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Green Logistics 5.0: a review of sustainability-oriented innovation with foundation models in logistics

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Abstract

Purpose – The paper uses foundation models to integrate the green approach in Logistics 5.0. Such integration is innovative in logistics and leads to a more sustainable and prosperous future. By harnessing the power of foundation models and incorporating sustainable principles, this paper can systematize the logistics industry's environmental framework, increase its social responsibility and ensure its long-term economic viability.

Design/methodology/approach – Generalizing environmental sustainability goals requires a multi-layered innovation approach incorporating corporate philosophy, products, processes and business models. In this paper, this comprehensive approach is not just a strategy but a necessity in the current global context. This paper uses the sustainability-oriented innovation (SOI) method, crucial for achieving explicit environmental, social and economic impacts.

Findings – Artificial intelligence, especially foundation models, can contribute to green logistics by optimizing routes, reducing packaging waste, improving warehouse layouts and other functions presented in the paper. At the same time, they can also consider social, economic and governance goals.

Research limitations/implications – Artificial intelligence algorithms present challenges such as high initial investment, regulatory compliance and technological integration.

Practical implications – The paper contains implications for developing environmentally sustainable logistics, which is currently one of the most significant challenges. The framework presented can apply to logistics companies.

Originality/value – This paper fulfills an identified need to study sustainability in logistics. The framework is entirely original and not present in the literature. It is essential to help design and implement innovative logistics approaches.

Keywords Logistics 5.0, Foundation models, Transportation, Warehousing, Sustainable-oriented innovation, Green logistics, Inventory management, Industry 5.0

Paper type Research paper

1. Introduction

Logistics contribute substantially to damage to the environment. Finding all possible ways to improve the situation with innovative solutions is essential. Foundational models can provide a substantial contribution. It is essential to analyze their contribution to the resolution of these problems also by considering all possible challenges and how to overcome them,

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This paper addresses the crucial aspect of Logistics 5.0 (L5.0), which is the integration of specific FMs into logistics within the general framework of Industry 5.0 (Nicoletti, 2023). These models, such as machine learning algorithms and predictive analytics, can contribute significantly to green logistics by optimizing routes, reducing packaging waste, and improving warehouse layouts (Reyana and Kautish, 2024). The use of these specific FMs in logistics can have a profound impact on the environment. Organizations can significantly reduce their carbon footprint and minimize waste generation by optimizing routes and reducing packaging waste. In addition, using these FMs in logistics can improve demand forecasting accuracy, reducing the likelihood of overproduction and waste generation.

This paper aims to use foundation models (FMs) to sustainably innovate logistics in this effort to denominate L5.0. Pursuing sustainability goals requires a multi-layered approach to innovation that incorporates the corporate philosophy, products, processes, and business models (Stanko and Rindfleisch, 2023). This approach is consistent with sustainability-oriented innovation (SOI) to achieve explicit environmental, social, and economic impact (Adams *et al.*, 2016). Artificial intelligence/AI), especially FMs, can contribute to green logistics by optimizing routes, reducing packaging waste, and improving warehouse layouts (Coza, 2024). These FMs, a subset of AI, use advanced algorithms to process and analyze data, enabling them to make predictions and recommendations. In addition, these models can predict product returns, suggest sustainable recycling practices, and optimize energy consumption, leading to numerous benefits, including energy optimization, packaging reduction, sustainable transportation, and improved reverse logistics. This synergy can drive the development of innovative solutions, encourage collaboration, and drive sustainable practices throughout the supply chain. By harnessing the power of FMs and embracing sustainable principles, the logistics industry can reduce its environmental footprint, strengthen its social responsibility, and ensure its long-term economic viability (Savastano *et al.*, 2022). Khan *et al.* (2022) had the prime objective of investigating the determinants of Logistics 4.0 adoption in the context of a developing country, specifically India. These authors establish ten determinants of Logistics 4.0 after a survey of the relevant literature and the input of industry experts. The findings show that top management support, information technology infrastructure, and financial investment are the most significant determinants of Logistics 4.0 adoption.

The benefits of these specific FMs in L5.0 go beyond environmental sustainability, as they can also improve the efficiency and effectiveness of logistics operations, leading to cost savings and significantly increased customer satisfaction. Despite the numerous benefits of these specific FMs in logistics, their implementation faces some challenges. One major challenge is the high initial investment required to develop and implement AI models (Dwivedi *et al.*, 2021). In addition, regulatory compliance and technological integration pose significant hurdles to introducing these specific FMs in logistics (Balakrishna *et al.*, 2024). In addition, the lack of standardization of logistics processes and the complexity of supply chains can complicate the implementation of FM solutions. This paper considers the challenges and discusses the ways to remediate them.

Integrating the green approach and L5.0 can revolutionize the logistics industry and lead to a more sustainable and prosperous future. L5.0, which represents the next generation of logistics, is characterized by integrating FMs, blockchain, digital twins, and the Industrial Internet of Things (IIoT) into logistics operations (Hanumantu, 2024). This synergy can drive the development of innovative solutions, promote collaboration, and support sustainable practices throughout logistics. By leveraging FMs and implementing sustainable principles, the logistics industry can reduce its environmental footprint, strengthen its social responsibility, and ensure long-term economic viability. The potential benefits of FMs in L5.0 are vast, and their implementation is crucial for the sustainable development of the logistics industry. While there are challenges, the benefits of the proposed use of FMs in logistics far outweigh the costs, and their adoption is critical to the long-term sustainability of the logistics industry.

