# Smart Warehouses at Logistic Centers

Shahriyar Guliyev
*Department of Electronics and Information Technology*
*Nakhchivan State University*
Nakhchivan, Azerbaijan
shahriyarguliyev@ndu.edu.az
ORCID: 0009-0009-3433-2816

Tarxan Orujov
*Department of Electronics and Information Technology*
*Nakhchivan State University*
Nakhchivan, Azerbaijan
texranorucov@ndu.edu.az

***Abstract*—Smart warehouses at logistic centers represent a transformative shift in the logistics landscape. Integrating cutting-edge technologies such as IoT sensors and AI, these facilities optimize inventory management and streamline operations. Real-time monitoring of inventory levels allows for proactive replenishment, while autonomous material handling systems reduce manual labor. AI-driven predictive maintenance minimizes equipment downtime, ensuring operational efficiency. Data analytics provide valuable insights into supply chain operations, enabling informed decision-making. With optimized storage space utilization and streamlined order fulfillment processes, smart warehouses promise increased efficiency and superior customer experiences, driving operational excellence in the logistics sector.**

***Keywords*—Smart Warehouses, Logistic Centers, IoT Sensors, AI Integration, Inventory Management, Autonomous Material Handling, Predictive Maintenance, Data Analytics, Operational Efficiency, Customer Experience**

## INTRODUCTION

In the execution phase of the Revitalized Silk Road project, transportation and logistics face significant challenges, primarily revolving around warehouse operations and terminals. Key issues include:

- Efficient Product Retrieval:
  - Implementation of smart Warehouse Management Systems (WMS) utilizing robots for product search and retrieval.
- Strategic Alerts:
  - Timely notification systems for the depletion of strategic products like grain.
- Transport Management:
  - Monitoring of shipments, ensuring quality storage, and driver tracking using GNSS/GPS modules.

Moreover, the establishment of logistics warehouses along the central point of the Nakhchivan-to-China and Nakhchivan-to-Europe railway highlights the necessity for long-term storage capabilities.

The paper outlines the transformative impact of smart warehouses at logistic centers, facilitated by cutting-edge technologies like IoT sensors and AI. These advancements optimize inventory management, enable proactive replenishment, and reduce manual labor through autonomous material handling systems. AI-driven predictive maintenance ensures operational efficiency, while data analytics provide insights for informed decision-making. Smart warehouses promise increased efficiency and superior customer experiences, driving operational excellence in the logistics sector. Warehouses play a vital role in transportation logistics, involving various operations like acceptance, placement, and dispatch. They are classified based on storage duration, product type, and ownership form, serving specific purposes tailored to meet diverse industry requirements. Warehouse management systems (WMS) streamline daily planning, organization, and workforce management, providing visibility into inventory and integrating with other systems for seamless operations. WMS benefits include cost reduction, real-time information management, and improved efficiency. The introduction also highlights AI-aided warehouse management, citing examples of smart warehouses globally. These advancements contribute to economic growth, competitiveness, and enhanced supply chain operations. Smart warehouses represent a significant evolution in logistics, promising substantial benefits for various industries and economies.

Thanks to my mother Zahra Seyidgizi for supporting my research and education.

## I. WAREHOUSES IN TRANSPORTATION LOGISTICS

### A. Warehouse Logistics Principles and Conditions

Warehouse logistics involves the preparation of accepting goods from a specific point, storing them for a certain period, and then delivering them to desired destinations. The duration of storage directly influences warehouse types. Warehouse operations include acceptance, placement, counting, collection, verification, and dispatch, forming the basis of efficient transportation. Systematic research directly impacts operational efficiency. Warehouses are classified based on storage duration and product type.

*1) Types of Warehouses:*

- Open-air warehouses
- Closed-air warehouses
- Cold storage warehouses

*2) Steps in Storage Activities:*

i. Planning arrival time of transportation vehicles
ii. Arrival of transportation vehicles
iii. Unloading of transportation vehicles
iv. Placement of goods into the warehouse
v. Storage and preparation for transfer
vi. Dispatch of goods

*B. Classification of Warehouses*

Warehouses are classified based on various criteria, including:

1) Relation to logistic activity
2) Type of goods
3) Ownership form
4) Relation to logistics providers
5) Functional purpose
6) Level of specialization

*C. Warehouses per Property type*

Warehouses are essential for storage and distribution of goods.

