logistics

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Smart Warehousing as a Wave of the Future

Hokey Min

Maurer Center 312, Department of Management, Schmidthorst College of Business, Bowling Green State University, Bowling Green, OH 43403, USA; hmin@bgsu.edu

Abstract: *Background*: The unprecedented supply chain disruptions caused by the prolonged COVID-19 pandemic forced many firms to change their way of doing business dramatically. These changes include quickly responding to the growing demand for online orders and the corresponding direct shipments to customer locations. These changes have been further accelerated by rapid technological innovations resulting from the fourth industrial revolution (Industry 4.0). One of the most notable technological transformations that we have witnessed is the growing popularity of smart warehousing concepts. Although smart warehousing may represent a wave of the warehousing future, the published literature rarely documents its underlying principles, specific application targets, and potential impacts on supply chain performance. This research aims to identify key drivers of the digital warehousing revolution and describe important value propositions for warehousing automation. *Methods*: To help companies develop smart warehouses successfully as an integral part of a supply chain link, I conceptualize an ideal smart warehousing system, design its basic architecture, propose specific milestones for monitoring the progress of smart warehouse development, and then, identify critical success factors for its full utilization in today's volatile warehousing environment. This paper employed qualitative content analysis to conceptualize smart warehousing development and establish a smart warehousing framework. *Results*: A smart warehouse will bring many managerial benefits, including warehousing cost efficiency, labor productivity, and agility in the era of the knowledge economy. *Conclusions*: This paper will enable companies to accelerate digital transformation and improve their competitiveness amid the post-pandemic industrial revolution.

Keywords: smart warehousing; warehousing technology; innovation; the fourth industrial revolution; change management

Citation: Min, H. Smart Warehousing as a Wave of the Future. *Logistics* **2023**, *7*, 30. https://doi.org/10.3390/logistics7020030

Academic Editor: Robert Handfield

Received: 7 April 2023
Revised: 4 May 2023
Accepted: 11 May 2023
Published: 17 May 2023

1. Introduction

Extended lockdown, sheltering-in-place, transportation restrictions, and absenteeism resulting from the COVID-19 pandemic exposed various weaknesses in the global supply chain and disrupted supply chain activities. Accenture [1] reported that an overwhelming majority (94%) of Fortune 1000 companies experienced supply chain disruptions due to COVID-19 and suffered negative business impacts. Many firms were pressured to change their conventional supply chain practices to mitigate the adverse ripple effect of these disruptions. According to a survey of senior executives across industries conducted by McKinsey [2], a vast majority (93%) of them indicated that they intended to make their supply chains more flexible, resilient, and agile. As an effective way to achieve such a supply chain goal, many companies have begun to embrace innovation that adds value to their supply chain partners and customers through digitizing processes and communication [3]. The heart of this innovation centers around the "intellitization" (knowledge creation), integration, automation, and virtualization of supply chain activities. Intellitization, facilitated by the fourth industrial revolution (Industry 4.0), aims to drive massive productivity gains through greater access to the wealth of real-time information and digital transformation.

Digital transformation dictates how a company creates and delivers value to its customers by rapidly adopting computerized technology. This transformation entails the digitization (computerization) of physical resources and their integration with the global internet network built upon the Internet of Things (IoT). IoT connects physical objects to different computing devices to "talk" to (communicate with) each other and exchange data over the internet. IoT equipped with real-time human–machine user interfaces, advanced networking, and security platforms, has become crucial for developing artificial intelligence (AI) [4,5]. This developed AI could be a brain for a smart warehouse system. In particular, man–machine interfaces that can convert human-intelligible commands into machine-readable commands, and the reverse conversion of machine feedback into human-understandable information, would be essential for debugging warehousing deficiencies, detecting pre-maintenance needs before actual warehousing equipment failures, and the subsequent reduction in warehousing equipment failure frequencies [5–7].

At the core of the smart warehouse system is a cyber–physical system (CPS) that allows for autonomous decision-making capability based on the seamless integration of cyber (computation) and physical components (e.g., machines) and the real-time information gathered from the IoT. As shown in Figure 1, CPS is designed to integrate sensor technology, data computation, and information networking into "smart" physical objects and infrastructure by connecting them to IoT [5,7,8]. The emergence of the CPS supported by sensor technology, which mimics human sensing capabilities (e.g., musical–rhythmic, visual–spatial, verbal–linguistic, logical–mathematical, and bodily–kinesthetic sensing), has blurred the boundary between man and machine and has begun to replace humans' roles in managing business activities [5,7]. That is to say, the machine provides humans with more free time and leeway, reduces human error, and improves adaptability to today's dynamically changing business environments. In addition, CPS fueled by IoT can enhance machine-to-machine (M2M) connectivity, which, in turn, increases the opportunity for faster and more accurate communication between supply chain partners [5]. Since the improved connectivity among multiple warehouses and supply chain partners enables them to collaborate and interact with each other more frequently, the CPS can create synergies among supply chain partners via digitally linked information/communication networks. In a nutshell, CPS can transform the way humans interact with physical systems (e.g., machines) and drive endless innovation. Therefore, it is worth assessing the true value of CPS and exploring the possibility of leveraging CPS for automated warehousing operations. Up to this point, CPS has been successfully utilized in the agriculture, aeronautics, education, energy, healthcare, manufacturing, and transportation sectors [5,9,10].

One of the fruitful applications of CPS may include the development of a smart warehouse where people work together with collaborative robots through human–machine interactions. In a smart warehouse, warehousing operations are digitally integrated and monitored based on the real-time information available on various computing devices, including laptops, smartphones, and tablets. Generally, a smart warehouse is an intelligent warehouse of the future that can create flexible, reconfigurable, and agile warehousing environments by automating warehousing activities and running diagnostics for any need, in order to enable the repair and improvement of warehousing equipment and information technology via harmonious communication among all the computer systems, mobile devices, machinery, automated guided vehicles (AGVs), and equipment on the warehouse floor. As shown in Figure 2, critical components of the smart warehouse include (1) CPS; (2) cloud computing services; (3) Internet of Things (IoT); (4) automated control platforms; (5) warehouse management systems (WMS); and (6) collaborative robots (so-called "cobots").

