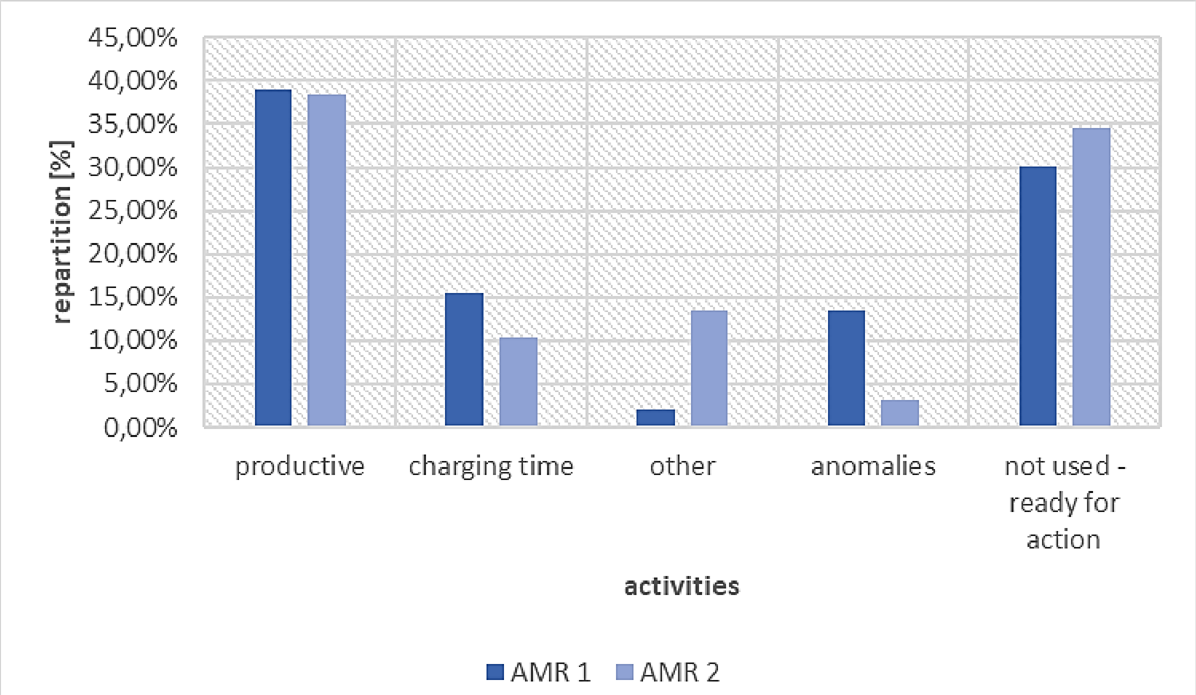

Figure 3. AMRs' activities repartition.

Source: Own study.

From the comprehensive analysis conducted, it was observed that both robots, AMR1 and AMR2, had substantial intervals during which they were ready and operational but had no assigned tasks. To delve into specifics, for AMR1, this idle or ready state without a task made up roughly 30% of its entire operational time. On the other hand, AMR2 had a slightly higher percentage at around 35%. Such statistics imply that the robots are currently not operating at their full potential or capacity. In fact, they have a significant bandwidth to manage more tasks, suggesting that if there's a future uptick in operational requirements, these robots would be well-equipped to handle them. This scenario of the robots being ready for tasks but not having any, particularly in the context of a warehouse setting, speaks volumes about the warehouse management's efficiency and robustness. It appears that the management has effectively developed a system that ensures there's a buffer or a resilience factor, especially when it comes to handling tasks related to empty pallet manipulation. This resilience can be crucial in times of increased demand, ensuring that the system can handle unexpected surges without any hitches. For a more detailed breakdown of the types of tasks that AMR1 has been handling, Figure 4 provides a clear representation. This figure maps out all the tasks that AMR1 undertook in the past six months, giving insights into its operational patterns and distribution of tasks.

