

## Dynamic Warehousing: An AI Approach

Sam M. P. Marino <sup>1</sup>

\*Corresponding author

<sup>1</sup> PhD Candidate, James Cook University, Cairns, Australia, Sam.Marino@my.jcu.edu.au

### ABSTRACT

This literature research paper investigates how dynamic warehousing, through artificial intelligence (AI), advances sustainable warehousing. This paper studies AI's role as a significant enabler of dynamic warehousing, concentrating on the research framework, establishing that AI drivers interacting with AI enablers advance AI-driven warehousing. It will also scrutinise AI's role in supply-side inputs and demand-side capabilities in modelling sustainable, cost-effective, smart, dynamic warehousing. With the evolution of warehousing and, in particular, the more extensive scale of facilities within the supply-demand chain, AI systems in real-time facilitate advanced warehouse operations, improving scalability, optimising storage, and enhancing fulfilment processes. This research paper examines the impact of AI on the operational efficiency of dynamic warehousing, encompassing inventory management, order fulfilment, space utilisation, and demand forecasting. The transformation of Australian warehousing to a more dynamic future that drives workflow optimisation will rely on advanced AI systems and intelligent technologies. With the growth of e-commerce and M-commerce, enhanced AI data network systems support further development of faster logistical solutions. The anticipated advantages of dynamic warehousing include agility in meeting market demands, optimised productivity and warehouse sustainability, all highlighting their importance in the future of warehousing. With the advancement of AI and associated technologies, dynamic warehousing will facilitate a shift towards greater operational effectiveness, reduced environmental impact, lowered operational costs and enhanced worker well-being

*Keywords:* Artificial intelligence (AI), digital technologies, warehouse management systems, robotics, machine learning (ML), autonomous warehousing, internet of things (IoT), communications connectivity, software solutions.

### INTRODUCTION

Throughout the years, warehousing has evolved from simple community storerooms to high-tech, multi-million-dollar facilities. Regardless of these enhancements, the purpose of warehousing remains the same. They continue to provide storage centres within the supply-demand chain, guaranteeing integrated end-to-end connectivity between all processes and facilitating an efficient flow of goods (Kumar *et al.*, 2021).

The principle of smart warehousing emerged from Industry 4.0, also known as the "Fourth Industrial Revolution," which was featured as the German government's technology strategy at the Hanover Fair in 2011. (Kunmar *et al.*, 2021). Industry 4.0 represents the merging of system-to-system data integration, automation and advanced computing to enhance industrial processes, transforming everyday lives in society by combining the digital and physical worlds through AI, IoT, and robotics technologies.

Global warehousing operations in 2018 comprised approximately ninety per cent of manual operations, with negligible to minimal automation. Moving forward, businesses are increasingly integrating automation with intelligent technologies to automate warehouse operations. Incorporating advanced technologies enhances resource utilisation, reduces operational costs, improves efficiencies, and enhances organisational IT skills (Pontius, 2018). With the increasing demand for e-commerce and m-commerce, there is a growing need for cost-effective order processing, which drives the need for smart warehousing. By integrating real-time data processing, smart warehousing can process large quantities of ordered items daily with precision proportional to the size of the operations. These operations must continually evolve digital systems to align with production demands and maintain warehouse efficiencies and competitiveness (Immerman *et al.*, 2019). Warehouse automation is rapidly advancing, with the implementation of advanced robotics, automation, and collaborative robotics systems (Mahmut *et al.*, 2022).

The development and implementation of technological advances in smart warehousing operations have improved operational accuracy, reduced labour costs, optimised efficiency and improved a company's return on investment (ROI). With the growth of the global supply chain and the development of advanced automation, information technology (IT) and communication technologies have transformed warehousing (Kumar *et al.*, 2021).

The transformation of warehousing systems from traditional to fully automated digital systems comes with challenges. Due to increased demand, warehousing operations are strained with scalability and fulfilment issues. The industry recognises the need for improved warehouse capabilities, and implementing smart warehousing digital integration provides a valuable way to comply with the changing competitive landscape (Kumar *et al.*, 2021).

Transforming smart warehousing into highly adaptable and efficient dynamic warehousing will increase order fulfilment, reduce costs, improve scalability, enhance productivity, and facilitate real-time implementation of changing demands (Bolu *et al.*, 2021).

Artificial Intelligence (AI), the Internet of Things (IoT), and Machine learning, supported by real-time monitoring and analytics, optimise workflows and resource allocation, facilitating dynamic operations. The optimisation of slotting and layout guarantees practical space usage and adaptation to inventory needs (van Geest *et al.*, 2021). During peak times, AI-driven route optimisation benefits robot and worker productivity (Delalic *et al.*, 2020). Torchio *et al.* (2023) state that implementing AI and IoT facilitates the improved prioritisation of customer orders, guaranteeing faster order fulfilment. They also recognise that due to the complexity of AI systems, there is a need for skilled personnel to maintain these tech systems.

To maintain adaptable and sustainable dynamic warehouse systems, AI, through IoT, manages operational demands, workforce requirements, and energy efficiency (Cannava *et al.*, 2023). Data collection from IoT devices, including sensors, cameras and RFID tags combined with AI and Machine Learning (ML) analysis, optimises predictive maintenance, reduces equipment downtime, and enhances operational reliability (Pech *et al.*, 2021).

Advanced forecasting, automation, and real-time adaptability, enabled by AI-driven systems, transform warehousing into more dynamic systems, optimising efficiency, flexibility, and sustainability (Tang *et al.*, 2022). AI-enabled dynamic warehousing adapts operations to meet market demands, reducing costs and environmental impact (Cannava *et al.*, 2023).

### **Existing State of Play for Warehousing in Australia**

Major Australian logistics and retail players, including Amazon, Woolworths, Coles, and Australia Post, as well as online specialists Kogan and Temple & Webster, are investing millions of dollars in their supply chains and constructing smart, automated warehouses and fulfilment centres (DHL Logistics of Things, Insites, 2023).

Australian demand consumption has continued to grow over 2024 and 2025, in line with population growth. Development-ready land in the capital cities supports increased pre-commitment and speculative leasing activity (Henderson *et al.*, 2023).

Increasing land prices in Australia are driving companies to enhance their existing warehouses by automating existing sites. Refurbishing existing warehouses has refined efficiencies and lowered costs by improving data management systems and scalability. Integrating IoT and AI-driven technologies is essential to maintaining agile, cost-effective, and adaptable operations. The refinement of scalable systems has been instrumental in developing dynamic warehousing (Ulmamei, 2025).

### **The Evolution of Warehousing**

Traditional warehousing involves basic machinery and manual labour to organise inventory and fill orders. The inherent problem with the traditional system is the increased operational inefficiencies, which include increased errors and higher operational costs. The development of advanced automation, comprising autonomous systems, robotics, and artificial intelligence (AI) that interface with warehouse management systems (WMS), provides capabilities for automated sorting and picking, real-time inventory tracking, and data-driven decision-making, facilitating the transition to smart, dynamic warehousing operations.

Using computer management systems reduces errors, the need for repetitive worker activities and manual data analysis (Jenkins, 2020). Zunic *et al.* (2018) argue that warehouse management systems drive efficiencies across warehouse platforms and logistics supply chains. Warehouse management systems optimise warehouse storage, picking, and transfer fulfilment by utilising digital, automated, and real-time stock item planning and tracking.

Zhang *et al.* (2021) maintain that market leaders, such as Alibaba, deliver value to the organisation through dynamic warehouse management enabled by AI technologies, personnel, and input-to-output processes. They found that the further development of AI capabilities, including Artificial Intelligence (AI), Machine Learning (ML) algorithms, robotics, and warehouse management systems, would enable further growth in operational agility and productivity.

Automation, advanced technology, and AI have automated product sorting, inventory tracking and data-driven decision-making, facilitating the replacement of many manual tasks, minimising labour costs, reducing errors and improving efficiency. Warehouse management system advancement has enabled operational simplicity and optimised storage and logistics solutions (Zunic *et al.*, 2018). Alibaba has demonstrated that integrating human resources and operational processes driven by AI technologies increases productivity and more cost-effective warehousing operations (Zhang *et al.*, 2021).

### **Research Framework: Dynamic Warehousing – An AI approach**

This research framework combines AI drivers and AI enablers to achieve an AI-driven sustainable warehousing strategy, delivering dynamic warehousing.

## LITERATURE REVIEW

### AI Drivers

AI-driven solutions, including AI capabilities across various technologies, innovation, and resources, are crucial to developing sustainable and dynamic warehousing. Khan *et al.* (2022) state that 'integrating AI capabilities such as machine learning (ML), real-time data processing, and production adaptability facilitates the optimisation of AI systems to process complicated actioned operations, including real-time inventory management, predictive analytics, and route optimisation.' These systems reside within and help drive the technologies, innovation, and resource capabilities domains.

Other elements of warehouse optimisation, facilitated through AI technologies, incorporate real-time computer vision and robotic process automation to improve automated sorting, picking, and packing, as well as real-time tracking, while being driven by intelligent decision-making systems (Jenkins, 2020). Again, these systems reside within and help drive the technologies, innovation, and resource capabilities domains.

Optimising warehousing processes with real-time data is crucial to the adaptability of AI drivers in predicting AI innovations. Combining AI-driven robotics, dynamic slotting, machine learning (ML), and predictive maintenance enhancements improves warehousing processes and capabilities based on both historical and real-time data (Ahmadi, 2023). AI resources, incorporating data infrastructure and cloud platforms, process and incorporate real-time analytics and scalability when managing large volumes of operational data. These drivers enable warehousing to conform to fluctuating market pressures while maintaining long-term efficiency (Gayialis *et al.*, 2022).

### AI Enablers

AI enablers, including AI qualities, performance, economic value, servicing, risk mitigation, and communicative connectivity, are crucial in developing sustainable, dynamic warehousing. These enablers enable AI systems to respond quickly to changing market environments and operational pressures, ensuring continuous layout and workflow optimisation (Khan *et al.*, 2022). Implementing these enablers with real-time data processing progressively adapts operations by consolidating processes that control inventory and operational workflows (Rimele *et al.*, 2021).

AI enablers have a direct influence on AI performance and economic value. Increased AI performance reflects elevated production, faster fulfilment, reduced errors, reduced costs, and improved operational efficiency (Snartland, 2023). AI's economic value is realised by efficiently utilising resources, reducing costs, and improving the return on investment (ROI) (Singh *et al.*, 2023).

AI risk mitigation and servicing enable sustainable operations. Planned servicing facilitated by predictive maintenance scheduling increases equipment life, reduces downtime and supports operational dependability (Pech *et al.*, 2021). The combination of AI mitigation enablers, including real-time system monitoring and predictive analysis, mitigates the risk of system failures, data breaches, and operational risks, ensuring secure warehouse operations (van Geest *et al.*, 2021).

AI communicative connectivity integrates the Internet of Things (IoT) and cloud-based systems to support real-time communications between platforms, enabling real-time decision-making, enhanced resource allocation and improved efficiencies between workers and automated systems (Ahmadi, 2023). AI warehousing success relies on enablers that support real-time flexibility, efficiency and security.