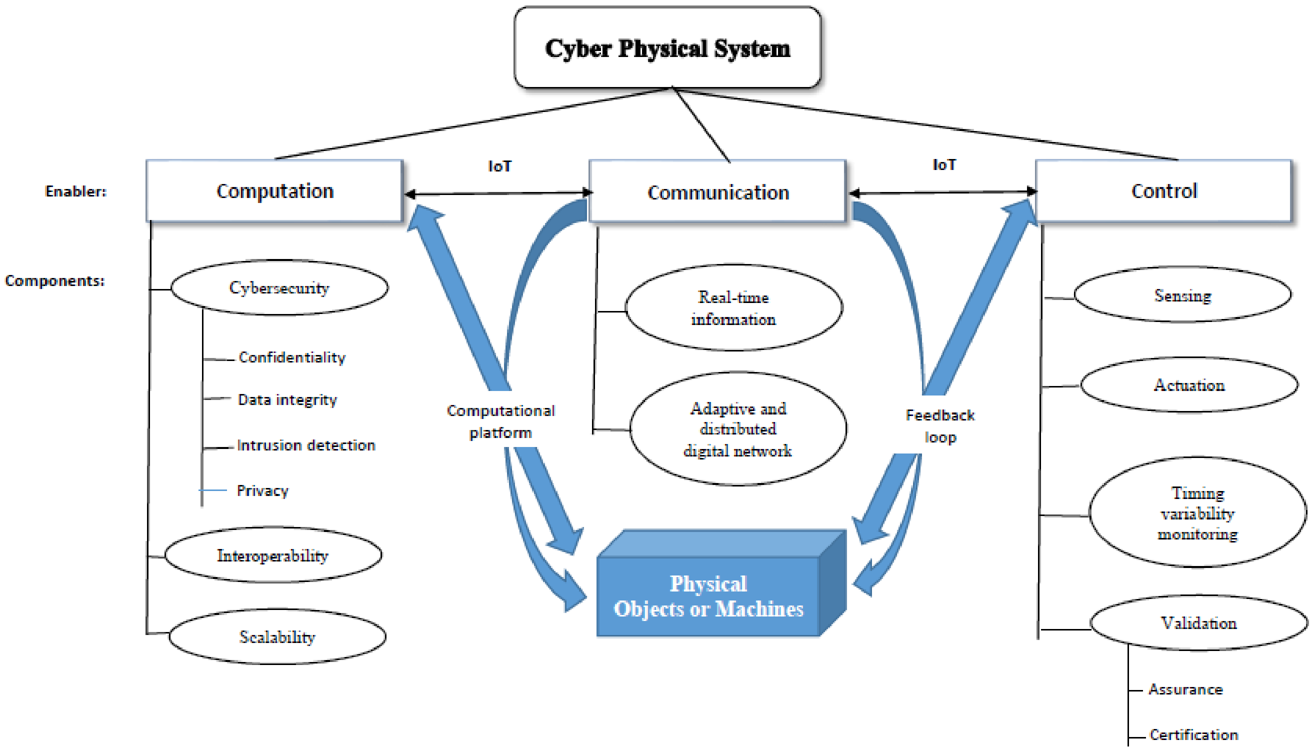

Figure 1. Key Elements of a Cyber–Physical System.

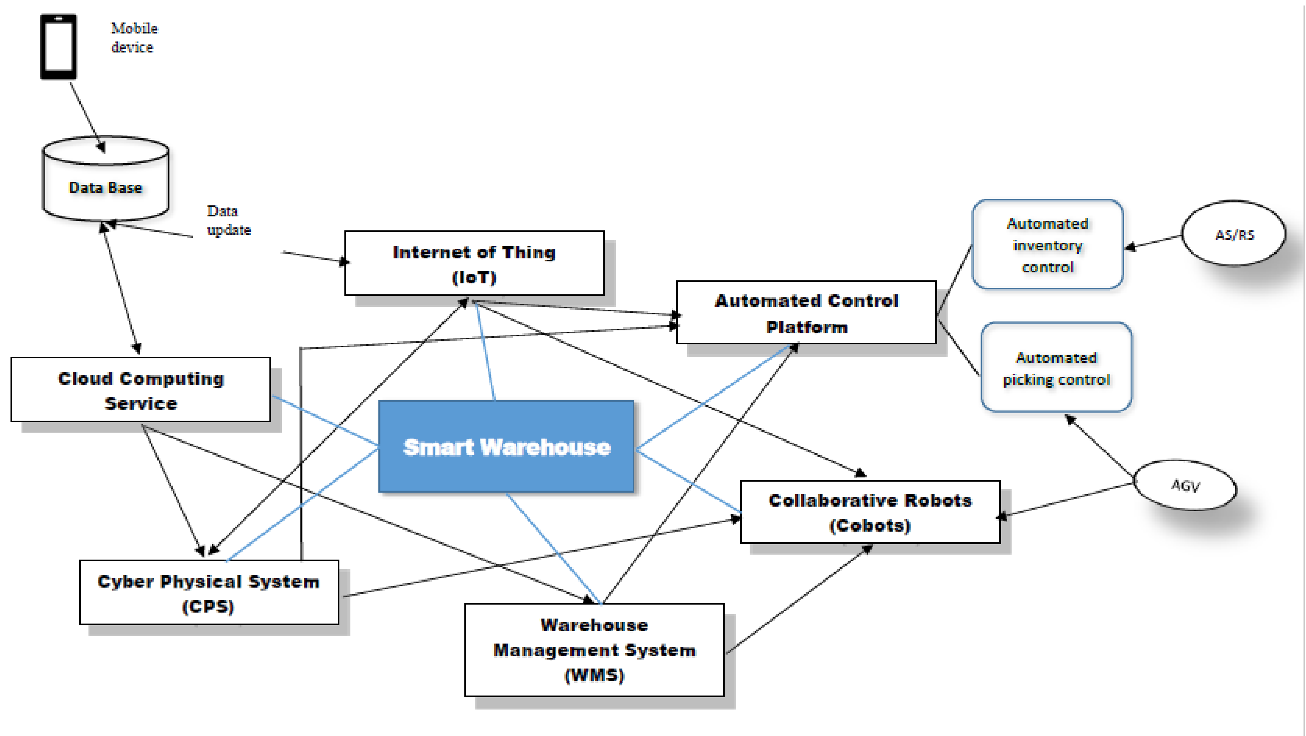

Figure 2. Critical Components of a Smart Warehouse.