They are categorized based on property type.

*1) **Special Warehouses**:*

i Owned and operated by individual enterprises.
ii Can be used exclusively by a single enterprise.
iii Accounted for in the balance sheets of respective firms.
iv Leased out under long-term contracts.

*2) **State Warehouses**:*

- Serve as public warehouses accessible for general use.
- Maintain state ownership status.
- Store goods prohibited for production or sale by the state.
- Used for stimulating local producers.

*3) **Municipal Warehouses**:*

i Owned by municipal organizations or local government bodies.
ii May be leased or shared.
iii Store goods prohibited for production or sale by municipalities.
iv Stimulate local producers.

Understanding different types of warehouses is crucial for logistics and supply chain management.

Each type serves specific purposes and supports economic activities.

*D. Services Available in Warehouses*

In the logistics domain, warehouses serve as crucial hubs for the efficient management of goods and materials, catering to various types of ownership structures. The services provided by warehouses are diverse and tailored to meet the specific needs of different entities. Based on the ownership type, warehouses can be classified into three main categories:

1) **Private Warehouses:** These warehouses are owned and operated by individual firms or companies, providing exclusive storage facilities for their own products. Private warehouses offer specialized services tailored to the requirements of the owning entity, including customizable storage solutions, inventory management, and order fulfillment services.
2) **Public Warehouses:** Public warehouses, also known as open-access warehouses, are owned and managed by governmental or municipal authorities. These warehouses serve as shared storage facilities accessible to multiple businesses and individuals on a rental basis. Public warehouses offer a wide range of services, including temporary storage, handling, and distribution of goods for various clients. They play a crucial role in supporting local industries, facilitating trade, and managing surplus or restricted commodities.
3) **Joint Venture Warehouses:** Joint venture warehouses are collaborative ventures between multiple entities, such as joint stock companies, cooperative enterprises, or consortiums. These warehouses are established through contractual agreements among the participating parties, pooling resources and expertise to create shared storage infrastructure. Joint venture warehouses offer cost-effective solutions for storage and distribution, allowing partner organizations to optimize their logistics operations and enhance supply chain efficiency.

Each type of warehouse ownership structure offers distinct advantages and caters to different industry requirements. Whether it's the dedicated storage capabilities of private warehouses, the accessibility of public warehouses, or the collaborative benefits of joint venture warehouses, the services available in warehouses play a vital role in driving logistical efficiency and supporting economic activities.

*E. Functions of Warehouses*

Warehouses are differentiated based on their functional purpose:

1) **Buffer Reservoir Warehouses:** Ensuring the uninterrupted flow of the production process.
2) **Terminal Warehouses:** Serving the purpose of transferring loads in transportation networks when executing mixed, combined, intermodal, and other types of shipments.
3) **Commission Warehouses:** Designated for the formation of orders according to the specific requirements of customers.
4) **Storage Warehouses:** Ensuring the storage of warehoused goods.
5) **Special Warehouses:** Such as customs warehouses, temporary storage warehouses, yards, and returnable packaging warehouses.
6) **Transit Warehouses:** Used for the transshipment of goods between different transportation modes and for short-term storage of products.

Warehouse specialization is characterized by the degree of specialization of goods and variety, as well as the nature of the main warehouse operations.

- **Specialized Warehouses:** Limited to one or several groups of products.
- **Narrowly Specialized Warehouses:** Specialized in storing or processing a specific type of product.
- **Specialized Warehouses with a Wide Range of Products:** Store various groups of products, such as black and non-ferrous metals, as well as all types of food products.

In addition to the classification based on specialization, warehouses are also classified according to technical characteristics,

the character of the technical process, the area they occupy, and the transportation link.

- **Technical Characteristics:** Divided into general merchandise warehouses (storing goods that are not perishable and do not require special conditions) and special purpose warehouses (such as refrigerators, oil tanks, paper and timber warehouses, measuring devices and scales, salt and kerosene warehouses, refrigerators, etc.).
- **Character of the Technical Process:** Individually mechanized, fully mechanized, semi-mechanized, and automated warehouses.
- **Area Occupied:** Small, medium, and large warehouses. Small warehouses cover an area of 5,000 square meters, medium warehouses approximately 5,000-15,000 square meters, and large warehouses cover an area of more than 100,000 square meters.

