

**SUSTAINABLE DIGITAL TRANSFORMATION IN
WAREHOUSING PROCESSES: OPPORTUNITIES AND
CHALLENGES**

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In the pursuit of sustainability, the logistics industry faces the need to modernize and optimize its processes, with digitalization emerging as a key factor for efficiently managing warehousing processes, reducing resource consumption, and enhancing operational transparency. This article analyzes the opportunities for digitizing warehousing processes to achieve sustainability, as well as the challenges faced by the logistics industry in striving for sustainable digital transformation.

Digital warehousing - logistics facilities that use knowledge to improve processes and reduce redundancies and achieve full traceability of production [1]. The latest technologies are changing the field of warehousing, improving accuracy, efficiency and decision-making. The analysis of scientific literature made it possible to distinguish the benefits of digitalization of storage processes (see Table 1).

According to researchers [9], smart robots consist of various sensors and powerful processors that allow extensive sensing, intelligent decision-making and precise behavior. Intelligent robots are increasingly being used to replace manual operations, reduce errors and improve efficiency and safety. Based on employee experience and reports, manual searches for missing pallets can take up to three hours. For this reason, according to the authors, the advantage of the digital system is obvious [4].

Green Logistics is defined as management practices and measures aimed at reducing environmental impact not only by reducing CO₂ emissions, but also by limiting other air pollutants that are released by burning fossil fuels, misusing other natural resources, and mismanaging waste [10].

Sustainable logistics holistically takes into account not only economic and environmental aspects, but also indicators of social sustainability, i.e. job creation and work environment [9]. Therefore, the goal of sustainable logistics is to balance the social and economic performance of the logistics system with its ecological reliability by managing the system's operations.

Table 1 - Benefits of digitizing warehousing processes. [2] [3] [4] [5] [6]

| Technology | Benefits |
|--|--|
| Internet of things | An interconnected network of physical devices that may include electronics, software, sensors, actuators, and communication components. These devices can communicate and exchange data. |
| Artificial intelligence | Using its algorithms, it enables the company to predict the level of demand for each product at each warehouse location, triggering a process that automates millions of decisions every day, balances multiple and competing KPIs, improves availability and reduces waste, and significantly reduces rack space. |
| QR codes and RFID tags | The use of tags/codes provides the ability to store large amounts of data, equipped with appropriate antennas to facilitate data reading and writing to the code/tag, and is inexpensive and easy to use. |
| Combinations of blockchain technologies are connected together in digital networks with Internet of Things systems | Helps achieve business goals in the logistics and transportation business. Together, these technologies ensure real-time visibility and seamless collaboration between processes and chain partners. |
| Automation | The latest generation of automation technology provides the flexibility to handle different types of products and adapt to fluctuations in demand, allowing for the efficient storage, handling and sorting of large product flows. The development is in line with the general shift from manual material handling to advanced automated systems aimed at increasing logistics efficiency (eg reducing picking and sorting costs). |
| Robotics | It requires little space, offers flexibility to manage various demand requirements and can operate 24/7. |
| Warehouse management systems based on cloud technology | Can improve order fulfillment speed and accuracy. In addition, it can increase receiving time, inventory accuracy and warehouse productivity when picking orders. For intangible benefits, it can improve the packaging method and inventory can be tracked using RFID. In addition, employee morale can be improved. |

Digitization initiatives for sustainability offer warehouses clear opportunities. Figure 1 highlights the benefits in warehouse processes, the socio-economic environment of the warehouse and the environment.