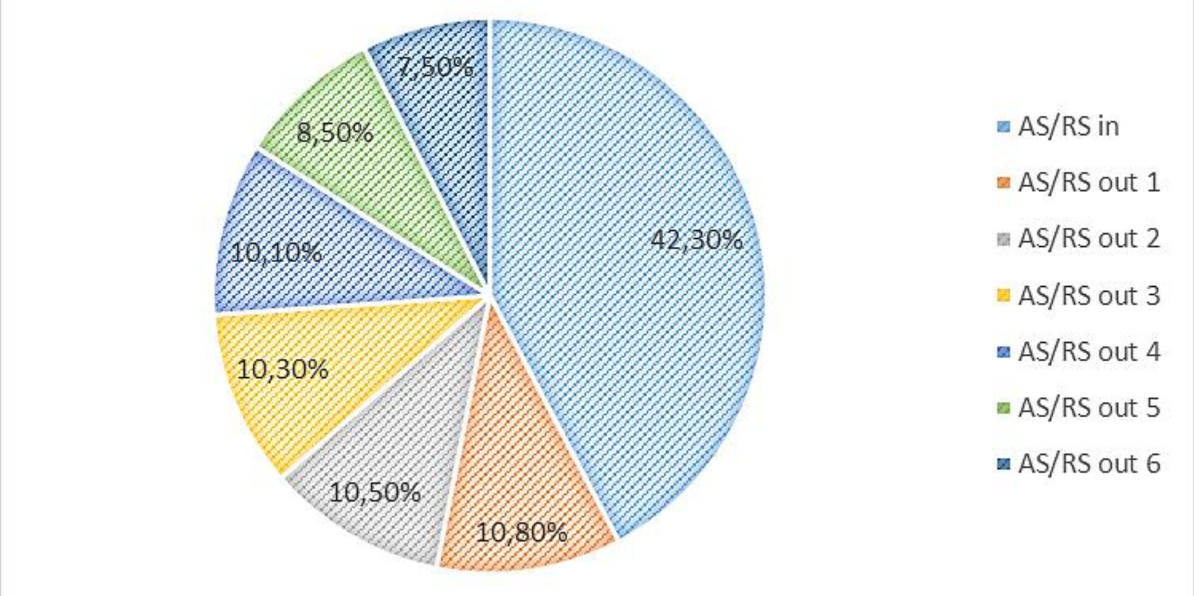

Figure 4. AMR1 tasks repartition.

Source: Own study.

From the in-depth analysis undertaken, a noteworthy observation regarding AMR1's operations emerged. It was seen that AMR1 is predominantly engaged in operations associated with retrieving empty pallets from the AS/RS output modules, with this activity accounting for approximately 57% of its tasks. In contrast, the task of transporting these empty pallets back to the AS/RS input modules made up a smaller fraction of its operations. However, it's essential to highlight that this disparity in percentages is not overly pronounced or significant, implying that the robot isn't overly biased towards one operation over the other. A further interesting observation from the analysis is that, when we delve deeper into the types of operations AMR1 performs at various AS/RS output points, we find that there's a remarkable consistency. AMR1 seems to execute a nearly equal number of operations across all available AS/RS output modules. This pattern strongly suggests that the workload distribution for AMR1 has been well-thought-out and optimized, leading to a balanced operational approach. Such a balanced distribution is indicative of efficient warehouse management practices, ensuring that no particular module or point is overly stressed or underutilized. For a comparative perspective on robotic operations, Figure 5 provides a visual representation of the tasks carried out by AMR2.

This visual breakdown can offer insights into how AMR2's operations stack up against AMR1, potentially highlighting any operational trends or patterns specific to that robot.

