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SUSTAINABILITY IN MANUFACTURING LOGISTICS: LITERATURE REVIEW OF CONCEPTS AND FUTURE PERSPECTIVES

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Abstract. This article reviews the evolving concept of sustainability in manufacturing logistics, focusing on the integration of sustainable practices across supply chains. A comprehensive literature review was conducted and key aspects of sustainability in manufacturing logistics were analysed, such as resource optimisation, waste reduction and the role of third-party logistics services. The study highlights the challenges faced by manufacturing logistics in achieving sustainability, including technological, regulatory and operational barriers, and explores future opportunities such as green technologies and digital tools to enhance transparency. A key finding is the importance of coordinated industry efforts for advancing sustainability while maintaining competitiveness.

Keywords: Manufacturing Logistics, Sustainability, Sustainable Manufacturing Logistics, Optimisation, Eco-Friendly Practices

INTRODUCTION

Research relevance and problem. Sustainability in manufacturing logistics solves critical challenges that impact the environment, operational efficiency, regulatory compliance, ethical practices and innovation. To address the problem of climate change and strive for carbon neutrality, the carbon footprint of various aspects of logistics has been analysed to determine its alignment with global policies and initiatives (Chunglam et al., 2024). Regulatory compliance poses additional challenges, requiring adherence to environmental laws and standards. Ethical concerns related to labour conditions and supply chain (SC) transparency are also paramount, especially in global manufacturing contexts. Moreover, the need for innovation drives the search for sustainable solutions that can enhance competitiveness while reducing environmental impact.

Key issues include the environmental footprint of traditional logistics practices, such as air and water quality degradation and resource depletion, alongside inefficiencies and high costs in logistics operations. Addressing these challenges through research can contribute to advancing sustainable practices in manufacturing logistics, thereby fostering environmental stewardship, operational effectiveness, regulatory adherence, ethical responsibility and innovation leadership within the industry.

Research object: the exploration of sustainable practices in manufacturing logistics, with a particular focus on reducing the carbon footprint, optimising resource utilisation, and integrating innovative technologies in SC management to meet global sustainability goals.

Research aim: the aim of this research was to conduct a comprehensive literature review of sustainability in manufacturing logistics, examining key concepts, current practices and future perspectives, with the goal of identifying opportunities and challenges for enhancing sustainability throughout the SC.

Research objectives:

1. To analyse the main concepts and methods of sustainability in manufacturing logistics, based on academic sources.
2. To identify the challenges faced by manufacturing logistics in achieving sustainability.
3. To review future perspectives and trends that will shape the development of sustainability in the context of manufacturing logistics.

Research focus: the focus of this article was the exploration of sustainability practices and strategies within manufacturing logistics, with particular attention paid to concepts, methods and future directions for integrating environmental, economic and social sustainability throughout the logistics and SC processes

Research methods – literature review. Analysing and synthesising existing academic and industry research into sustainability in manufacturing logistics, focusing on key concepts, methods and emerging trends.

SUSTAINABLE MANUFACTURING LOGISTICS – LITERATURE REVIEW

The manufacturing system consists of several elements that are closely interconnected. These elements typically include facilities, people and equipment. In addition to these elements, software and procedures, which can also have a significant impact on production processes, should be considered. One such procedure is logistics, which encompasses all processes from the procurement of raw materials to the delivery of a finished product to the end consumer.

Since the early 1990s, major transformations have shaped the business landscape. Globalisation has redefined competitive dynamics, with customers increasingly demanding timely, cost-effective delivery of the right materials, precisely when and where needed. Logistics involves the strategic management of the supply, transportation and storage of materials, components and finished goods across both organisational and marketing channels. It functions as a crucial element within supply chain management (SCM) (Başkol, 2010), encompassing tasks such as procurement, inventory management, transportation, fleet operations and the collection and analysis of data for reporting purposes (Gelmez & Zerenler, 2020).

Logistics as an academic discipline was first defined in the 1950s, with the development of MRP I (material requirements planning), a system for planning production resource needs. A decade later, MRP I was enhanced with capacity planning algorithms, leading to the creation of MRP II (manufacturing resource planning). In the 1970s, advances in computer technology accelerated information flows, paving the way for the development of fully integrated logistics systems. These systems helped reduce costs and gradually replaced manual labour with mechanisation (Straka et al., 2020). Initially, logistics played a crucial role in transporting military personnel, equipment and supplies. While logistics remains vital in the military, today the term is more commonly associated with the movement of commercial goods within SCs (Essex, 2019).

