Smart Warehouses: Logical Architecture for Logistics 4.0

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This article proposes an approach based on Industry 4.0 technologies for building smart warehouses aiming to improve the performance of this logistic system operation. It is considered that the development of general and scalable logical warehouse architecture was to increase the traceability, reliability, and agility of intralogistics activities. It was observed potential gains (structuring and well-organized operations, orchestration of technological resources to improve logistical performance, reduction of human intervention in the process, increased productivity, and proof of operation errors) when modeling and simulating the proposal presented to build a testbed.

Keywords: Smart Warehouse. Enabling Technologies. Logistics 4.0.

Introduction

In recent years, logistics has acquired an essential role in organizational strategies, such as the importance and relevance of its macro processes for the objectives: supplies, production, and distribution. Logistics is responsible for managing order processing, inventories, transportation, storage combination, material handling, and packaging [1]. A challenge of logistics management is the integrated and systemic vision of all the organization's processes.

Logistics represents a significant differential in the management of the flow of materials and information of the companies when well executed in a planned manner, from the client's order to the delivery of the product to the final consumer, seeking to meet the demands with fast deliveries, with quality, and at the lowest possible cost.

Given the current scenario of intense transformations, adaptations, and reinventions in the manner of interaction with customers, partners, and suppliers, logistics in companies need to be rethought to meet a significant number of deliveries in a short period. To do that, it has become indispensable to establish different distribution channels, make the storage environment more flexible, invest in technology, and apply innovative methods that account for the growing complexity of the supply chain involved.

The development of an efficient distribution system that incorporates multichannel communication involves the application of integration technologies between the logistical links to allow process customers to contact suppliers through the most convenient channels and receive their orders in the shortest possible time. Consequently, companies tend to migrate part of their inventories to warehouses or distribution centers, which have well-structured, fast and secure internal logistics to accommodate this new demand.

Thus, this article will demonstrate the importance of warehouses as support for logistics activities. A warehouse is a physical environment where raw materials and finished or semi-finished products are allocated and destined for the next cycle of the production or distribution chain. Storage operations are complex logistics system activities that require methods and tools that ensure speed, flexibility, and accuracy to meet the requirements of the processes they serve. For Hong [2], warehouses are meaningful elements in the logistic process because their operational performance determines the efficacy of logistics. However, inefficient management of this space can lead to high operational costs caused by a poorly

Received on 16 December 2021; revised 22 February 2022.
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J Bioeng. Tech. Health 2022;5(1):18-24.

defined layout, inadequate handling equipment, and/or excessive material handling [3].

The so-called enabling technologies of Industry 4.0 present enormous potential to make warehouses computationally intelligent and can meet the most demanding operating conditions of logistic systems with autonomous or automated storage operations. According to Pacchini [4], autonomous robots, computer simulations, systems integration, internet of things, cybersecurity, cloud computing, additive manufacturing (3D printing), augmented reality, and analytics based on big data are some of the technologies that enable the automation of traditional warehouse functions evolving them into smart warehouses.

Companies should know the steps involved in introducing smart warehouse solutions, and balance this with the risk factors which encompass this process. A careful evaluation and consideration of these specifics are required to minimize the costs and risks involved.

This paper proposes a generalizable and scalable warehouse architecture to increase the traceability, reliability, and agility of intralogistics activities based on Industry 4.0 technologies. Given the current obstacles and opportunities for implementing industry 4.0 concepts in intralogistics operations, an approach will be presented for enabling technologies into smart warehouses by building a logical architecture. The results of applying the architecture will be demonstrated on a testbed using computer modeling and simulation.

Intelligent Warehouse Approach to Logistics 4.0

In the new context of Industry 4.0, the industry aims to complete automation of its manufacturing complex, including suppliers, distributors, and customers, seeking the constant search for increased efficiency, using mainly the various enabling technologies that support it. For Hermann and colleagues [5], the main pillars of Industry 4.0 are the Internet of Things supported by Cyber-Physical Systems (CPS) and represented in manufacturing as production elements such as robots, machines, and other devices that gain connectivity and communication abilities.

