ISBN 978-83-975865-0-5

Transport Problems 2025

Conference proceedings

UNDER THE HONORARY PATRONAGE OF

Silesian University of Technology

Krajowa Reprezentacja Doktorantów

XVII INTERNATIONAL SCIENTIFIC CONFERENCE

25-27.06 2025

Katowice - Wisła- Žilina

23-24.06.2025

Katowice-Mysłowice

XIV INTERNATIONAL SYMPOSIUM OF YOUNG RESEARCHERS

Dedicated to the 80th anniversary of the Silesian University of Technology

Silesian University of Technology
Faculty of Transport and Aviation Engineering

Transport Problems 2025

Dedicated to the 80th anniversary
of the Silesian University of Technology

Proceedings

XVII International Scientific Conference
XIV International Symposium of Young Researchers

UNDER THE HONORARY PATRONAGE OF

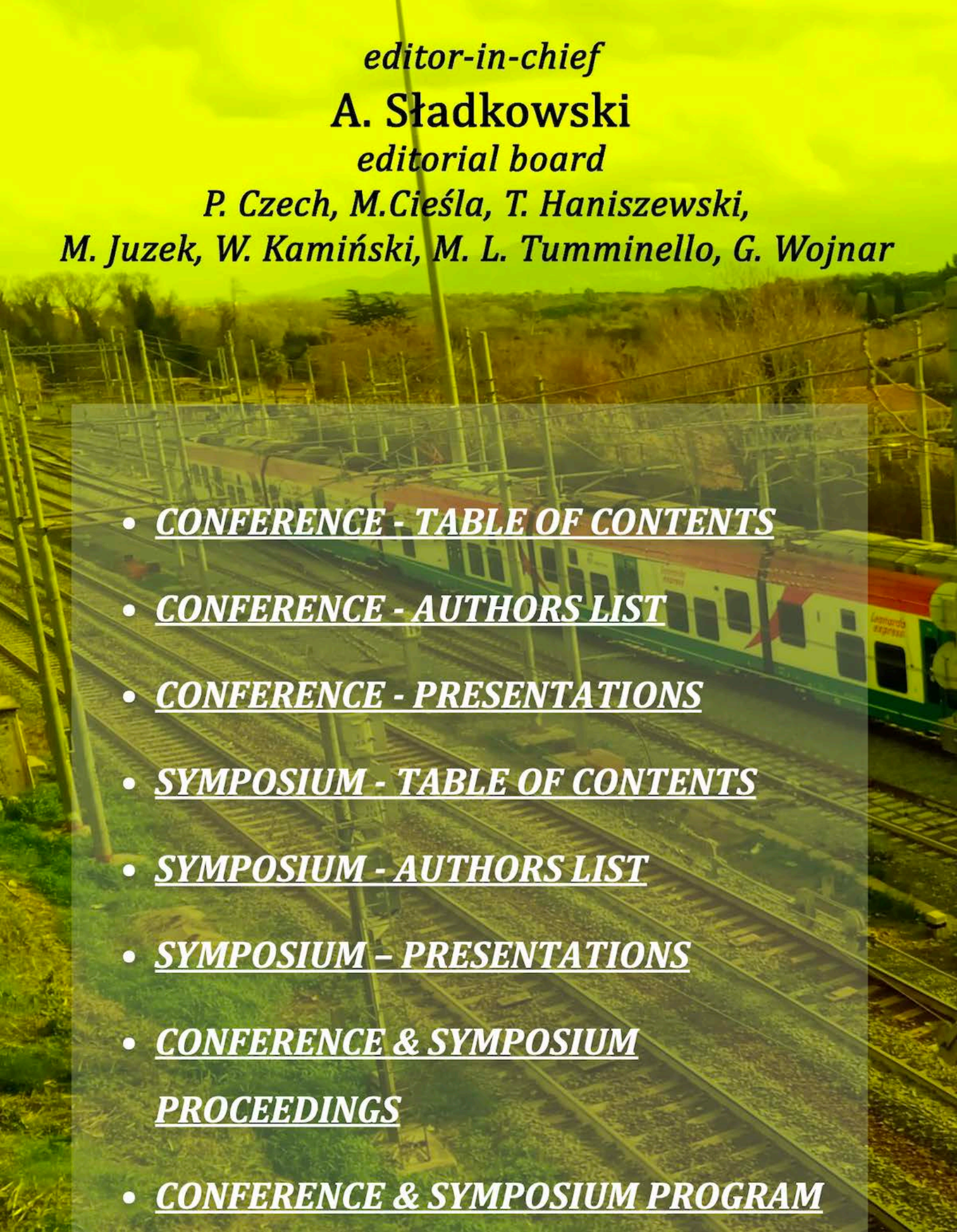
Silesian University of Technology

Krajowa Reprezentacja Doktorantów KRD

ISBN 978-83-975865-0-5

Media patronage:
Transport Problems International Scientific Journal
ISSN 1896-0596, The Silesian University of Technology,
Faculty of Transport and Aviation Engineering

Transport Problems
International Scientific Journal



- ***CONFERENCE - TABLE OF CONTENTS***
- ***CONFERENCE - AUTHORS LIST***
- ***CONFERENCE - PRESENTATIONS***
- ***SYMPOSIUM - TABLE OF CONTENTS***
- ***SYMPOSIUM - AUTHORS LIST***
- ***SYMPOSIUM – PRESENTATIONS***
- ***CONFERENCE & SYMPOSIUM PROCEEDINGS***
- ***CONFERENCE & SYMPOSIUM PROGRAM***

XIV INTERNATIONAL SYMPOSIUM OF YOUNG RESEARCHERS TRANSPORT PROBLEMS 2025

TABLE OF CONTENTS

No.	Author, title	Pages	
		Begin	End
1	Karla-Simina ANISIA, Eugen GHITA Optimization of energy consumption for the EA electric locomotive within Unicom Tranzit	1066	1079
2	Wafa BOULAGOUAS, Mohammed MOUDA Assessing traffic congestion management strategies for sustainable transport networks: a multi-criteria decision making model	1080	1090
3	Artur BUDZYŃSKI, Kacper JACHYM, Marta BUDZYŃSKA, Maria CIEŚLA, Svetlana KUNSKAJA Air traffic forecasting in Europe: a machine learning approach	1091	1099
4	Beibit DAULETBAY, Aleksander SŁADKOWSKI Robotic automation of warehouse servicing for various types	1100	1107