Since the heart and soul of a CPS's control mechanism are sensors and actuators, they play a crucial role in successfully applying smart warehousing technologies. In a broad sense, sensors can measure pressure, temperature, moisture, gas flows, magnetic fields, radiation, and ultrasound, while allowing computation of the mean, standard deviation, and variance for a set of measurements [5,7,11,12]. As such, they can help detect any abnormality and damage to the warehousing infrastructure and process. Data obtained from sensors allow for faster reaction to any problems and help eliminate potential issues, such as employee mistakes, idling workers, accidental risk, theft, pilferage, spoilage, diversion, and equipment breakdown, before completing the warehousing process. Cloud computing services provide on-demand computing resources, such as data, software, platform, and infrastructure, via hosted internet services, thus enhancing computing power while saving costs and making smart warehousing technologies more accessible and scalable [5,7].

IoT is an overarching concept designed to link a network of computers, humans, and physical objects to the ubiquitous internet [5,7,13–15]. Through enhanced traceability and ubiquitous connectivity, IoT facilitates data gathering/sharing/synchronization, machine-to-machine communication, interaction, and channel integration across the supply chain [5,7,13,16]. Thus, IoT can ramp up the flow of real-time streaming data in an automated warehouse, and subsequently help constantly monitor and control all the moving parts of the warehouse through real-time information exchange and sharing. In other words, IoT improves the opportunity to promptly respond to changing warehousing conditions and take quick corrective action, if necessary. IoT also helps plan, provide, and execute mobility solutions based on the information created by IoT while helping to connect and automate warehousing equipment and tools. The primary role of IoT is to help managers derive business insights or intelligence from the collected, filtered data through data visualization or tracking, and subsequently facilitate managers' responses to external and internal business activities [5,7,13,14,17,18].

An automated control platform primarily consists of two components: (1) automated inventory control and (2) automated picking control. In a typical warehouse setting, inventory logging, cycle counting, inventory replenishment, and slotting are routine tasks. However, the manual handling of these tasks will be prone to errors in data, transcription, and execution, and subsequently, can cause unwanted disruption in warehousing operations. An automated inventory control platform is an essential prerequisite to smart warehousing. An automated inventory control platform automates cycle counting, inventory tracking, inventory item tagging, inventory deployment/location planning, space planning for inventory stocking, etc., while reporting, synthesizing, and updating inventory-related data in real time. This platform can be aided by an automated storage and retrieval system (AS/RS) that aims to create synergies between many different types of technologies, software, hardware, vehicles, and robotics to streamline and automate the handling, storage, deposition, and retrieval of inventory items in a warehouse [19]. Order picking has long been recognized as the most expensive warehousing activity, and thus, has become the main target of cost-saving automation efforts [20]. The inclusion of automated picking platforms can increase picking efficiency and accuracy by using various innovative picking tools, such as voice-activated and pick-to-light picking tools designed to reduce picking time and human error.

A warehouse management system (WMS) is intended to comprehensively consolidate all warehousing data into one easily accessible platform to provide a complete view of warehouse work and material flows, and thus, enhance visibility throughout warehousing activities. It is also designed to speed up order processing time, provide instant order status information, and increase warehouse space utilization and labor productivity [21]. A collaborative robot ("cobot") is an industrial robotic technology built and programmed to work safely alongside workers. It allows machines and humans to work side by side on the same task simultaneously, and in the same area. Material handling is an application area where cobots can especially come into play since they can automate the tasks of palletizing, moving heavy materials from the receiving dock to the storage location, and verifying incoming material quality [22,23]. Cobots can be aided by automated guided vehicles (AGVs) that can ramp up AS/RS, putaway, loading, and unloading activities by following digital paths through the warehouse. Eventually, AGVs can reduce material damage risk during material movements, increase inventory accuracy, and boost material handling efficiency.

In the following sections, this paper will be organized in the following order: the research methodology; a description of the key research agenda, architecture, implementation plans, and managerial implications of smart warehousing; and future research directions.

2. Research Methodology

Smart warehousing incorporates multiple automated and interconnected technologies to improve warehousing agility, scalability, and visibility. Due to the inherent difficulties of integrating and harmonizing various technologies simultaneously, its practical implementation is scarce. Only a few companies are constructing and operating smart warehouses at this moment. Since it is difficult to document the challenges and opportunities of smart warehousing in practice, research on smart warehousing is still nascent, as noted by van Geest et al. [24]. The limited smart warehousing practice constrains the potential sampling of smart warehousing data. Therefore, conventional empirical research based on questionnaire surveys or analytical studies predicated on mathematical/simulation models is not feasible for smart warehousing research. We employed a qualitative research method primarily based on content analysis as an alternative research tool that is non-conventional but easier to comprehend and implement. This qualitative research methodology is inductive rather than deductive, and will help provide in-depth information about the emerging smart warehousing trend and its managerial ramifications [5,25–27]. Another rationale for the proposed qualitative content analysis is its scalability, which allows us to handle a large amount of textual material available from many public domains, such as published articles, books, internet sources, and field studies. This scalability helps generalize study observations and eases the concern about the subjective interpretation of textual material. The main objective of this qualitative content analysis is the systematic (iterative), concept-driven examination of recorded documents, including published texts, archives, and social media materials [5,27,28]. This paper addresses the following research questions to achieve this objective.

1. What elements (components) are essential for a smart warehouse system?
2. How are those elements interconnected with each other, and how can they be synchronized and integrated to make warehousing operations more intelligent and successful?
3. What are the key drivers for a smart warehouse system, and how do they affect the smart warehouse architecture?
4. What are a smart warehouse system's key value propositions or managerial benefits?
5. How do we keep a smart warehouse project on track? What meaningful performance metrics can monitor a smart warehousing project and assess smart warehousing outcomes?