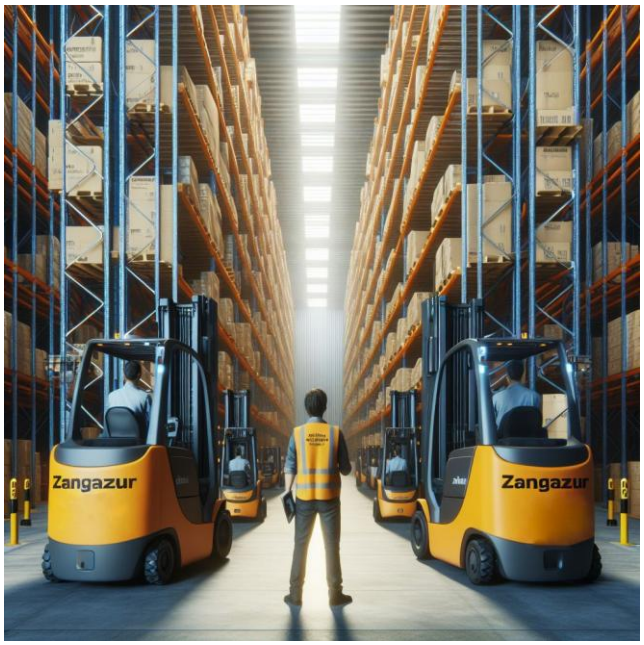


Fig. 1: Getting load from racks by forklifts.[1]

## II. Warehouse Management Systems

A Warehouse Management System (WMS) is a software application designed to support and optimize warehouse functionality and central distribution leadership. These systems streamline the management of daily planning, organization, workforce, routing, and control of resources, facilitating the management of material movement and storage within and outside the warehouse, while also assisting workers in material handling and storage tasks.

The operational management includes controlling temperature, humidity, ventilation, air quality, pressure, and products loading, placement, and location adjustment [1].

[1]This image was generated using GenAI with DALL·E 3 model.

Smart warehouse is a technology-driven logistics solution, where tasks delegated to humans are performed by state-of- the-art software and equipment [2].

1) **Functionality:** WMS enables organizations to manage and control warehouse operations from the time goods or materials enter the warehouse until they leave. Operations include inventory management, picking processes, and verification.
2) **Visibility:** WMS provides visibility into an organization's inventory at any time and location, whether within the enterprise or in transit. It can manage supply chain operations from suppliers or wholesalers to warehouses and then to retail or distribution centers.
3) **Integration:** WMS often integrates with Transportation Management Systems (TMS) or Inventory Management Systems to work seamlessly with real-time data, managing information about orders, shipments, receipts, and movements of goods.

### *A. Scaling WMS*

Warehouse management systems come in various types and implementation methods, typically depending on the size and nature of the organization. They can range from standalone systems in larger enterprise resource planning setups or as part of a supply chain execution package.

- **Complexity:** WMS can vary widely in complexity, from simple manual document or spreadsheet use in small organizations to complex WMS programs used by small to medium-sized businesses (SMBs) and larger enterprises. Some WMS solutions are specially tailored to the size of the organization, while many vendors offer WMS products scalable for various organizational sizes.
- **Customization:** WMS can be designed or configured for specific organizational requirements. For example, an e-commerce vendor may use a WMS with different functionalities than a brick-and-mortar retailer. Additionally, a WMS can be designed or configured for specific types of goods sold by the organization, such as sporting goods, which may have different requirements than grocery items.

### *B. Routine Management Functions of WMS*

Warehouse Management Systems (WMS) perform various routine management functions to streamline warehouse operations and enhance efficiency.