5	Vitaly DUDNIK, Wawrzyniec PANFIL, Wojciech MOCZULSKI, Robert ŻBIKOWSKI, Yevhenii SHKVAR Feasibility study of propulsion system integration for heated balloons	1108	1120
6	Mikhail FATKHI, Gulnara NURPEISSOVA, Dina PANYUKOVA, Akerke MUZAPPAROVA, Kerey PANYUKOV Identification of vulnerable sections of mountain roads in Kazakhstan using digital elevation models and spatial analysis	1121	1126
7	Michał GRZYBOWSKI, Jakub MŁYŃCZAK, Lucyna SOKOŁOWSKA, Michał MATOWICKI Modelling of railway signalling relay circuits with TLA+	1127	1140
8	Daulet ISKAKOV, Aleksander SŁADKOWSKI Advantages and disadvantages of WMS systems	1141	1151

Keywords: AGV (Automated Guided Vehicles), AMR (Autonomous Mobile Robots), AS/RS (Automated Storage and Retrieval Systems), WMS (Warehouse Management System)

Beibit DAULETBAY*
Satbayev University
Satbayeva 22, 050000 Almaty, Kazakhstan
Aleksander SŁADKOWSKI
Silesian University of Technology, Faculty of Transport and Aviation Engineering
Krasińskiego 8, 40-019 Katowice, Poland
* *Corresponding author*. E-mail: mower1110@gmail.com

ROBOTIC AUTOMATION OF WAREHOUSE SERVICING FOR VARIOUS TYPES

Summary. This work is devoted to the analysis and practical recommendations for robotization and automation of warehouses of various types. In the context of the growing need for efficiency, accuracy and cost-effectiveness of warehouse operations, automation is becoming a key factor in the competitiveness of logistics companies. The project considers the classification of warehouses, criteria for choosing robotic solutions, examples of successful implementation in Europe, a comparative analysis of technologies (AGV, AMR, AS / RS, WMS) and the cost-effectiveness of implementation. Particular attention is paid to the adaptation of solutions to the type of warehouse: from small (<1000 m²) to large facilities (>10,000 m²). Key indicators before and after the implementation of automation are analyzed, including productivity, picking accuracy, cost reduction and payback period (ROI). The work concludes with practical recommendations for choosing the optimal technologies for each type of warehouse.