These CPSs are integrated with intelligent sensors generating big data supported by artificial intelligence (AI) capable of generating more assertive decision making using a massive amount of data, having as its main benefit to analyze and draw conclusions in real-time, besides offering predictions to improve performance or predict failures of machines or processes.

On the other hand, autonomous automation contributes to robots that do not need to be precisely programmed. Because of AI, they can learn and improve their procedures without much human interference [6]. In the context that Logistics 4.0 or Intelligent Logistics is a notorious evolution of traditional logistics, in synergy with Industry 4.0, which brings in its concept of the application of information technologies with high impact power throughout the supply chain. According to Galindo [7], the logistic systems improve flexibility, adapt to market changes, and bring companies closer to customer needs, allowing them to improve the level of service and reduce storage and production costs. Szyman'ska and colleagues [8] complements the definition of Logistics 4.0 with two approaches: (1) procedural, which means increasing the efficiency and performance of supply chain members; (2) technical, which includes the cited technologies of Industry 4.0, such as digitization, automation, mobility, and IoT.

Therefore, logistics processes are considered intelligent when they can communicate and transmit information about the organization autonomously to those responsible for the process [9]. Data from all operations are closely monitored and synchronized in cyberspace, creating a network in which data can be shared in real-time [10].

The intelligent warehouse architecture proposed in this research work for a logistics 4.0 considers, as suggested by Harrison and colleagues [11] and Orellana and Torres [12], four main requirements: the devices that compose the system, the connectivity between these devices aiming at integration, the possibility of the hardware to be digitally integrated by a regular and interoperable logical architecture extended to the communication of the systems and, finally, the 100% digitized environment.