3. Architecture of the Smart Warehouse System

The success of smart warehousing lies in its adopter's ability to identify and leverage value drivers while tailoring smart warehousing to the adopter's specific needs. Figure 3 lists key value drivers for smart warehousing. These include: (1) IoT with internal sensors that help gather real-time data within the warehouse network and subsequently support the live control and monitoring of routine warehousing activities, including quality inspection, slotting, cross-docking, cycle counting, and space planning. (2) The CPS-driven integration of IoT with physical objects that enhance M2M connectivity, and thus, speed up responses to fulfillment errors, inventory classification and restocking needs, and safety alerts [5]. (3) Edge computing that brings data processing power to the edge of the warehouse computer network, and thus, data storage and computation can be performed locally even in a remote location. Edge computing will prevent data loss in the event of limited internet connectivity in a remote location, and can reduce customer response time without severe interruption or delay [5,29]. (4) Mass "servitization" (e.g., value-added services (VAS)) offerings that help develop customized self-warehousing and order processing built upon business intelligence tools such as AI. (5) Intelligent automation that can copy or imitate human actions for coordinating material flows within the warehouse, and can diagnose warehousing process anomalies/errors and detect warehousing inefficiencies on a real-time basis. Such capability prompts immediate corrective action with the suggested right procedures or tools to help fix problems instantly.

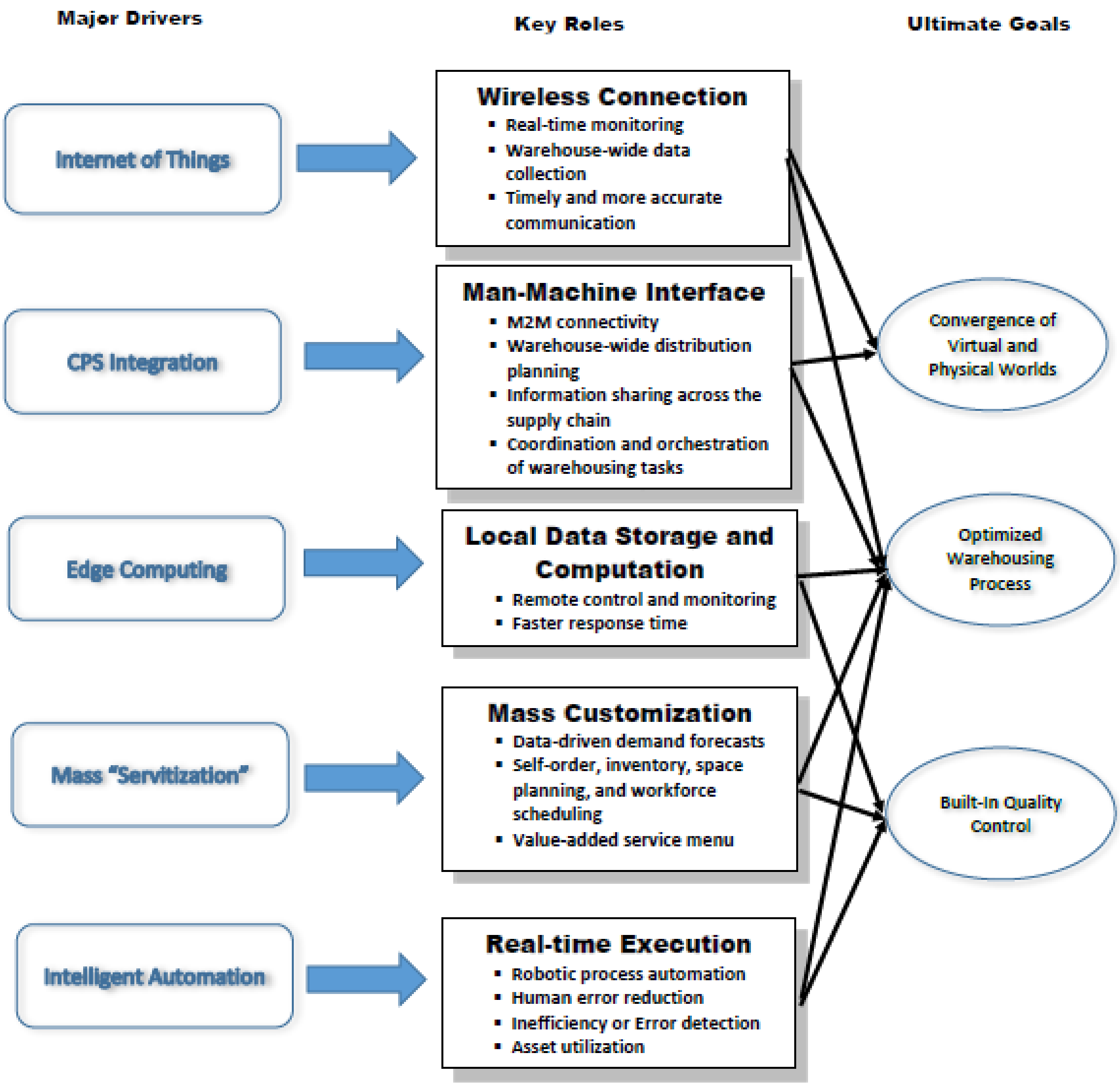

Figure 3. Key Drivers of Smart Warehousing.

Among the above drivers, CPS is critical in integrating various warehousing technologies that are essential for automating warehousing activities. To elaborate, CPS helps monitor the interfaces among physical entities and computing devices within the multi-dimensional architecture by extracting, processing, storing, analyzing, and transferring data in real time [5,20,30]. As shown in Figure 4, CPS can be divided into three automation modules: (1) end-point access, (2) network service, and (3) the security automation module. Multiple interconnected technologies with the highest data security standards support these modules. These technologies encompass networked robotics, miniaturized sensors and actuators, a programmable logic controller (PLC), supervisory control and data acquisition (SCADA), warehouse management systems (WMS), and distribution resource planning (DRP). CPS eventually paves the way for smart warehousing by interconnecting everything online and controlling warehousing operations without direct human involvement.

