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COMPARATIVE ANALYSIS OF DISTRIBUTION NETWORK DESIGN MODELS IN EUROPEAN AND CROATIAN GROCERY SECTORS

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Abstract

The study explores the evolution and application of distribution network design models in European and Croatian grocery supply chains, addressing operational efficiency, consumer satisfaction, and sustainability. Despite extensive research on supply chain management, a comparative analysis of centralized, direct store delivery, and hybrid distribution models in these contexts is lacking. Employing a mixed-methods approach, the study combines literature review, case studies, and secondary data collection to evaluate the effectiveness of these models based on cost efficiency, responsiveness, and adaptability. Findings indicate that centralized models dominate due to cost efficiency and scalability, while hybrid models are increasingly adopted for their flexibility and ability to handle perishability. Croatian grocery retailers predominantly use centralized systems, with limited examples of hybrid and cooperative models. This study highlights the need for future research on integrating emerging technologies and sustainable practices to address evolving market demands and supply chain challenges.

Keywords: Distribution Network Design, Food Supply Chain, Centralized Distribution, Hybrid Distribution Models, Direct Store Delivery, European and Croatian Grocery Retail

1. INTRODUCTION

The grocery retail sector is a vital component of the European economy, serving as a primary source of food and essential goods for millions of consumers.

In recent years, the sector has faced numerous challenges, including shifting consumer preferences, the rise of e-commerce, and disruptions caused by global events such as the COVID-19 pandemic. These factors have necessitated a re-evaluation of distribution network design models to enhance efficiency, reduce costs, and improve service levels. In particular, the Croatian grocery sector, while sharing many characteristics with its European counterparts, presents unique challenges and opportunities that warrant a focused analysis.

Despite the growing body of literature on distribution network design (DND), there remains a significant gap in comparative studies that specifically address the differences between existing DND models, and regional specifics (e.g. European and Croatian) in grocery sectors. Current research often emphasizes broad trends and technological advancements without delving into the nuanced operational strategies employed by retailers in different geographic contexts (Zhao et al., 2014, Mangina & Vlachos, 2005, Zhao et al., 2014; Nowak et al., 2022). This lack of targeted analysis limits the ability of grocery retailers and policymakers to make informed decisions regarding the optimization of their distribution networks (Kumar & Kumar Singh, 2021). As such, there is a pressing need for a comprehensive examination that not only highlights the existing models but also identifies best practices and areas for improvement (Bowersox et al., 2021). Mangiaracina et al. (2015) identified additional gap in their literature review on DND - qualitative factors influencing design of distribution network have been considered in only 11 papers out of 126 (i.e. 9 per cent).

To address this need, the paper conducts a comparative analysis of DND models in the European and Croatian grocery sectors. By evaluating the strengths and weaknesses of various approaches, including centralized distribution and direct store delivery, this study aims to provide actionable insights that can enhance operational efficiency and customer satisfaction. The analysis incorporates case studies, empirical data, and theoretical frameworks to offer a robust understanding of how different distribution strategies impact supply chain performance.

The remainder of this paper is structured as follows. Section II outline the methodology of the research, section III and IV review the existing literature on DND, focusing on key concepts and models relevant to the grocery sector. Section V outlines the methodology employed in the comparative analysis, detailing the criteria for selecting case studies and data sources and presents the findings of the analysis, highlighting the distinct characteristics of distribution models in the European and Croatian contexts. Finally, Section VI discusses the implications of these findings for practitioners and policymakers, offering recommendations for optimizing DND in the grocery sector.

By bridging the gap between theory and practice, this paper aims to contribute to the ongoing discourse on distribution network optimization, ultimately supporting the growth and resilience of the grocery retail sector in Europe and Croatia.

2. METHODOLOGY

The paper employs a mixed-methods approach to investigate the DND models utilized by leading grocery retailers in Europe and Republic of Croatia. The methodology encompasses both qualitative and quantitative research methods, allowing for a comprehensive analysis of the various distribution strategies and their impacts on operational efficiency, consumer satisfaction, and sustainability. Research methodology steps are presented at Figure 1.