### Sustainability

AI technologies drive and enable advanced productivity, reduce waste and operational costs and underpin sustainable AI warehousing (Snartland, 2023). Sustainable warehouse systems, including energy consumption, inventory management, environmental monitoring and operational optimisation, improve overall operational efficiencies when integrated into warehouse systems (Sekala *et al.*, 2024). AI-driven systems drive improved service and resource optimisation (Cannava *et al.*, 2023).

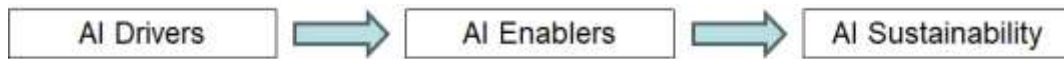
Sustainable AI-powered warehousing enables businesses to improve operations, reduce costs and operate more efficiently, ensuring ongoing economic sustainability. The monitoring and control of AI systems and components, including systems such as AI-powered HVAC, enable these systems to operate more efficiently, reducing operational costs and, in turn, minimising their impact on the environment (Sekala *et al.*, 2024). The use of historical inventory data to populate AI systems enables AI algorithms to control inventory management systems with improved inventory management parameters, thereby ensuring enhanced operational efficiency (Fadzli & Nawawi, 2024). AI plays a crucial role in predictive maintenance. It can monitor energy consumption and identify early malfunctions, minimising equipment downtime and maximising equipment efficiencies (Wang, 2023).

Sustainable warehousing continues to evolve and improve due to the influence of AI systems on warehouse operations. Inventory management, optimised work routes, reduced travel time and improved productivity are enhanced by the influence of real-time AI data analysis (Delalic *et al.*, 2020). Continuous monitoring and data analysis lead to increased efficiencies by optimising

energy use, reducing excess inventory levels, and minimising stockouts, thereby improving operational efficiency and customer satisfaction (Fadzli & Nawawi, 2024). AI-enabled warehouse systems influence automated operations tasks, including advanced robotics and enhanced picking processes (Bolu *et al.*, 2021). Improved worker well-being through AI-powered robotics reduces physical injuries among workers, enhances workplace safety, and enables workers to focus on more complex tasks, resulting in increased productivity (Linardo *et al.*, 2024). The advancement of AI analytics contributes to the improved efficiencies of AI systems and their influence on sustainable AI warehousing.

### Dynamic Warehousing AI Framework

The dynamic warehousing AI framework comprises three interconnected components. The framework and foundation elements comprise AI driver inputs and their associated constructs, which are fundamental components necessary to establish AI within the warehouse environment. Followed by AI Enablers that focus on actionable components that improve operations, and finally, AI sustainability that combines the preceding components to facilitate the utilisation of AI systems to deliver sustainable AI warehousing.



**Figure 1:** Dynamic Warehousing AI Framework Source: Adapted from Marino (2025)

Figure 1: Represents the graphical impression of the framework and illustrates the flow from AI Drivers (components by the entity) to AI Enablers (components that can be acted upon or changed by the entity), when combined, move towards achieving AI Sustainability (a likely targeted outcome of the entity). This framework structure approach explains the interactions between the AI driver and AI enabler warehousing components, indicating the necessary factors to achieve sustainable AI warehousing.

#### AI Drivers: AI Capacities

The power of data processing, machine learning algorithms and process adaptability are critical to developing AI systems (Khan *et al.*, 2022). The research scrutinises the effect of these capabilities and how AI enablers manage more complex warehouse tasks to improve warehouse efficiency.

**Optimisation algorithms:** Hamdy *et al.* (2022) describe how AI optimises warehouse processes and operations. Using AI algorithms to examine and analyse historical data, including various market trends, helps plan for periods of higher demand. Predictive stock analysis enables efficient inventory management, thereby reducing both overstock and stockout positions. The continued development of AI algorithms will enhance real-time analysis of substantial amounts of data, enabling warehouse operations to operate with reduced downtime by circumventing the typical problems of labour shortages, production bottlenecks, and inventory stockouts.

**Machine learning:** Ledbury (2024) highlights that Machine Learning (ML) is critical in advancing advanced technological capabilities as AI develops beyond traditional processes. AI examines and analyses warehouse operational data to predict future workflow needs, allowing for improved slotting and sequencing processes. Dhaliwal (2021) asserts that AI controls warehouse robotics systems, including automated guided vehicles (AGV). These robots utilise AI and machine learning to plan routes and navigate warehouse workspaces, thereby enhancing operational efficiency. Ahmadi (2023) also notes that AI and machine learning can collect and analyse operational data from IoT devices to predict and plan operational processes, thereby optimising warehouse operations.

**Predictive analysis:** Fadzli & Nawawi (2024) assert that through real-time and historical data analysis, AI algorithms can predict demand while maintaining appropriate stock levels to meet customer demands and increase profitability by reducing overstock positions, thus maintaining optimum stock levels. AI algorithms enabling predictive analysis have improved inventory management and warehouse operational efficiency.

**Real-time data processing:** Hamdy *et al.* (2022) state that AI algorithms in real-time can analyse vast amounts of data. These advancements in AI analytics facilitate the progression of predictive analysis, allowing warehouse operating systems to make real-time data-driven decisions based on market trends and customer behaviour. Pech *et al.* (2021) add that utilising a range of technological devices, such as IoT devices, which include RFID tags, cameras, sensors, and other devices, can collect and transmit real-time data on location, sound, humidity, vibration, and temperature to warehouse management systems.

**Robotic process automation:** Bolu *et al.* (2021) maintain that AI-driven robots optimise order-picking processes by optimising warehouse picking routes and processes, as well as automating tasks such as order fulfilment and inventory tracking. Kembro *et al.* (2022) argue that AI-powered robots can optimise inventory management and picking by efficient sorting, picking, packing and order fulfilment, thus minimising the need for warehouse workers.

**Autonomous navigation:** Dhaliwal (2021) asserts that AI is crucial for controlling advanced automated guided vehicles (AGVs) and other robotic systems. Computer vision and machine learning (ML) enable robots to navigate, pick, pack and process stock effectively. Torchio (2023) states that AI-assisted route optimisation is critical to transporting goods efficiently around warehouses. AI Algorithms constantly assess robot positions, warehouse layout, obstacles and other robots to plan and execute the picking and processing of goods. Kubasakova *et al.* (2024) note that utilising AI's influence in route planning prevents operational congestion, collisions, and blocking of robot travel paths, thereby resulting in efficient stock movement and operations.

**Collaborative robotics (Cobot):** With advancements in technology and robotics, robots can now safely perform repetitive and hazardous tasks once performed by human workers, offering benefits including reduced workplace injuries, increased productivity, and the promotion of employee well-being. (Licardo *et al.*, 2024). Bolu *et al.* (2021) maintain that AI-driven robotics *contributes to advancing dynamic warehousing.*

## AI Technologies

The platforms and tools used in smart warehousing include robotics, IoT devices and predictive analysis (Aldoseri *et al.*, 2023). This research examines the impact of AI technologies on warehouse processes, ranging from automation to real-time tracking and inventory management.

**Machine learning algorithms:** Ahmadi (2023) notes that Artificial Intelligence (AI) and Machine Learning (ML) are critical technologies in optimising warehouse operations. AI and ML analyse and process operational data from Internet of Things (IoT) devices to optimise warehouse operations by identifying patterns, detecting process anomalies and providing insight into predictive strategies.

**Predictive analytics platform:** Hamdy *et al.* (2022) describe how the use of artificial intelligence (AI) enhances warehouse processes through AI algorithms that analyse historical data and forecast customer demand and market trends. Predictive AI analysis optimises inventory management by preventing stockouts and excess stock holdings.

**Internet of things (IoT) devices:** Integrating technologies into Smart warehousing supports the processing of multiple technology data sources. These technologies include the Internet of Things (IoT) sensors that supply real-time data on tracking goods and equipment. Machine learning (ML) enables predictive maintenance, and AI optimises inventory forecasting (van Geest *et al.*, 2021). Selvaraj (2021) notes that smart warehousing utilises the Internet of Things (IoT) sensor networks to monitor real-time data.

**Edge computing platforms:** Warehouse Management Systems (WMS) and data-driven decision-making are integral to Smart warehousing operations. Collecting and processing inventory data, equipment status and work activity data through these platforms facilitates efficient resource allocation and informed decision-making regarding stock management and fulfilment processes (Sahara & Aamer, 2022). Kudelska *et al.* (2020) maintain that by leveraging historical data and real-time demand patterns, AI-powered demand forecasting data can enable warehouse managers to forecast staffing requirements accurately and optimise warehouse operations.

**Optimisation Algorithms:** Smart warehousing relies heavily on advanced Warehouse Management Systems (WMS) and AI algorithms to optimise warehouse operations. Operational data gathering and real-time data processing enhance warehouse decision-making, optimising warehouse layouts, resource allocation, stock management and order fulfilment (Sahara & Aamer, 2022).

Loiret *et al.* (2020) claim that in response to the changing demands, Dynamic Warehousing algorithms facilitate warehouse layout optimisation by adapting to inventory needs and space utilisation requirements. Tubis *et al.* (2023) claim that AI algorithms enhance the efficiency of automated guided vehicles (AGVs) and automated material handling robotics, enabling accurate and efficient goods processing.

**Cloud computing platforms:** Gayialis *et al.* (2022) state that cloud computing enables vast amounts of data to be stored remotely and accessed via the Internet from multiple sources and locations, allowing for the control of warehouse operations.

## AI Innovation

The development of innovative AI applications is constantly advancing and improving (Singh *et al.*, 2023). The research highlights how innovative AI development can enhance operational efficiencies and predict and address challenges within the warehouse environment.

**AI-driven autonomous mobile robots and automated guided vehicles:** Torchio (2023) states that AI algorithms are crucial in developing and optimising robotics and Automated Guided Vehicles (AGV) operations. AI algorithms evaluate warehouse layouts, obstacles, and human and other robot traffic in real-time to optimise robot and AV routes while transporting goods within a warehouse. Kubasakova *et al.* (2024) note that AI algorithms work dynamically to play an essential role in warehouse route design for the movement of Automatic Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs), preventing collisions, congestion, and route blocking. Warehouse routes utilise laser-guided systems to detect obstacles, workers and robot movement in real-time, adjusting route travel patterns to allow for the effective movement of goods and efficient operations. Jenkins (2020) states that other essential operational systems, including autonomous smart pallets and shelving, provide effective transportable solutions.

**Collaborative robots:** Mon (2023) claims that the collaboration of Robots and human workers creates a workplace environment that improves production, minimises workplace injuries and fosters an environment of employee well-being.

**Self-learning systems:** Ahmadi (2023) notes that advanced Artificial Intelligence (AI) and Machine Learning (ML) technologies analyse, process and learn from data gathered from Internet of Things (IoT) devices, such as sensors and cameras. Tracking movement patterns and movement flow data analysis enhances and enables dynamic warehouse operations.