Logistics involves the efficient transfer of goods from suppliers to production sites, and from production sites to final consumption locations, in a cost-effective manner, while maintaining an acceptable level of quality agreed upon with the customer (Zinkevičiūtė & Vasiliauskas, 2013). Logistics is the process of planning and executing the efficient transportation and storage of goods from their origin to their point of consumption. Typically, large retail companies or manufacturers manage key parts of their logistics networks, but many businesses outsource this function to third-party logistics (3PL) providers (Essex, 2019).

Logistics, in fulfilling its primary task of supplying goods and services to meet consumer needs in the most efficient manner (Zinkevičiūtė & Vasiliauskas, 2013), also has specific objectives. According to Essex (2019), the goal of logistics is to meet customer demands promptly and cost-effectively. Straka et al. (2020) assert that the objective of logistics is to create a unified, integrated and optimised flow of materials from various parts of the system to ensure the continuous exchange of goods and services.

Zinkevičiūtė and Vasiliauskas (2013) outline two primary goals of logistics:

1. To plan and coordinate all processes to achieve a high level of customer service and the highest quality of service at the lowest cost.
2. To deliver products of the right quality, in the right quantity, to the right customer, at the right place, at the right time, while maximising profit.

Regardless of the specific definition of logistics or the goals set, logistics will always be understood as the coordination of actions that ensure the movement of goods. In other words, logistics encompasses all operations that repeatedly occur to transform raw materials into products, which are then delivered to the end consumer at their location.

Logistics, together with marketing, are vital elements of any manufacturing or trading business. Marketing tasks, including product promotion, pricing strategies and customer segmentation, are crucial for driving revenue and establishing brand identity. Conversely, logistics operations, such as SCM, transportation, and warehousing, are essential for ensuring the timely and intact delivery of products to customers (Spivakovskyy et al., 2023). Effective marketing helps to attract and retain customers, influencing their purchasing decisions and fostering brand loyalty. Efficient logistics guarantee that products are delivered to customers on time and in good condition, enhancing customer satisfaction and trust. Together, marketing generates the demand and drives sales, while logistics fulfils these demands by managing the flow of goods from production to the end consumer, ensuring a seamless and efficient operation that supports the overall business objectives.

Table 1. Marketing and logistics operations characteristics in manufacturing and trading firms (Spivakovskyy et al., 2023)

Marketing activities	Logistics activities
Market research: Production and trading enterprises must conduct thorough market research to pinpoint customer needs and desires. These data are vital for crafting marketing strategies and product offerings that closely match customer preferences.	SCM: Logistics encompasses overseeing the entire SC, from sourcing raw materials to delivering finished products to consumers. This entails coordinating activities across various departments and collaborators, including suppliers, manufacturers, distributors and retailers.
Branding: Businesses must establish a robust brand identity to distinguish themselves in the marketplace. This involves developing a distinctive brand identity, messaging, and visual elements that resonate effectively with their target audience.	Transportation: Logistics encompasses the coordination of the movement of goods between locations. This includes selecting the most efficient and cost-effective transportation methods, overseeing logistics providers and ensuring punctual delivery.
Product development: Companies must continually innovate by introducing new products or enhancing existing ones to maintain market relevance. This involves allocating resources to research and development, product design and rigorous testing.	Inventory management: Logistics involves overseeing inventory levels to ensure products are available when needed by customers. This entails predicting demand, managing production schedules and optimising inventory to minimise costs while maximising customer satisfaction.
Sales and distribution: Marketing includes establishing effective sales and distribution channels to reach customers efficiently. This encompasses selecting appropriate sales channels, devising pricing strategies, and managing product distribution to retailers or wholesalers, or directly to consumers.	Customer service: Logistics plays a pivotal role in customer service by influencing order fulfilment speed, delivery accuracy and overall product quality. Companies must invest in robust customer service systems and processes to consistently meet customer expectations.

The unique characteristics of marketing and logistics activities in production and trade enterprises underscore their critical roles in navigating SCs, meeting customer demands and driving competitive advantage in the marketplace. Efficient coordination between these functions is essential for ensuring seamless operations and maximising business success.

Logistics processes are an integral part of the effective functioning of a manufacturing company. These processes do not operate autonomously but ensure the achievement of the primary goals of the manufacturing enterprise. To gain a competitive advantage in today's market, cost reduction is a fundamental prerequisite. Consequently, logistics activities offer extensive opportunities for the targeted management of SC costs within a manufacturing company (Zinkevičiūtė & Vasiliauskas, 2013). Specifically, logistics processes involve the strategic planning, implementation and control of the movement and storage of goods, services and information within an SC. This includes everything from sourcing raw materials, managing inventory and coordinating transportation, to handling finished goods and ensuring they reach the end customer efficiently and cost-effectively.