1) **Daily Planning:** WMS facilitates the consolidation of daily plans, including workload selection, workforce allocation, and estimation of required labor and transportation resources. It ensures that orders are dispatched, carriers are informed about loading and dispatching, and customers' requirements are met.
2) **Order Prioritization:** Organizing incoming orders for batch processing can be done in multiple ways to meet user needs. The primary objective is to prioritize orders deliberately and select them sequentially if there is no meaning for the company to transport and deliver orders to a carrier. Initial organization methods include wave

TABLE I: Applications and Economic Impact

| Economic Impact | Description |
|---|---|
| Enhanced Efficiency | Smooth operations in production and transportation networks |
| Cost-Effectiveness | Savings in logistics operations |
| Improved Customer Service | Timely delivery of goods |
| Streamlined Supply Chain | Reduced lead times |
| Economic Growth and Competitiveness | Reduced operational costs and improved market competitiveness |
| Economic Diversification | Support for niche markets |
| Increased Trade Activity | Promotion of commerce and international trade |
| Employment Opportunities | Job creation in logistics, manufacturing, and support services |
| Infrastructure Enhancement | Improved transportation networks and storage facilities |

planning or wave picking, ensuring minimal need for space allocation and supporting monitoring of progress throughout the day, creating a workflow for eliminating/reducing last-minute requests for carrier departure or delay in job.

3) **Workforce Management:** Assigning tasks and areas to employees using work waves to minimize organization. This function can also be used to divide individual orders into logical work units and assign them separately to potential individuals to fulfill simultaneously, meeting requirements for sequential processing and physical layout, such as separating individual checkout collection from each unit collection and also pallet load collection, increasing productivity and supporting Control.
4) **Documentation and Compliance:** Ensuring the implementation, use, and suitability of documented processes and procedures within the WMS to characterize the company's business and service levels (e.g., International Organization for Standardization 9000 (www.iso.org)). This function can also be used to divide individual orders into logical work units and assign them separately to potential individuals to fulfill simultaneously, meeting requirements for sequential processing and physical layout, such as separating individual checkout collection from each unit collection and also pallet load collection, increasing productivity and supporting Control.
5) **Monitoring and Control:** Providing stages for monitoring progress throughout the day, responding to problems in a timely manner, and providing information for performance analysis.

Path planning problem in multi-robot warehouse systems is especially challenging, since finding best and collision-free paths are affected by many warehouse specific parameters as well as dynamically changing environment due to movement of the robots in the system [3].

### *C. Inventory Management*

Inventory management is a crucial aspect of Warehouse Management Systems (WMS), facilitating the control and optimization of warehouse operations from goods entering the warehouse to their departure.

- **Functionality:** WMS systems streamline daily planning, organization, workforce management, routing, and resource control. They simplify the management of material movement and storage within and outside the warehouse, providing assistance to workers in material handling and storage tasks.
- **Visibility:** WMS offers visibility into inventory from the time goods enter the warehouse until they leave. It manages supply chain operations, including those from suppliers or wholesalers to warehouses, and further to retail or distribution centers.
- **Integration:** WMS often integrates with Transportation Management Systems (TMS) or Inventory Management Systems. This integration allows seamless handling of real-time data regarding orders, shipments, receipts, and movements of goods.

Study by Emir C. et al. explores data visualization method in 3D space that includes actual positions, volumes and space relations of the chunks of data that are being visualized. Data that is being visualized is real-time information provided by the smart warehouse management system about packages distributed on pallet places within a warehouse [4].

### *D. Benefits of WMS*

Despite the complexity and cost of implementation and use, organizations derive benefits from the application and use of WMS.

1) **Cost Reduction:** Implementing WMS can reduce labor costs, increase inventory accuracy, improve agility and accuracy, reduce errors in picking and shipping, and improve customer service.
2) **Real-time Information:** Modern warehouse management systems work with real-time data, enabling the organization to manage the latest information about activities such as orders, deliveries, receipts, and movements of goods.

Retailers are increasingly investing in automation, with significant expenditure increases noted [5].

## III. AI-AIDED WMS IN SMART WAREHOUSES

As AI has been explored mainly in Machine Learning, Machine Reasoning and Robotics fields, we'll look in broad.

Smart warehousing is a term that is gaining increased attention, often in connection with Industry 4.0, Logistics 4.0, and IoT [5].

One of the ways warehouses acquire robots is through a business model called Robot as a Service (RaaS), where robots are either leased or sold as a service. Such a service is called pay-per-pick, where costs are computed by the tasks the robots can perform [6]–[8].

### A. Enhanced Inventory Management

In addition to barcode and automation technologies, Industry 4.0 is now more powerful with several technologies such as NarrowBand IoT (NB-IoT), near-field communication (NFC), radio-frequency identification (RFID), global positioning system (GPS), wireless sensor network, Wi-Fi, and robotics [9]–[11].