1. INTRODUCTION

Modern logistics and warehousing are experiencing a period of intense transformation caused by a combination of factors: the growth of e-commerce, the complexity of supply chains, and the shortage of qualified personnel. This problem is especially acute in Central and Eastern European countries, including Poland, where warehouses face a shortage of workers, high staff turnover, and uneven workload depending on the season. This situation gives rise to the need to find solutions that can ensure the stability, accuracy, and efficiency of warehouse operations.

Against this background, the introduction of robotic technologies into warehouse service processes is particularly relevant. The use of automated vehicles, pickers, sorters, and warehouse management systems (WMS) allows you to minimize the impact of the human factor, reduce costs, and adapt to market challenges. However, the effectiveness and feasibility of robotization depends on many factors, including the type of warehouse, its size, the specifics of the stored goods, and the intensity of operational processes.

Purpose of research. Analysis of the efficiency and feasibility of introducing robotics into the processes of servicing warehouses of various types in conditions of labor shortage and increasing requirements for the accuracy and speed of logistics operations.

Research objectives:

1. Classify warehouses by the type of stored products.
2. Identify challenges faced by warehouses in Poland under labor shortage conditions.
3. Structured technologies - from AGV to AS/RS.
4. Define criteria to assess the feasibility of automation for specific warehouses.

5. Analyze case studies of warehouse automation and compare their outcomes with traditional approaches.
6. Develop tailored recommendations for implementing robotic solutions based on warehouse-specific and external factors.

2. CLASSIFICATION OF WAREHOUSES AND FEATURES OF THEIR AUTOMATION

Classification of warehouses is key to choosing the right automation solutions. Robotics is not a universal tool: the efficiency of implementation directly depends on the characteristics of the processed goods, storage conditions, the level of repeatability of operations and other factors. In this work, seven main types of warehouses are identified: piece, bulk, liquid, refrigerated, hazardous, high-rack and universal.

1. Piece warehouses are warehouses that work with individual units of production (boxes, packages, parts), usually in a wide range. This format is especially typical for e-commerce, pharmaceuticals and the fashion segment. High accuracy of picking, fast processing of small orders and flexible routing are important here. AMR, pick-to-light, shuttle systems, automated conveyors and WMS integration are most often used.

2. Bulk warehouses are used to store products that are received and processed without individual packaging (grain, coal, ore, building mixtures). These warehouses require specific equipment (cranes, grabs, augers) and are rarely automated using standard logistics robots. However, it is possible to implement robotic cranes and sensors to control volume and temperature.

3. Liquid warehouses are designed to store liquid substances in tanks or cisterns (oil, chemicals, beverages). Automation most often concerns the control of levels, temperatures and pressures, as well as robotic loading. Integration with a sensor system and industrial automation (PLC, SCADA) is important here.

4. Cold storage warehouses are used to store products at low temperatures (food, medicine). In such conditions, the speed and accuracy of operations are especially important, since low temperatures reduce the permissible processing time. Robots here increase productivity and labor safety. AS/RS, AMR and automated storage areas resistant to low temperatures are used.

5. Dangerous goods (explosive, toxic, radioactive) require strict safety standards. Robots here help minimize human contact with hazardous substances. AGVs with spark protection, remote-controlled robotic grippers, and automatic fire extinguishing systems linked to WMS are popular.

6. High-rack warehouses are warehouses with vertical storage organization, where multi-level racks up to 15–20 meters high are used. AS/RS, stacker cranes, and vertical elevator systems are widely used at such facilities, which significantly reduce the area and speed up access to products.

3. KEY TECHNOLOGIES AND ROBOTS IN WAREHOUSE AUTOMATION

Modern warehouse logistics is undergoing a significant transformation due to the introduction of various technologies and robotic systems. This allows for increased process efficiency, reduced errors, reduced human error, and lower operating costs. This section discusses the key technologies and robots that are used today for warehouse automation.

Automated Mobile Robots (AMRs) and Automated Guided Vehicles (AGVs)

AMRs and AGVs are among the most common solutions for automating the movement of goods in warehouses. AGVs (Automated Guided Vehicles) are vehicles that move along pre-set routes using magnetic belts or induction paths. They are well suited for repetitive tasks in a warehouse but require a fixed infrastructure.