Effective logistics management can lead to significant cost savings through optimised inventory levels, reduced transportation expenses and improved SC coordination. It can also enhance customer satisfaction by ensuring timely delivery and high-quality service. Moreover, advanced logistics strategies can help to minimise waste, improve resource utilisation and increase overall productivity, thereby supporting the sustainability and profitability of the manufacturing company.

From a marketing perspective, manufacturing means the processing of objects with the aim of giving them the properties necessary for consumption. The objects being processed are certain materials and raw materials needed for the production of goods (Minalga, 2008). Manufacturing forms the foundation of any nation and plays a pivotal role in modern society, encompassing diverse activities ranging from textile production to steel manufacturing. At its core, manufacturing involves the transformation of raw materials into essential goods that meet societal needs. The industry is structured into distinct divisions based on the types of raw materials utilised:

1. Agro-based industries: These include sectors such as cotton, wool, jute, sugar, tea, coffee, silk, textile, rubber, and others that rely heavily on agricultural produce.

2. Mineral-based industries: This category comprises industries involving iron and steel, aluminium, cement, oil, and gas, which depend primarily on mineral resources for production (Maurya et al., 2023).

Manufacturing is a complex system in which the processes involved include the supply of raw materials, the use of those raw materials in manufacturing the product, and the delivery of that product (Zinkevičiūtė & Vasiliauskas, 2013). A product is considered fully produced only when it has been delivered to the location of final consumption or further processing. All elements of the production system require resources used in the creation of the product: human, material, informational, natural and financial. These resources, utilised by companies, are transformed in various ways to produce the final goods, services or information needed for consumption.

The manufacturing process encompasses several distinct stages. It begins with the creation of a new product, which involves research, design and development to meet market demands. This is followed by investments in necessary resources, such as technology, equipment and workforce, to support production. The next stage involves the procurement of raw materials, ensuring that all necessary components are available for manufacturing. The actual production phase then takes place, in which raw materials are transformed into finished goods through various manufacturing processes. Finally, the completed products are marketed and sold, reaching consumers and generating revenue for the company. Each stage is crucial for ensuring that the end product meets quality standards and consumer expectations (Zinkevičiūtė & Vasiliauskas, 2013). At each stage of the production process, distinct and stage-specific tasks are addressed. The decision-making and strategies chosen at each phase significantly impact a company's operational efficiency, economic outcomes and the level of consumer satisfaction with their product. Appropriate navigation of these tasks ensures that the production process runs smoothly, resources are used optimally and the final product meets the quality and expectations of the market, thereby contributing to the overall success and competitiveness of the company.

During the manufacturing process, operations are carried out to produce the final product, which must meet certain quality standards. The quality of the product depends primarily on how it is perceived by the consumer, and secondly, on the technological aspects of the production process. Therefore, quality is considered to be the extent to which consumer expectations are satisfied. Several elements of the production process necessary to achieve quality are reported in the literature:

1. Production activities – methods applied to manufacture products that satisfy consumers and meet a company's goals.
2. Efficiency of the production process – the degree of alignment between the results of the production process and an organisation's objectives (Zinkevičiūtė & Vasiliauskas, 2013).

Manufacturing encompasses various processes that transform raw materials into final products. Utilising human, material, informational, natural and financial resources, these processes create, extract, process or modify products to make them suitable for consumption. Production can be tangible or intangible and is considered complete when the product is delivered for final consumption or further processing.

Manufacturing logistics is a field that focuses on increasing the efficiency and effectiveness of logistics processes within the manufacturing industry. In the manufacturing industry, goods are produced, so raw materials, components and finished products must be transported from one stage of the production process to another.

Hadaś et al. (2014), Minalga (2008), and Zinkevičiūtė & Vasiliauskas (2013) argue that logistics activities can be functionally divided into three areas:

- Supply logistics – internal procurement logistics that involve all of the actors in the SC involved in sourcing the materials needed to create a product and transporting them to the production site.
- Manufacturing logistics – the logistics within a company to ensure the synchronisation of the functions of all production units at the lowest possible cost.
- Distribution logistics – external outbound logistics directly linked to the final customer of the product. Distribution logistics is the main link between the manufacturer and the final consumer.

Thus, according to Zinkevičiūtė & Vasiliauskas (2013), the following generally accepted relationship applies: *Logistics = supply + manufacturing + distribution*.

Manufacturing logistics encompasses all activities from the receipt of goods to their dispatch. The primary goal of manufacturing logistics is to provide effective logistical support for production through

material planning, which includes the planning, execution and control of material flows. Consequently, effective and well-functioning manufacturing logistics ensures minimal inventory levels, short production times, a high degree of production flexibility and a consistent focus on customer satisfaction (Hadaś et al., 2014).