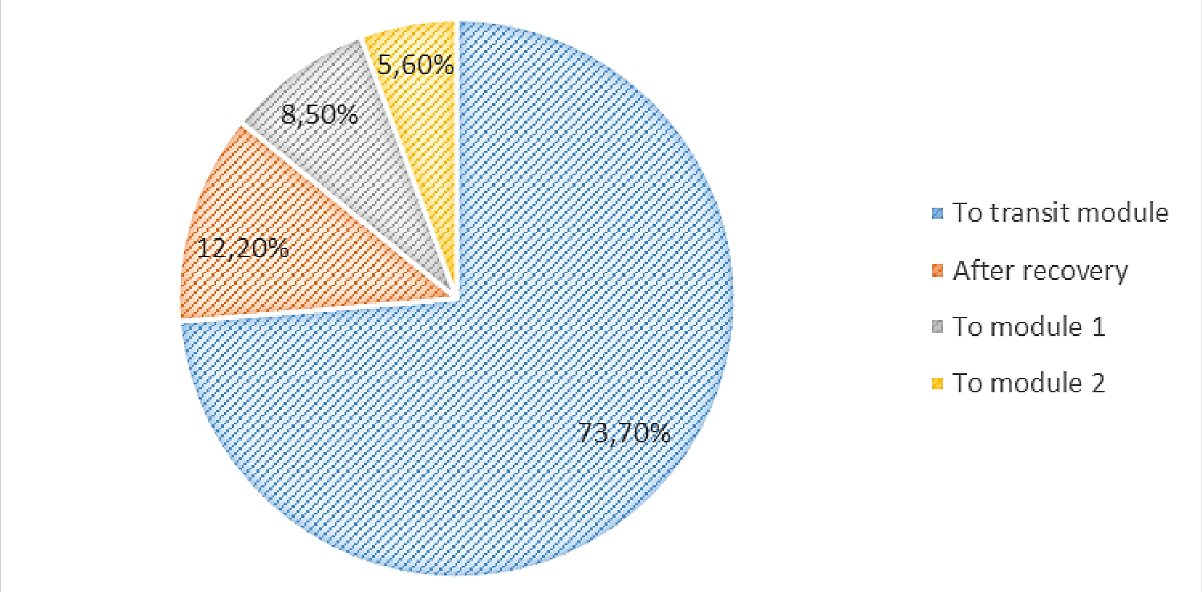

Figure 5. AMR2 tasks repartition.

Source: Own study.

In a detailed assessment of AMR2's activities, a distinct operational pattern emerges. A significant portion of its tasks, specifically over 70% within the last six months, is dedicated to the movement of empty pallets to the transit area. This high percentage underscores the importance and priority of this task in AMR2's list of duties. Such a focused approach towards a single, primary operation hints at the strategic significance of this task in the overall warehouse workflow. While this dominant task occupies the majority of AMR2's operational bandwidth, it's important to note that the robot is not solely limited to it. There are other tasks that AMR2 undertakes, albeit with a lower frequency. However, in the grand scheme of things, these tasks are considered secondary or incidental. Their sporadic nature suggests that they might arise due to specific circumstances or unique requirements and are not part of the robot's routine functions. For a broader perspective on how AMR2's operations compare with another robot in the same environment, figure 6 offers valuable insights. This graphical representation breaks down the number of operations executed by both AMR1 and AMR2, distributed across different days of the week. By examining this, stakeholders can gain a clearer understanding of the operational rhythm and consistency of these robots throughout a typical week, identifying peaks, troughs, and potential areas of optimization.