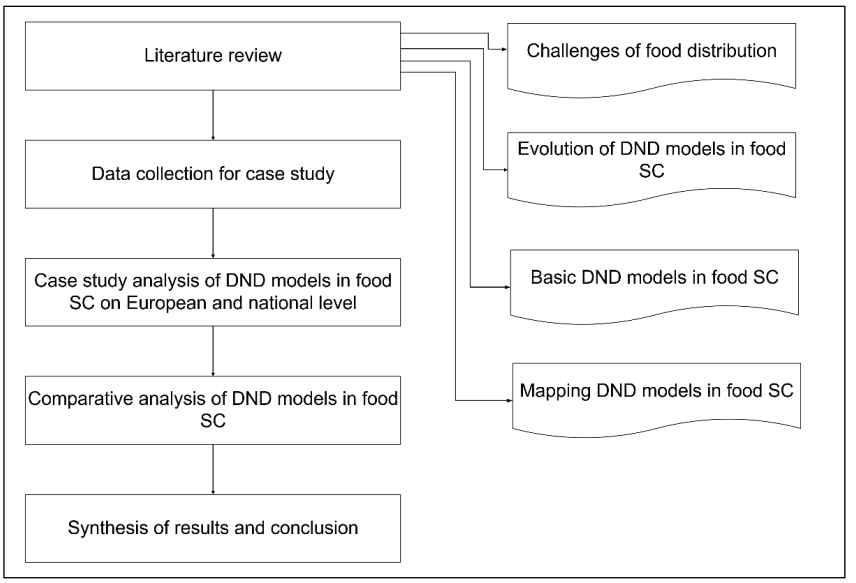

Figure 1 Research methodology flow

Source: author.

The first phase of the methodology involves a thorough literature review to establish a theoretical framework for understanding DND models in the grocery sector. This review will include academic articles, industry reports, and case studies that discuss historical and contemporary distribution practices.

Additionally, method of supply chain mapping will be employed as a visual tool to illustrate the flow of goods, information, and resources within the distribution networks of selected grocery retailers. This method will help identify key components such as suppliers, distribution centers, transportation routes, and retail outlets. By mapping these elements, the study aims to analyze how different distribution models operate in practice, and visualize relationships between various stakeholders involved in food distribution.

Based on the data collection for the case study analysis, as well for the quantitative data, a comparative analysis will provide characteristics of the three main DND models in the food supply chain compared according to efficiency and operational criteria, and based on the analysis of European and Croatian distribution model, previous research and the author's experience.

Finally, the findings from both quantitative and qualitative analyses will be synthesized to draw conclusions about the effectiveness of various DND models in the European grocery sector. This synthesis will provide actionable recommendations for retailers looking to optimize their distribution strategies in response to changing market dynamics.

3. GROCERY DISTRIBUTION AND DND MODELS

3.1. Challenges of Food Distribution

Food distribution faces numerous challenges that hinder the equitable and efficient delivery of food to communities. Logistical issues, such as poor infrastructure and inadequate cold chain systems, significantly impede the distribution of perishable goods, leading to increased food waste (Sengul Orgut & Lodree, 2023). Economic factors, including rising transportation costs due to fuel price volatility, disproportionately affect lower-income communities and resource-scarce regions (Bhati & John, 2024). Climate change can introduce disruptions like extreme weather, which delay deliveries and compromise food quality. Social and political inequities arise from systemic inefficiencies and corruption, often preventing aid from reaching the most vulnerable populations, such as internally displaced persons (Nazirullah & Ullah, 2023). While technological advancements can reduce inefficiencies and corruption, their uneven integration across regions creates gaps in accessibility and implementation. Addressing these challenges requires multi-faceted strategies, including technological upgrades, policy reforms for equitable distribution, and investment in resilient infrastructure. Enhancing transparency and involving local communities in the distribution process can also help mitigate corruption and inefficiency. According to Jámbor & Nagy (2022), flexibility, as well as communication and coordination skills, are key to managing contemporary threats in food supply chain and increasing its resilience. Food distribution systems are further complicated by issues related to perishability, temperature control, food safety, regulatory compliance, and evolving consumer demands. Perishability is critical for products like fruits, vegetables, dairy, and seafood, which have short shelf lives and require rapid transportation to prevent spoilage. Inefficient supply chains and transportation delays exacerbate food waste, with perishable goods accounting for a significant portion of global food waste (Sengul Orgut & Lodree, 2023). Temperature control and food safety are essential for maintaining food quality during distribution. Cold chain logistics, involving refrigeration and temperature-controlled storage, are vital for preserving perishable foods. However, inadequate facilities can lead to spoilage and contamination,

posing health risks. Regulatory compliance adds complexity, as food distributors must adhere to strict safety and quality standards, which vary by region. Insufficient resources or knowledge, particularly among smaller distributors, often lead to non-compliance (Nazirullah & Ullah, 2023). Evolving consumer demands further complicate food distribution. Modern consumers prioritize freshness, convenience, and sustainability, pressuring distributors to innovate. Trends like online grocery shopping and the demand for organic products require flexibility in distribution models, as seen with platforms like Zomato, which face challenges in maintaining quality and punctuality (Bhati & John, 2024).