Minalga (2008) believes that manufacturing logistics manages the material flows that occur within a manufacturing company during the technological process. To optimise production processes, specific logistics tools and solutions are prevalent in the production area, forming the core of production logistics. In addition, logistics and transportation are crucial aspects of production environments. In these settings, logistics costs significantly impact the overall cost of goods sold (Aghamohammadzadeh et al., 2020).

In summary, manufacturing logistics is critical for achieving operational excellence in manufacturing. It ensures that materials are effectively managed, production processes are optimised and customer demands are met with high efficiency and flexibility. Through strategic planning, execution, and control of material flows, production logistics helps manufacturers maintain a competitive edge in the market. Logistics processes are vital for achieving operational efficiency and cost-effectiveness, both of which are essential for sustaining competitiveness in the modern industrial landscape. By integrating robust logistics strategies, manufacturers can streamline operations, reduce costs and enhance their ability to respond quickly to market changes, thereby solidifying their position in the industry.

Sustainability in Manufacturing Companies

When researchers analyse the concept of sustainability, its ambiguity diminishes, and its meanings become more focused and less varied compared with those presented by other authors. Researchers identify different uses and meanings of the concept of sustainability (Salas-Zapata & Ortiz-Muñoz, 2019):

1. The term sustainability is frequently used by scholars and researchers to denote the incorporation of social and environmental criteria or qualities into *human actions*. These actions may involve products or processes that inherently involve interactions between humans and ecosystems.
2. Sustainability is discussed as a *societal objective*. Scholars, researchers and professionals often assert that a system is sustainable when it pursues specific goals.
3. Sustainability is the behaviour of a *reference system*. The terms used to describe this behaviour include resilience, adaptive capacity, robustness, balance, equilibrium, the ability to cope with disturbances, and the maintenance of social–ecological systems.
4. Sustainability is used to signify researchers' intent to address variables that evaluate the environmental, social and ecological performance of a reference system. Thus, from this perspective, sustainability can be viewed as a *method for studying* specific systems (Salas-Zapata & Ortiz-Muñoz, 2019).

Sustainability is not a standalone concept but rather a characteristic that signifies the longevity of practices and the utilisation of material resources to sustain those practices over time. It holds a prominent position in contemporary discourse, often implicitly critiquing societal norms and practices (Krieg & Toivanen, 2021). Sustainability is used to signify researchers' intent to address variables that evaluate the environmental, social and ecological performance of a reference system. Thus, from this perspective, sustainability can be viewed as a method for studying specific systems. Researchers analyse various factors such as resource efficiency, waste reduction and long-term ecological balance to understand how systems can maintain their functionality and support human well-being over time. This approach not only helps in assessing current practices but also in devising strategies for future improvements, ensuring that societal development does not compromise the health of our ecosystems.

The core idea of sustainability revolves around the triple bottom-line, emphasising a balanced and minimal approach to addressing environmental, economic and social dimensions (Paras & Pal, 2024). Taylor (2014) views the environment as a crucial factor in sustainability. According to world systems theory, if the global environment is seen as a complex system, the growth of core regions cannot offset their environmental impact by shifting it to peripheral regions, especially when this shift hinders poverty reduction.

The intersection of innovation and sustainability within manufacturing companies can be explored through various lenses. This includes developing new sustainable products and services, as well as enhancing internal practices across human resources, manufacturing, sales, after-sales services and real estate management to foster sustainability-oriented approaches.

Manufacturers need to adopt more sustainable

business models while still maintaining and improving their profit margins. This transition can be complex, as implementing environmentally friendly systems requires investments that increase costs but can also provide a competitive edge by creating unique customer value. Strategic transformation is particularly challenging for firms in stable industries due to their underdeveloped capabilities for generating environmental, societal and economic value (Kohtamaki et al., 2024).

Barletta et al. (2021) state that sustainable manufacturing can be defined as the combination of transformation processes and supporting business practices that create products in a manner that:

1. Supports nature's functions and diversity, minimises the concentration of man-made substances and conserves the Earth's resources.
2. Ensures the long-term profitability of the SC involved in product realisation.
3. Positively contributes to the physical, psychological and social well-being of employees, product users and local communities.

As stated by Rantala et al. (2022), cultivating an appropriate organisational culture is crucial for addressing social and environmental challenges (Geradts and Bocken, 2018). Five key elements that underpin sustainability-oriented innovations within companies are emphasised. These are setting clear goals; allocating sufficient budget and resources; fostering collaborative efforts to engage employees with suppliers, customers and other stakeholders; providing positive reinforcement; and implementing accountability measures that prioritise the creation of social and environmental value. For sustainability efforts to have a lasting impact, integration with diverse subject areas and simultaneous adoption of digital solutions are essential (Rantala et al., 2022).