2. Research objectives

Given the limitations of the existing literature on FMs and the increasing importance of logistics, this paper has two research objectives (RO):

RO1. Comprehensively review, analyze, and clarify the concepts that enable the implementation of L5.0 to support sustainability and derive a conceptual framework for L5.0 in line with sustainable-oriented innovation.

RO2. Validate the conceptual framework of L5.0 against practical use cases with a focus on using FMs that contribute to compliance with sustainability and identify the added value for businesses.

3. Methodologies

This paper combines cutting-edge FM solutions with sustainability-oriented innovation best practices to create a resilient, adaptable, friendly environment. This study thoroughly examines the current state and prospects of the L5.0 framework and uses a multi-layered approach to gain a nuanced understanding. This approach consists of three interrelated components: a thorough literature review, in-depth interviews with various stakeholders from academia and industry, and developing an integrated functional and technical framework to deploy FM solutions effectively. The literature review provides a wealth of perspectives based on diverse industry experience and insights. Based on this framework, the authors conducted extensive interviews with experts and practitioners to validate and refine their understanding of global 5PL logistics providers and smaller Italian 3PL providers. As part of this process, draft use cases were described and verified through business implementation, resulting in a functional and technical framework, including tools and solution approaches to analyze the transformation to L5.0 solutions and tools.

Looking at sustainability-oriented innovation is essential. A research approach based on the following steps is at the base of *t* the analysis. This paper examines how innovation promotes sustainability efforts. It leverages diverse perspectives to find innovative solutions to sustainability challenges by analyzing the “why,” the “what,” the “who, ”the “when,” the “where,” and the “how” (5 W+1H) of sustainability-oriented innovation (Lasswell, 1932; Pan and Kosicki, 1993). The paper analyzed the challenges connected with the implementation of the framework and organized them according to the 4 Ms of the cause-effect analysis of Ishikawa: Machines, Manpower, Materials, and Methods (Nicoletti, 2012).

This framework is an important milestone that provides a concrete basis for developing and deploying the L5.0 model and framework. By combining theoretical insights with practical expertise, this research and review make a meaningful contribution to the further development and implementation of FMs. It ultimately increases their potential to drive sustainability-oriented innovation and growth in the logistics landscape.

4. Results of the review

This section examines recent academic research on sustainability-oriented innovation (SOI), its impact on logistics, and the use of FMs. The focus is on the internal dynamics of SOI in organizations and the potential of Industry 5.0 to create a more sustainable logistics landscape.

4.1 Sustainability-oriented innovation

The concept of SOI forms the basis for this discussion. Pioneering research by Adams *et al.* (2016) presents a framework for understanding SOI in organizations. Table 1 shows some of

Table 1. Main differences between traditional and SOI innovation

	Traditional innovation	Sustainability-oriented innovation
Goal	Gain a competitive advantage	Achieving Triple Bottom Line results
Innovation focus	Technology and Markets	People and Organization
Capabilities and resources needed	Mainly internal	Internal and external, accessed through collaboration
Pervasiveness	Stand-alone (involves a single unit/department)	Integrated (a significant part of the organization)
Knowledge needed	Specialistic	Multidisciplinary
Change needed	Incremental or radical	Systemic
Organization's view of society	Insular (focused on itself)	Systematic (part of the organizational ecosystem)

Source(s): Elaborated by the authors' from Adams *et al.*, 2016; Ermini *et al.*, 2024

the differences concerning traditional innovation. This framework emphasizes the need for deliberate change in various aspects of an organization. These changes include products, processes, practices, and the mindset and values of the organization. Achieving sustainability goals requires a multi-layered perspective on innovation encompassing the organization's philosophy, values, products, processes, practices, and business models (Adams *et al.*, 2016). The framework proposed by Adams *et al.* (2016) frames this complex concept beyond traditional market-driven innovation and encompasses a new organizational culture and values that have an overall positive impact by addressing environmental, social, and economic goals. Sustainability-oriented innovation (SOI) will be the natural evolution of the innovation concept, as all innovations must make their environmental, social, and economic impacts explicit (Iñigo and Albareda, 2016). Table 1 summarizes and compares the main characteristics of traditional and Sustainability-oriented innovation.

Kneipp *et al.* (2023) look in more detail at the practical effects of SOI. Their study examines the positive influence of SOI practices on the business models of Brazilian industrial organizations. Their results show a clear correlation between the implementation of SOI and improved business models and underline the economic viability of sustainable practices. Aka (2019a, b) adds another dimension to understanding SOI by emphasizing its process-oriented nature. Her work explores the crucial role of interactions and transformations between managers and stakeholders. By focusing on how these interactions unfold over time, Aka (2019a, b) sheds light on the dynamic nature of SOI development in organizations. The research presented by Miranda *et al.* (2023) examines an essential tool for fostering SOI: open innovation. Open innovation refers to integrating external knowledge and expertise into an organization's innovation process. Miranda *et al.* (2023) explore how various open innovation mechanisms, such as crowdsourcing and collaboration with non-profit organizations, can be used to address sustainability challenges. Their findings show that the current focus is on environmental innovation, suggesting a potential gap in addressing the broader social aspects of sustainability. They acknowledge organizations' inherent challenges in balancing social, environmental, and financial objectives and emphasize the need for further research to address these complexities.

4.2 Foundation models (FM)

A comprehensive survey of the taxonomy and evolution of multimodal FMs demonstrates their capabilities, focusing on the transition from specialist models to general-purpose assistants (Li *et al.*, 2024). A paper examines FMs' decision-making scope and provides conceptual tools and technical background for understanding the problem space and exploring new research directions (Yang and Lin, 2020). Awais *et al.* (2023) discuss the open challenges and research directions for FMs, including difficulties in their evaluations and benchmarking, gaps in their real-world understanding, limitations of their contextual understanding, biases, vulnerability to adversarial attacks, and interpretability issues. They review recent developments in this field, covering a wide range of applications of FMs systematically and comprehensively. A comprehensive list of FMs is available at https://github.com/awaisrauf/Awesome-CV-Foundational-Models.