3.2. The evolution of DND models in food supply chain

The evolution of DND models has been significantly influenced by advancements in logistics, technology, and changing consumer demands. Historically, distribution models have transitioned from simple, linear approaches to complex, integrated systems that prioritize efficiency, responsiveness, and sustainability.

In the early 1900s, *food distribution was primarily localized*, with producers selling directly to consumers or local retailers. The logistics were simple, relying on basic transportation methods such as horse-drawn carts and railroads. This period was characterized by a lack of formal distribution strategies, and the focus was on meeting local demand without the complexities of modern supply chains (Perdana et al., 2020).

As the food industry grew and urbanization increased, *in mid-20th century centralized distribution (CD) models began to emerge*. The rise of the industrial revolution brought about the need for more structured distribution systems as companies began to scale their operations. Retailers recognized the need for efficiency and cost reduction, leading to the establishment of large distribution centres (DCs) that served multiple retail outlets. The concept of centralization was rooted in the idea that consolidating inventory could lead to economies of scale, allowing companies to serve larger markets more effectively (Milewski, 2020). This model allowed for bulk purchasing and streamlined logistics, which were essential for managing the increasing volume of food products.

The limitations of CD models, particularly in terms of responsiveness and freshness (need for faster delivery times and fresher products), led to *the development of direct-to-store delivery (DSD) models in the late 20th century*. DSD allowed suppliers to transport products directly to retail outlets, bypassing DCs altogether. This model gained traction in the food industry, where perishability is a critical concern. DSD models were able to significantly reduce handling and storage times that products reach consumers quickly and in optimal condition (Gomez et al., 2021), while flexibility of DSD systems also enabled retailers to respond more rapidly to local demand fluctuations, a crucial factor in maintaining customer satisfaction.

In response to the challenges posed by both CD and DSD models, *hybrid distribution* models began to emerge *in the late 20th and early 21st centuries*. These models combine elements of both approaches, allowing organizations to leverage the strengths of each while mitigating their weaknesses. For instance, hybrid systems may centralize non-perishable inventory while utilizing DSD for perishable goods. This flexibility has been shown to improve overall supply chain efficiency and reduce food waste by optimizing inventory management (Prastiti, 2023). The integration of digital technologies has further transformed DND, both on local and global level (Nowak et al, 2022). The advent of big data analytics, artificial intelligence (AI), and the Internet of Things (IoT) has enabled real-time decision-making and optimization, enhancing the capabilities of hybrid models. Organizations can now analyze consumer behavior, forecast demand, and adjust their distribution strategies, accordingly, leading to improved operational efficiency (Abounacer et al., 2014).

Today, the focus on sustainability and resilience has become increasingly important in the design of food supply chains. The COVID-19 pandemic highlighted the vulnerabilities of global supply chains and underscored the need for more resilient distribution strategies. Research indicates that food supply chains must adapt to environmental shocks and uncertainties, emphasizing the importance of flexibility and local sourcing (Bolici, 2011). The rise of short food supply chains (SFSCs) and local food networks reflects this trend, as consumers increasingly demand transparency and sustainability in their food sources.

3.3. Emergence of Alternative Food DND Models and Adaptation to e-Commerce Requirements

Historically, the conventional food system has been characterized by the dominance of large corporations and a high number of intermediaries (Paciarotti et al., 2022). This has resulted in various environmental, economic, and social externalities, including a reduction in biodiversity, problems in ecosystems, the increase of obesity, and the inability to obtain reliable information on food provenance and quality (Paciarotti et al., 2022). The current 'conventional' long food distribution system is not sufficient to fulfil the growing consumer demand for more sustainable, ecological, and healthier food options (Pardillo-Baez et al., 2020).

In response to the limitations of the conventional food system, alternative food distribution models have emerged, which aim to 're-socialize' and 're-spatialize' food through closer and more 'authentic' relationships between producers, consumers, and their food (Paciarotti et al., 2022; Pardillo-Baez et al., 2020). These alternative models often involve shorter supply chains, direct-to-consumer channels, and a focus on locally produced and organic foods. Researchers have increasingly turned their attention to studying these 'alternative' food networks, drawing upon an apparent abundance of case studies and individual examples, such as farmers' markets (Pardillo-Baez et al., 2020; Paciarotti et al., 2022; Venn et al., 2006). However, these studies have often faced methodological

considerations, as the 'alternative' nature of these networks can be complex to define and measure.