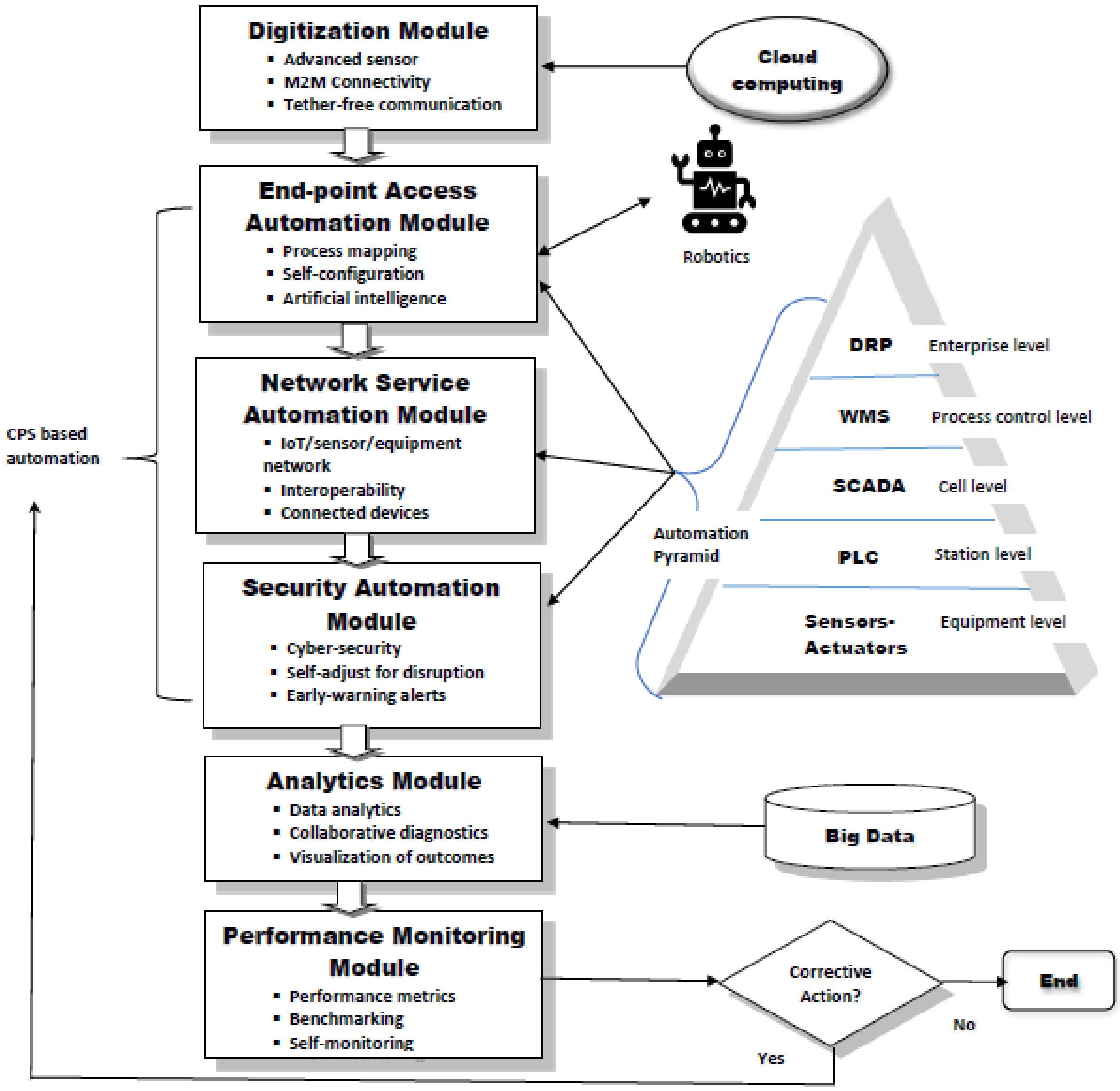

Figure 4. Architecture of the Prototype Smart Warehouse (partially adapted and modified from [5,7]).

Regarding details of technologies that comprise the automation pyramid, DRP integrates and synchronizes all facets of distribution planning. DRP is a management process that uses time-phased logic to manage distribution inventories, transportation, and material flows across the distribution pipelines while determining the needs of inventory stocking locations and ensuring a match between supply sources and demand [19,31]. DRP helps develop distribution planning that results in warehouse-wide optimization at the enterprise (or macro) level. In a smart warehouse system, WMS should supplement DRP to create synergies between DRP and WMS, as shown in Figure 5. DRP should also be connected to other technologies at the micro levels. These technologies include SCADA and PLC.