4.3 Industry 5.0

The thesis by Hanumantu (2024) looks at the emerging concept of Industry 5.0 and its potential impact on supply chains. This new paradigm integrates advanced technologies with human-centric approaches to create more sustainable, resilient, and efficient supply chains. The technological foundations of L5.0 include further advances in automation, AI, IoT, and data analytics (Lazzaris *et al.*, 2022; Zhu, 2024). The optimization of the logistics processes, the improvement of decision-making, and the increase in transparency and control of the entire supply chain can use these technologies. An essential aspect of L5.0 is the focus on sustainability and environmental responsibility (Trstenjak *et al.*, 2023). Green logistics practices are introduced, including environmentally friendly transportation, warehousing, and packaging (Atiku *et al.*, 2024)). This solution aligns with broader societal goals of reducing carbon emissions and environmental impacts in supply chains.

Trstenjak *et al.* (2023) investigate the current level of awareness of Industry 5.0 among Croatian manufacturers. Their findings show a limited understanding of the digital aspects of Industry 5.0 but a greater openness to incorporating “green” elements into logistics processes. This solution requires educational initiatives and industry support to help organizations fully grasp the opportunities of Industry 5.0 to achieve sustainability goals. Unlike previous industrial revolutions focused primarily on automation and efficiency, L5.0 strongly emphasizes human-machine collaboration (Lazzaris *et al.*, 2022). This approach highlights the importance of workforce development in L5.0. Human resources need to develop to work effectively with advanced technologies. This solution includes upskilling the existing workforce and adapting educational programs to prepare the future logistics workforce. The implementation of L5.0 concepts requires careful consideration of various factors. A paper proposes a model for implementing L5.0 based on the decision support systems paper (Frederico, 2021). This model considers payback time, initial investment requirements, implementation complexity, and alignment with green logistics principles. The aim is to provide organizations with a structured approach to transition to L5.0 capabilities. L5.0 represents a paradigm shift in how logistics and supply chain operations are designed and implemented. Combining advanced technologies with human-centric and sustainable approaches aims to create more resilient, efficient, and environmentally friendly supply chains (Zaid *et al.*, 2024; UK Essays, 2028).

Further research is needed to fully understand the impact and best practices for implementing L5.0 across different industries. Villar *et al.* (2023) use a systematic literature network analysis to develop a framework for Supply Chain 5.0. This framework identifies critical aspects of this new paradigm, including AI, big data, and the IIoT. These technologies are promising for optimizing supply chains, leading to higher efficiency and a lower environmental footprint.

This paper addresses logically all the critical aspects of integrating FMs (FMs) into logistics to achieve L5.0 and shows how this synergy can impact green logistics by optimizing routes, reducing packaging waste, and enhancing warehouse layouts.

4.4 Entrepreneurial approach and digitization

Studies illustrate and explain the relationship between entrepreneurial orientation and sustainable intention and how digitalization moderates the relationship between innovation and entrepreneurial founding intention. These studies provide foundational insights into sustainable business practices and logistics-related entrepreneurial orientations.

Khodor *et al.* (2024) analyze Lebanese women's entrepreneurial orientation and propensity to start new sustainable businesses by examining the mediating function of dynamic capabilities and the moderating influence of digitalization. Dynamic capabilities are a crucial mechanism through which entrepreneurial orientation positively influences the intention to start a sustainable business. Structural equation modeling was used in the study, which enables a systematic investigation of the interaction between the constructs to examine the correlations and dynamics between the variables.

Thanasi-Boçe *et al.* (2023) describe the drivers and outcomes of sustainable entrepreneurship, focusing on the challenges and prospects of sustainable entrepreneurship in North Macedonia (NM). The paper discusses a business case that is an excellent example of its leadership in sustainable entrepreneurship and its positive impact on the community and beyond. Lessons are drawn from the challenges and best practices of sustainable entrepreneurship in NM, and suggestions are made for adopting these practices in other countries in conjunction with the actions needed for implementation.

Makhloufi, L. (2024) examines how big data analytics (BDA) capabilities affect green absorptive capacity (GAC) and green entrepreneurship orientation (GEO). He uses the dynamic capability view, BDA, and knowledge-sharing literature.

5. Sustainability-oriented innovations (SOIs) and logistics 5.0

Sustainability-oriented innovations (SOI) are geared towards the well-being of the environment and society and, at the same time, create value for organizations. SOI breaks through conventional thinking regarding trade-offs and can be divided into three levels of sustainability orientation. Sustainability-relevant innovations involve creating products or services with a clearly defined customer need. Sustainability-oriented innovations are products or services developed with sustainability in mind, such as Nike's Flyknit technology (Kopnina *et al.*, 2023). Sustainability-oriented innovations are products or services that solve environmental problems, such as Patagonia's R&D portfolio (Albareda and Hajikhani, 2019).

Most organizations have relied on manual efforts from their internal resources for innovation activities in the past, nowadays. Due to ever-changing business environments, a shift towards the support of modern solutions, particularly AI, can substantially help actors committed to sustainability for the collaborative development of SOIs (Adams *et al.*, 2016; Idrees *et al.*, 2023; Yang and Lin, 2020; Zhou *et al.*, 2015). The successful development of SOIs also requires organizations to strategically orchestrate the available resources (Carnes *et al.*, 2017).