Consistent performance improvement arises not merely from adopting specific improvement programmes but also from senior management's efforts to identify and develop manufacturing capabilities that are crucial to a company's competitiveness. An example is the capability to rapidly switch between products (Barletta et al., 2021). Accordingly, the degree to which companies incorporate sustainability into their strategy is strongly influenced by the mindsets of senior managers, understood as the reference framework that managers use to shape and formulate arguments and interpretations, as well as to select issues, decisions, knowledge areas, and processes to engage with. Thus, senior managers are crucial in integrating the concept of sustainability into organisations (Tollina & Vej, 2012).

Sustainability aims to reduce resource use and environmental impact by optimising the product-service lifecycle, encompassing sustainable decisions in design, manufacturing, delivery and reuse (Kohtamaki et al., 2024). Accordingly, Rantala et al. (2022) state that manufacturing companies must balance economic, environmental and social goals across their operations, acknowledging impacts throughout the value network. Sustainable manufacturing involves smart resource use, leveraging technology, regulations and social practices to create products that achieve these objectives, benefiting both the environment and human well-being.

Manufacturing companies face the complex task of grasping sustainability across multiple dimensions, such as indicators, business models, motivations, challenges, opportunities and regulatory implications. However, this presents a significant challenge as companies often prioritise specific indicators and strive to comprehend existing and forthcoming legislation.

Sustainability signifies the longevity of practices and the utilisation of material resources to sustain those practices over time. It is used to evaluate the environmental, social and ecological performance of a reference system, highlighting the environment as a crucial factor. Senior managers play a vital role in integrating the sustainability concept into organisations by shaping arguments and interpretations and by selecting issues, decisions, knowledge areas, and processes to engage with. Manufacturing companies must balance economic, environmental and social goals across their operations, acknowledging the impacts throughout the value network.

Sustainable Logistics

Logistics are crucial for business success, ensuring efficient and rapid deliveries at minimal time and cost. However, traditional logistics can have a significant negative impact on the environment. Sustainable logistics seeks to mitigate this by applying sustainability principles to transportation, warehousing and packaging functions (Turčínková, 2024).

Sustainable logistics and SCs integrate economic, environmental and social dimensions of sustainability, managing internal and external materials, information and capital. In a sustainable SC, meeting social and environmental criteria is crucial, alongside fulfilling customer needs and economic requirements to maintain competitiveness (Paras & Pal, 2024). There are three primary themes in sustainable logistics and SCM (Grant et al., 2017):

1. Reverse logistics.
2. Emissions assessment.
3. The 'greening' of logistical activities and SC.

Sustainability is connected to corporate social responsibility (CSR), as a socially responsible company should minimise its impact on the natural environment. However, CSR extends beyond environmental concerns to encompass fair trade, good employment practices and maintaining appropriate relationships with customers, suppliers and other stakeholders (Grant et al., 2017).

Sustainability in logistics can be understood as an integral component of logistics management. Sustainability performance should be considered as an influence on traditional logistics systems rather than in isolation. For instance, if senior management mandates that all suppliers be approved by the sustainability department or decides to increase the use of sea transport for shipping goods, these actions will impact other aspects of the logistics system. This might redefine the supplier base or alter the time management of the logistics flow (Björklund & Piecyk-Ouellet, 2021).

Maurya et al. (2023) believe that sustainable logistics employs various methods to bridge the gap between the economy and the environment, focusing on reducing environmental impacts associated with logistics operations, especially those related to greenhouse gases, transportation, packaging and warehousing. According to Hanus (2024), sustainable logistics seeks to minimise the carbon footprint, waste and pollution throughout all SC stages, from production and storage to transportation and product distribution to end customers. Key solutions include implementing smart, eco-friendly warehouses and modernising the transportation fleet.

Sustainable logistics practices, such as green transportation and eco-friendly packaging, play a significant role in environmental conservation. Regions that embrace sustainable logistics align with global trends and can attract environmentally conscious businesses. The European Union, a leader in combating climate change, aims to achieve complete carbon neutrality by 2050 (Kowalska et al., 2023).

In the long term, implementing strategies that make company logistics more sustainable offers numerous and major benefits, which are summarised in Table 2.

Table 2. ***Benefits of implementing sustainable logistics*** **(adopted from Turčínková, 2024).**

Benefit	**Explanation**
Environmental benefits	Sustainable logistics optimises resource use, reduces air pollution and aims to improve water quality, ensuring the preservation of these scarce resources for future generations.
Economic advantages	A key aspect of sustainable logistics is the elimination of unnecessary costs, leading to substantial savings. This includes improved operational efficiency through waste reduction, optimisation of transportation routes, use of alternative fuels, and better inventory management, which can reduce storage space requirements. These measures enhance productivity and profitability.
Strategic value	Beyond meeting regulatory requirements from governmental bodies and non-profit organisations, customers increasingly demand eco-friendlier solutions. Implementing sustainable logistics helps companies stay competitive, comply with legislation, gain a competitive edge, improve their reputation and boost customer satisfaction and loyalty.