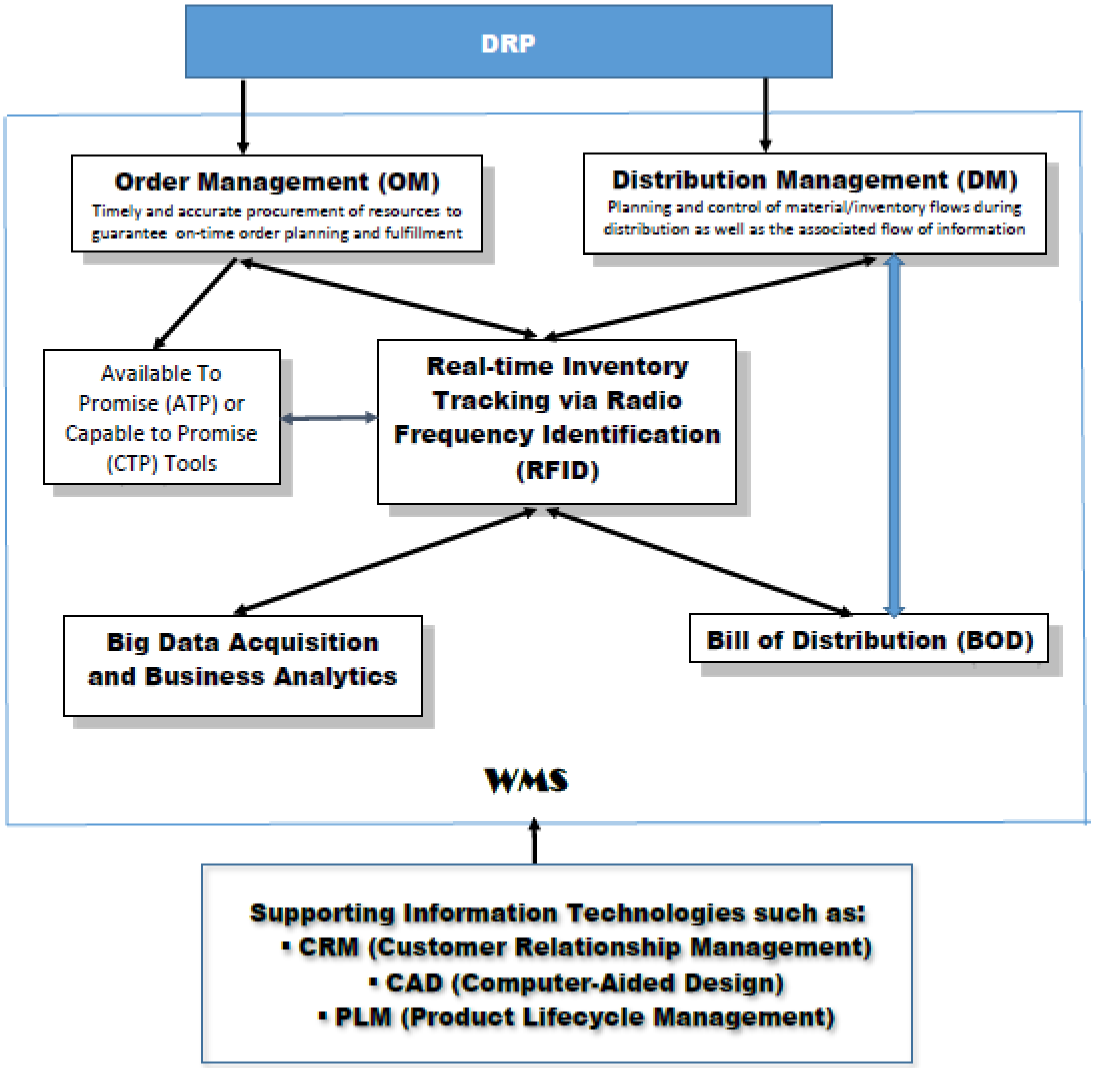

Figure 5. DRP and WMS Integration.

SCADA is a system of software and hardware elements that is generally used to control dispersed assets and industrial processes locally or in remote locations using centralized data acquisition and supervisory control [5,7,32–34]. It intends to monitor, collect, and process real-time data remotely while directly connecting and interacting with devices such as sensors through human–machine interface software [5,7,32,33]. As such, SCADA can be used for multiple warehouses scattered over wider geographic locations. In SCADA, a programming logic controller (PLC) is often used as a field device that plays the role of a remote terminal unit (RTU) and can control a specific process, equipment function, or entire warehousing activities when wire-based communications are unavailable. PLC can aid SCADA in controlling local operations, such as collecting sensor data and monitoring the local environment for early warning systems [5,7,32]. SCADA and PLC can communicate with each other via shared memory. Through such communication, PLC can feed big data to SCADA [5,7,32,33].

PLC is a microprocessor-based, solid-state industrial computer control system that performs discrete or sequential logic to create a computer network in remotely located facilities [5,35]. PLC generally functions by receiving information from sensors or input devices, processing the collected data, and generating outputs based on guidelines pre-programmed into the device. These sensors can monitor critical equipment operating parameters such as temperature, force, pressure, vacuum, flow, inclination, acceleration, and vibration [5,7,36]. Simply put, PLC can sense when warehousing equipment, such as conveyors and folk-lift trucks, is not operating at the desired or optimum levels, and can automatically adjust the equipment's operating parameters so that the desired performance can be maintained, even when the surrounding working environments and conditions are less than ideal [5,7,36].

4. Managerial Benefits of the Smart Warehouse

A smart warehouse that exploits intelligent equipment with machine-learning capabilities can bring numerous benefits to warehousing operations. Some of those benefits include:

- *Reduced inventory levels via improved supply chain visibility*. The rationale is that enhanced visibility of warehousing operations through the embedment of DRP within WMS increases real-time information availability. Such visibility allows warehousing workers to see all the potential bottlenecks and problematic areas well in advance and take corrective action. In addition, the enhanced warehousing visibility gives warehousing workers a bird's eye view of the entire warehouse and how its various pieces function. For example, suppose inventory errors or delayed order picks are detected. In that case, warehousing workers can immediately figure out where they originated, and thus, can act before the problems become worse.
- *Improved warehousing agility* and faster customer response time are created due to the embedded sensor technology as it quickly recognizes fulfillment errors through automation. In addition, a smart warehouse system equipped with software as a service (Saas) can save time by nullifying the need for time-consuming on-premises warehousing software updates by completing these necessary updates on the fly.
- *Enhanced labor productivity* through increased automation and human–robotics cooperation, without minimal human involvement, in the entire warehousing process. Warehousing automation limits the need for on-site human staff and helps companies better prepare for the busiest times of the year, such as the Thanksgiving and Christmas holidays. It also reduces the time needed for warehousing workers to complete tasks such as order picking, packing, and shipping.
- *Higher return on assets (ROA)* through fully utilizing warehousing equipment.
- *Better service quality control* through earlier detection of anomalies and performance monitoring with embedded sensors. For example, vibration sensing can give the warehouse manager an early warning alert when warehousing equipment, the AS/RS, and AGVs need immediate maintenance or repair.

Despite the enormous benefits of the smart warehouse system specified above, a smart warehouse can pose many challenges. These challenges include downgraded or menial warehousing work for human workers because automation tends to transfer the skill required to perform work from human workers to machines; thus, it reduces the need for skilled labor and subjugates human workers to machines or robots [5,7,37]. Another concern with smart warehouses is the affordability of smart warehousing, which requires a considerable start-up investment for automation, sensor technology, technology infrastructure, system user training, and business intelligence development. 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. Furthermore, a smart warehouse can pose stiff challenges in integrating multiple technologies for building, transmitting, storing, retrieving, and securing data.