**AI-powered predictive maintenance:** Pech *et al.* (2021) argue that AI-enabled predictive maintenance forecasting can assist warehouse managers in planning for scheduled maintenance, thereby reducing breakdown maintenance costs and enhancing warehouse operational performance. Proto *et al.* (2020) note that AI and ML analytics, displayed through data visualisation dashboards, enable managers to monitor the real-time status of warehouse equipment and operations, as well as plan and act on preventative maintenance data recommendations. Mohanraj *et al.* (2019) maintain that AI-enabled data analysis helps warehouse managers identify problem areas of the warehouse machinery before breakdowns occur. This reduces unplanned downtime and avoids unexpected disruptions to warehouse operations.

**AI-powered demand forecasting:** Singh *et al.* (2023) highlight that advanced AI demand forecasting facilitates improved warehouse operations, including predictive warehouse route design and advanced inventory management. Demand forecasting is essential for a more dynamic warehouse environment.

## AI Resources

For companies to take full advantage of the capabilities of advanced AI and the benefits it brings, they must have the following essential resources, including Internet of Things (IoT) sensors, data infrastructure, trained specialist technical Staff and financial backing to support the design, installation and operation of the AI-driven warehouse systems (Pech *et al.*, 2021).

**Datasets:** Hamdy *et al.* (2022) state that the development of AI algorithms will continue, and the analysis of vast amounts of warehouse data will enable warehouse managers to predictively address production bottlenecks, inventory management, and labour shortages. AI-driven predictive analytics and decision-making will drive operational efficiency by optimising warehouse operations based on warehouse IoT data, market trends, and customer behaviour.

**AI development framework:** Gayialis *et al.* (2022) note that an AI framework includes AI algorithms and Machine learning capabilities to analyse and process data to support real-time warehouse operations. Tang *et al.* (2022) suggest that predictive analysis machine learning algorithms can forecast future demand, manage inventory levels and predict potential issues with warehouse operations.

**Cloud computing platforms:** Gayialis *et al.* (2022) state that cloud computing allows users to manage large quantities of data from multiple sources remotely and manage operations in various locations. The security and reliability of cloud computing enable the advancement of warehouse operations.

**IoT devices and sensors:** Pech *et al.* (2021) state that Internet of Things (IoT) technologies, including RFID tags, cameras, sensors, and alternative devices, gather and communicate data, such as location, speed, vibration, humidity, temperature, and sound, to enhance warehouse operational decision-making.

**Data management systems:** Ahmadi (2023) states that data management systems, such as AI-powered warehouse management systems, provide the necessary digital visibility and control to enhance warehouse operations. Gayialis *et al.* (2022) also state that cloud computing provides remote data storage, analytics and processing from and to multiple sources and locations via the World Wide Web.

**Robotics systems:** Tubis *et al.* (2023) emphasise that AI algorithms play a crucial role in enhancing and automating the efficient material handling and advanced operations of Automated Material Handling Robotics (AMHR) and Automated Guided Vehicles (AGVs) robotics systems.

## AI Enablers

**AI qualities:** These refer to characteristics of AI systems that influence performance and reliability, including scalability, flexibility and adaptability (Khan *et al.*, 2022). This research examines the qualities that enhance the performance of AI in sustainable warehousing.

**Adaptability:** van Geest *et al.* (2021) emphasise that advanced AI data analysis facilitates the dynamic planning of warehouse activities, guaranteeing efficient resource assignment and operations. Lorenc *et al.* (2020) maintain a dynamically adapting warehouse layout that is dependent on real-time data, allowing for effective space utilisation and efficient inventory management.

**Scalability:** AI capacities empower businesses to rapidly reconfigure warehouse layouts and workflows, enabling them to react to changing market environments and dynamic customer demand. Dynamic warehousing enables organisations to be more agile, quickly adjusting to evolving stock profiles and inventory demands, ensuring seamless scalability and responsiveness to market fluctuations (Sodiya *et al.*, 2024).

**Real-time processing:** Integrating advanced AI, machine learning, and real-time data processing enables warehouses to automate tasks, optimise resource allocations, and rapidly adapt to changes, ensuring flexibility and responsiveness in a competitive market (Rimele *et al.*, 2021).

**Precision:** Zhang *et al.* (2021) emphasise that AI enhances mixed-order systems by restructuring workflows, detecting and correcting errors, and ensuring smooth processing for different types of orders throughout the entire fulfilment process.

**Autonomy:** Kembo *et al.* (2022) argue that AI-powered robots and automation transform warehouse operations. AI-powered robots can efficiently sort, pick, and organise inventory, speeding up order fulfilment.

**Predictive capabilities:** Hamdy *et al.* (2023) describe how Artificial Intelligence (AI) optimises warehouse operations through advanced AI algorithms that process and analyse real-time and historical data, as well as external influences, to predict future needs. Predictive analysis enables warehouses to optimise inventory levels, reduce excess stock and prevent inventory stockouts.

**Learning capability:** Ahmadi (2023) notes that advanced Artificial Intelligence (AI) and Machine Learning (ML) analyse data accumulated from various Internet of Things (IoT) devices, such as sensors, cameras, and locators, to identify optimal picking, packing, and real-time tracking, providing insights and predictions for optimising warehouse operations.

**Efficiency:** Min (2023) states that by leveraging AI-powered demand forecasting, warehouses can enhance inventory controls, manage excess stock levels, minimise stockouts, and improve supply chain efficiency.

**Safety:** Aksa *et al.* (2021) claim that safety is improved by performing predictive maintenance, which helps warehouse managers detect and prevent faults that could compromise workers' safety, productivity, and product quality.

## AI Performance

Measurable outcomes of AI implementation include increasing production throughput, reduced errors, and faster order fulfilment (Sartland, 2023). The research examines the positive impact of AI on cost savings and overall operational performance.

**High-speed data processing:** Khan *et al.* (2022) highlight that real-time high-speed monitoring and AI analytics in dynamic smart warehousing involve adaptive task planning and the integration of advanced technologies to enhance warehouse efficiency and optimisation.

**Accuracy:** Dowie *et al.* (2021) describe how evaluating AI's effectiveness in smart warehousing extends beyond its mere presence. AI tracks how accurately AI algorithms perform tasks, including demand forecasting, dynamic storage allocation, and robot path optimisation.

**Real-time decision-making:** Artificial intelligence (AI) driven automation and real-time data-driven decision-making in warehouse operations enhance efficiency, leading to accelerated order fulfilment, real-time processing times, and overall operational efficiency (Sahara & Aamer, 2022).

**Adaptive learning:** AI-powered Machine learning (ML) capabilities can predict and adaptively learn to optimise warehouse layout configurations and improve the efficiency of picking travel routes (Sartland, 2023).

**Energy efficiency:** Ibekwe *et al.* (2024) note that AI facilitates the selection of energy-efficient equipment and participation in demand response programs, enabling adjustments to energy consumption in response to external factors. Mauro *et al.* (2022) state that AI optimises energy harvesting technologies, such as solar panels, ensuring efficient energy utilisation within warehousing.

**Autonomous operations:** AI-enabled real-time inventory tracking, advanced technology, automation, automated sorting, and data-driven decision-making replace labour-intensive tasks, decreasing reliance on manual labour, minimising errors, and enhancing efficiency (Jenkins, 2020).

**Predictive optimisation:** Hamdy *et al.* (2022) state that AI algorithms will continue to evolve, enabling real-time analysis of large datasets. Helping warehouse managers stay ahead of issues, including stockouts, bottlenecks, and labour shortages, keeping operations running smoothly. AI will continue to advance predictive analytics, enabling warehouses to make smarter, data-driven decisions and fine-tune their operations in line with market trends and customer behaviour.

**AI economic worth:** The financial value of AI implementation includes cost reductions and return on investment (ROI) (Singh *et al.*, 2023). The research explores how AI contributes to the economic sustainability of warehouse operations.

**Cost reduction:** Shoushtari *et al.* (2022) emphasise that warehouses can improve productivity, reduce costs, and enhance customer satisfaction by leveraging AI. Fuchtenhans *et al.* (2023) state that intelligent lighting systems, controlled by AI, adjust brightness and scheduling based on natural light and occupancy, ensuring lights are only on when necessary. Intelligent lighting systems offer significant potential for decreasing warehouse energy consumption compared to traditional lighting methods. Beyond cost savings, these systems can enhance the environmental impact of warehouses.

**Increased efficiency:** Sahara *et al.* (2022) note that real-time monitoring and analytics benefits increase efficiency through AI deployment, leading to more efficient warehouse operations, reducing manual errors, and optimising resource utilisation. Cost savings are realised through AI-driven analytics and can help improve inventory management, reduce operational costs, and improve overall cost-effectiveness.

**Enhanced accuracy:** Zhang *et al.* (2021) highlight that AI improves the effectiveness of order management systems by consistently improving automated operations, distinguishing inconsistencies, and facilitating end-to-end fulfilment across order picking, shipping, tracking, delivery, and returns for multiple order types.

**Scalability:** AI will rapidly reconfigure warehouse layouts and workflows, enabling quick adaptation to changing market conditions and customer demands. This dynamic flexibility enables organisations to adjust seamlessly to shifting stock profiles and inventory needs, ensuring scalability and responsiveness. AI enables warehouses to scale operations efficiently, handling increased order volume without requiring proportional investment in labour and infrastructure (Sodiya *et al.*, 2024).

**Better demand forecasting:** Hamdy *et al.* (2022) describe various ways AI algorithms can analyse market trends, historical data and external factors to predict future demand and optimise warehouse operations. Predictive demand forecasting enables warehouses to optimise inventory levels. Reduce excess stock and prevent stockouts.

**Optimised resource utilisation:** Min (2023) states that warehouses can enhance inventory control by minimising stockouts, reducing excess stock and optimising supply chain efficiency by leveraging AI-powered demand forecasting. Zhang *et al.* (2021) maintain that AI helps streamline warehouse management by optimising picking routes and automating order fulfilment and inventory tracking processes.

**Reduced lead times:** Sahara & Aamer, (2022) state that using Artificial Intelligence (AI) driven automation and data-driven decision-making significantly enhances warehouse efficiency, leading to optimised order fulfilment, decreased processing times, reduced lead times, and improved overall operational efficiency.

**Improved customer satisfaction:** Fadzli & Nawawi, (2024) assert that dynamic warehousing ensures products are always available to meet customer demands by minimising stockouts. Simultaneously, it eliminates excess inventory, maximising profitability by reducing carrying costs. This approach, driven by real-time data insight and predictive AI, transforms how inventory is managed, helping to ensure operational efficiency and customer satisfaction.

**Increased agility:** Integrating artificial intelligence (AI) technologies and digital network connectivity enables smart warehousing to achieve enhanced productivity, operational agility, and risk mitigation while meeting customer demand for rapid delivery (Burston *et al.*, 2023). The scalability of smart warehousing solutions enables seamless adjustment to fluctuating inventory levels and changing business demands, ensuring optimal resource allocation and agility in a dynamic marketplace (Chen & Damian, 2024).