It is essential to determine which factors are most important to the organizations from the point of view of an Industry 5.0 organization and at what stage of the innovation process integrate them, as suggested by Aka (2019a, b). Work is required to analyze the level of integration of the factors and their impact on the sustainability performance of the organizations. It is essential to analyze the barriers that prevent the establishment of collaboration processes for SOI and the barriers that appear when the collaboration process occurs (Biclesanu *et al.*, 2021). The framework in this paper starts with some basics of the study by Miranda *et al.* (2023). It modifies and extends them substantially by incorporating concepts from the authors' experience based on sustainability-oriented innovation. The framework can be valuable for organizations using innovation to guide their sustainability-focused innovation efforts. Looking at sustainability-oriented innovation is essential. Starting from the research of Miranda *et al.* (2023), this study also examines how innovation promotes sustainability efforts. This core element focuses on how sustainable operations innovation facilitates knowledge sharing and enables organizations to access external expertise. It leverages diverse perspectives to find innovative solutions to sustainability challenges by analyzing the “why,” the “what,” the “who,” the “when,” the “where” (5 Ws), and the “how” (1 H) of sustainability-oriented innovation. It is possible to create a robust conceptual framework. Figure 1 can be referenced to visually represent the key elements identified through this exploration of the 5 Ws and 1 H framework.

6. FMs: empowering green logistics

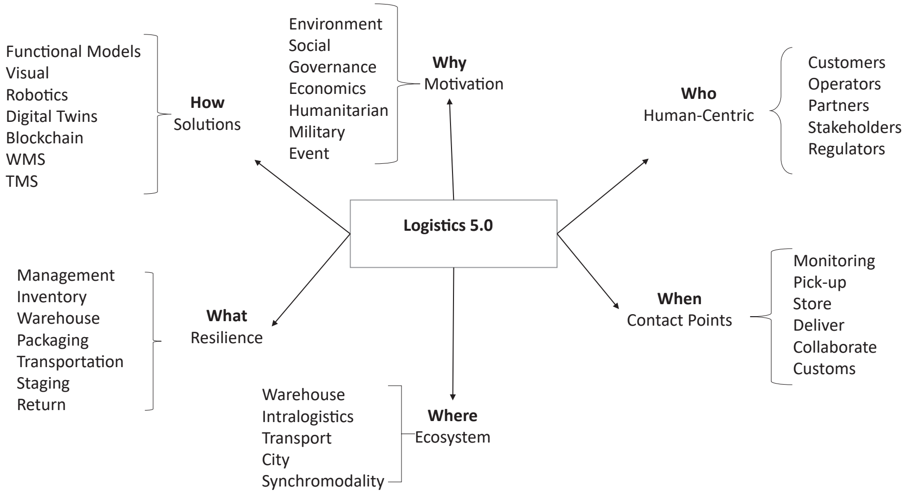
FMs are AI models designed to be general-purpose, large-scale, and flexible (Kolides *et al.*, 2023). They are created to perform a wide range of tasks rather than specific ones and are typically trained on large amounts of data with many parameters. Their flexibility allows them to be fine-tuned for specific tasks, making them adaptable to various applications. Examples of FMs include language models that can generate human-like text, image models that can generate, classify, or manipulate images, and multimodal models that process and integrate multiple forms of data, such as text and images (Myers *et al.*, 2024). These models are “foundational” because they can be used as the basis for building more specialized AI applications, much like how a foundation supports a building (Waqas *et al.*, 2023).

7. Logistics 5.0

The following sections define the concept and evolution of L5.0 and review the use of FM models to support the entire logistics lifecycle from inventory control and management to packaging, improvement, warehouse optimization, staging support, transportation management, operations, and reverse logistics implementation.

7.1 Logistics 5.0: concept and evolution

L5.0 represents the next generation of logistics, integrating advanced technologies such as IIoT, AI, robotics, and digital twins, with a strong focus on sustainability. This development is driven by improving logistics operations’ efficiency, flexibility, and environmental



Source(s): Authors’ own work

Figure 1.
5 Ws and 1 H of logistics 5.0

sustainability. AI-powered decision support systems can help logistics managers make more informed, multi-criteria decisions about investments, green initiatives, and other strategic priorities (Skitsko, 2023). Distribution logistics is a service that covers the entire transportation of goods. Warehouse and distribution logistics deals with packaging, storage, transportation, inventory control and management, reverse logistics, staging, and transportation. Warehousing and distribution logistics are used to reduce the cost of delivering finished products to customers while maintaining or improving service levels. The global warehouse and distribution logistics market is growing significantly due to the increasing demand for an efficient, cost-effective supply chain with shorter lead times. Below is the list of FM support for L5.0, based on the "what" of the general framework presented.

For instance, FMs can be used to optimize warehouse layouts for energy efficiency, predict demand patterns to minimize overstocking or plan delivery routes to reduce fuel consumption. These are just a few examples of how FMs can be applied in L5.0 to promote sustainability. AI integrates data from IIoT sensors, telematics, and other sources to create real-time visibility across the supply chain and enable better coordination and responsiveness. (Villar *et al.*, 2023). AI optimizes logistics operations to reduce energy consumption, emissions, and waste, supporting the goals of green L5.0 (Skitsko, 2023; Villar *et al.*, 2023).

In a proactive sense, FM can support circular business models in several ways (Montes-Pineda and Garrido-Yserte, 2024). These supports include dynamic pricing (reducing the price of food as it approaches its expiry date to reduce food waste), matching algorithms (applicable to sharing or second-hand platforms to efficiently connect people with the things they want, from clothing to flats), or on predictive demands (applicable to reverse logistics to glass or medicine recycling).