5. Smart Warehouse Implementation Plan

Though a smart warehouse can bring many significant benefits, its full range of benefits cannot be realized soon after its implementation. Therefore, a smart warehouse project should be monitored closely based on step-by-step performance milestones. In other words, a performance measurement system (PMS) for the smart warehouse is needed. The PMS begins with the development of measurement attributes (e.g., performance metrics and key performance indicators). Table 1 proposes that these measurement attributes gauge a smart warehouse implementation project's maturity and progress levels. According to the maturity stage of the smart warehouse project, we classified the smart warehouse implementation progress into five categories: (1) groundbreaking; (2) automation; (3) digitization; (4) connectivity expansion and orchestration; and (5) knowledge creation, as recapitulated in Table 1.

Table 1. Maturity Stages and Measurement Attributes of Smart Warehousing.

Maturity Stage	1	2	3	4	5
Capability Level	**Groundbreaking**	**Automation**	**Digitization**	**Connectivity Expansion and Orchestration**	**Knowledge Creation**
Key action plans	■ Waste elimination ■ Value-added service (VAS) menu development ■ Process simplification ■ Process and equipment standardization ■ 5-S program implementation	■ Order, inventory, and space planning automation ■ Workforce scheduling automation ■ Quality inspection automation ■ Human–robot interaction	■ Data collection from all machines on the shop floor ■ Distribution plan digitization ■ Quality inspection digitization ■ Remote monitoring	■ IT/OT integration ■ Strategic alliance ■ Big data monitoring ■ Data/information sharing ■ Real-time communication	■ Error/malfunction detection ■ Early warning system ■ Rule-based expert system ■ Business intelligence
Measurement attributes (including key performance indicators)—examples	■ Asset utilization rate (e.g., percent equipment utilization, yield rate) ■ Market response time ■ Throughput ■ Cycle time ■ Overall equipment effectiveness (OEE), including equipment idle time ■ Fill rate effectiveness ■ Warehouse agility	■ Robotics usage ■ Automatic guided vehicle (AGV) and automatic guided cart (AGC) usage for material handling ■ Housekeeping benchmarks ■ Workload reduction ■ Labor productivity	■ Noise data reduction level ■ Data accuracy and timeliness level ■ Data cleaning and filtering capacity ■ Data query time ■ Real-time data access and updates ■ Cyber risk assessment ■ Mobility ■ Capital expense saving	■ Supply chain resiliency level ■ Breadth and length of supply chain partnerships ■ Warehouse network level for centralization ■ Network level for security	■ Brain-storming and learning through quality circles ■ Organizational learning through knowledge externalization and transfer ■ Mutual trust level ■ Process innovation

6. Conclusions and Future Outlooks on Smart Warehousing

With the rapid advances in digital technology and the widespread adaptation of Industry 4.0, many warehouses view smart warehousing as a wave of the future. Smart warehousing is intended to compress the time taken to serve customers, utilize assets and labor, and improve warehousing efficiency by enabling free information exchange among warehousing workers and equipment, and between warehouses. Despite its enormous benefits, smart warehousing initiatives pose many complex challenges due to their newness, security, and implementation costs, and the need for a radical transformation of the traditional warehousing paradigm and changes in protocols (such as remote monitoring and the control of warehousing activities, predictive remote maintenance and repairs, warehouse-wide human–robot collaboration, virtually guided self-service, automatic closed-loop feedback mechanisms, and automatic recovery from service failures). This paper proposes a detailed architecture of a smart warehouse to ease such challenges, and offers practical guidance for a smooth transition from conventional legacy systems to the revolutionary smart warehouse system. Then, it explains what companies need to build a successful smart warehouse. This paper also proposes key performance metrics that are valuable for monitoring the progress of a smart warehousing project.

To conclude, the main contributions of this paper are to create new knowledge bases by establishing foundational conceptual frameworks and underlying protocols that enable companies to start their smart warehousing journey with step-by-step guidance. The proposed smart warehousing guidelines will drive other cost-saving or revenue-enhancing opportunities in times of austerity and the unchartered new normal created by the COVID-19 pandemic. Despite the novel research attempts made in this paper, this paper can be a point of departure for other extended studies on smart warehousing. Potential future research agendas may include the examination of key motivators and inhibitors for smart warehouse implementation based on a detailed case or empirical studies, and assessing the impact of warehouse automation on overall warehousing productivity if a large sample is available after the widespread applications of smart warehousing. Another fruitful research agenda, as an extension of this study, includes incorporating blockchain technology into a smart warehousing architecture [38,39].