## AI Servicing

The maintenance and support of AI systems involves effective and reliable servicing by trained technical personnel (Aldoseri *et al.*, 2023). The research examines the impact of regular servicing on the longevity and reliability of AI systems, ensuring continuous improvement and adaptation.

**Predictive maintenance:** Pech *et al.* (2021) claim that AI-powered predictive maintenance can assist warehouse managers in minimising operational downtime by prolonging equipment life, reducing maintenance costs, and increasing operational efficiency. Mahanraj *et al.* (2019) maintain that predictive maintenance offers several advantages, including reducing unplanned downtime and alerting warehouse managers to potential issues before they escalate into breakdowns, thereby allowing them to schedule repairs or replacements in advance and avoid disruptions to operations.

**Real-time monitoring:** Khan *et al.* (2022) highlight that real-time monitoring and analytics, coupled with AI deployment in dynamic, smart warehousing, involve adaptive task planning and the integration of advanced technologies driven by artificial intelligence (AI) to enhance warehouse operational efficiency, responsiveness, and total operational management. This method utilises analysis and real-time data processing driven by AI algorithms to optimise different facets of warehousing, including inventory management, order fulfilment, and resource utilisation.

**Remote support capabilities:** Ahmadi (2023) notes that advanced technologies, including AI and machine learning (ML), can analyse the data gathered by IoT devices, recognise patterns, discover anomalies, and provide insights and predictions for optimising warehouse operations. Gayialis *et al.* (2022) state that cloud computing delivers support services, including remote storage, processing, and analytics, over the Internet, allowing for remote access and management of vast amounts of data from multiple sources and locations, enabling the scaling up or down of warehouse operations.

**Operational optimisation:** Hamdy *et al.* (2022) describe various ways AI optimises warehouse operations, including demand-driven AI algorithms that forecast through analysis of historical data, market trends, and external details to predict future operational demand. Predictive analytics enables warehouses to optimise inventory levels, reducing excess stock and preventing stockouts.

**Data analysis:** van Geest *et al.* (2021) emphasise that advanced AI data analysis enables real-time adaptation of warehouse workflows, ensuring efficient resource allocation and streamlined operations.

### AI Risk Mitigation

Strategies are crucial for managing and mitigating potential risks associated with AI systems, including system failures, data breaches, and ethical concerns (Van Geest *et al.*, 2021). The research examines how effective risk mitigation contributes to the stability and security of AI-powered warehousing operations

**Predictive analytics and risk forecasting:** Gayialis *et al.* (2022) note that AI development, including advanced AI algorithms and Machine learning (ML), is employed to analyse data in real-time. Advanced AI algorithms can predict trends, forecast risks, identify patterns, and make informed decisions based on historical and current information. Tang *et al.* (2022) claim that AI and machine learning can facilitate advanced predictive analytics to forecast demand, optimise inventory levels, and identify potential issues or bottlenecks in warehouse operations.

**Real-time monitoring and alerts:** Khan *et al.* (2022) highlight that real-time monitoring analytics and risk management, coupled with AI deployment in dynamic, smart warehousing, involve adaptive task planning and the integration of advanced technologies, including Artificial intelligence (AI), to enhance warehouse operations. This method utilises real-time data analytics and AI algorithms to optimise different warehousing processes, including inventory management, order fulfilment and resource utilisation. Proto *et al.* (2020) note that data visualisation and dashboards can display data and analytics from AI and ML in an interactive and user-friendly manner, enabling warehouse managers to monitor, alert, plan and act on the information and recommendations provided.

**Inventory management and stockout prevention:** Advanced technology, automation, and AI now enable real-time inventory tracking, automated sorting and data-driven decision-making, replacing labour-intensive tasks, decreasing the need for workers, minimising errors, and enhancing efficiency (Jenkins, 2020). Hamdy *et al.* (2022) describe various ways AI optimises warehouse operations, including demand forecasting. Using AI algorithms to analyse market trends, historical data, and various other factors in real-time optimises predictive demand forecasting. Predictive analytics enables warehouses to optimise inventory levels, reduce excess stock and prevent stockouts.

**Supply chain risk management:** Min (2023) states that warehouses can enhance inventory levels, minimise stockouts, reduce excess inventory and enhance supply chain efficiency by leveraging AI-powered demand forecasting. Zhang *et al.* (2021) maintain that AI enables enhanced warehouse operational management by efficiently navigating through warehouses, optimising picking routes, and automating processes like order fulfilment and inventory tracking.

**Error reduction through automation:** Kembo *et al.* (2022) argue that AI-powered robots and automation are transforming warehouse operations. AI-powered robots can efficiently sort, pick, pack, and organise inventory, reducing errors and speeding up order fulfilment.

**Cybersecurity enhancement:** The reliance on digital systems and increased concerns about data security significantly heighten the vulnerability to cyberattacks. Businesses must prioritise implementing effective cybersecurity processes to protect important data. Organisations can mitigate the risk associated with cyber threats by fortifying their systems with advanced security protocols, encryption, and constant monitoring. Taking a proactive stance in cybersecurity safeguards valuable information, which helps maintain customer trust and protects the brand reputation (van Geest *et al.*, 2021).

**Compliance and regulatory adherence:** AI systems can be programmed to ensure warehouse operations comply with industry regulations and standards. van Geest *et al.* (2021) describe the critical factors, which include ensuring accessibility and easy access for material handling equipment and prioritising safe operations to mitigate collision risk and comply with safety regulations. Moleda *et al.* (2023) add that integrating equipment repair history diagnostics and compliance with regulatory requirements enhances the warehouse manager's maintenance planning decision-making process.

**Dynamic risk adjustment:** Hamdy *et al.* (2022) explain that AI algorithms are designed to advance continually, enabling real-time analysis of vast data volumes and providing warehouse managers with the tools to address stockouts, bottlenecks, and labour shortages before they become significant problems. They note that this helps maintain smooth, uninterrupted operations and that AI will continue to push predictive analytics forward, enabling warehouses to make smarter, data-driven decisions and fine-tune their operations around market trends and customer behaviour, while also helping to manage risks linked to changing conditions.

### AI Communicative Connectivities

Explores how AI systems integrate and communicate with other digital infrastructure within the warehouse environment (Ahmadi, 2023). The research assesses how strong communicative connectivities enable seamless data exchange, real-time decision making and overall operational coordination.

**IoT integration:** Ahmadi (2023) highlights that AI and machine learning (ML) technologies can process data collected from IoT devices, spot patterns, detect anomalies, and offer insights and predictions to help optimise warehouse operations. Selvaraj (2021) explains that smart warehouses use sensor networks fitted with various IoT devices to monitor real-time data. These sensors continuously track various factors, such as goods movement, temperature, and humidity, delivering real-time updates across multiple operational areas.

**Inter-system communication:** Ahmadi (2023) states that AI-powered Warehouse Management Systems (WMS) support the oversight and transparency required for effective hybrid operations. Data-driven decision-making is pivotal in smart warehousing, where Warehouse Management Systems (WMS) play a crucial role. These software platforms monitor and record real-time updates on inventory quantities, equipment functionality, and worker performance, optimising warehouse layouts, efficient resource allocation, and informed decisions regarding stock management and fulfilment processes (Sahara & Aamer, 2022).

**Collaborative robot communication:** Bolu *et al.* (2021) maintain that AI-driven robots contribute to the streamlined management of warehouses by adeptly navigating through the facility, optimising the picking process, and automating various tasks such as order fulfilment and inventory tracking. Min (2023) claims their ability to collaborate with human workers and adapt to dynamic environments enhances productivity.

**Cloud connectivity:** Gayialis *et al.* (2022) explain that cloud computing provides services such as storage, processing, and analytics over the Internet, enabling access to and management of large volumes of data from multiple sources and locations, with the flexibility to scale resources up or down as needed. Ahmadi (2023) points out that AI and machine learning (ML) technologies can analyse the data gathered from IoT devices, detect patterns, identify anomalies, and offer insights and predictions to optimise warehouse operations.

**Real-time data sharing:** Hamdy *et al.* (2022) explain that AI algorithms will continue to advance, making it possible to analyse vast amounts of data in real-time and allowing warehouse managers to proactively manage stockouts, bottlenecks, and labour shortages, helping to keep operations running smoothly. They also highlight that AI will further drive the development of predictive analytics, allowing warehouses to make smarter, data-driven decisions and optimise their operations in line with changing market trends and customer behaviour.

**Predictive communication:** Sahara *et al.* (2022) emphasise that smart warehousing relies heavily on seamless data integration, measured by the effective integration of data. This metric assesses how well real-time data from diverse sources, like inventory levels, order trends, and robot performance, is integrated and analysed. Smart warehousing can optimise decision-making and resource allocation by creating a unified data picture, leading to a more efficient and responsive warehouse environment. Dowie *et al.* (2021) describe how evaluating AI's effectiveness in smart warehousing extends beyond mere presence. AI effectiveness measures how efficiently and accurately AI algorithms perform tasks such as demand forecasting, dynamic storage allocation, and robot path optimisation. Assessing AI's overall contribution by monitoring metrics such as predictive accuracy for demand forecasting and robot downtime enables continuous improvement and fine-tuning of the algorithms to ensure the maximum benefits of automation and optimisation within the smart warehouse.

## Sustainability

Sustainability in dynamic warehousing is a complex mix of contributing constructs. Each delivers an aspect of ongoing competitiveness.

### AI Warehousing:

The goal is to establish a sustainable warehouse management model where AI continuously enhances productivity, reduces waste, and supports long-term operational objectives (Spartland, 2023). AI warehousing represents the culmination of the research framework, where all AI drivers and AI enablers converge to create a sustainable AI warehouse system. The research aims to demonstrate how AI can create an efficient, cost-effective, resilient, and dynamic warehousing environment that supports long-term business success.

**Continuous energy optimisation:** Cannava *et al.* (2023) describe how warehouses have transformed from mere storage hubs to highly functional facilities where diverse processes ensure efficiency and meet service-level demands. This shift has increased energy consumption, often making warehouses highly energy-intensive. AI offers a multifaceted approach to optimising energy usage and reducing warehouse waste. Sekala *et al.* (2024) add that through continuous energy consumption monitoring, AI systems pinpoint areas of inefficiency, facilitating real-time adjustments to optimise energy usage.

**Ongoing refinement and optimisation:** Downie *et al.* (2021) describe how evaluating AI's effectiveness in warehousing extends beyond its mere presence. AI effectiveness measures how efficiently and accurately AI algorithms perform demand forecasting, dynamic storage allocation, and robot path optimisation tasks. Assessing AI's overall contribution by monitoring metrics such as prediction accuracy for demand forecasting and robot downtime enables continuous improvement and fine-tuning of the algorithms to ensure they maximise the benefits of automation and optimisation within warehousing.