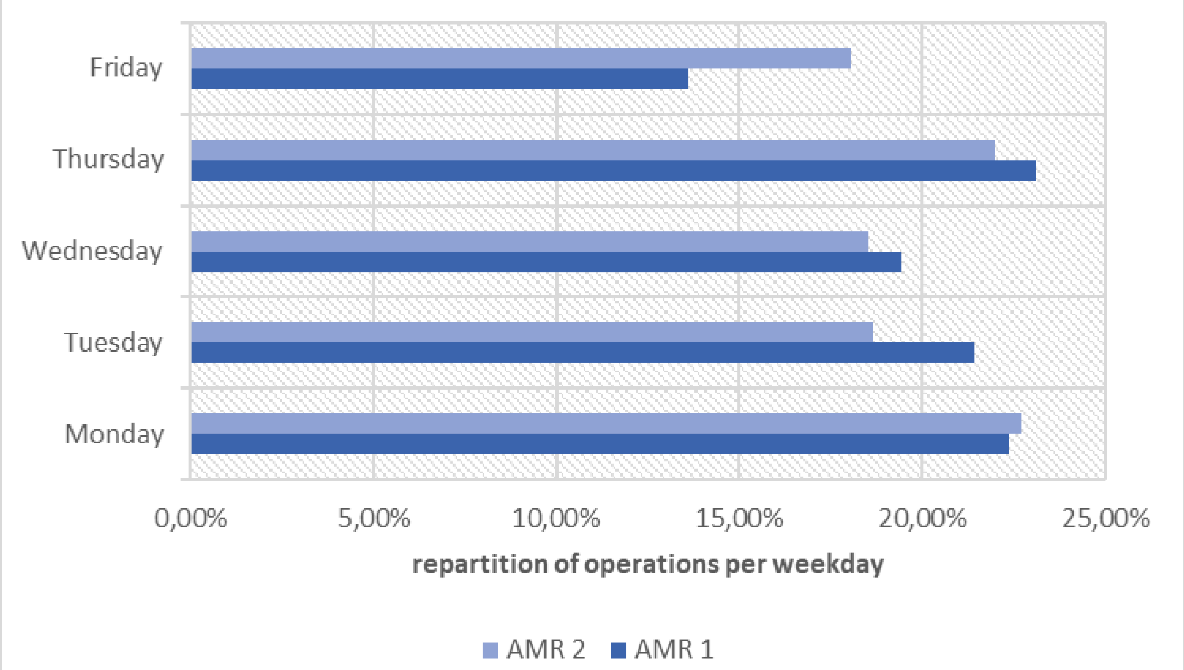

Figure 6. Repartition of operation per weekday.

Source: Own study.

As seen in the illustration, both robots exhibit irregular work patterns throughout the week. This inconsistency primarily stems from the fluctuating demand for their services. This variability provides opportunities and a foundation for more flexible planning of their tasks and for expanding their operational scope within the logistics operator's warehouse management. Figure 7 showcases the operational costs of the AMR robots in the studied case, compared to the costs generated by traditional forklifts operated by human personnel.

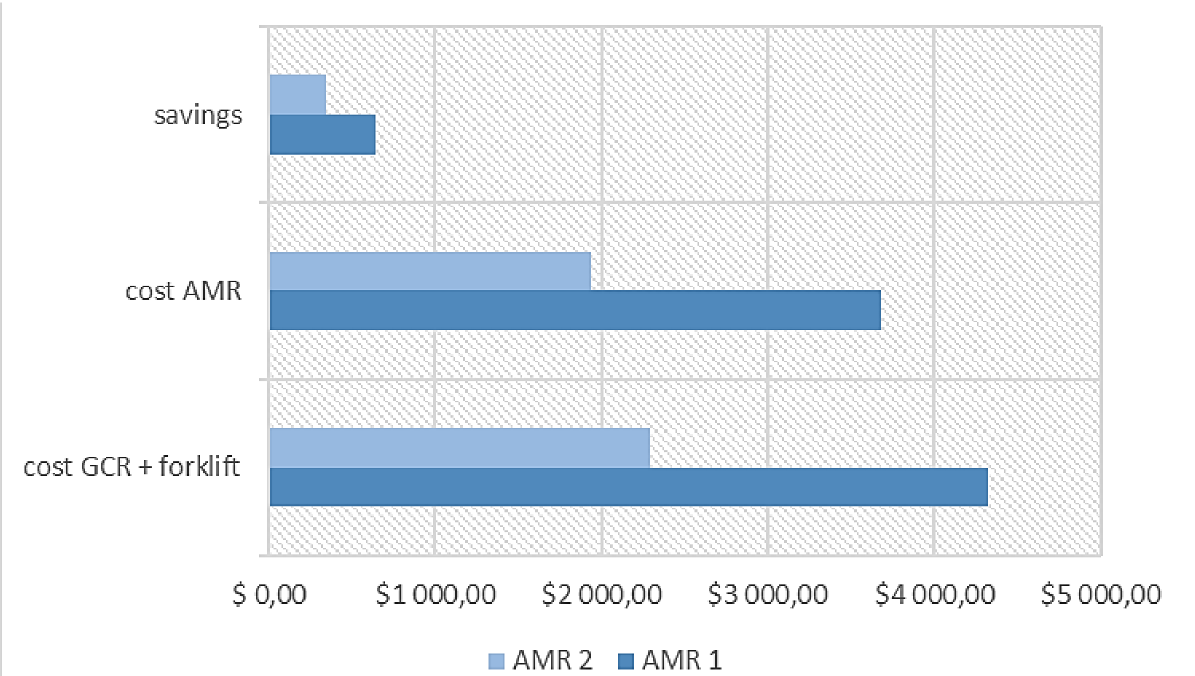

Figure 7. Average monthly costs & savings comparision.