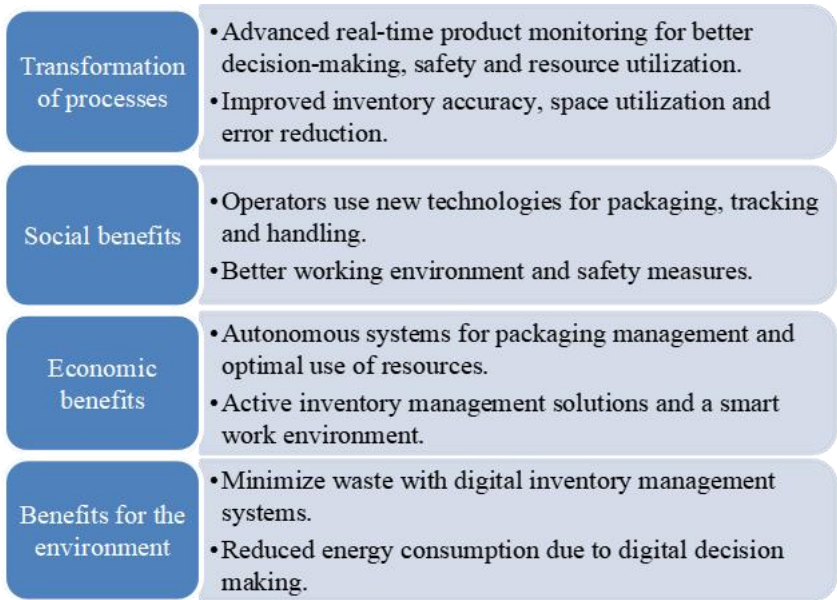


Fig. 1. Sustainable warehouse after implementing Industry 4.0 technologies in the warehouse [11]

According to researchers [12], warehouses have an important social aspect, they create jobs. Therefore, the well-being of the workforce must also be an important part of sustainability.

Researchers [13] demonstrated that two warehousing companies were influenced and improved their sustainable performance, air emissions, personnel safety and visibility specifically by automated warehousing systems. Digitization of warehousing processes for sustainability is determined by various factors (see Table 2), which can both encourage and complicate the implementation and application of digital transformation in the logistics business.

The research conducted by the researchers examines how digitization has affected process optimization and decision-making for sustainability, with a focus on Pakistan's manufacturing sector. The authors [20] emphasize that environmental legislation has a significant inhibiting effect on sustainability practices, digitization of processes and decision-making.

Table 2 - Factors promoting and limiting the application of digital technologies in warehousing processes for sustainability [14] [15] [16] [4] [9] [17] [18] [19] [20]

| Digitalization of Warehousing Processes | |
|--|--|
| Promoting factors | Restricting factors |
| <ul style="list-style-type: none"> • Green Deal: Reducing energy consumption through digitalization solutions, sorting and recycling waste, and increasing social responsibility; • Circular Economy Action Plan: Minimizing waste and resource use, promoting reuse, repair, recycling, and sustainable consumption, while exploring opportunities for renting, borrowing, or even sharing services; • Prolonged manual labor processes; • Decreasing error rates; • Increased warehouse efficiency; • Improved cargo safety; • Reduced warehousing process cycle time; • Lower energy consumption. | <ul style="list-style-type: none"> • Complexity of IT systems; • High financial investments; • Lack of employee skills; • Insufficient technological knowledge; • High level of IT requirements; • Security risks; • Lack of confidentiality; • Carbon footprint; • Lack of government support; • Legal issues; • Shortage of qualified labor; • Political challenges; • Old/traditional warehouse concepts; • Availability of digital technologies. |

The findings provide guidance for industries, decision-makers and researchers on how to develop strategies that effectively use digitization for sustainability and contribute to the achievement of the Sustainable Development Goals (SDG-9, SDG-11, SDG-12 and SDG-13).

Conclusions

Digitization is an essential element of modern logistics management, allowing to optimize warehouses, reduce the need for manual work and ensure the accuracy and flexibility of operations. Advanced technologies such as automation and robotics are transforming warehousing processes, increasing efficiency and the ability to quickly adapt to market changes, leading to greater profitability and customer satisfaction. In addition, digitization makes a significant contribution to sustainability by reducing environmental pollution and promoting responsible use of resources. However, the adoption of digital technologies faces challenges such as high financial investments, skills shortages and complex IT systems. These

factors require the right strategy and expert support to maximize the benefits of digitization.

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