7.2 FMs for inventory control and management

AI can automate repetitive, time-consuming logistics tasks such as order fulfillment, inventory management, and customer service to increase productivity. (Villar *et al.*, 2023).

Fundamental models and inventory management are closely related concepts in operations research and supply chain management. Inventory models, mathematical tools used to optimize inventory levels and minimize associated costs, are critical in determining orders' optimal quantity and timing to meet demand while balancing costs. In contrast, FMs are large neural networks with deep learning capabilities trained on large data sets adapted for various tasks. Initially developed for natural language processing, FMs can support various areas, including manufacturing and supply chain management. Inventory management can be supported in various ways, including demand forecasting, supply chain optimization, predictive maintenance, process optimization, and customer retention.

FMs can create more accurate demand forecasts by analyzing historical sales data, inventory levels, and market trends, allowing for better inventory planning. They can also process large amounts of data to identify bottlenecks, optimize production schedules, and make purchasing decisions to optimize supply chain operations.

In summary, while inventory models provide the mathematical underpinnings for inventory optimization, FMs can improve inventory management by leveraging their ability to process large amounts of data and adapt to different tasks (Villacis *et al.*, 2024).

7.3 FMs for packaging improvement

The FMs optimize packaging design by analyzing product dimensions and suggesting designs that use minimal materials while ensuring product protection (Camilleri *et al.*, 2023). They also use predictive analytics to evaluate historical data and predict product damage during transport to optimize packaging according to specific requirements. In addition, the models select sustainable materials by analyzing the environmental impact of different packaging materials and suggesting environmentally friendly alternatives.

7.4 FMs for warehouse optimization

Warehouses often need more utilized areas due to efficient layout planning. FMs can analyze product dimensions and storage requirements data and pick patterns to identify these underutilized areas (Torchio, 2023). This solution enables optimized product placement that minimizes operator walking distances and reduces energy consumption due to unnecessary movements in the warehouse. Simulations to optimize the flow of traffic within a warehouse are crucial for efficient operations (Nicoletti and Appolloni, 2024). FMs can support the simulation of different warehouse layouts and traffic patterns. By simulating different scenarios, these models can identify configurations that minimize walking distances for picking and packing operations, improve overall operational flow, and reduce congestion in the warehouse. Dynamic inventory management: Inventory and product movement in a warehouse is constantly changing. FMs can analyze real-time data on these factors and suggest dynamic adjustments to the warehouse layout. This solution can include optimizing picking zones based on frequently accessed items or adjusting storage locations to improve picking efficiency and reduce congestion in high-traffic areas.

The FMs can forecast product demand, enabling adjustments to warehouse temperature control and further reducing energy consumption. In addition, the FMs perform predictive maintenance by analyzing sensor data to predict equipment failures and schedule preventive maintenance, thus reducing downtime and energy waste. In addition, the FMs can optimize lighting based on occupancy and daylight, resulting in significant energy savings.

7.5 FMs for staging

Staging is a process in which products or shipments are manually removed and placed in separate, consolidated areas for inspection. It supports docks, warehouses, and all areas where consolidation and inspection are required. Logistics staging is a critical component of inventory management and distribution (Richards and Grinsted, 2024). It involves preparing and organizing inventory for efficient storage and retrieval, sorting and grouping products according to various criteria, and temporarily storing goods before moving to the following supply chain stage.

Integrating FMs with logistics supply can lead to significant improvements. FMs can optimize staging configurations to minimize handling and improve order fulfillment speed by analyzing order patterns, shipping routes, and warehouse layouts. In addition, FMs can predict short-term fluctuations in demand and recommend real-time adjustments to staging areas to ensure that high-demand items are easily accessible. FMs can optimize staffing in staging areas by analyzing historical data and current workloads, improving overall efficiency.

FMs can provide computer vision systems that inspect products during the staging process and detect defects or faulty items before they are shipped (Sundaram and Zeid, 2023). In outbound logistics, these models can analyze traffic patterns, weather, and delivery priorities to optimize loading sequences and suggest the most efficient delivery routes. By incorporating fundamental models into logistics delivery, companies can achieve more efficient inventory management, lower operating costs, and higher customer satisfaction through faster and more accurate order fulfillment. By processing and analyzing large amounts of data, these FMs enable more informed decision-making and continuous optimization of logistics processes.

7.6 FMs for transportation management and operations

Route optimization is achieved by analyzing traffic patterns and delivery locations through FMs that minimize fuel consumption and emissions by optimizing delivery routes

(Zhang *et al.*, 2024). Depending on the distance and urgency of the delivery, FMs can suggest using environmentally friendly means of transportation, such as rail and electric vehicles, and consolidating deliveries in certain areas to reduce the number of trips (Dattero-Snell, 2023). Predictive analytics can analyze large amounts of data to forecast demand, predict disruptions, and optimize inventory, routing, and other logistics operations. This solution enables more proactive and responsive logistics management (Skitsko, 2023; Villar *et al.*, 2023). Autonomous operations support self-driving vehicles, autonomous material handling equipment, and automated warehouses to reduce manual labor and improve efficiency. Extracting information from invoices, bills of lading, and other logistics documents can take time and effort. FMs can automate this process, saving time and resources. By analyzing historical data and external factors, FMs can identify potential disruptions in logistics, allowing organizations to take proactive measures to mitigate risk (Zekhnini *et al.*, 2024). FMs can recognize patterns in sensor data and equipment performance logs to predict potential failures, enabling proactive maintenance and reducing downtime. FMs can track variables such as machine performance and energy consumption to gain insights that optimize complex transportation processes and improve overall productivity. FMs can create personalized product and transportation recommendations, enabling more efficient customer service based on customer data (Rane, 2023).