Source: Own study.

The costs and savings presented are averaged monthly values based on data from the last six months. The GCR (general cooperation rules) costs are associated with costs set by the logistics service provider, standard task execution times, human labor expenses, as well as the costs of using, operating, and charging a forklift. AMR costs include the robot's operational costs and energy consumption costs related to its charging. As indicated by the six-month observations, even when the AMR robots are not utilized to their full potential (a significant portion of their time was on standby, ready to undertake a task without having a mission they could execute), automating such processes results in cost savings.

5. Discussion

The results of our study suggest that both machines, AMR1 and AMR2, are not being fully utilized in the current warehouse configuration, operating at only about 65-70% of their potential. Such long periods of inactivity might reflect various factors. On one hand, this might result from the robots being introduced with an anticipated higher workload that has not yet materialized. On the other hand, it's worth considering the efficiency with which these robots complete their tasks - it is possible that they finish them faster than their human counterparts, thus having more downtime. This is corroborated by studies already found in literature, e.g., by Konstantinidis et al. (2022), Guérin et al. (2016), and Chen et al. (2020). Analyzing the benefits derived from automating non-value-added processes, such as handling empty pallets, allowed the study to uncover significant potential cost savings. An important aspect here, however, is the prioritization of tasks for these robots, which currently experience substantial idle times. The topic of setting robot work priorities in warehouses is a compelling research subject discussed in studies like Selmair et al. (2020) and Hmidach et al. (2020). Automating these tasks not only frees up resources but also reduces the chances of errors, ensuring smoother and more efficient operations. The fact that even underutilized robots can lead to cost savings, as shown in our study, speaks to potential benefits. Apart from costs, service quality, speed, and reliability also experience significant improvements. In light of these findings, a debate could be started on whether the autonomy of processes that don't directly add value might seem like overinvesting. However, gains related to efficiency, potential scalability, and benefits from future-proofing argue for such investment. The issue of substantial AMR investment costs, which must be compared to operational savings, is discussed in studies like Pugliese et al. (2022) and Žulj et al. (2022). Warehouses, especially those managed by 3PLs, are tasked with diverse operations with fluctuating demand, and such flexibility might be better managed with autonomous systems than manual ones. This study has provided key insights, but like any study, it has its limitations. The biggest limitation is focusing exclusively on a specific 3PL provider. While this offers depth, the findings might not be universally applicable across all warehouses or industries. Moreover, the study was conducted over six months, which might not capture all seasonal fluctuations or potential operational changes.

Future research could examine a broader spectrum of 3PL providers and extend the duration to account for year-round activity. Research could also focus on other non-value-added processes to assess whether the benefits observed during empty pallet handling also extend to other operations. Another intriguing direction would be a more detailed examination of the AMR decision-making algorithms for further utilization optimization. The autonomization of non-value-added processes seems promising for the logistics sector, offering both operational efficiency and cost savings. With advancing technology and growing pressure for faster and more efficient delivery, such automation is likely to become the norm rather than the exception.

6. Conclusions

Both AMR1 and AMR2 robots, though not utilized to their full potential, were found to have considerable operational bandwidth. This implies the potential for increased workload, if and when required, without the need for additional investment. Despite the robots operating below their capacity, there were notable savings when compared to traditional human-operated forklift methods. This implies that even partial autonomization can lead to cost benefits. The study provided detailed insights into how tasks were distributed amongst the robots. For instance, AMR1's balanced task distribution across various AS/RS output modules signifies well-optimized warehouse management practices. In contrast, AMR2's operations were more focused, pointing to its strategic role within the warehouse. The robots' ready states, even during idle times, underscore the resilience and flexibility embedded in the system, suggesting a robust buffer for unexpected surges in operational demands. The most significant being its focus on a single 3PL provider, which might not be representative of the broader industry. While the findings are deep, they might not necessarily be widely applicable. Additionally, the six-month study period may not capture the entire spectrum of seasonal variations and operational changes.