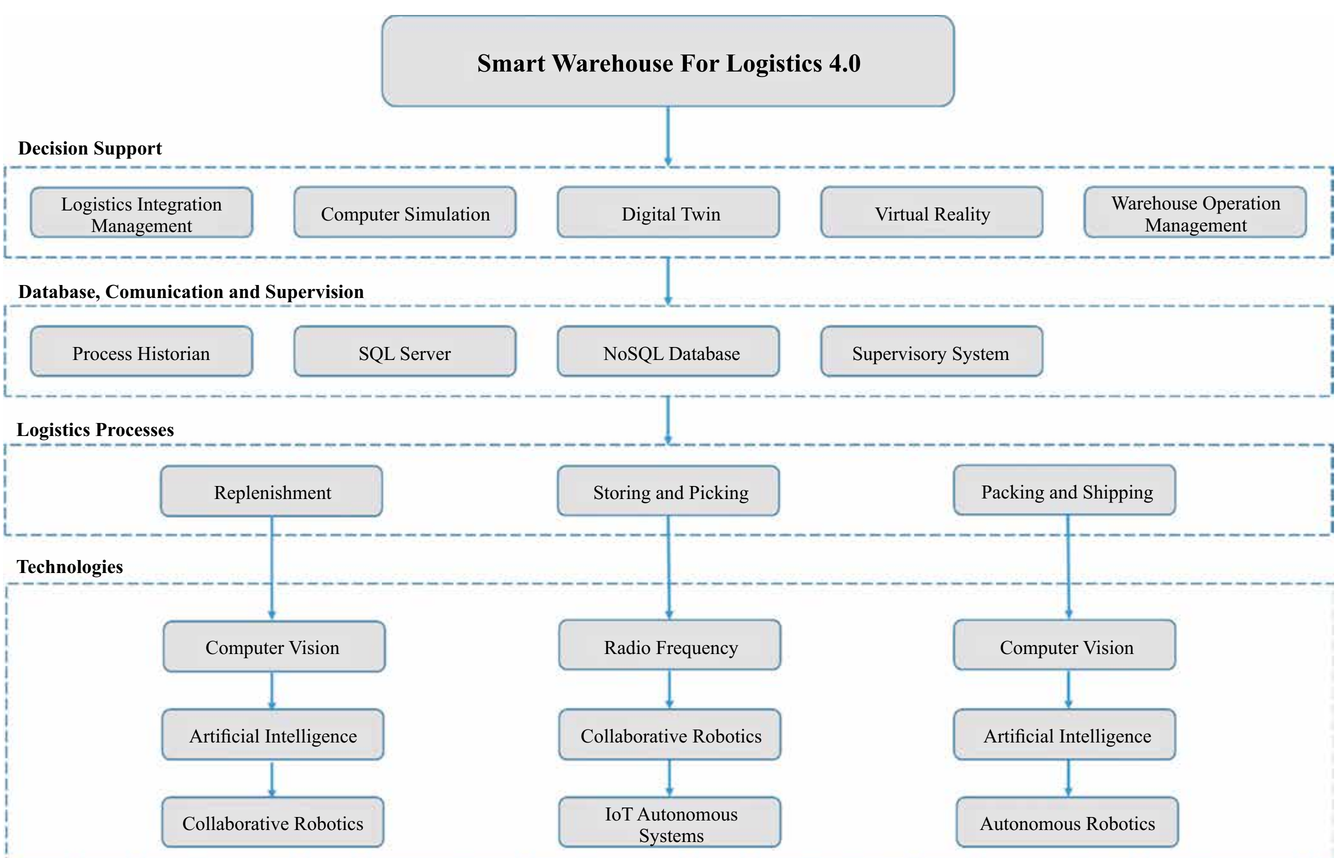
Materials and Methods

We did a state of the art research to understand the relevant concepts about intelligent warehouses, followed by an evaluation of the needs involved in logistics operations and to define the functions that obtain a modular architecture. We followed four steps [13]: we defined the system functions, determined the connections between them, built a matrix to analyze these connections, and finally defined the modules. The modules are sets of functions with the same characteristics to meet a specific need of the system.

Figure 1 presents the proposed architecture, with an overview of the system according to its modules and the respective enabling technologies contained therein. For the development of the architecture, we examined a series of requirements to identify the technologies that most impact the intralogistics operation times related to warehouses, such as communication structure, automation of operations, integration of technologies, monitoring and tracking of products, human intervention and modularity. Each technology selected to compose the architecture was derived from an in-depth analysis of technological solutions applied in logistics operations already available in the market and to transform a traditional logistics operation into a logistics 4.0, identifying the most repetitive activities, rework, inflexibility, as well as those that required greater agility and security.

The first module (Decision Support) uses Computational Simulation with the aid of

Figure 1. The logical architecture proposed for intelligent warehouses.



Virtual Reality as decision support tools to predict scenarios and find the best solution in an environment with minimal risks and without interrupting the real operation but feeding it back in real-time according to the digital twin paradigms. This approach allows stakeholders to interact with the virtualization of the operation in real-time and thus enable improvements in planning activities and mitigate possible errors in the operation.

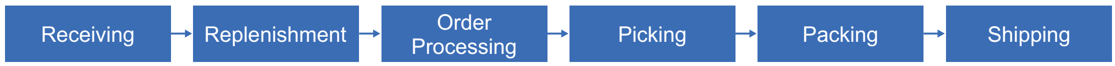
The second module (Database, Communication, and Supervision) represents the communication infrastructure of the concept and the interface to the operators. The supervisory system manages a database of the system and transacts information with the controllers of the PSCs that operate the system for integrated operation. Communication between PSCs can occur via wireless or wired fieldbus networks (we adopted Modbus TCP/IP protocol for simplification). The database will store information about the items and orders to record the logistic process status. An SQL Server database is the basis of the internal system, but NoSQL databases for the supplier, customer, and market data and process historians can be added for predictive analyses. The controllers of the various equipment and processes execute the routines determined by the supervisory system or the logic established between CPSs, including the movement of collaborative and autonomous robots, as the logistics application determines.