Conversely, it is important to consider the challenges that come with implementing sustainable strategies in logistics. There is often a lack of awareness and information among management and staff, and a shortage of skilled professionals, which can result in errors and poor planning. Sustainable logistics adds complexity, requiring extra planning and coordination, and collaboration with SC partners can be challenging if they are not aligned with sustainability goals. Integrating IT systems presents issues around compatibility and the need for extensive training. Financial constraints are significant, as investments in new technologies, equipment and training are needed. Customer demand for greener products remains low due to budget limitations and a lack of trust. Resistance to change is common, driven by uncertainty and scepticism about any potential benefits. Additionally, greenwashing is prevalent, leading to customer distrust and difficulty in identifying genuine sustainability efforts (Turčínková, 2024).

Sustainable logistics integrates sustainability principles into transportation, warehousing and packaging, aligning with CSR to minimise environmental impact and influence traditional logistics systems. It employs various methods to reduce environmental impacts across SC stages, focusing on greenhouse gases, transportation efficiency,

eco-friendly packaging, and waste reduction, thus playing a crucial role in environmental conservation. In the long run, implementing strategies to transform company logistics into more sustainable practices offers several significant benefits, but it also comes with challenges.

Sustainability in Manufacturing Logistics

Sustainability in manufacturing logistics encompasses the strategic integration of environmental, social and economic factors across all facets of SC operations. This approach aims to reduce adverse environmental impacts such as resource consumption and pollution, while also addressing social responsibilities, including fair labour practices and community engagement. Economically, sustainable manufacturing logistics seeks to optimise resource use, enhance operational efficiency, and foster innovation in product design and logistics management. By prioritising sustainability, manufacturing companies can not only mitigate risks associated with regulatory compliance and resource scarcity but also gain competitive advantages through improved brand reputation, cost savings, and resilience in the face of evolving market demands and environmental challenges.

Sustainable logistics involves managing manufacturing, raw materials, inventories and finished goods from origin to end-user consumption, aiming to minimise negative impacts on the triple bottom-line. It also incorporates reverse value chain operations such as reduction, reuse, repair, recovery, disassembly, refurbishing, remanufacturing and recycling, which can greatly influence the environmental, social and economic dimensions of sustainability (Paras & Pal, 2024).

Businesses face obstacles in achieving sustainable growth in manufacturing logistics, including challenges such as increasing manufacturing costs and overhead expenses, as well as intensified market competition. To enhance sustainability, companies are increasingly leveraging 3PL services, which have been greatly enhanced by modern technologies, offering real-time information and improved transparency. Advanced technologies have had a beneficial impact on the effectiveness of 3PL services in sustainable manufacturing SCM (Qureshi, 2024).

Sustainability benefits from logistics and lean manufacturing systems, which are widely recognised for their effectiveness and form the foundation of globally renowned just-in-time production systems, known for their practical application in manufacturing (Nakashima & Surendra, 2015).

According to Melquiades et al. (2020), sustainability is a defining feature of reverse logistics, involving the operational processes of handling post-consumer and post-sale waste, as well as managing the flow of information from the end consumer to the manufacturer. The objective is to either revalorise these materials or, ultimately, ensure environmentally appropriate disposal, thereby contributing to the consolidation of sustainability concepts within the business environment, grounded in environmental, social and economic development principles.

In the context of sustainability in manufacturing logistics, it is managed to ensure competitive returns on capital assets while meeting the legitimate needs of internal and external stakeholders and responsibly addressing the impact of operations on people and the environment. Two key strategies for achieving sustainability in SCs have been identified: supplier management and SCM for sustainable products (Paras & Pal, 2024).

Sustainability in manufacturing logistics aims to optimise resource utilisation, improve operational efficiency and drive innovation in product design and logistics management. It encompasses the management of manufacturing processes, raw materials, inventories and finished goods from origin to end-user consumption, aiming to minimise adverse impacts on the triple bottom-line of environmental, social and economic factors. Increasingly, companies are adopting 3PL services enhanced by modern technologies, which provide real-time information and greater transparency. Sustainability is enhanced by lean manufacturing and logistics systems, which are recognized for their efficiency and essential contribution to just-in-time production worldwide. Additionally, sustainable logistics includes reverse logistics, managing post-consumer and post-sale waste, and ensuring that operations meet the needs of stakeholders while responsibly addressing environmental impacts.