- Utilization of smart WMS with robotic capabilities for efficient product retrieval.
- Implementation of advanced algorithms for real-time inventory tracking and alerting, ensuring timely replenishment of strategic goods.

### B. Optimized Logistics Operations

- Integration of GNSS/GPS devices for precise vehicle tracking and route optimization.
- Utilization of temperature and humidity sensors for monitoring cargo conditions, guaranteeing quality preservation.

### C. Automated Handling Processes

Smart warehouses usually employ Robotic Mobile Fulfillment Systems (RMFS) to ensure security, accuracy, and productivity [6].

- Deployment of automated forklifts (e.g., Autokar) for seamless loading and unloading operations.
- Implementation of RFID technology for efficient container identification and tracking.

### D. Streamlined Transportation Management

- Adoption of smart terminals for multi-modal transportation coordination, facilitating swift cargo transfers between trucks, trains, and ships.
- Integration of intelligent algorithms for optimizing truck driver schedules and ensuring compliance with regulations.

Example project, by Emir Z. in [12], the supply chain procedures carried out in the warehouse were reviewed before and after implementing software that handles warehouse transactions, noting, more improvement can be achieved by implementing more advanced data mining and artificial intelligence techniques in warehouse processes. Paper [13] proposes similar alternative called intelligent WMS (i-WMS). That system consists of five subsystems: Intelligent Logistic System, Intelligent Warehouse System, Real-time Transportation Monitoring, Sales Forecasting System, and Intelligent Sales Summary System [12].

### E. World Practice

The real smart warehouse is still far away, but some fields of storage can be 'smart' now [2].

*1) China's Automated Logistics Port:* The world's first fully automated multimodal transport terminal is now operational at Nansha Port in Guangzhou, China, integrating advanced technologies such as Beidou navigation, 5G communications, artificial intelligence, and autonomous vehicles [14]. The New Qianwan Container Terminal at Qingdao Port is Asia's first fully automated port, marking a significant milestone in the realm of intelligent ports worldwide [15]. China's automation investments in ports focus on Qingdao, Yangshan, and Ningbo-Zhoushan. Qingdao, Asia's first fully automated port, holds the global efficiency record. Yangshan and Ningbo-Zhoushan are pivotal in China's economic growth [16].

*2) Around the World:* Contributing to the recent and limited literature on smart warehousing, our study proposes 16 propositions related to automation and complementary technology, as well as pathways toward smart warehousing, based on empirical insights from leading Swedish retailers [5].

Also, there is a good paper by Zuchowski writing, "The incorporation of artificial intelligence into warehouse every activity will theoretically be possible, but will it be financially effective?" [2]..

## IV. Vehicle Operations

### A. Railways

- Railside Warehouses: Located near railway tracks to facilitate connections with main railway lines.

### B. Cargo Transportation

- Relaside Warehouses: Positioned alongside entry railway lines, facilitating access only for truck and freight transportation.

### C. Maritime Transport

- Portside Warehouses: Located adjacent to river or sea ports for efficient handling of goods.

### D. Air Transport

- Available for transitional airports like in Istanbul or Frankfurt, can be applied accordingly to Baku.

## V. Applications and Economic Impact

- Applications: Various applications include inventory management, order fulfillment, and distribution.
- Economic Impact: Enhanced efficiency and cost-effectiveness, improved customer service, and streamlined supply chain operations contribute to economic growth and competitiveness.

As shown in Table I, the applications and economic impact of smart warehouse management systems are significant.

As mentioned in [1], [17], a quiet revolution in the adoption of state-of-the-art technologies is seeming to be undergoing in warehouses and distribution centers. The warehouse is on the trajectory to engage in itself many of the capabilities that

TABLE II: Types of Smart Warehouses

| Complexity | Description |
|---|---|
| Simple | Utilize manual documents or spreadsheets for inventory management. Common in small organizations. |
| Complex | Employ advanced WMS programs for medium to large enterprises. Offers comprehensive functionalities for managing warehouse operations. |
| Customized | Tailored WMS solutions to meet specific organizational requirements. Adapted based on business needs and nature of goods. |

are sought in the vision of Industrial Internet of Things (IIOT). The ultimate goal of the IIoT in warehousing is the automated warehouse concept. IIoT, or in more generic words, IoT-enabled warehouses are still in their early stages.