The third module (Logistic Processes) presents the stages of the logistic process served by the system (outbound processes), which are focused on customer service, supported by the "seven rights (7Rs)" strategy, that is, to deliver the "right product", in the "right quantity", in the "right quality", in the "right place", at the "right time" for the "right customer" and the "right cost" [14, 15]. The fourth module (Technologies) presents the selected technologies of the system for its operation at the physical level. They represent the technological concepts existing in the hardware that uses these concepts to perform their functionalities in the system. The technologies are organized in the three stages of the logistic process so that it is possible to visualize at which stage each technology was implemented.

The integration of technologies and interactions between humans and machines to promote the better performance of the system, reduction of logistic waste, and time-saving encompass the construction of the system. The goal of automation and intelligence in warehouse operations is that processes become less dependent and respond adequately to the variability inherent in human work. Thus, obstacles such as lack of system integration, poor use of space, counterflows in the movement of materials, operational errors from human intervention, fatigue, excessive bureaucracy, communication failures, long delivery times, deficiencies in the traceability of processes, and products are overcome. The proposed smart warehouse approach enables, by the continuous learning that is inherent to it, to gradually eradicate these obstacles and to evolve synchronized with the best-emerging technologies for smart warehouses. To prove the method, demonstrate the potential gains, and the technical viability of the presented logical architecture, a testbed was developed using modeling software and computational simulation, based on the case of a partner company, located in Joinville-SC, Brazil. The company operates in the logistics segment, supplying the needs of its customers with solutions for moving, storing, and transporting products, the focus of the study in question. The warehouse has 740m² and 10% of this area was for the testbed (72m²) (Figure 2).

The traditional logistics operation was virtualized as a strategy to test technologies used to meet the necessity of the operation. The development of the computational model was based on some assumptions: nature of the product handled, investment restrictions, orchestration of resources, available space, mandatory process flow, flexibility, and the minimum frequency of receipt and dispatch of materials handling, and storage operation. The logic for the computational model was developed in FlexSim® software using the ProcessFlow module. ProcessFlow has a variety

Figure 2. Flowchart of the warehouse operation.



of activity blocks, and as the process flow diagram is built in the software, logic can be developed within each block and related to the 3D model. SketchUP® was used to develop the 3D components most similar to the physical components of the warehouse. Then the FlexSim® 3D model imported them. Figure 3 shows the main parameters inserted in the logic configuration.

The time parameters were calculated by observing the activities of the traditional warehouse operation and recording the time of each activity using a stopwatch, obtaining the averages and standard deviations. These values were computed into the model as a normal statistical distribution. The datasheets of the selected equipment acquired information on the operation speed of each piece of equipment.

The logic of the warehouse operation was organized into processes to facilitate the follow-up of activities during the execution of the 3D model. Figure 4 demonstrates the approximate idea of the logic construction.

This operation tends to become an intelligent operation, which occurs when solutions are pointed out, autonomously or automatically, that assist the system users in the decision-making processes, analyze the history, and allow the connection of new technologies to the existing system.

Figure 3. The main parameters collect for the simulation logic.

1	Operator loading time
2	Operator unloading time
3	Forklift loading time
4	Forklift unloading time
5	Item dimensions
6	Equipment speed

Results and Discussion

The results presented with the computational simulation allowed for more realistic analyses regarding potential gains, such as the structuring and systematization of operations, increased efficiency, accuracy, error reduction, optimization of warehouse space utilization, increased safety in operations, facilitation in the identification of bottlenecks in the logistics process, improvement in the visualization and general perception of each stage of the operation, improvement of the operator's working conditions, and reduction in the time it takes to dispatch orders.

We compared the time of the current processes with the data generated by the computational modeling, which predicts data from the testbed operation. Thus, we identified a projection of increased productivity between the traditional process and logistics 4.0 with the application of the enabling technologies mentioned (Figure 5).

Conclusion

The presented structure is a low investment option because the technology involved can be found in equipment and systems already available in the market, and its integration is done using hardware and software modules with content-oriented approaches, able to operate in heterogeneous scenarios, involving devices from different suppliers with minimal adaptation and short implementation time. It also allows automation in stages for minimal interruption of current operations and a lower volume of financial investment. A step forward for the concept

Figure 4. Example of the FlexSim® process flow and its connections.