**Enhancing resource utilisation and productivity:** Delalic *et al.* (2020) note that AI algorithms analyse historical data, current conditions, and factors such as order volume, item locations, and worker availability to recommend optimal routes for human workers picking, packing, or restocking items, resulting in decreased travel time and enhanced productivity. Bolu *et al.* (2021) maintain that AI-driven robots contribute to the streamlined management of warehouses by adeptly navigating through the facility, optimising the picking process, and automating various tasks such as order fulfilment and inventory tracking. Min (2023) claims their ability to collaborate with human workers and adapt to dynamic environments enhances productivity. Zhang *et al.* (2021) employ flexible order strategies based on real-time data, ensuring a seamless flow from manufacturers to customers. Shoushtari *et al.* (2021) emphasise that warehouses can improve productivity, reduce costs, and enhance customer satisfaction by leveraging AI.

AI-driven route optimisation plays a pivotal role in enhancing warehouse efficiency. Delalic *et al.* (2020) note that AI algorithms analyse historical data, current conditions, and factors such as order volume, item locations, and worker availability to recommend optimal routes for human workers picking, packing or restocking items, resulting in decreased travel time and enhanced productivity.

**Dynamic inventory management:** Fadzli & Nawawi, (2024) assert that dynamic warehousing ensures products are always available to meet customer demands by minimising stockouts. Simultaneously, it eliminates excess inventory, maximising profitability by reducing carrying costs. This approach, driven by real-time data analysis and predictive AI algorithms, transforms inventory management, guaranteeing operational optimisation.

**Continuous environmental impact monitoring:** Sekala *et al.* (2024) add that through continuous energy consumption monitoring, AI systems pinpoint areas of inefficiency, facilitating real-time adjustments to optimise energy usage. Fuchtenhans *et al.* (2023) state that intelligent lighting systems, controlled by AI, dynamically adjust brightness and scheduling based on natural light and occupancy, ensuring that lights are only on when necessary. Intelligent lighting systems offer significant potential for decreasing warehouse energy consumption compared to traditional lighting methods. Beyond cost savings, these systems can enhance the environmental impact of warehouses.

Shaer *et al.* (2023) also add that AI-driven HVAC systems analyse environmental data to optimise real-time heating, ventilation, and air conditioning settings. Route optimisation for autonomous vehicles considers factors such as traffic patterns and load weight, thereby minimising energy consumption during warehouse operations. Ibekwe *et al.* (2024) state that AI also aids in selecting energy-efficient equipment and participating in demand response programs to adjust energy consumption in response to external factors. Maturo *et al.* (2022) state that AI optimises energy harvesting technologies, such as solar panels, ensuring efficient energy utilisation within the warehouse.

Wang (2023) describes how predictive maintenance powered by AI enables early identification of potential equipment malfunctions, thereby minimising downtime and energy waste. Overall, AI integration offers comprehensive solutions to reduce costs, minimise environmental impact, and enhance operational efficiency in warehouse energy management.

**Employee well-being and enhancement:** Artificial intelligence (AI) and advanced robotics enhance safety by handling heavy lifting tasks and operating in hazardous environments, reducing workplace injuries and promoting increased productivity and employee well-being. Linardo *et al.* (2024) maintain that the implementation of advanced robotics significantly improves safety in warehouse operations. Robots effectively handle heavy lifting tasks and operate in hazardous warehouse environments, thereby minimising the risk of workplace accidents for human workers. This enhanced safety measure ensures a secure working environment, promoting the well-being of employees and leading to increased productivity and overall operational efficiency (Licardo *et al.*, 2024).

**Research framework objectives:** As illustrated in Figure 1, the research framework provides a structured approach to understanding how AI can be effectively integrated into warehousing operations to achieve the research objectives. By exploring the relationships between AI Drivers, AI Enablers, and Sustainable AI warehousing, the framework enables a comprehensive analysis of how AI contributes to dynamic, sustainable warehousing.

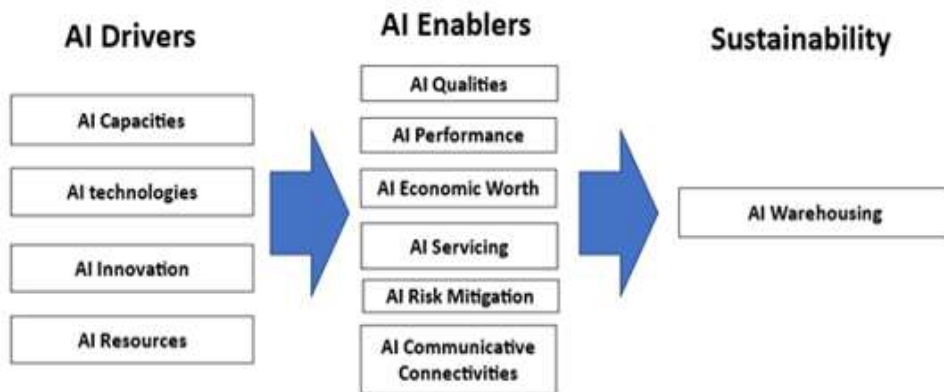
Figure 1 also highlights the importance of considering current and long-term factors when implementing AI into warehousing. AI Drivers and AI Enablers focus on current capabilities and the impact of AI. At the same time, the AI sustainability component of the framework ensures that the system designs endure, addressing future challenges and opportunities.

### Study Research Model

The study research model builds on the literature and the constructs outlined earlier, integrating them into the dynamic warehousing AI framework as illustrated in Figure 1. This expanded framework suggests that a more comprehensive, sequential flow can occur in dynamic warehousing environments with the implementation of AI. Following this sequential AI development flow, the framework can serve as a foundational approach for developing a research model tailored to AI-driven warehousing.

Figure 2 represents this proposed Dynamic Warehousing AI research framework, summarising the current critical elements presented in the literature and deemed necessary in developing a successful AI-driven warehouse model. AI Drivers, AI Enablers, and the ultimate aim of sustainability within AI warehousing are the three main components of this framework.

Figure 2 also delineates the current literature-sourced measurement item blocks relevant to each construct. Each measurement item will be framed within a separate Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), and can be used to frame the necessary measurements for a structural equation modelling research approach.



**Figure 2.** Dynamic Warehousing Framework Model Source: Adapted from Marino (2025)

## METHODOLOGY

### Dynamic Warehousing Model

This Figure 2 framework is developed to assess dynamic warehousing using CB-SEM. Participants are to be drawn from leading warehousing facilities across Australia. Possible CB-SEM pathways across the proposed framework model are now delineated.

### Linear Regression Interconnectors

The literature has supported numerous pathways between the constructs of the research framework. Section 9 and Figure 3 provide the relationships between constructs as one progresses from left to right.

These relationships include the causal linkages or interconnectors and explain how the left-side constructs affect the constructs on the right side and the regression relationship between the two constructs. Collectively, these individual regressions between pairs of constructs combine to interlink all the constructs of the research model into a network of cause and effects, focusing on delivering a sustainable AI warehousing system.

First, this study examines AI drivers, their impact on AI enablers, and the relevant hypothesis pathways that are key constructs. Secondly, it examines how AI enablers directly influence sustainable AI warehousing outcomes. Thirdly, AI drivers impact the sustainability of AI-driven warehousing systems. It explores how enablers interact and form interconnected networks with one another, reinforcing systems-wide functionality and adaptability. Therefore, this broad accumulation of related and relevant literature supports the proposed model and its hypothesised linkages.

### Figure 2 AI Drivers: Literature Support for Path Hypotheses

**AI capacities to AI qualities:** AI capacities, such as data, machine learning, scalability, and adaptability, shape the robustness and reliability of AI systems in warehousing (Khan *et al.*, 2022).

**AI technologies to AI performance:** Technologies, including robotics, predictive analytics, and IoT devices, directly influence throughput, reduce errors, and increase fulfilment speed and performance metrics within a warehouse (Aldoseri *et al.*, 2023; Snartland, 2023).

**AI innovation to AI economic worth, AI performance, AI qualities, AI servicing, and AI communicative connectivities:** Innovative AI development enhances financial viability, operational efficiency, system adaptability, maintenance support, and digital communication (Singh *et al.*, 2023; Pech *et al.*, 2021; Aldoseri *et al.*, 2023).

**AI resources to AI servicing, AI economic worth, AI risk mitigation:** Infrastructure, experience, and financial input drive servicing quality, Return on Investment (ROI) and risk reduction (Pech *et al.*, 2021; van Geest *et al.*, 2021).

**AI technologies for AI risk mitigation and AI servicing:** Technologies enhance system reliability and mitigate errors and system failures (Aldoseri *et al.*, 2023).

**AI capacities to AI economic worth, AI communicative connectivities:** Foundational capacities support financial returns and collaborative AI-system communication (Kan *et al.*, 2022).

### Figure 2 AI Enablers: Literature Support for Path Hypotheses

**AI performance to AI risk mitigation / AI economic worth:** High-performing systems lower operational risk and improve cost outcomes (van Geest *et al.*, 2021; Meisingseth *et al.*, 2023).

**AI qualities to AI communicative connectivities:** Operational robustness enhances the integration of AI-to-AI and AI-to-human systems (Hamdy *et al.*, 2022).

**AI servicing to AI risk mitigation:** Effective maintenance support system resilience and risk reduction (Aldoseri *et al.*, 2023 van Geest *et al.*, 2021).

The above hypotheses provide a theoretically grounded and methodologically structured understanding of the proposed model pathways, underpinning AI implementation in warehouse systems. The framework hypotheses across this proposed model also support scholarly and practical insight into building intelligent, scalable, sustainable warehouse infrastructure.

### Figure 2 AI Capabilities / AI Technologies: Literature Support for Path Hypotheses to Warehousing Sustainability

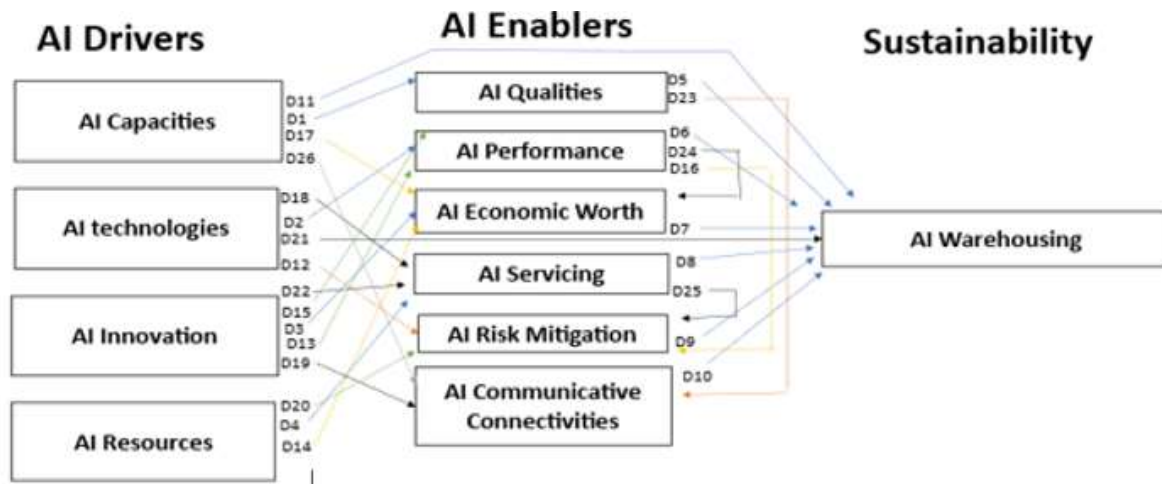
**AI capabilities / AI technologies to AI warehousing:** Advanced capabilities and technologies underpin the adaptability of systems and support their prolonged sustainability (Khan *et al.*, 2022; Aldoseri *et al.*, 2023).