Today, DND models continue to evolve, driven by the increasing complexity of global supply chains and the growing emphasis on sustainability. The rise of e-commerce has necessitated the development of more agile and responsive distribution systems that can accommodate rapid changes in consumer demand. As a result, companies are increasingly adopting omnichannel strategies that integrate various distribution methods to enhance customer experience and operational efficiency (Song et al., 2016). But situation in food supply chain is different due to limitations connected with nature of products (perishability, temperature control and other request for product flow). Therefore, some distribution strategies (e.g. use of parcel lockers or full omnichannel distribution) are rarely used in food supply chain distribution networks.

Integrating an online channel into an established traditional business serving customers in a building (physical store location or brick-and-mortar business) presents unique challenges, particularly in distribution logistics. Successful food retailers address these challenges strategically to ensure their online and physical channels complement each other rather than compete. When online traffic is initially low, retailers often start with the elementary fulfilment model: in-store picking. This approach involves fulfilling online orders directly from the inventory of existing physical stores. Starting with in-store picking allows retailers to leverage their current infrastructure without significant additional investment. It also minimizes the risk of dedicated fulfilment centres diverting sales away from physical stores. As online demand grows, retailers can progressively transition to more advanced distribution models, such as utilizing warehouse distribution centres specifically for online orders. This shift enables them to handle increased online traffic more efficiently and scale their e-commerce operations without overburdening individual stores. The initial use of in-store picking offers additional benefits. Store staff fulfilling online orders can provide real-time feedback on stock levels, promptly reporting out-of-stock items. Immediate communication facilitates faster replenishment from central warehouses, improving overall inventory management (Amin, 2022). Consequently, the online channel contributes to the success of physical stores by enhancing product availability.

4. BASIC DND MODELS IN FOOD SUPPLY CHAIN

Food distribution responds to traditional and emerging challenges by constantly balancing between centralization and decentralization in the creation and development of its distribution network. Centralized distribution and direct store delivery are the two main types of DND models in the food supply chain. All the development of DND models in the last few decades is aimed at combining these two models in a constant search for the best way to use their advantages, and to overcome or limit their disadvantages. These new DND models are usually called hybrid distribution models (HD) and new variants of them are constantly appearing in the food supply chain.

4.1. Direct store delivery distribution in food supply chain

The Direct Store Delivery (DSD) distribution model is a logistics strategy where manufacturers deliver products directly to retail stores, bypassing traditional distribution centers. This model was prevalent in the food supply chain for long time, especially for perishable goods, due to its ability to enhance freshness and reduce lead times. The DSD model has gained traction among major food companies, with studies indicating that a significant proportion of fast-moving consumer goods (FMCG) firms have adopted this approach to optimize their supply chains (Amorim et al., 2013).

The structure of the DSD model is primarily defined by the direct relationship between manufacturers and retailers, where manufacturers are responsible for delivering products straight to retail locations. This arrangement often involves a decentralized distribution network that allows for quicker response times to consumer demand (Kurtuluş et al., 2020). The DSD system is a distribution systemin which suppliers typically bypass traditional DCs (or use their own regional DCs) which can lead to a more streamlined supply chain (Figure 2). For instance, Gittelsohn et al. (2021) highlight the importance of direct connections between local producers and retailers, which can enhance the efficiency of food distribution in urban settings. Caspi et al. (2015) observed that many small grocery stores rely on direct deliveries for fresh produce, which underscores the importance of DSD in ensuring that healthy food options are readily available to consumers.

In terms of material flow, the DSD model facilitates the direct transfer of goods from manufacturers to retail shelves, allowing for immediate stocking upon delivery. The information flow in this model is also critical, as real-time data on inventory levels and sales can be communicated back to manufacturers, enabling better demand forecasting and inventory management (Kurtuluş et al., 2020).

For supplier (manufacturers or distributors), the DSD model offers several advantages. It allows for better inventory management, as manufacturers can monitor stock levels and sales trends directly from the retail environment, and many times directly from customers themselves. Huge significance stems from frequent contact with retail stores a retailer's employees in them, allowing suppliers to have higher impact on retailer's orders. Additionally, the direct relationship with retailers can foster stronger partnerships and collaboration, enhancing trust and commitment (Dunning, 2016). For smaller retailers, DSD can lead to increased efficiency in operations. By allowing manufacturers to handle in-store replenishment, retailers can focus on customer service and sales rather than logistics (Kurtuluş et al., 2020). This model can also improve the freshness of perishable goods, which is crucial for customer satisfaction and can lead to higher sales (Amorim et al., 2013). Furthermore, retailers may benefit from reduced costs associated with warehousing and inventory management (Kurtuluş et al., 2020).