7.7 FMs for reverse logistics implementation

Unplanned returns can disrupt transportation and warehouse operations and lead to waste (Appolloni *et al.*, 2022). FMs can analyze historical data on customer returns, product types, and purchasing behavior. By identifying patterns and trends, these models can predict the likelihood of product returns, allowing warehouses to plan efficient processing of returned items. This proactive approach minimizes delays and reduces the environmental impact of managing unexpected returns. Not all returned products need to be disposed of. FMs can analyze data on the condition and functionality of returned products. Based on this analysis, the model can suggest ways to refurbish returned products for resale or find alternative uses within the warehouse operation. This approach reduces the amount of waste generated by discarding perfect items. It minimizes the need to manufacture new products, further reducing the environmental footprint of the logistics chain. Logistics generate waste during operation, including packaging material, damaged products, and electronic waste. FMs can analyze data on the composition and volume of these waste materials. By analyzing this data, the FMs can suggest the most environmentally friendly recycling options for the different types of waste. This solution ensures responsible waste management and reduces the environmental impact of warehouse operations.

8. Transformative approach of FMs

Conventional logistics faces several challenges, including inefficient energy use, where lighting, ventilation, and cooling systems consume much energy. Another challenge is excessive packaging waste, as bulky packaging materials increase transportation costs and cause landfills. In addition, emissions from delivery vehicles pollute the environment and release greenhouse gasses. FMs can transform logistics and warehousing by optimizing energy consumption, reducing packaging waste, and improving transportation routes (Oloruntobi *et al.*, 2023). They can also optimize warehouse layouts, predict product returns, and suggest sustainable recycling methods. These models are helpful for various tasks, including text-based tasks, image recognition, and route optimization. The benefits of FMs include energy optimization, packaging reduction, sustainable transport, warehouse layout optimization, and improved reverse logistics. Using these models, logistics organizations can gain a competitive advantage, improve efficiency, reduce costs, and increase customer satisfaction. Implementing FMs is associated with several challenges (Myers *et al.*, 2024). Table 2 lists the main challenges, organized according to the 4 Ms of Ishikawa: Machines, Manpower, Materials, and Methods (Nicoletti, 2012). Figure 2 provides a cause-and-effect illustration of the challenges to reach the objective of a green L5.0. Despite these challenges, the opportunities for collaboration and innovation in L5.0 make FMs an exciting and promising development in the industry.

9. Extensions

Future research could explore the application of advanced FMs, such as deep learning and neural networks, to further optimize logistics operations and improve sustainability. In addition, exploring the potential of integrating FM with other technologies, such as blockchain and IIoT, could lead to a more comprehensive and sustainable logistics system. It is essential to analyze the social impact of the introduction of FM in logistics, including job displacement and training needs, to ensure a smooth transition to a more sustainable industry.

The introduction of FMs in logistics also has its limitations. Reliance on high-quality and available data can be challenging, especially in logistics operations with incomplete or inaccurate data. Significant investment in infrastructure and training may be required, which can be a barrier for small and medium-sized enterprises. There is also a risk that FMs might perpetuate existing biases and inequalities if they are not developed with fairness and equity in mind. Continuous updates and maintenance are necessary to ensure FM systems remain effective and efficient, and the potential for job displacement requires retraining and upskilling of the workforce.

In summary, the integration of FM in logistics has the potential to revolutionize the industry and lead to a more sustainable and prosperous future. However, it is crucial to work to overcome the challenges and limitations of introducing FM and ensure responsible development and application, with ethical considerations and transparency at the forefront.

10. Results

This paper achieves the two proposed ROs in different ways. Concerning RO1, this paper constructs the functional and technological framework of L5.0, clarifying key elements that define this approach and promoting a collective understanding of the concept and its framing terminology. The review and framework cover all essential elements, including areas for FM deployment, identifying challenges, and capitalizing on opportunities. L5.0 is relevant to many organizations and leading logistics providers pursuing multiple objectives: Cost, Service Quality, Flexibility, and Sustainability. L5.0 is a dynamic, digital design and operating model built for the long term and serves as a constantly updated reference model for organizations. It can use multiple data sources to generate realistic short- and long-term modeling results. The need for real-time/*post-hoc* updates of L5.0 depends on the use cases' planning, operational, and monitoring purposes.

This paper is a contribution to RO2. Several AI algorithms form the technical framework. FMs can significantly improve the effectiveness and efficiency of logistics operations. AI can optimize warehouse layout, space planning, and route optimization in the planning phase through algorithmic analysis, predictive modeling for capacity planning and demand forecasting, automatic generation of design layouts for efficient storage and retrieval, and route optimization. On the operational side, AI can use predictive analytics for inventory management and demand forecasting, automate task assignment and scheduling for logistics workers, and provide real-time monitoring and reporting for improved supply chain