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Accenture. Supply Chain Disruption: Supply Chain Networks of the Future Must Have Resilience and Sustainability at Their Heart. Unpublished Report. 2021. Available online: https://www.accenture.com/us-en/insights/consulting/supply-chain-disruption (accessed on 1 March 2023).
2. Alicke, K.; Barriball, E.; Trautwein, V. *How COVID-19 Is Reshaping Supply Chains*; Unpublished McKinsey Report; McKinsey & Company: Washington, DC, USA, November 2021.
3. Crittenden, A.B.; Crittenden, V.L.; Crittenden, W.F. The digitalization triumvirate: How incumbents survive. *Bus. Horiz.* **2019**, *62*, 259–266. [CrossRef]
4. ThSisinni, E.; Saifullah, A.; Han, S.; Jennehag, U.; Gidlund, M. Industrial Internet of Things: Challenges, opportunities, and directions. *IEEE Trans. Ind. Inform.* **2018**, *14*, 4724–4734.
5. Min, H. Developing a smart port architecture and essential elements in the ear of Industry 4.0. *Marit. Econ. Logist.* **2022**, *24*, 189–207. [CrossRef]
6. Caggiano, A.; Teti, R. Digital manufacturing cell design for performance increase. *Procedia CIRP* **2012**, *2*, 64–69. [CrossRef]
7. Min, H. Smart factory: A game changer or another fad in the era of the fourth industrial revolution. *Int. J. Technol. Manag.* **2022**, *89*, 26–45. [CrossRef]
8. NSF. Cyber-Physical Systems: Enabling a Smart and Connected World. 2018. Available online: https://www.nsf.gov/news/special_reports/cyber-physical/ (accessed on 11 January 2022).
9. Chen, H. Applications of cyber-physical system: A literature review. *J. Ind. Integr. Manag.* **2017**, *2*, 1750012. [CrossRef]
10. Lee, E.A. The past, present and future of cyber-physical systems: A focus on models. *Sensors* **2015**, *15*, 4837–4869. [CrossRef] [PubMed]
11. Kersey, A.D. A review of recent developments in fiber optic sensor technology. *Opt. Fiber Technol.* **1996**, *2*, 291–317. [CrossRef]
12. Wilson, J.S. *Sensor Technology Handbook*; Elsevier: Amsterdam, The Netherlands, 2004.
13. Xia, F.; Yang, L.T.; Wang, L.; Vinel, A. Internet of things. *Int. J. Commun. Syst.* **2012**, *25*, 1101–1102. [CrossRef]
14. SAS. *A Non-Geek's A-to-Z Guide to the Internet of Things*; Unpublished White Paper; SAS Institute: Cary, NC, USA, 2018.
15. Faulds, D.J.; Raju, P.S. An interview with Chuck Martin on the Internet of Things. *Bus. Horiz.* **2019**, *62*, 27–33. [CrossRef]
16. Caro, F.; Sadr, R. The Internet of Things (IoT) in retail: Bridging supply and demand. *Bus. Horiz.* **2019**, *62*, 47–54. [CrossRef]
17. KaaIoT Technologies. What Is an IoT Platform? 2019. Available online: https://www.kaaproject.org/what-is-iot-platform (accessed on 11 January 2022).
18. Kahn, M. What's an IoT Platform, and What Role Does It Play? 2019. Available online: https://www.business.att.com/learn/research-reports/whats-an-iot-platform-and-what-role-does-it-play.html (accessed on 11 January 2022).
19. Andres, M. Automated Warehouse Systems: What Is ASRS and How Can It Help? 2021. Available online: https://www.tmhnc.com/blog/automated-warehouse-systems-asrs-how-it-can-help (accessed on 12 January 2022).
20. Min, H. *The Essentials of Supply Chain Management: Theory and Applications*; Amazon Direct Publishing: Seattle, WA, USA, 2022.
21. Min, H. The applications of warehouse management systems: An exploratory study. *Int. J. Logist. Res. Appl.* **2006**, *9*, 111–126. [CrossRef]
22. Bloss, R. Collaborative robots are rapidly providing major improvements in productivity, safety, programming ease, portability, and cost while addressing many new applications. *Ind. Robot.* **2016**, *43*, 463–468. [CrossRef]
23. Vicentini, F. Collaborative robotics: A survey. *J. Mech. Des.* **2021**, *143*, 040802. [CrossRef]
24. van Geest, M.; Tekinerdogan, B.; Catal, C. Smart warehouses: Rationale, challenges and solution directions. *Appl. Sci.* **2022**, *12*, 219. [CrossRef]
25. Barnett-Page, E.; Thomas, J. Methods for the synthesis of qualitative research: A critical review. *BMC Med. Res. Methodol.* **2009**, *9*, 59. [CrossRef] [PubMed]
26. Basias, N.; Pollalis, Y. Quantitative and qualitative research in business & technology: Justifying a suitable research methodology. *Rev. Integr. Bus. Econ. Res.* **2018**, *7*, 91–105.
27. Myers, M.D. *Qualitative Research in Business and Management*; Sage Publications Limited: Thousand Oaks, CA, USA, 2019.

28. Flick, U.; von Cardorff, E.; Steinke, I. *A Companion to Qualitative Research*; Sage Publications: Thousand Oaks, CA, USA, 2004.
29. Mehtre, A. Edge Computing—Key Drivers and Benefits for Smart Manufacturing. 2017. Available online: https://iiot-world.com/smart-manufacturing/edge-computing-key-drivers-and-benefits-for-smart-manufacturing/ (accessed on 12 March 2022).
30. Xu, B.; Zhang, L. Multi-dimensional architecture modeling for cyber-physical systems. In *Advances in Computer Science and Its Applications*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 101–105.
31. Martin, A.J. *Distribution Resource Planning: The Gateway to True Quick Response and Continual Improvement, Revised Edition*; John Wiley & Sons, Inc.: New York, NY, USA, 1995.
32. Stouffer, K.; Falco, J. *Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security*; Special Publication 800-82, National Institute of Standards and Technology; US Department of Commerce: Washington, DC, USA, 2006.
33. Boyer, S.A. *SCADA: Supervisory Control and Data Acquisition*; International Society of Automation: Pittsburgh, PA, USA, 2009.
34. Inductive Automation. What Is SCADA? 2018. Available online: https://inductiveautomation.com/resources/article/what-is-scada (accessed on 13 March 2022).
35. Groover, M.P. *Automation, Production Systems, and Computer-Integrated Manufacturing*, 3rd ed.; Prentice Hall Press: Upper Saddle River, NJ, USA, 2007.
36. Hackworth, J.R.; Hackworth, F.D. *Programmable Logic Controllers: Programming Methods and Applications*; Pearson Education: Saddle River, NJ, USA, 2004.
37. Bright, J.R. *Automation and Management*; Division of Research, Graduate School of Business Administration, Harvard University: Boston, MA, USA, 1958.
38. Zhang, G.; Yang, Y.; Yang, G. Smart supply chain management in Industry 4.0: The review, research agenda and strategies in North America. *Ann. Oper. Res.* **2023**, *322*, 1075–1117. [CrossRef] [PubMed]
39. Kumar, S.; Raut, R.D.; Priyadarshinee, P.; Narkhede, B.E. Exploring warehouse management practices for adoption of IoT-blockchain. *Supply Chain. Forum Int. J.* **2023**, *24*, 43–58. [CrossRef]