Autonomous Mobile Robots (AMRs) are more flexible systems that use cameras and sensors to build a warehouse map and independently plan routes. This increases adaptability to changes in the warehouse configuration and allows working in a mixed environment with people.

Automated Storage and Retrieval Systems (AS/RS)

AS/RS are complex systems that include racks, conveyors and robotic manipulators for automatic placement and retrieval of goods. They are widely used in high-rack and piece warehouses where maximum storage density and high order processing speed are required. Implementation of AS/RS allows to significantly reduce the time of operations and increase the accuracy of picking.

Thermal scanners and Pick-to-Light systems

Technologies of visual support of operators also play an important role. Thermal scanners are used to control the temperature of products, which is especially important in refrigerated and hazardous warehouses.

Pick-to-Light is a system of illumination for picking goods, which directs the employee to the required storage location using light indicators. This minimizes errors in order picking and speeds up the picking process.

Conveyors, packaging and palletizing

Conveyor systems ensure continuous movement of goods between warehouse areas - from receiving to shipping. Modern conveyors are equipped with sensors that track movement and help integrate the process with WMS (Warehouse Management System).

Packing and palletizing robots automate the processes of packing and placing goods on pallets, which reduces the workload of employees and increases productivity. They are especially useful in large warehouses with a mass flow of goods.

Information technologies: ERP, WMS, RFID and scanners

Automation of warehouse processes is impossible without modern information systems. ERP (Enterprise Resource Planning) and WMS (Warehouse Management System) provide inventory management, resource planning and control of operations in real time.

RFID (Radio Frequency Identification) is a radio frequency identification technology that allows you to automatically read information from goods and storage locations without direct visual contact. This speeds up inventory and reduces errors.

Barcode and QR code scanners are widely used to register receipts and shipments. The integration of all of the listed technologies allows us to create a unified warehouse management system with a high degree of transparency and control.

4. CRITERIA FOR CHOOSING ROBOTICS

The choice of optimal solutions for robotization of warehouse processes depends on many factors that must be carefully analyzed before implementation. Successful automation should take into account not only the technical characteristics of the equipment, but also the specifics of the warehouse, product features, and economic feasibility. This section discusses the key criteria that influence the choice of robotization technologies.

Volume and dynamics of turnover

The first important criterion is the volume and intensity of turnover of goods in the warehouse. Warehouses with high turnover require fast and flexible solutions to minimize order processing time. For example, for warehouses with large volumes of similar products, automated conveyors and AS / RS systems are suitable, which can ensure high picking speed. For warehouses with a more diverse range and smaller volumes, AMR mobile robots are better suited, which can easily adapt to changes in routes and tasks.

Labor intensity and the human factor

Automation can significantly reduce the workload on personnel, especially when performing routine and monotonous operations. It is important to consider the level of qualification of workers and the possibility of their retraining to work with new technologies. Robotics helps to reduce errors associated with the human factor, such as incorrect assembly or damage to goods. When choosing robotic systems, it is necessary to evaluate the extent to which they are able to replace or supplement human labor, as well as how the organization of labor and staff will change.

Repeatability and standardization of operations

Robotics is most effective with a high degree of repeatability and standardization of processes. For example, in warehouses with typical operations - acceptance, storage, selection and packaging of similar goods - the introduction of automatic systems can significantly increase productivity and reduce costs. If the processes vary greatly, flexibility and the ability to quickly reconfigure equipment are required, which is often preferably implemented through mobile robots or universal automated complexes.

Product characteristics

Features and requirements for products also have a significant impact on the choice of robotics. Warehouses with dangerous, fragile or perishable goods require special technologies that take into account the storage and handling conditions. For example, robots that can operate at low temperatures are suitable for refrigerated warehouses, while those with increased safety requirements are suitable for hazardous warehouses. Automation should ensure the safety and integrity of products, minimizing their damage.

Economic feasibility

One of the key factors when choosing robotics is the economic feasibility of implementing technologies. It includes an assessment of the costs of purchasing, installing, integrating and maintaining robotic systems, as well as calculating potential savings due to increased productivity, reduced errors and reduced labor costs. An important indicator is the payback period (ROI), which for most warehouse projects ranges from 2 to 5 years.

Technological maturity

The choice of technologies depends on their level of development and availability on the market. The most mature and proven solutions usually provide stable operation and a lower risk of failures. New technologies can offer innovative advantages, but require additional testing and adaptation to specific warehouse conditions. It is necessary to evaluate technical support, availability of service departments and scalability.