This research contributes to the field of management sciences. By delving deep into the nuances of autonomization within the logistics sector, the study offers valuable insights for practitioners, especially those in warehouse management. The data-driven approach provides a sound base for future research, be it in expanding the scope to other 3PL providers or in analyzing other non-value-added processes. Autonomization, especially of non-value-added processes, presents a compelling proposition for the logistics sector, offering enhanced operational efficiency and significant cost savings. As the realm of management science continues to evolve, leveraging technology to optimize and enhance processes will be paramount, and this research stands as a testament to such an evolution. However, presented case study focuses only on one 3PL so in the future the research should be expanded. Research on the larger sample could provide the results which could strongly contribute to the literature that assists managers in the decision-making process.

References

1. Amiri, A.M., Ferguson, M.R., Razavi, S. (2022). Adoption patterns of autonomous technologies in Logistics: evidence for Niagara Region. *Transportation Letters, 14(7),* 685-696.
2. Azzemou, R., Noureddine, M. (2021). Adding Value by Handling of Logistics: Study Case in Algeria. *International Journal of Academic Accounting, Finance & Management Research, Vol. 5 Iss. 6,* 23-29.
3. Chen, Y., Xu, A., He, Q.C., Chen, Y.J. (2023). Smart navigation via strategic communications in a mixed autonomous paradigm. *Production and Operations Management.*
4. Chen, Y., Yang, C., Song, B., Gonzalez, N., Gu, Y., Hu, B. (2020, December). *Effects of autonomous mobile robots on human mental workload and system productivity in smart warehouses: A preliminary study*. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol. 64, No. 1 (pp. 1691-1695). Los Angeles, CA: SAGE Publications.
5. Christopher, M. (2016). *Logistics & supply chain management.* London: Pearson.
6. Cortes, H., Daaboul, J., Le Duigou, J., Eynard, B. (2016). Strategic Lean Management: Integration of operational Performance Indicators for strategic Lean management. *IFAC-PapersOnLine, 49*, 65-70.
7. Dossou, P.E., Torregrossa, P., Martinez, T. (2022). Industry 4.0 concepts and lean manufacturing implementation for optimizing a company logistics flows. *Procedia Computer Science, Vol. 200,* 358-367.
8. Fragapane, G., Koster, R., Sgarbossa, F., Strandhagen, J.O. (2021). Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. *European Journal of Operational Research, Vol. 294, Iss. 2*.
9. Furmans, K., Gue, K.R. (2018). *A framework for modeling material handling with decentralized control*. Proceedings of the 15th IMHRC (Savannah, Georgia. USA), 17.
10. Guérin, F., Guinand, F., Brethé, J.F., Pelvillain, H. (2016, December). *Towards an autonomous warehouse inventory scheme*. Symposium Series on Computational Intelligence (SSCI). IEEE, pp. 1-8.