### Figure 2 AI Enablers: Literature Support for Path Hypotheses to Warehousing Sustainability

**AI qualities, AI performance, AI economic worth, AI servicing, AI risk mitigation, AI communicative connectivities to AI warehousing:** Each enabler contributes uniquely to sustainable outcomes through improved efficiency, reduced waste, effective maintenance, and systems reliability (Hamdy *et al.*, 2022; Snartland, 2023; van Geest *et al.*, Ahmadi, 2023).

### AI Dynamic Warehousing and Structural Equation Modelling

Figure 3 below summarises the hypotheses discussed earlier in Figure 2, the structural model. Figure 3 presents the detailed research model suitable for structural equation modelling and exploring AI dynamic warehousing while aiming to expose or identify innovative strategies likely capable of delivering sustainability within a dynamic AI-powered warehouse environment. By investigating the relationships and interactions depicted in Figure 3, this study seeks to uncover new insights and methods for optimising AI warehousing sustainability.



**Figure 3:** AI Dynamic Warehousing: A CB-SEM Modelling Approach Source: Adapted from Marino (2025)

### ANALYSIS and RESULTS

This study is planned as a mixed-methods analysis, with CB-SEM or PLS-SEM as the quantitative analysis and NVivo as the qualitative analysis of firm representatives from the most advanced warehousing operators in Australia. Findings should elucidate pathways for developing even smarter, dynamic warehousing solutions in the immediate future.

### DISCUSSION

This literature review has critically examined the convergence of artificial intelligence (AI) and dynamic warehousing, revealing an intricate network of independent components that collectively shape modern warehousing operations efficiently, adaptably, and sustainably. Central to this transformation are the AI Drivers, including capabilities, technologies, innovations, and resources that serve as foundational facilitators of intelligent systems. When effectively deployed, these drivers influence downstream AI Enablers, including quality, performance, economic value, servicing, risk mitigation, and communicative connectivity.

The review highlights how AI capabilities, such as machine learning (ML), real-time data processing, and predictive analytics, empower warehouses to shift from reactive to proactive operations. As warehousing tasks grow in complexity and volume, these AI elements allow for intelligent automation, minimising human error while enhancing precision and speed.

AI Enablers serve as performance multipliers, particularly in qualities such as scalability, real-time adaptability, and learning capabilities. These qualities enable AI systems to evolve with changing dynamics, ensuring operational continuity and economic value, as measured by cost efficiency. Return on investment (ROI) and resource optimisation are critical outcomes, validating AI's strategic value beyond functional automation.

The Interconnections between AI Drivers and Enablers support a feedback loop reinforcing warehouse sustainability. Servicing and risk mitigation, often underemphasised, are shown to be pivotal to guaranteeing the longevity and dependability of AI systems. Regular predictive maintenance, cybersecurity integration, and adherence to regulatory compliance are vital for mitigating disruptions and maintaining system integrity.

AI-driven warehousing is about harnessing technological capacity and integrating digital systems in a coordinated manner. Strong, communicative connections via IoT, cloud integration, and real-time data sharing foster seamless operations and decision-making, further reinforcing the sustainability goal.

The Australian context underscores the urgency of these innovations. With rising land prices, limited urban infrastructure, and surging e-commerce demands, retrofitting existing warehouse sites with scalable AI solutions has become a practical and economically necessary step. Australian companies are already investing heavily in AI-enabled fulfilment centres, aligning well with the literature's emphasis on digital transformation as a critical imperative.

The Dynamic Warehousing AI framework proposed in this review provides a structured lens through which to examine how, for example, AI capabilities translate into operational value and sustainability. The interrelationships captured through hypothesised linear regression pathways provide a robust platform for further testing, ideally through a Structural Equation Modelling (SEM) approach.

### CONCLUSION

Integrating AI into dynamic warehousing signifies a transformative shift in managing, optimising, and sustaining warehouses. This literature review confirms that AI has evolved from an operational tool to a core component of a viable strategy for achieving operational excellence, economic resilience, and environmental sustainability in warehousing.

This paper lays the groundwork for a research agenda that explores the constructs through qualitative modelling by mapping the interplay between AI Drivers, Enablers and the overarching sustainability goal. The proposed framework captures the essence of AI-driven warehousing as a living system that adapts, learns, scales and endures.

AI is the cornerstone of this transformation as warehousing continues evolving in response to growing demand and shrinking profit margins. AI's ability to optimise processes, reduce risks, and generate long-term value reinforces its role as a critical enabler of future-proof logistics. The next step is to validate this framework through structured research methodologies, such as Structural Equation Modelling (SEM), to provide actionable insights that inform both industry practice and academic theory.

### FUTURE RESEARCH

As future market pressures, efficiencies, and technologies advancements are likely to enhance and change warehousing into the future, additional ongoing studies around AI and warehousing innovation can further advance this study's research over the long-term. Hence, future studies, or an update of this study, likely need to reassess the future possibilities around dynamic warehousing prior to any full quantitative and/or qualitative study being undertaken. This study can expand further by including management of operational data, and/or how scalability of the warehouse is to be managed. For example, in the past month of July 2025 enormous advance in robotics have occurred with the announcement that by 2030 Elon Musk's company will have released over one million Optimus Prime robots into the marketplace. These autonomous robots will likely be working in warehousing and manufacturing domains. Thus, fully robotic warehousing, smarter ordering, processing, and delivery systems, plus further shifts in the perspective of dynamic warehousing towards continual (24/7/365), faster, and zero error processing systems is all possible in the very near future.

### REFERENCES

- Ahmadi, S. (2023). Optimising Data Warehousing performance through machine learning algorithms in the cloud. *International Journal of Science and Research (IJSR)*, 12(12), 1859-1867. <https://doi.org/10.21275/SR231224074241>
- Ahmadi, S. (2023). Security and privacy challenges in cloud-based data warehousing: A comprehensive review. *International Journal of Computer Science Trends and Technology (IJCTST)*–Volume, 11.
- Aksa, K., Aitouche, S., Bentoumi, H., & Sersa, I. (2021). Developing a web platform for managing the predictive maintenance in smart factories. *Wireless Personal Communications*, 119(2), 1469-1497. <https://doi.org/10.1007/s11277-021-08290-w>
- Albert, P. W., Rönnqvist, M., & Lehoux, N. (2023). Trends and new practical applications for warehouse allocation and layout design: a literature review. *SN Applied Sciences*, 5(12), 378. <https://doi.org/10.1007/s42452-023-05608-0>
- Aldoseri, A., Al-Khalifa, K., & Hamouda, A. (2023). A roadmap for integrating automation with process optimisation for AI-powered digital transformation. <https://doi.org/10.20944/preprints202310.1055.v1>
- Ali, S. S., Khan, S., Fatma, N., Ozel, C., & Hussain, A. (2024). Utilisation of drones in achieving various applications in smart warehouse management. *Benchmarking: An International Journal*, 31(3), 920-954. <https://doi.org/10.1108/BIJ-01-2023-0039>
- Ballantyne, A., & McFarlane, A. (2022). JLL Logistics and Industrial Market Overview, Q4 2022. *JLL*. Retrieved from <https://www.jll.com.au/en/trends-and-insights/research/australian-industrial-market-overview-4q22> (accessed 16 March 2023).
- Binos, T., Bruno, V., & Adamopoulos, A. (2021). Intelligent agent-based framework to augment warehouse management systems for dynamic demand environments. *Australasian Journal of Information Systems*, 25. <https://doi.org/10.3127/ajis.v25i0.2845>
- Bolu, A., & Korçak, Ö. (2021). Adaptive task planning for multi-robot smart warehouse. *IEEE Access*, 9, 27346-27358.
- Burston, B., Ciesielski, M., Wilson, J., & Kaliza, L. (2023). Navigating The Path To Performance (Knight Frank Outlook Report No. 2023-9619, pp. 1–36). Knight Frank. Retrieved from: <https://content.knightfrank.com/research/2156/documents/en/outlook-report-2023-9619.pdf> (accessed 16 March 2023).
- Burston, Ben., & Dean, K. (2021). The last mile race challenging urban logistics. Knight Frank. Retrieved from <https://content.knightfrank.com/research/2271/documents/en/urban-logistics-australia-july-2021-8221.pdf> (accessed on 26 June 2024)
- Cannava, L., Perotti, S., & Petrillo, A. (2023). *The role of digital technologies in improving energy efficiency at logistics facilities: a state-of-the-art*. ResearchGate. Retrieved from [https://www.researchgate.net/publication/374951559\\_The\\_Role\\_of\\_Digital\\_Technologies\\_in\\_Improving\\_Energy\\_Efficiency\\_at\\_Logistics\\_Facilities\\_A\\_State-of-the-Art](https://www.researchgate.net/publication/374951559_The_Role_of_Digital_Technologies_in_Improving_Energy_Efficiency_at_Logistics_Facilities_A_State-of-the-Art) (accessed 16 March 2023).
- Cassettari, L., Currò, F., Mosca, M., Mosca, R., Revetria, R., Saccaro, S., & Galli, G. (2021). A 4.0 automated warehouse storage and picking system for order fulfilment. In *Lecture Notes in Engineering and Computer Science: Proceedings of The World Congress on Engineering*. Retrieved from [https://www.iaeng.org/publication/WCE2021/WCE2021\\_pp317-327.pdf](https://www.iaeng.org/publication/WCE2021/WCE2021_pp317-327.pdf) (accessed 16 March 2023).
- Celik, M., & Sural, H. (2019). Order picking in parallel-aisle warehouses with multiple blocks: complexity and a graph theory-based heuristic. *International Journal of Production Research*, 57(3), 888-906.