Category	Challenge	Description
Machines		
	Software	Software is a set of instructions or programs that tell a computer what to do. It is a collection of data, instructions, and algorithms that operate on a computer system. Software can be considered the opposite of hardware, which refers to the physical components of a computer. The software includes applications, operating systems, utilities, and programming languages. Software provides instructions that enable a computer to perform specific tasks and solve problems
	Hardware	FM is a system with high security, stability, and reliability requirements. Companies should build a hardware infrastructure to ensure the configurability of the Foundation Mode (FM) implementation and the real-time accuracy of the data
	Network	A telecom network is a system of interconnected devices and infrastructure. It enables communication services such as voice, data, and video transmission. Telecom networks use a combination of wired and wireless technologies. They include equipment such as switches, routers, and cell towers. Telecom networks allow for communication and data exchange over local and global distances
	Equipment	The production of different products requires different equipment or processes/modes of the same equipment. Proper equipment preparation provides accurate data for FM implementation and ensures "zero defects"
	Infrastructure	It is the primary consideration, including enterprise size, production capacity, and other enterprise infrastructure conditions, which can determine the parameters of FM implementation in L5.0 enterprises in digital transformation, thus affecting its implementation
	VR/AR	Virtual reality (VR) constitutes a computationally generated simulation of a tridimensional milieu, immersing users within a digitally constructed realm, thereby occluding the physical environment. The requisite hardware encompasses a headset or helmet equipped with a screen and sensors, facilitating user interaction with the virtual environment via controllers or gestural inputs. Augmented reality (AR) superimposes digital information upon the tangible world, enhancing the physical environment with virtual objects, sounds, or textual overlays. Utilizing a device's camera, AR displays digital content in real-time, enabling user interaction via smartphones, tablets, or smart glasses
	LLM	A Large Language Model (LLM) represents a sophisticated AI paradigm meticulously trained on expansive corpora of textual data. Its primary objective is to process and generate linguistic outputs akin to human language, demonstrating a profound comprehension of syntactical structures and semantic nuances. LLMs can address inquiries, generate novel text, summarize existing content, and engage in conversational dynamics with human counterparts. Through exposure to vast datasets and the implementation of intricate algorithms, LLMs can discern patterns and relationships, facilitating a wide range of applications, including chatbot development, language translation, and content creation

(*continued*)

Table 2.
List of the main challenges

Category	Challenge	Description
Manpower		
	Customer preparation	In order to achieve the goals of L5.0 to successfully actualize the objectives of L5.0, the FM must possess a comprehensive and accurate understanding of customer needs and preferences and effectively communicate pertinent information regarding customer expectations, thereby ensuring a harmonious alignment between customer requirements and organizational outputs. The FM must know the customer requirements precisely and effectively and provide information about the customers
	Key users	Key users constitute a subset of individuals directly influenced by and derive significant utility from a particular product, service, or project. As primary beneficiaries and end-users, they possess distinct necessities, requirements, and anticipations. These individuals provide invaluable feedback and experiential insights, which are crucial for enhancing the output's overall quality, efficacy, and user experience, thereby informing iterative improvements and refinements
	Management	The process of management encompasses a multifaceted paradigm comprising the strategic coordination and allocation of resources, the establishment of organizational structures and protocols, and the monitoring and regulation of outputs, with the ultimate objective of achieving efficacious and efficient outcomes through the optimal utilization of available resources, and the adaptation to dynamic internal and external environments
	Team	Collaborative teamwork entails the collective establishment of shared objectives, the prioritization of tasks through a consensus-driven approach, and the strategic allocation of resources to optimize output, ensuring the unified accomplishment of shared goals and facilitating a synergistic environment where individual strengths are leveraged to enhance collective performance
	Vendor	A vendor constitutes a vital entity, encompassing an individual or organizational framework, that fulfills a crucial role by providing essential goods or services, satisfying specific requirements, and necessitating and forming a fundamental link in the logistical chain of supply and demand
	Stakeholders	Stakeholders encompass individuals or entities that exercise leadership, coordination, and supervision over the endeavors of others, thereby assuming a pivotal role in orchestrating collective efforts, fostering collaborative synergy, and ensuring the effective implementation of strategies and initiatives through vigilant monitoring and guidance
Materials		
	Data collection	Data collection entails the capacity to gather and assimilate a diverse array of data points and status updates throughout the entire product lifecycle, spanning from order inception to final product delivery, thereby facilitating the optimization of product management processes and enabling informed decision-making through leveraging comprehensive and accurate insights
	Data analysis	Through the facilitation of bidirectional communication and the utilization of advanced data analytics capabilities, the organization's strategic objectives and plans are not only disseminated to production personnel but also, reciprocally, the manufacturing process's progress and status are reported back to pertinent departments, fostering a closed-loop information cycle that enables informed decision-making, enhanced operational transparency, and optimized production workflow management

Table 2. (*continued*)