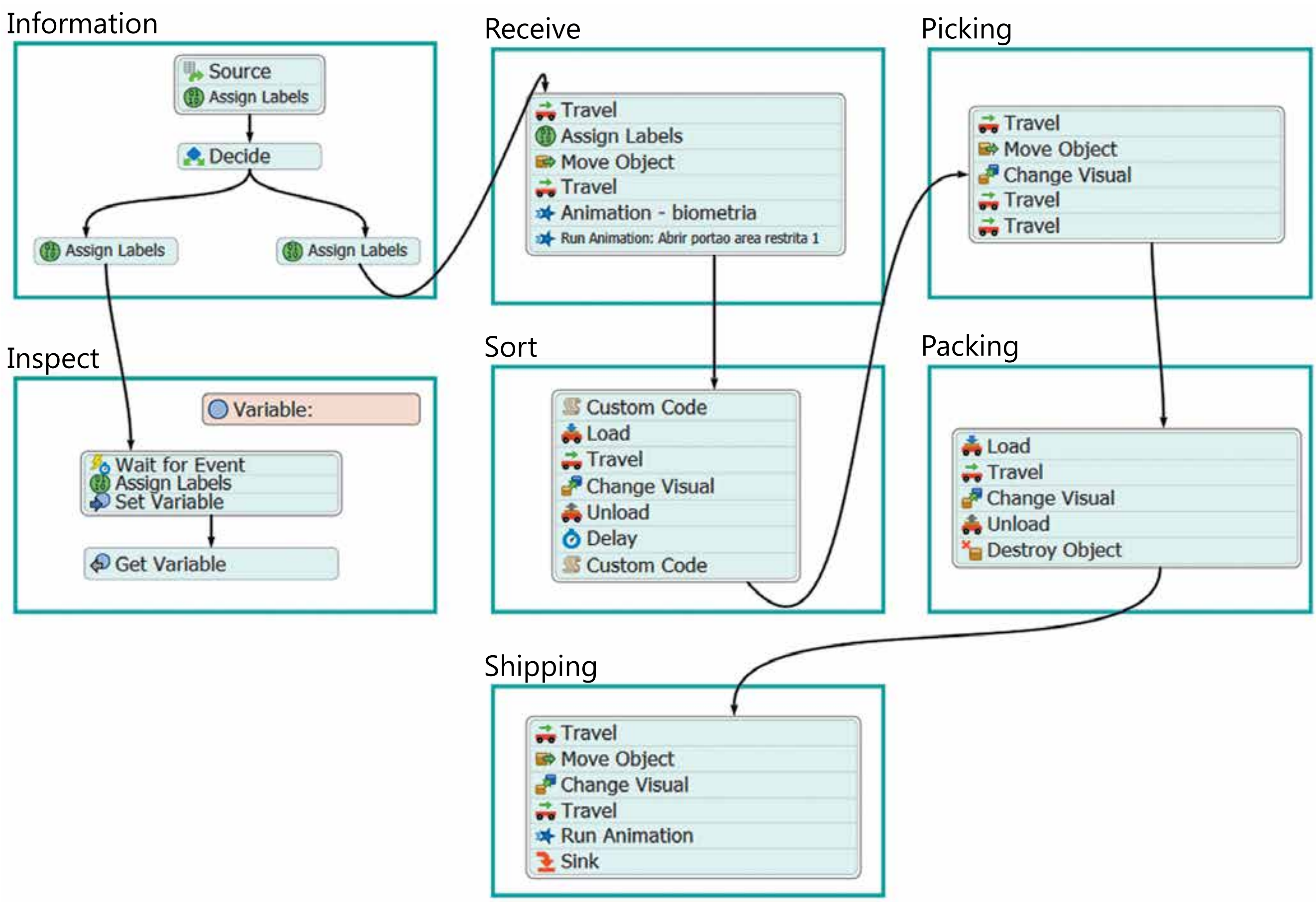
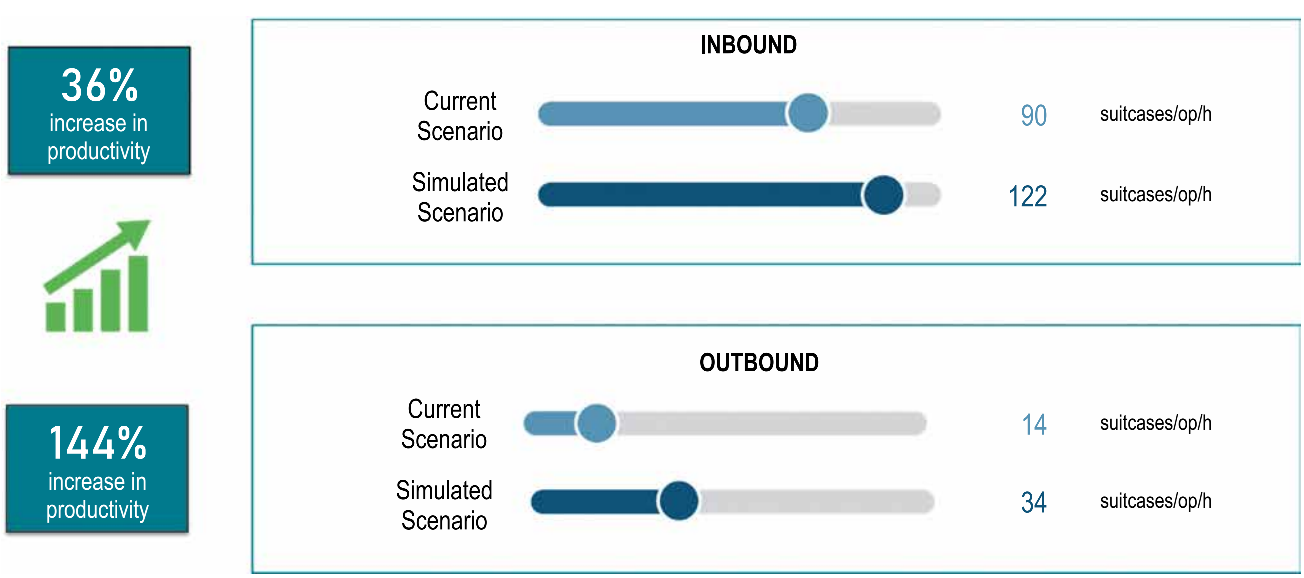