- Chang, Y. W., Hsu, P. Y., Chen, J., Shiau, W. L., & Xu, N. (2023). Utilitarian and/or hedonic shopping—consumer motivation to purchase in smart stores. *Industrial Management & Data Systems*, 123(3), 821-842.
- Chen, H., & Damian, M. A. E. (2024). Warehouse management information system technology review. *International Journal of Emerging Technologies and Advanced Applications*, 1(3), 24-32.
- Cheng, S. W., Choy, K. L., & Lam, H. Y. (2015). A workflow decision support system for achieving customer satisfaction in warehouses serving the machinery industry. *IFAC-PapersOnLine*, 48(3), 1714-1719.
- Chi, C., Wu, S., Xia, D., & Wu, Y. (2023). Dynamic picking and storage optimisation of robotic picking systems. *Wireless Personal Communications*, 128(1), 1-23.
- Cosma, A., Conte, R., Solina, V., & Ambrogio, G. (2024). Design of KPIs for evaluating the environmental impact of warehouse operations: A case study. *Procedia Computer Science*, 232, 2701-2708.
- Chung, S. H. (2021). Applications of smart technologies in logistics and transport: A review. *Transportation Research Part E: Logistics and Transportation Review*, 153, 102455, 1-17.
- Culler, D., & Long, J. (2016). A prototype smart materials warehouse application implemented using custom mobile robots and open source technology developed using emguCV. *Procedia Manufacturing*, 5, 1092-1106.
- Cummins, L. (2021). *Amazon Robotics fulfilment centre*. Amazon Australia. Retrieved from: <https://www.aboutamazon.com.au/news/economic-impact/construction-of-the-largest-warehouse-ever-built-in-australia-is-well-underway-creating-jobs-for-western-sydney> (accessed 16 March 2023).
- Delalić, S., Žunić, E., Alihodžić, A., & Selmanović, E. (2020). The order batching concept implemented in actual smart warehouse. In *Proceedings 2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)* (pp. 1685-1690). IEEE.
- Destro, I. R., Staudt, F. H., Somensi, K., & Taboada, C. (2023). The impacts of inventory record inaccuracy and cycle counting on distribution center performance. *Production*, 33, e20220077.
- Dhaliwal, A. (2021). Reinventing logistics: Use of AI & robotics technologies. *Business Research and Innovation*, 147.
- DHL Logistic of Things, (2023). *Australia's E-Commerce Companies Are Getting A Boost With Warehouse Automation*. DHL Logistics of Things. Retrieved from <https://lot.dhl.com/australia-e-commerce-boost-warehouse-automation/> (accessed 16<sup>th</sup> March 2023).
- Ding, W. (2013). Study of smart warehouse management system based on the IOT. In *Proceedings Intelligence Computation and Evolutionary Computation: Results of 2012 International Conference of Intelligence Computation and Evolutionary Computation (ICEC 2012)* (pp. 203-207), Springer.
- Dixit, P., Nargundkar, A., Suyal, P., & Patil, R. (2023). *Intelligent Warehouse Automation Using Robotic System*. In *Intelligent Systems and Applications: Select Proceedings of ICISA 2022* (pp. 435-443). Springer Nature Singapore.
- Dong, D. G. (2023). Design and development of Intelligent Logistics Tracking System based on computer algorithm. *International Journal for Applied Information Management*, 3(2), 58-69.
- Downie, B., Gyöngyösi, M., & Kuehl, C. (2021). Artificial intelligence in materials handling: How machine learning tools boost warehouse safety, productivity and cost-effectiveness. *Journal of Supply Chain Management, Logistics and Procurement*, 4(1), 6-16.
- Fadzli, M. A. F. M., & Nawawi, S. W. B. (2024). Automated Storage and Retrieval System for Warehouse. *ELEKTRIKA-Journal of Electrical Engineering*, 23(1), 88-95. <https://doi.org/10.11113/elektrika.v23n1.471>
- Falatouri, T., Darbanian, F., Brandtner, P., & Udokwu, C. (2022). Predictive analytics for demand forecasting—a comparison of SARIMA and LSTM in retail SCM. *Procedia Computer Science*, 200, 993-1003.
- Faveto, A., Traini, E., Bruno, G., & Lombardi, F. (2021). Development of a key performance indicator framework for automated warehouse systems. *IFAC-PapersOnLine*, 54(1), 116-121. <https://doi.org/10.1016/j.ifacol.2021.08.013>
- Félix-Cigalat, J. S., & Domingo, R. (2023). Towards a digital twin warehouse through the optimisation of internal transport. *Applied Sciences*, 13(8), 4652. <https://doi.org/10.3390/app13084652>
- Füchtenhans, M., Glock, C. H., Grosse, E. H., & Zaroni, S. (2023). Using smart lighting systems to reduce energy costs in warehouses: A simulation study. *International Journal of Logistics Research and Applications*, 26(1), 77-95.
- Granillo-Macías, R. (2020). Inventory management and logistics optimisation: a data mining practical approach. *LogForum*, 16(4).
- Hamdy, W., Al-Awamry, A., & Mostafa, N. (2022). Warehousing 4.0: A proposed system of using node-red for applying Internet of things in warehousing. *Sustainable Futures*, 4, 100069.
- Hamilton, J. R., Maxwell, S. J., Ali, S. A., & Tee, S. (2024). Adding external artificial intelligence (AI) into internal firm-wide smart dynamic warehousing solutions. *Sustainability*, 16(10), 3908.
- Hammler, P., Riesterer, N., & Braun, T. (2023). Fully dynamic reorder policies with deep reinforcement learning for multi-echelon inventory management. *Informatik Spektrum*, 46(5), 240-251.
- Henderson, J., Crawford, L., Birch, J., Potter, N., Halai, Y., Salar, R., & Lu, C. (2022). *Colliers Outlook for Australian Warehouse Demand, Q2 2022* [PowerPoint presentation, pp. 1–11]. Colliers. Retrieved from: <https://www.Colliers.com.au/download-article?itemid=c14c8b87-f25b-4b6f-b3ab-1025e1dc3138> , (accessed 16 March 2023)
- Hoitan, S. A. (2023). *Optimising the Role Allocation Process in Warehouses: Digitalisation of the Daily Rostering Process by Integrating AI and IoT Technologies*. Retrieved from <https://www.diva-portal.org/smash/get/diva2:1776698/FULLTEXT01.pdf> (accessed 15 July 2025).

- Ibekwe, K. I., Umoh, A. A., Nwokediegwu, Z. Q. S., Etukudoh, E. A., Ilojiana, V. I., & Adefemi, A. (2024). Energy efficiency in industrial sectors: A review of technologies and policy measures. *Engineering Science & Technology Journal*, 5(1), 169-184.
- Immerman, G. (2019). Industry 4, The History, Benefits, and Technologies. MachineMetrics. Retrieved from <https://www.machinemetrics.com/blog/what-is-industry-4-0> (accessed 17<sup>th</sup> March 2023).
- Islam, S., & Uddin, K. (2023). Correlated storage assignment approach in warehouses: A systematic literature review. *Journal of Industrial Engineering and Management*, 16(2), 294-318.
- Jarašūnienė, A., Čižiūnienė, K., & Čereška, A. (2023). Research on impact of iot on warehouse management. *Sensors*, 23(4), 2213.
- Jenkins, A., (2020). Warehouse Automation Explained: Types, Benefits & Best Practices. *NetSuite*. Retrieved from: <https://www.netsuite.com/portal/resource/articles/inventory-management/warehouse-automation.shtml> (accessed 17<sup>th</sup> March 2023).
- JLL Australia. (2021). Smart warehouses spread to new markets: Retailers are turning to robots amid rising expectations for fast deliveries. *JLL Australia*. Retrieved from <https://www.jll.com.au/en/trends-and-insights/investor/smart-warehouses-spread-to-new-markets> (accessed 16<sup>th</sup> March 2023).
- Kalkha, H., Khiat, A., Bahnasse, A., & Ouajji, H. (2023). The rising trends of smart e-commerce logistics. *IEEE Access*, 11, 33839-33857.
- Kalkha, H., Khiat, A., Bahnasse, A., & Ouajji, H. (2024). Enhancing Warehouse Efficiency with Time Series Clustering: A Hybrid Storage Location Assignment Strategy. *IEEE Access*, 12, 52110-52126.
- Kechagias, E. P., Konstantakopoulos, G. D., & Papadopoulos, G. A. (2022). A Predictive Maintenance System for Reverse Supply Chain Operations. *Logistics*, 6(1), 4.
- Kellermayr-Scheucher, M., Niedermeier, M., & Brandtner, P. (2023). Applications and Perceptions of Workforce Management Systems for Warehouse Operation-Results and Findings from Expert Interviews. *Procedia Computer Science*, 219, 255-262.
- Kembro, J., Norrman, A., (2022). The transformation from manual to smart warehousing: An exploratory study with Swedish retailers. *International Journal of Logistics Management*, 33(3), 941-974. <https://doi.org/10.1108/IJLM-11-2021-0525>
- Khan, M. G., Huda, N. U., & Zaman, U. K. U. (2022). Smart warehouse management system: Architecture, real-time implementation and prototype design. *Machines*, 10(2), 150.
- Kubasakova, I., Kubanova, J., Benco, D., & Kadlecová, D. (2024). Implementation of automated guided vehicles for the automation of selected processes and elimination of collisions between handling equipment and humans in the warehouse. *sensors*, 24(3), 1029.
- Kudelska, I., & Niedbał, R. (2020). Technological and organisational innovation in warehousing process—research over workload of Staff and efficiency of picking stations. *E+M Ekonomie a Management*, 23(3), 67–81. <https://doi.org/10.15240/tul/001/2020-3-005>
- Kumar, S., Narkhede, B. E., & Jain, K. (2021). Revisiting the warehouse research through an evolutionary lens: a review from 1990 to 2019. *International Journal of Production Research*, 59(11), 3470-3492.
- Laçi, M., Koçak, A. B., İntizamoğlu, Y., Gökdemir, B., & Cevher, O. (2021). A Business and ROI Model for Intelligent Storage and Warehouse Solutions. *ResearchGate*. Retrieved from [https://www.researchgate.net/publication/360835588\\_A\\_Business\\_and\\_ROI\\_Model\\_for\\_Intelligent\\_Storage\\_and\\_Warehouse\\_Solutions](https://www.researchgate.net/publication/360835588_A_Business_and_ROI_Model_for_Intelligent_Storage_and_Warehouse_Solutions) (accessed 15 July 2025).
- Ledbury, S. (2024) Reshoring, software, and expanded AI: key warehouse trends for 2024. *Swisslog Blog*. Retrieved from: <https://www.swisslog.com/en-au/case-studies-and-resources/blog/key-warehouse-automation-trends-for-2024> (accessed on 30 June 2024)
- Lesch, V., Müller, P. B., Krämer, M., Hadry, M., Kounev, S., & Krupitzer, C. (2023). Optimising storage assignment, order picking, and their interaction in mezzanine warehouses. *Applied Intelligence*, 53(15), 18605-18629.
- Licardo, J. T., Domjan, M., & Orehovački, T. (2024). Intelligent Robotics—A Systematic Review of Emerging Technologies and Trends. *Electronics*, 13(3), 542.
- Lorenc, A., & Lerher, T. (2020). PickupSimulo—prototype of intelligent software to support warehouse managers decisions for product allocation problem. *Applied Sciences*, 10(23), 8683.
- Lukinskiy, V., Lukinskiy, V., Ivanov, D., Sokolov, B., & Bazhina, D. (2023). A probabilistic approach to information management of order fulfilment reliability with the help of perfect-order analytics. *International Journal of Information Management*, 68, 102567.
- Mahmut, T. (2022). Warehousing 4.0 in logistics 4.0. In I. Lyigun & O. F. Gorcun (Eds.), *Logistics 4.0 and future of supply chains* (pp. 111-125). Singapore: Springer. [https://doi.org/10.1007/978-981-16-5644-6\\_7](https://doi.org/10.1007/978-981-16-5644-6_7)
- Maturo, A., Buonomano, A., & Athienitis, A. (2022). Design for energy flexibility in smart buildings through solar based and thermal storage systems: Modelling, simulation and control for the system optimisation. *Energy*, 260, 125024.
- Meisingseth, A. S., & Nilsson, J. (2023). Smart Warehouses: A case study of organisational planning in unpredictable environments (Master's thesis, Jönköping University). Retrieved from <https://www.diva-portal.org/smash/get/diva2:1781388/FULLTEXT01.pdf> (accessed 15 July 2025).
- Min, H. (2023). Smart Warehousing as a Wave of the Future. *Logistics*, 7(2), 30.
- Minashkina, D., & Happonen, A. (2023). A systematic literature mapping of current academic research linking warehouse management systems to the third-party logistics context. *Acta Logistica (AL)*, 10(2).