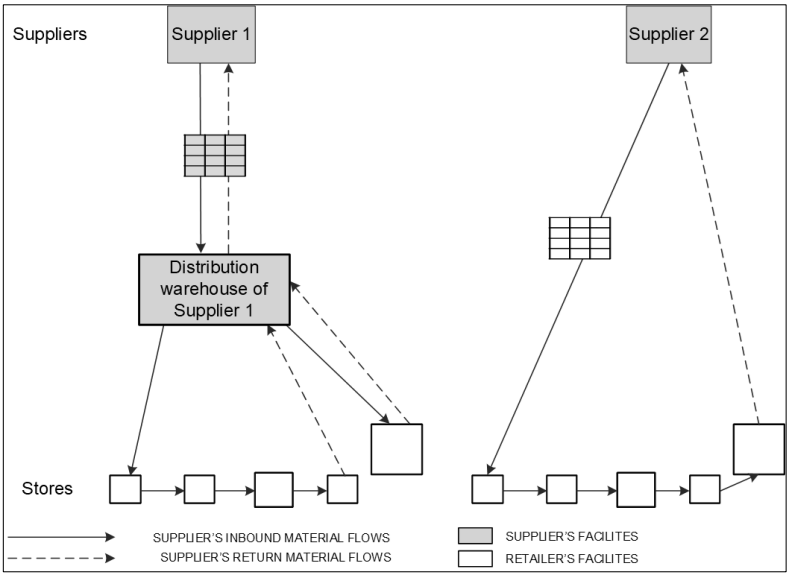

Figure 2 Direct to store delivery distribution system food supply chain

Source: author.

Despite its benefits, the DSD model also presents challenges. For suppliers, the reliance on direct deliveries can lead to increased transportation costs, particularly if the delivery routes are not optimized (Rosales et al., 2018). Additionally, managing relationships with multiple retailers can be complex and resource-intensive (Kurtuluş et al., 2020). While DSD can reduce some operational burdens, for retailers it may also lead to a lack of control over inventory management. Retailers may find themselves dependent on manufacturers for stock levels, which can lead to issues if manufacturers fail to deliver on time or if there are discrepancies in inventory management (Rosales et al., 2018). Moreover, the DSD model may not be suitable for all types of products, particularly those that require significant warehousing or bulk storage (Kurtuluş et al., 2020).

4.2. Centralized distribution in food supply chain

The CD system is a logistics model that consolidates inventory and distribution operations at a limited number of distribution centres (DCs). This model is particularly prevalent in the food supply chain, where managing perishable goods efficiently is crucial. The CD model is characterized by specific material and information flows, structural components, ownership of key facilities, and other characteristics that are important for retailers, vendors, and consumers.

Structure of CD model consist of distribution centres, transportation network, and information flow.

CD model typically feature one or more large DCs strategically located to serve multiple retail outlets (stores). This DC is owned by retailers and responsible for receiving, storing, and distributing food products to various locations (Figure 3). The most important and efficient characteristics of these DCs is crossdocking warehouse strategy enhancing the flow of goods, decreasing inventory holding costs, and decreasing delivery times to the stores (Dujak, 2019). The design of DCs often additionally includes advanced storage systems, such as temperature-controlled environments for perishable items, to ensure product quality and safety.

Transportation network in a CD is designed to optimize routes and minimize costs. Products are transported from suppliers to the DCs and then distributed to retail locations. The use of large trucks for bulk transportation is common whenever is possible to fulfil the truck, allowing for economies of scale. Mostly it is in case of supplier's deliveries to retailer's central DC, and for deliveries between central and regional DCs. At the same time, small trucks are usually facing challenges of last-mile-delivery to numerous retail stores.

Information flow in CD is based on advanced information systems employed to track inventory levels, monitor product movements, and forecast demand. This data-driven approach enables real-time decision-making, which is essential for maintaining optimal stock levels and ensuring timely deliveries. Information system is also used for generation of automated order – one joint order, to one supplier, for all stores.