Also, another important aspect is sustainability as in Lu Z. writes, smart warehouses usually consume much more energy than traditional manual warehouses because more automated facilities are used in smart warehouses. Increasing energy consumption in warehouses becomes a major component of warehouse operational costs. Meanwhile, the increase in energy consumption produces extra carbon emissions to nature, which is the main cause of climate change. Sustainable warehouses aim to pursue sustainability goals, such as energy efficiency, greenhouse gas emission reduction, cost reduction, and throughput time minimization. Sustainability is a common thread running through strategic, tactical, and operational decisions of the sustainable warehouse [18].

Again another important aspect highlighted by Hokey M. is cybersecurity: Given that an IoT platform is essential for a smart warehouse, a smart warehousing environment can create security issues (e.g., cyber-attacks and hacking) associated with the IoT platform [19].

## Conclusion

Smart warehouses at logistic centers, leveraging IoT sen- sors and AI/ML, revolutionize inventory management and streamline operations. Real-time monitoring enables proactive replenishment, while AI-driven predictive maintenance min- imizes downtime. Data analytics offer insights for informed decision-making, promising efficiency and superior customer experiences. Understanding warehouse logistics principles and classifications is crucial, optimizing storage and distribution. Warehouses, based on ownership and purpose, offer diverse services crucial for logistics and supply chain management. Warehouse management systems (WMS) play a pivotal role, streamlining operations and enhancing efficiency. They offer visibility, integration, and scalability, catering to organizational needs. Routine management functions, inventory management, and benefits of WMS contribute to operational excellence. The integration of AI in warehouse management promises further advancements. World practices, such as China's automated logistics ports, showcase the potential of smart warehouses. Various applications and economic impacts, including enhanced efficiency and economic growth, highlight the significance of smart warehouses. Authors' contributions, incorporating SME insights and novel solutions, ensure a comprehensive understanding. The generative AI disclosure acknowledges the artwork's creation, enhancing the manuscript's visual appeal. Overall, smart warehouses represent a paradigm shift in logistics, driving operational excellence and economic growth.

## Competing interests

The authors declare that they have no competing interests regarding the publication of this paper.

## Generative AI Disclosure

Authors declare that a colored electronic artwork illustrating smart-WH was generated using GenAI in Microsoft Edge, DALL·E 3 ANN model (see Figure 1).


## Acknowledgment

Thanks to my mother Zahra Seyidova for all the support and motivation during my research.


## Abbreviations

| Abbreviation | Meaning |
|---|---|
| ANN | Artificial Neural Networks |
| ML | Machine Learning |
| NLP | Natural Language Processing |
| IoT | Internet of Things |
| WH | Warehouse |
| WHM | Warehouse Management |
| WMS | Warehouse Management System |
| APL | Automated Logistics Port |
| i-WMS | intelligent WMS |

## Author Contribution

SG wrote the manuscript, conceptualizing the WMS and smart-WMS systems. TO, as an SME (Subject Matter Expert) in Transportation & Logistics, provided essential field exami- nations, documentation, and lecture notes, offering novel ideas in the field. SG proposed feasible system overviews for smart WMSes, drawing from TO's insights. SG accumulated and summarized the previous articles about subject matters. Both authors contributed to interpreting data. SG formulated the concept of a "Smart Warehouses". All co-authors gave final approval for submission.

## REFERENCES


[1] S. Jabbar, M. Khan, B. N. Silva, and K. Han, "A rest-based industrial web of things' framework for smart warehousing," *The Journal of Supercomputing*, vol. 74, no. 9, pp. 4419–4433, 2018. [Online]. Available: https://doi.org/10.1007/s11227-016-1937-y

[2] W. Z˙uchowski, "The smart warehouse trend: Actual level of technology availability," *Logforum*, vol. 18, no. 2, p. 7, 2022. [Online]. Available: https://doi.org/10.17270/J.LOG.2022.702

[3] A. Bolu and Korc¸ak, "Path planning for multiple mobile robots in smart warehouse," in *2019 7th International Conference on Control, Mechatronics and Automation (ICCMA)*, Nov. 6-8 2019, pp. 144–150. [Online]. Available: https://doi.org/10.1109/ICCMA46720.2019.8988635