Challenges in Achieving Sustainability in Manufacturing Logistics

Sustainability in manufacturing logistics is a key goal as industries work to reduce environmental impact and maintain competitiveness. Adopting sustainable practices can enhance efficiency, cut costs and boost reputation, but the path to sustainability is complex, and achieving sustainability in manufacturing logistics is far from straightforward. Numerous challenges arise at various stages of the SC, from technological adoption to regulatory compliance.

One of the primary challenges in achieving sus-

tainability is technological barriers. The high costs associated with implementing green technologies can be a major deterrent, requiring substantial investments in both infrastructure and employee training. Additionally, the lengthy implementation times involved often delay progress towards sustainability goals, making it more difficult for companies to rapidly adopt environmentally friendly practices.

The complexity of global SCs further complicates efforts towards sustainability. Coordinating vast and intricate supply networks is challenging, especially when partners operate in regions with different regulations or lack the same commitment to sustainable practices. Ensuring that all stakeholders comply with green standards can be challenging, as some may resist these changes or be slow to adopt new processes.

Regulatory and legal challenges also play a significant role in hindering sustainability. Companies are often obliged to navigate a maze of environmental regulations that vary from country to country. This diversity in legal frameworks adds complexity to global operations, while compliance costs can place a strain on businesses, particularly smaller ones, and they may find it difficult to keep up with ever-evolving regulations.

Internal resistance within organisations can also impede progress. Employees and decision-makers may be reluctant to alter long-standing processes, viewing them as more convenient or cost-effective in the short term. Moreover, companies that lack a corporate culture that embraces sustainability may struggle to implement long-term changes, instead prioritising short-term gains.

Economic pressures further exacerbate the challenges. Market competition often drives businesses to focus on immediate cost reductions rather than long-term sustainability. For companies operating on tight margins, balancing profitability with the costs of adopting green practices can be a daunting task. Additionally, securing sustainable resources can be difficult due to their limited availability, causing bottlenecks in SCs.

Innovation and research gaps also pose challenges. Some sectors lag in the development of green technologies, slowing the transition to more sustainable processes. There is a need for continuous research and innovation to overcome these technological and economic barriers and make it possible for manufacturing logistics to meet sustainability targets.

In conclusion, achieving sustainability in manufacturing logistics is hindered by technological, regulatory and economic challenges, as well as internal resistance within organisations. Overcoming these obstacles will require coordinated efforts across industries, government support, and continuous innovation. By addressing these challenges, companies can move towards more sustainable practices, contributing to environmental preservation while maintaining competitiveness in the global market.

Future Perspectives Regarding Sustainability in Manufacturing Logistics

As we look ahead to the future of sustainability in manufacturing logistics, it becomes increasingly evident that the integration of sustainable practices will continue to redefine industry norms. Embracing advances in technology, strategic planning and global cooperation will be pivotal in addressing environmental impacts while enhancing operational efficiency. This discussion explores innovative approaches, evolving trends and the transformative potential of sustainable logistics in shaping a resilient and environmentally responsible manufacturing landscape.

Green logistics and distribution highlight the substantial impact of increasing quantities of solid waste on sustainable development. To mitigate this challenge, the green packaging approach is employed, encompassing the entire lifecycle of packaging materials (Maurya et al., 2023). Accordingly, logistics service providers should also focus on developing new recycling and waste management solutions in collaboration with customers. Policymakers should encourage these improvements by supporting both individual and sector-wide actions that leverage current and future technologies (Grant et al., 2017). Additionally, environmental concerns have previously been overlooked during the creation of new products and processes, prompting the adoption of green design principles to foster environmentally friendly alternatives. Hazardous waste was typically disposed of in convenient locations without undergoing treatment. Introducing green concepts into the design phase is an effective way to address these issues. It is argued that green design should prioritise three key objectives for a sustainable future:

- Efficient management of renewable resources to ensure sustainability.
- Reduced reliance on non-renewable resources.
- Elimination of toxic and harmful emissions into the environment (Maurya et al., 2023).

As the field of logistics encompasses a variety of technical tools, such as vehicles, production and handling equipment, robots, and, more recently,

drones (Straka et al., 2020), logistics and transport service providers should promote industry-wide commitment to enhancing existing facilities by retrofitting green technologies and investing in new building technologies (Grant et al., 2017). Additionally, by digitising their marketing and logistics activities, companies can reduce their carbon footprint by minimising paper-based processes and optimising transportation routes. Furthermore, companies can adopt ethical and sustainable practices by ensuring that the digital tools and platforms they use comply with privacy and data protection regulations (Spivakovskyy et al., 2023). Digital product passports will be integral to future sustainability efforts in production, aiming to enhance transparency across SCs. This digital system will provide detailed product information to stakeholders, such as composition, origin and manufacturer details, fostering a circular production system (Paras & Pal, 2024).