Flexibility and scalability

Modern warehouses require systems that can be easily adapted to changing business requirements - product range expansion, seasonal peaks or changes in layout. Flexibility of solutions is manifested in the ability to quickly change robot routes, reconfigure equipment or integrate new modules. Scalability is important for gradual implementation of automation without significant capital expenditures from the very beginning.

5. ROBOTIZATION CASES AND RECOMMENDATIONS FOR WAREHOUSES OF DIFFERENT SIZES

Automation and robotization of warehouse processes manifest themselves differently depending on the size and specifics of warehouse premises. This section examines examples of the implementation of robotic solutions for warehouses of three categories: small (up to 1,000 m²), medium (1,000–10,000 m²) and large (over 10,000 m²). For each category, key recommendations are presented, as well as an analysis of cost-effectiveness and impact on productivity.

Small warehouses (up to 1000 m²)

Small warehouses are characterized by limited space and, as a rule, a smaller assortment of goods. In such conditions, the implementation of large-scale AS/RS systems is often impractical due to high capital costs and limited space. Instead, mobile AMR robots, Pick-to-Light systems and compact conveyor lines become the optimal solution.

MicroFulfillment Center — France (Paris)
• Operator: Carrefour
• Area: ~700 m²
• Warehouse type: automated micro center for e-grocery
• Solution: implementation of mini-AutoStore + robotic lifts + integration with WMS

Tab. 1

Comparative analysis of indicators before and after the introduction of robotics for a small warehouse

	Before	After
Assembly of 1 order:	18–25 min	6–8 мин
Errors	~6%	<1%
Performance	<400 orders/day	<1000 orders/day
Additionally	Frequent delivery delays during peak hours	Increase storage density by 300%
ROI	~2.5 years	

Medium warehouses (1,000–10,000 m²)

Medium warehouses often handle a wider range of products and have complex logistics with different storage and processing areas. Here, combined solutions can be used: automated rack systems AS/RS for storage, AGV for transporting goods and integrated warehouse management systems.

Zalando Fulfillment Partner — Poland (Gryfino)
• Warehouse type: clothing and footwear warehouse (e-commerce)
• Area: about 8,000 m² (pilot robotic zone)
• Solution: implementation of AMR, partial automation of picking zones

Tab. 2

Comparative analysis of indicators before and after the introduction of robotics for a medium warehouse

	Before	After
Assembly of 1 order:	25–30 min	12–15 мин
Assembly accuracy	~93%	99,2%
1 worker processed	~100 orders/day	180-200 orders/day
Additionally	Reducing peak overtime on Black Friday by 60%	
ROI	~3 years	

Large warehouses (over 10,000 m²)

Large warehouses require a comprehensive approach to automation, including large-scale automated storage and transportation systems, integration with ERP and advanced WMS, as well as the use of robots for palletizing and packaging.

IKEA Distribution Center — Poland (Gliwice)
• Area: 115,000 m²
• Type: furniture, heavy-duty cargo
• Solution: automated cranes, AGV platforms, WMS

Tab. 3

Comparative analysis of indicators before and after the introduction of robotics for a large warehouse

	Before	After
Storage efficiency:	- 40%	+60%
Damage to packaging	Frequent damage to packaging	-75%
Additionally	Operational savings ~€1.2 million/year	
ROI	~4.5 years	

6. CYBERSECURITY IN WAREHOUSE ROBOTICS

Modern warehouse automation and robotics significantly increase the efficiency of processes, but at the same time create new vulnerabilities in the field of information security. The growth in the number of connected devices, integration with corporate information systems and the use of wireless technologies make warehouses an attractive target for cyberattacks. Therefore, the role of cybersecurity in robotics is becoming critical to ensure the sustainability and reliability of warehouse operations.

Threats and risks

The main threats to robotic warehouses include unauthorized access to robot control systems, interference with automated processes, theft or corruption of data, and denial of service (DoS) attacks. Examples include attacks on WMS and ERP systems that manage logistics flows and stocks, or interference with wireless sensors and controllers.

In addition, the growth in the number of IoT devices and mobile robots increases the attack surface, since each device is a potential entry point for intruders. Attacks on cyber infrastructure can lead to the suspension of warehouse operations, financial losses, delays in delivery times, and damage to the company's reputation.