[4] E. Cogo, E. Z˘unic´, A. Bes˘irevic´, S. Delalic´, and K. Hodz˘ic´, "Position based visualization of real world warehouse data in a smart warehouse management system," in *2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH)*, March 18-20 2020, pp. 1–6. [Online]. Available: https://doi.org/10.1109/INFOTEH48170.2020.9066323

[5] J. Kembro and A. Norrman, "The transformation from manual to smart warehousing: an exploratory study with swedish retailers," *The International Journal of Logistics Management*, vol. 33, no. 5, pp. 107–135, 2022, y2 - 2024/04/10. [Online]. Available: https://doi.org/10.1108/IJLM-11-2021-0525

[6] G. S. Oliveira, J. T. Carvalho, and P. D. M. Plentz, "An experimental analysis of smart warehouses' order flow in robot energy consumption," in *2022 Latin American Robotics Symposium (LARS), 2022 Brazilian Symposium on Robotics (SBR), and 2022 Workshop on Robotics in Education (WRE)*, Oct. 18-21 2022, pp. 276–281. [Online]. Available: https://doi.org/10.1109/LARS/SBR/WRE56824.2022.9996078

[7] M. Sprenger and T. Mettler, "Service robots," *Business & Information Systems Engineering*, vol. 57, pp. 271–274, 08 2015.

[8] ZDNet. (2022) Robots-as-a-service: New company introduces first 'goods-to-box' warehouse picking system. Accessed in 08-15-2022. [Online]. Available: https://www.zdnet.com/article/goods-to-box-picking-system-with-disruptive-business-model/

[9] M. van Geest, B. Tekinerdogan, and C. Catal, "Smart warehouses: Rationale, challenges and solution directions," *Applied Sciences*, vol. 12, no. 1, p. 219, 2022.

[10] X. Liu, J. Cao, Y. Yang, and S. Jiang, "Cps-based smart warehouse for industry 4.0: A survey of the underlying technologies," *Computers*, vol. 7, p. 13, 2018.

[11] O. Koksal and B. Tekinerdogan, "Feature-driven domain analysis of session layer protocols of internet of things," in *Proceedings of the IEEE International Congress on Internet of Things (ICIOT)*, Honolulu, HI, USA, June 2017, pp. 105–112.

[12] E. Z˘unic´, S. Delalic´, K. Hodz˘ic´, A. Bes˘irevic´, and H. Hindija, "Smart warehouse management system concept with implementation," in *2018 14th Symposium on Neural Networks and Applications (NEUREL)*. Belgrade: IEEE, November 2018, pp. 1–5.

[13] R. Pulungan, S. P. Nugroho, N. El Maidah, T. B. Atmojo, P. D. Hardo, and P. Pawenang, "Design of an intelligent warehouse management system," in *Information Systems International Conference (ISICO)*, 2013.

[14] G. Malheiros. (2022, August) World's first fully automated multimodal transport terminal is working in china. Datamar News. [Online]. Available: https://www.datamarnews.com/noticias/worlds-first-fully-automated-multimodal-transport-terminal-is-working-in-china/

[15] C. Daily. (2020, November) Qingdao port smart system a world first. Sci-Tech. Updated on November 17, 2020. [Online]. Available: https://chinascio.gov.cn/xwfbh/xwfbh/wqfbh/202011/t20201117_800273660.html

[16] P. T. Team. (2019, July) Watch: China's three biggest automated ports. Port Technology. [Online]. Available: https://www.porttechnology.org/news/watch_chinas_three_biggest_automated_ports/

[17] S. Banker. (2015, 07) The key challenge for the iot-enabled warehouse will be execution. Forbes. Accessed 17 Jun 2016. [Online]. Available: Online

[18] L. Zhen and H. Li, "A literature review of smart warehouse operations management," *Frontiers of Engineering Management*, vol. 9, no. 1, pp. 31–55, 2022.

[19] H. Min, "Smart warehousing as a wave of the future," *Logistics*, vol. 7, no. 2, p. 30, 2023.


## CORRESPONDING AUTHOR


For scholarly correspondence, SG, the designated corresponding author, may be contacted at:shahriyarguliyev@ndu.edu.az.