As Grant et al. (2017) note, shippers and buyers must assess product carbon footprints through the selection of raw materials, production process intensity, SC speed and length, and carbon-use impacts. They should implement measures to drive positive SC changes, establish packaging weight-reduction standards, seek cross-industry agreements on modular transit packaging, and adopt sustainable sourcing policies that consider carbon impacts, from production to rework activities. Additionally, according to Paras & Pal (2024), the objective is to ensure that all products are eco-friendly and circular, making extensive use of recycled materials. Innovations aim to cut waste and enhance reuse, repair and recyclability, requiring better design, expanded recycling, efficient waste management, sustainable procurement, and the promotion of eco-conscious consumption. As Grant et al. (2017) conclude, firms should start by understanding why they need a sustainable SC strategy, considering factors such as regulatory changes, market demand and competitive pressures.

To sum up, logistics service providers should collaborate with customers to develop new recycling and waste management solutions and promote the retrofitting of green technologies in existing facilities. Digitising marketing and logistics activities can reduce carbon footprints, while adopting ethical practices ensures compliance with privacy regulations. The digital product passport enhances SC transparency. Shippers and buyers should assess carbon footprints across SCs and implement measures such as packaging weight reduction and sustainable sourcing. The goal is to create eco-friendly, circular products using recycled materials. Innovations should focus on reducing waste, enhancing reuse and recyclability, and promoting sustainable consumption. Finally, firms need a sustainable SC strategy, considering regulatory changes, market demand and competitive pressures.

CONCLUSIONS:

1. Manufacturing logistics is an integral part of an efficient production system in a company, alongside other elements such as facilities, people, equipment and software. Manufacturing logistics is not a process in itself – it ensures the achievement of the main objectives of a manufacturing company, through the acquisition of raw materials and the delivery of manufactured products to the final consumer. The main objective of manufacturing logistics is to provide efficient logistical support to production through the planning, execution and control of material flows. Manufacturing logistics ensures minimum stock levels, the shortest possible production times, flexibility of production and continuous customer satisfaction.

2. Sustainability in manufacturing logistics focuses on optimising resource use, improving operational efficiency, and fostering innovation in product design and logistics management. It covers the management of manufacturing processes, raw materials, inventories and finished goods from origin to end-user, aiming to minimise negative impacts on environmental, social and economic factors. Companies increasingly adopt advanced 3PL services for real-time information and transparency. Lean manufacturing and logistics systems, essential for just-in-time production, further enhance sustainability.

3. Achieving sustainability in manufacturing logistics is challenging due to technological, regulatory and economic barriers, along with internal resistance within organisations. Overcoming these hurdles necessitates cross-industry collaboration, governmental backing and ongoing innovation. By tackling these issues, companies can advance towards more sustainable practices, supporting environmental preservation while remaining competitive in the global market.

4. As a future perspective, logistics service providers should collaborate with customers to develop recycling and waste management solutions while promoting green technologies. Digitising marketing and logistics can help to reduce carbon footprints, and ethical practices ensure compliance with privacy regulations. Shippers and buyers must assess SC carbon footprints and implement measures such as packaging reduction and sustainable sourcing. Inno-

vations should focus on eco-friendly products, waste reduction and sustainable consumption. Firms must have a sustainable SC strategy that addresses regulatory changes, market demand and competitive pressures.

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TVARUMAS GAMYBOS LOGISTIKOJE: KONCEPCIJŲ IR ATEITIES PERSPEKTYVŲ LITERATŪROS APŽVALGA

Vaiva MAČIENĖ

Santrauka

Straipsnyje nagrinėjamos besikeičiančios tvarumo sampratos gamybos logistikoje, daugiausia dėmesio skiriant tvarios praktikos integravimui į gamybos logistiką. Atlikus išsamią literatūros apžvalgą, analizuojami pagrindiniai aspektai, tokie kaip išteklių optimizavimas, atliekų mažinimas ir 3PL paslaugų vaidmuo. Akcentuojami iššūkiai, su kuriais susiduria gamybos logistika siekdama tvarumo, įskaitant technologinius, reguliavimo ir operatyvinius barjerus, ir nagrinėjamos ateities perspektyvos, tokios kaip žaliosios technologijos ir skaitmeninės priemonės, skirtos skaidrumui didinti. Apžvalgoje pabrėžiama koordinuotų pramonės pastangų svarba siekiant pažangių tvarumo sprendimų, kartu išlaikant konkurencingumą.

Reikšminiai žodžiai: Gamybos logistika, tvarumas, tvari gamybos logistika, optimizavimas, ekologiškos praktikos.

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