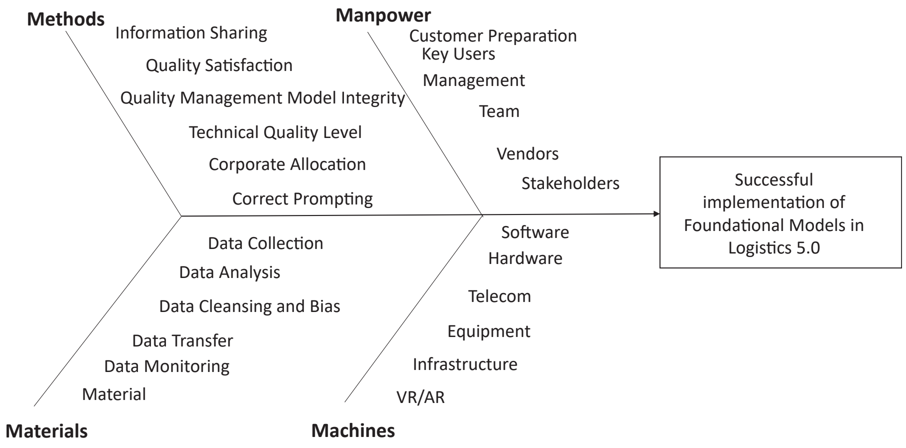
Category	Challenge	Description
	Data bias	Data bias is the systematic distortion of data collection, analysis, or interpretation that leads to misleading conclusions or results. It can have various causes, including data selection, measurement methods, or underlying assumptions, and can significantly affect the validity and reliability of research findings
	Data cleansing	Data cleansing entails systematically identifying and rectifying errors, inconsistencies, and inaccuracies within a dataset, necessitating the detection and removal or correction of missing, duplicate, or erroneous records. This rigorous process ensures data quality, reliability, and integrity, constituting a crucial precursor to data preprocessing and preparation for subsequent analysis or modeling endeavors. The resultant clean data mitigates errors, enhances decision-making efficacy, and amplifies overall data utility, contributing to downstream analytical applications' robustness and validity
	Data monitoring	Contemporary and precise data is leveraged for processing purposes, facilitating the timely dissemination of pertinent product information synchronously with real-time events unfolding in the factory. This approach enables the generation of reports that reflect current affairs, thereby providing stakeholders with an accurate and reliable snapshot of operational dynamics, fostering informed decision-making, and optimizing factory performance
	Data transfer	Data transfer facilitates the enablement of the FM to recalibrate production strategies, issue directives to production equipment to execute coordinated or simultaneous tasks and fulfill its pivotal role in integrating production and management processes, thereby bridging the gap between production and management activities. Moreover, data transfer is instrumental in determining the quality of the service process outcome, precisely the tangible result that the customer receives, thereby underscoring its criticality in ensuring the delivery of high-quality outcomes that meet customer expectations
	Material preparation	FMs facilitate the monitoring and surveillance of materials employed throughout the production process, thereby enhancing the traceability and accountability of product quality, identifying and mitigating potential quality control issues, and ultimately ensuring the manufacture of high-quality products that meet stringent standards and regulatory requirements
Methods		
	Information sharing	The manufacture of products necessitates the integration of external support, and thus, FMs must possess the capability to assimilate and reflect external information, encompassing product specifications, quality attributes, and material characteristics, facilitating the seamless incorporation of external data into the production process, and ensuring the accuracy, reliability, and comprehensiveness of product information
	Quality satisfaction	This metric offers the most unequivocal and straightforward assessment of the efficacy of FM implementation, serving as a crucial diagnostic tool to evaluate the appropriateness and adequacy of the current FM and informing data-driven decisions to modify or adjust the FM as needed, thereby ensuring optimal performance and continuous improvement

(*continued*)

Table 2.

Table 2.

Category	Challenge	Description
	Quality management model integrity	The integrity of the quality management model serves as a faithful reflection of the efficacy of the FM's quality module in ensuring the excellence of finished products, encompassing the meticulous control of processes preceding, during, and after implementation, as well as the tangible outcomes and achievements garnered throughout the various stages of production, thereby providing a comprehensive and accurate assessment of quality control measures
	Technical quality level	The technical quality level denotes the standard of excellence embodied in the output of the service process, precisely the tangible outcome that the customer receives and benefits from, as well as the caliber of the service delivery that the company provides to the customer, thereby encompassing both the customer's experiential aspect and the company's performance capability in terms of service quality
	Corporate allocation	This factor serves as the paramount transfer metric for the product throughout the entire production spectrum, spanning from the initial to the final process, thereby indicative of the product's capacity to seamlessly traverse all processes and ultimately culminate in the final product. This metric genuinely reflects the efficacy of the FM implementation in facilitating digital transformation within L5.0 enterprises, providing a tangible benchmark for assessing the success of this paradigm shift
	Prompting	The prompting process entails providing inputs, encompassing textual or visual stimuli designed to guide and orient the AI's response. Prompting strategies can be categorized into three forms: open-ended, structured, and primed, each tailored to elicit specific outcomes. The efficacy of prompting techniques profoundly impacts the quality and relevance of the AI's output. Moreover, crafting effective prompts is essential for fostering productive human-AI collaboration and facilitating seamless communication between humans, automation. and machines



Source(s): Authors' own work

Figure 2.
Cause-effect diagram of influential factors of FM in the implementation for a digital transformation

visibility. FM can use autonomous mobile robots (AMR) and automated guided vehicles (AGV) for efficient transportation, putaway, and retrieval, FM-driven sorting and packing systems for greater accuracy, and real-time item recognition and tracking for improved inventory management. FM can improve logistics safety through anomaly detection and alert systems, predictive maintenance of equipment and machinery, and improved monitoring and control systems. Organizations can increase efficiency, reduce costs, and improve their decision-making capabilities by integrating FM into logistics operations.

11. Conclusions

The green approach and L5.0 represent essential steps towards sustainable innovation and entrepreneurship. By aligning logistics operations with sustainability criteria, logistics organizations can achieve significant environmental benefits while increasing operational efficiency. The synergy between these two paradigms promises to lead the logistics industry toward a more sustainable and prosperous future.

The paper provides a multi-layered and generalized approach encompassing corporate philosophy, products, processes, and business models to support environmental sustainability goals. The paper emphasizes that this comprehensive approach is not just a strategy but a necessity in the current global context. This paper uses the Sustainability-Oriented Innovation (SOI) methodology, which is crucial for achieving explicit environmental, social, and economic impact.

Artificial intelligence, especially foundation models, can contribute to green logistics by optimizing routes, reducing packaging waste, improving warehouse layouts, and other functions presented in this paper. At the same time, they can address social, economic, and governance objectives. The paper explores the challenges of implementing AI algorithms, such as the high initial investment, regulatory compliance, and technological integration.

The framework presented in this paper is an essential tool for achieving ESG goals and a vital objective of this review.

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