11. Helmke, B. (2022). Digitalization in Logistics. In *Project Management in Logistics and Supply Chain Management*: Practical Guide with Examples from Industry, Trade and Services. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 179-201.
12. Hercik, R., Byrtus, R., Jaros, R., Koziorek, J. (2022). Implementation of Autonomous Mobile Robot in SmartFactory. *Applied Science, 12*, 8912.
13. Hernández, C., Bermejo-Alonso, J., Sanz, R. (2018). A self-adaptation framework based on functional knowledge for augmented autonomy in robots. *Integrated Computer-Aided Engineering*, *25(2)*, pp. 157-172.
14. Hmidach, S., El Kihel, Y., Amegouz, D., El Kihel, B., Regad, Y. (2020, December). *Optimizing warehouse logistics flows by integrating new technologies: Case study of an agri-food industry*. 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS), IEEE, 1-5.
15. Ikechukwu, A.J. (2019). Assessment of Organizational Performance of Private Manufacturing Companies: The Impact of Supply Chain Management Responsiveness. *Journal of System and Management Sciences*, *Vol. 9, No. 3*, 26-44.
16. Iwasa, M., Toda, Y., Saputra, A.A., Kubota, N. (2017). *Path planning of the autonomous mobile robot by using real-time rolling risk estimation with fuzzy inference*. Symp. Ser. Comput. Intell. (SSCI), Honolulu, HI, USA, 1-6.
17. Jum'a, L. (2020). The effect of value-added activities of key suppliers on the performance of manufacturing firms. *Polish Journal of Management Studies, Vol. 22 No. 1* , 231-246.
18. Konstantinidis, F.K., Balaska, V., Symeonidis, S., Mouroutsos, S.G., Gasteratos, A. (2022, June). *AROWA: An autonomous robot framework for Warehouse 4.0 health and safety inspection operations*. 30th Mediterranean Conference on Control and Automation (MED). IEEE, pp. 494-499.
19. Lasi, H., Fettke, P., Kemper, H.G., Feld, T., Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, 6*, 239-242.
20. Le-Anh, T., De Koster, M. (2006). A review of design and control of automated guided vehicle systems. *European Journal of Operational Research*, *171(1),* 1-23.
21. Liaqat, A., Hutabarat, W., Tiwari, D. et al. (2019). Autonomous mobile robots in manufacturing: Highway Code development, simulation, and testing. *The International Journal of Advanced Manufacturing Technology*, *104*, 4617-4628.
22. Loganathan, A., Ahmad, S. (2023). A systematic review on recent advances in autonomous mobile robot navigation. *Engineering Science and Technology, an International Journal*, *Vol. 40*, 101343.
23. Min, S., Zacharia, Z.G., Smith, C.D. (2019). Defining supply chain management: in the past, present, and future. *Journal of Business Logistics*, *Vol. 40, No. 1,* 44-55.
24. Morgan, J., Liker, J.K. (2006). *The Toyota product development system: integrating people, process, and technology*. New York: Productivity Press.

25. O'Brian, J. (2014). *Supplier Relationship Management. Unlocking the hidden value in your supply base.* London/Philadelphia/New Delhi: KoganPage.
26. Oyekanlu, E.A., Smith, A.C., Thomas, W.P., Mulroy, G., Hitesh, D., Ramsey, M., Kuhn, D.J., Mcghinnis, J.D., Buonavita, S.C., Looper, N.A., Ng, M., Ng'oma, A., Liu, W., Mcbride, P.G., Shultz, M.G., Cerasi, C., Sun, D. (2020). A Review of Recent Advances in Automated Guided Vehicle Technologies: Integration Challenges and Research Areas for 5G-Based Smart Manufacturing Applications. *IEEE Access, vol. 8,* 202312-202353.
27. Pugliese, G., Chou, X., Loske, D., Klumpp, M., Montemanni, R. (2022). AMR-assisted order picking: models for picker-to-parts systems in a two-blocks warehouse. *Algorithms, 15(11),* 413.
28. Selmair, M., Pankratz, V., Meier, K.J. (2020). Efficient Task Prioritisation for Autonomous Transport Systems. *ECMS*, 322-327.
29. Shneier, M., Bostelman, R. (2015). Literature review of mobile robots for manufacturing. *Nat. Inst. Standards Technol.*, Gaithersburg, MD, USA, Tech. Rep. NISTIR8022, May 2015.
30. Siegwart, R., Nourbakhsh, I.R., Scaramuzza, D. (2011). *Introduction to Autonomous Mobile Robots*. The MIT Press.
31. Tanaka, T., Yamafuji, K., Watanabe, H., Katae, T. (1998). Development of intelligent mobile robot for service use (2nd Report, Self position detection system using a visual sensor). *Transactions of the Japan Society of Mechanical Engineers, Vol. 64(628),* 4702-4709.
32. Ullrich, G. (2014). *The history of automated guided vehicle systems. Automated Guided Vehicle Systems - A Primal with Practical Applications*. Voerde, Germany: Springer, ch. 1, 4-14.
33. Womack, J.P., Jones, D.T. (2015). *Lean solutions: how companies and customers can create value and wealth together*. Free Press.
34. Yang, P.Y., Xi, Y., Zhang, X., Luo, L. M., Li, C. S.J., Yang, Y.C., Lee, S.H. (2013). The rise of the manufacturing service industry: the perspective of value- added chain model. *Chinese Management Studies, 7(3),* 403-418.
35. Žulj, I., Salewski, H., Goeke, D., Schneider, M. (2022). Order batching and batch sequencing in an AMR-assisted picker-to-parts system. *European Journal of Operational Research, 298(1),* 182-201.