- Minashkina, D., & Happonen, A. (2023). Warehouse Management Systems for Social and Environmental Sustainability: A Systematic Literature Review and Bibliometric Analysis. *Logistics*, 7(3), 40. <https://www.mdpi.com/2305-6290/7/3/40> (accessed on 9 June 2024)
- Miroedova, S. (2023). Thesis Study: analysis of the implementation of Artificial Intelligence in warehouses of e-commerce SMEs based on feasibility study (Master's thesis, LAB University of Applied Sciences). Retrieved from [https://www.theseus.fi/bitstream/handle/10024/812680/Miroedova\\_Sofia.pdf?sequence=2](https://www.theseus.fi/bitstream/handle/10024/812680/Miroedova_Sofia.pdf?sequence=2) (accessed 15 July 2025).
- Mohanraj, K., Vijayalakshmi, S., Balaji, N., Chithrakkannan, R., & Karthikeyan, R. (2019). Smart warehouse monitoring using IoT. *International journal of engineering and advanced technology*, 8(6), 3597-3600.
- Molęda, M., Małyśiak-Mrozek, B., Ding, W., Sunderam, V., & Mrozek, D. (2023). From Corrective to Predictive Maintenance- A Review of Maintenance Approaches for the Power Industry. *Sensors*, 23(13), 5970.
- Naseer, A., Naseer, H., Ahmad, A., Maynard, S. B., & Siddiqui, A. M. (2023). Moving towards agile cybersecurity incident response: A case study exploring the enabling role of big data analytics-embedded dynamic capabilities. *Computers & Security*, 135, 103525.
- Niaz, M. (2022). Revolutionising Inventory Planning: Harnessing Digital Supply Data through Digitization to Optimise Storage Efficiency Pre-and Post-Pandemic. *BULLET: Jurnal Multidisiplin Ilmu*, 1(03).
- Odimarha, A. C., Ayodeji, S. A., & Abaku, E. A. (2024). The role of technology in supply chain risk management: Innovations and challenges in logistics. *Magna Scientia Advanced Research and Reviews*, 10(2), 138-145.
- Ooi, J. X., Pang, X. T., & Teng, Z. X. (2023). The adoption of smart warehouse in Shah Alam: A qualitative study on the decisive factors (Doctoral dissertation, UTAR).
- Pasi, B. N., Mahajan, S. K., & Rane, S. B. (2020). Smart supply chain management: a perspective of industry 4.0. *Supply Chain Management*, 29(5), 3016-3030.
- Pech, M., Vrchota, J., & Bednář, J. (2021). Predictive maintenance and intelligent sensors in smart factories. *Sensors*, 21(4), 1470.
- Perotti, S., & Colicchia, C. (2023). Greening warehouses through energy efficiency and environmental impact reduction: a conceptual framework based on a systematic literature review. *The International Journal of Logistics Management*, 34(7), 199-234.
- Pontius, N. (2018). The complete guide to warehouse automation: basics of organization and warehouse labeling, automation technologies, best practices, and more. *Industry Resources, Warehouse Labels*. Retrieved from <https://www.camcode.com/blog/guide-to-warehouse-automation/> (accessed 16<sup>th</sup> March 2023).
- Proto, S., Di Corso, E., Apiletti, D., Cagliero, L., Cerquitelli, T., Malnati, G., & Mazzucchi, D. (2020). REDTag: a predictive maintenance framework for parcel delivery services. *IEEE Access*, 8, 14953-14964.
- Riméllé, Adrien, Philippe Grangier, Michel Gamache, Michel Gendreau, and Louis-Martin Rousseau. "E-commerce warehousing: learning a storage policy. *arXiv preprint arXiv:2101.08828* (2021). <https://arxiv.org/pdf/2101.08828>
- Sahara, C. R., & Aamer, A. M. (2022). Real-time data integration of an internet-of-things-based smart warehouse: a case study. *International Journal of Pervasive Computing and Communications*, 18(5), 622-644.
- Sarker, I. H. (2022). Ai-based modeling: Techniques, applications and research issues towards automation, intelligent and smart systems. *SN Computer Science*, 3(2), 158.
- Schlesinger, L. (2021). Australia plays 'Catch' up on e-commerce-led warehouse boom. *Australian Financial Review*. Retrieved from
- Schuhmacher, J., & Hummel, V. (2023). Development of an AI-Based Method for Dynamic Affinity-Based Warehouse Slotting Using Indoor Localisation Data. In *Smart, Sustainable Manufacturing in an Ever-Changing World: Proceedings of International Conference on Competitive Manufacturing (COMA'22)* (pp. 149-160). Cham: Springer International Publishing.
- Sękala, A., Błaszczak, T., Foit, K., & Kost, G. (2024). Selected Issues, Methods, and Trends in the Energy Consumption of Industrial Robots. *Energies*, 17(3), 641.
- Selvaraj, A. S., & Anusha, S. (2021). RFID enabled smart data analysis in a smart warehouse monitoring system using IoT. *Journal of Physics: Conference Series* (Vol. 1717, No. 1, p. 012022). IOP Publishing.
- Severns, M. (2022). Creating the Warehouse of the Future. *Blue Yonder Blog*. Retrieved from <https://blog.blueyonder.com/creating-the-warehouse-of-the-future/> (accessed 16<sup>th</sup> March 2023).
- Shaer, I., & Shami, A. (2023). Data-driven methods for the reduction of energy consumption in warehouses: Use-case driven analysis. *Internet of Things*, 23, 100882. <https://doi.org/10.1016/j.iot.2023.100882>
- Shoushtari, F., Ghafourian, E., & Talebi, M. (2021). Improving Performance of Supply Chain by Applying Artificial Intelligence. *International journal of industrial engineering and operational research*, 3(1), 14-23.
- Singh, N., & Adhikari, D. (2023). AI in inventory management: Applications, Challenges, & opportunities. *International Journal for Research in Applied Science and Engineering Technology*, 11(11), 2049-2053.
- Sodiya, E. O., Umoga, U. J., Amoo, O. O., & Atadoga, A. (2024). AI-driven warehouse automation: A comprehensive review of systems. *GSC Advanced Research and Reviews*, 18(2), 272-282.
- Tang, Y. M., Ho, G. T. S., Lau, Y. Y., & Tsui, S. Y. (2022). Integrated smart warehouse and manufacturing management with demand forecasting in small-scale cyclical industries. *Machines*, 10(6), 472.
- Torchio, F. (2023). Survey on automated systems for smart warehouses (Doctoral dissertation, Politecnico di Torino). Retrieved from: <https://webthesis.biblio.polito.it/secure/29879/1/tesi.pdf> (accessed 15 July 2025).

- Thakare, O. S., Gupta, A. K., Matawale, C. R., & Yadao, A. Investigation of Financial Performance Parameter of Inventory Turnover Ratio, Day Sales Inventory and Working Capital Ratio in Steel Industries. <https://doi.org/10.5281/zenodo.8241275>
- Tikwayo, L. N., & Mathaba, T. N. (2023). Applications of Industry 4.0 Technologies in Warehouse Management: A Systematic Literature Review. *Logistics*, 7(2), 24, 1-19.
- Tong, Q., Ming, X., & Zhang, X. (2023). Construction of sustainable digital factory for automated warehouse based on integration of ERP and WMS. *Sustainability*, 15(2), 1022.
- Tubis, A. A., & Rohman, J. (2023). Intelligent Warehouse in Industry 4.0—Systematic Literature Review. *Sensors*, 23(8), 4105.
- Ulmamei, D. (2025). Four 2025 trends shaping warehousing automation and intralogistics. *Australian Manufacturing Forum*. Retrieved from <https://www.australianmanufacturing.com.au/four-2025-trends-shaping-warehouse-automation-and-intralogistics/> (accessed 15 July 2025).
- van Geest, M., Tekinerdogan, B., & Catal, C. (2021). Smart warehouses: Rationale, challenges and solution directions. *Applied Sciences*, 12(1), 219.
- van Geest, M., Tekinerdogan, B., & Catal, C. (2021). Design of a reference architecture for developing smart warehouses in industry 4.0. *Computers in industry*, 124, 103343.
- Wang, F. (2023). Research on the application of artificial intelligence technology to promote the high-quality development path of the manufacturing industry. In *SHS Web of Conferences* (Vol. 154, p. 03001). EDP Sciences.
- Wahab, S. N., Rajendran, S. D., & Yeap, S. P. (2021). Upskilling and reskilling requirements in logistics and supply chain industry for the fourth industrial revolution. *LogForum*, 17(3), 399-410.
- Wang, Q., Alyahya, S., Bennett, N., & Dhakal, H. (2015). An RFID-enabled automated warehousing system. *International Journal of Materials, Mechanics and Manufacturing*, 3(4), 287-293.
- Wang, L., Wang, Z., Gumma, K., Turner, A., & Ratchev, S. (2024). Multi-agent cooperative swarm learning for dynamic layout optimisation of reconfigurable robotic assembly cells based on digital twin. *Journal of Intelligent Manufacturing*, 1-24.
- Zhang, D., Pee, L. G., & Cui, L. (2021). Artificial intelligence in E-commerce fulfillment: A case study of resource orchestration at Alibaba's Smart Warehouse. *International Journal of Information Management*, 57, 102304, 1-15.
- Zhang, D., Pee, L. G., & Cui, L. (2021). Artificial intelligence in E-commerce fulfillment: A case study of resource orchestration at Alibaba's Smart Warehouse. *International Journal of Information Management*, 57, 102304.
- Zhou, W., Piramuthu, S., Chu, F., & Chu, C. (2017). RFID-enabled flexible warehousing. *Decision Support Systems*, 98, 99-112.
- Zunic, E., Delalic, S., Hodzic, K., Besirevic, A., & Hindija, H. (2018). Smart warehouse management system concept with implementation. In *Proceedings 2018 14<sup>th</sup> Symposium on Neural Networks and Applications (NEUREL)* (pp. 1-5). IEEE. Belgrade, Serbia.