Protection level and security measures

To ensure the security of automated warehouse systems, a comprehensive approach is required, including technical, organizational, and administrative measures. Technical solutions include the use of data encryption, multi-factor authentication, regular software updates, and monitoring systems.

It is recommended to implement network segmentation to isolate critical robot control systems from general corporate networks. Role-Based Access Control (RBAC) allows you to limit the rights of users and systems, minimizing the risks of internal and external intrusion.

Equally important is regular vulnerability assessment and security testing (pentesting), as well as employee training in the basics of cybersecurity. Creating incident response procedures and recovery plans ensures a quick response and minimizes damage in the event of possible attacks.

Security tools: WMS, ERP, RFID and role-based access

Integration of warehouse management systems (WMS), enterprise resource planning (ERP) and RFID technologies allows not only to increase operational efficiency, but also to strengthen security. RFID tags and readers provide control over the movement of goods and equipment, preventing theft and errors.

Role-based access allows to delimit authority and eliminate the possibility of abuse. Modern systems have built-in mechanisms for auditing user actions, which facilitates the detection and investigation of incidents.

7. CONCLUSIONS

The robotic automation of warehouse servicing represents a transformative shift in logistics, enabling facilities to achieve significantly higher levels of speed, accuracy, safety, and operational efficiency. As this paper has demonstrated, different types of warehouses — from unit load and high-bay storage to cold, hazardous, and universal warehouses — benefit from tailored robotic solutions that address their unique operational challenges.

Through the classification of robotic technologies such as AGVs, AMRs, AS/RS, and integrated WMS, we have shown how modern warehouses can evolve from manual, labor-intensive systems to highly automated environments. Case studies from industry leaders including Carrefour, Zalando, IKEA, and Ocado illustrate measurable benefits such as reduced order picking time, improved space utilization, enhanced inventory accuracy, and significant cost savings within 2–3 years.

Nevertheless, successful implementation of robotic systems requires a strategic approach that considers warehouse type, scale of operations, investment capacity, and future growth. Challenges related to cybersecurity, workforce adaptation, and system integration must be proactively addressed. The importance of reliable data, robust infrastructure, and staff training is critical to ensure sustainable adoption.

In conclusion, robotic warehouse automation is not a question of if, but when and how. Companies that invest today in flexible, scalable, and intelligent automation systems will be better equipped to meet the dynamic demands of modern supply chains — and to remain competitive in an increasingly digital logistics landscape.

References

1. Ellithy, K. & Salah, M. & Fahim, I.S. & Shalaby, R. AGV and Industry 4.0 in warehouses: a comprehensive analysis of existing literature and an innovative framework for flexible automation. *The International Journal of Advanced Manufacturing Technology*. 2024. Vol. 134. P. 15–38. DOI: 10.1007/s00170-024-14127-0.
2. Azadeh, K. & De Koster, R.B.M. & Roy, D. Robotized and automated warehouse systems: review and recent developments. *Transportation Science.* 2019. Vol. 53(4). DOI: 10.1287/trsc.2018.0873.
3. Zhen, L. & Li, H. A literature review of smart warehouse operations management. *Frontiers of Engineering Management*. 2022. Vol. 9(10). P. 1-25. DOI: 10.1007/s42524-021-0178-9.
4. García, M.R. & Betts, K. & Ponce, E. *Identifying the Key Vulnerabilities in the Warehouses of the Future.* MIT Center for Transportation and Logistics. 2025. Available at: https://omnichannel.mit.edu/wp-content/uploads/2025/02/MIT_OmnichannelSupplyChain_WarehouseFutureVulnerabilities_2025_FullReport.pdf?utm_source
5. Meggiato, G. & Nterai, S. & Skowronski, E. et al. Warehouses against cyber-attack risks. *Proceedings of the International Conference on Industrial Engineering and Operations Management*. Istanbul, Turkey. March 7-10, 2022. P. 4572-4581. Available at: https://ieomsociety.org/proceedings/2022istanbul/883.pdf?utm_source
6. Sodiya, E.O. & Umoga, U.J. & Amoo, O.O. & Atadoga, A. AI-driven warehouse automation: A comprehensive review of systems. *GSC Advanced Research and Reviews*. 2024. Vol. 18(02). P. 272-282. DOI: 10.30574/gscarr.2024.18.2.0063.