Figure 5. Comparison between traditional inbound and outbound operations with the testbed (simulated scenario).



proposed here will be to seek platform-agnostic solutions independent of proprietary solutions for scalability and technological updating of the system.

The proposed architecture can be used as a strategy for other logistics operators who wish to automate their processes to make them intelligent. In the long run, successive small modernizations at shorter intervals make a more effective contribution than major upgrades at longer intervals.

Principles should be followed to build a modular architecture such as the analysis of the impact of enabling technologies on the operation through computer simulations and digital twin resources, to mitigate integration risks in advance, identify the processing capacity and the best structure for the flow of materials and information, as well as the trends and costs involved to generate the functions to be performed by the system. A relevant aspect was the determination of the database, communication network, and supervisory system to establish connectivity between the technological resources. Once well defined, they can provide the intended generalizable characteristic for customizations and implementations of technologies in intralogistics processes. Finally, promoting the integration of the set of Industry 4.0 enables technologies to promote an improvement in warehouse performance, with the reduction of logistics waste and time savings.

Therefore, companies aiming to modernize their intralogistics operations to increase their efficiency, flexibility, and connectivity, can take into consideration the suggested logical architecture with the combination of features aimed at intelligent warehouse systems, in a way that allows a planned configuration, able to interconnect through modern and secure communication networks, and a digital architecture designed to allow systems to behave in an integrated and coherent way.

A step forward in the concept proposed here will be to seek agnostic platforms, which are independent of proprietary solutions for the sake of scalability and technological updating of the system.

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