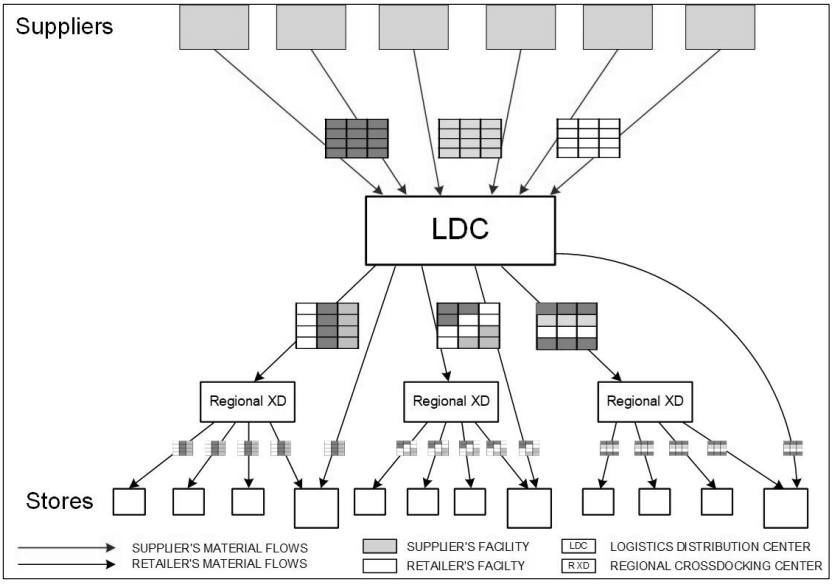

Figure 3 Centralized distribution system in food supply chain

Source: author.

In a CD model, material flow begins with suppliers delivering homogenous products shipments (goods from only one supplier) to the central DC, all based on joint order for all grocery retail stores (Figure 3). Once received, products are sorted, stored, and prepared for distribution to retail locations. If DC has crossdocking function, products are not even stored, but immediately order picking begins and they are quickly on their way to customers (retail stores) as heterogenous shipments (all products from different suppliers needed by certain store). It is important to highlight that majority of distribution is performed by retailers, taking on not only distribution costs, but also the possibility of optimizing them through economies of scale, better organization, more efficient use of technology and overall earlier control over the flow of goods.

The flow of materials is typically managed using warehouse management systems (WMS) that optimize storage and retrieval processes. For example, perishable goods may be prioritized for faster turnover to minimize spoilage. Information flow is facilitated through integrated logistics management systems that connect suppliers, DCs, and retail outlets. Additionally, important role is given to inventory systems integrated between retail DC, retail headquarter (e.g. purchasing department) and all retailer's stores. These systems enable the sharing of critical data, such as inventory levels, order statuses, and demand forecasts. Effective communication among stakeholders is essential for coordinating logistics operations and ensuring that products are delivered in a timely manner (Abasıkeleş-Turgut, 2016).

In CD systems, ownership of key facilities can vary. Large retailers, such as Tesco and Carrefour, typically own and operate their own distribution centres, allowing them to maintain control over logistics operations and inventory management. However, some companies may choose to outsource their distribution functions (or part of them – e.g. full truck load transportation) to third-party logistics (3PL) providers, which can offer specialized expertise and resources for managing centralized distribution networks.

When it comes to benefits of CD systems, they can achieve significant cost savings through economies of scale, allowing retailers to offer competitive pricing to consumers. By consolidating inventory (products are stored in fewer locations) and optimizing transportation routes, companies can reduce overall logistics costs. This consolidation allows for more accurate tracking of inventory levels and reduces the likelihood of stockouts or excess inventory (Melkonyan et al., 2020). CD systems facilitate better traceability of food products, which is essential for compliance with food safety regulations.

As any DND system, CD has certain challenges. While centralized systems offer cost efficiencies, they may struggle with responsiveness to local market demands. If not organized well, longer delivery times for extremely perishable items can lead to increased spoilage rates, which is a critical concern in the food industry. Additionally, CD systems can be vulnerable to disruptions, such as natural disasters or supply chain interruptions. Companies must develop robust contingency plans and risk management strategies to address these challenges and ensure continuity of supply. One approach is through developing sustainable food supply chain management system based on hyperledger fabric blockchain (Vo et al., 2021).

4.3. Hybrid Distribution Models in Food Supply Chain

The Hybrid Distribution (HD) model in the food supply chain integrates multiple distribution strategies and distribution models to optimize logistics, enhance responsiveness, and reduce waste. This model combines elements of CD networks with DSD or even direct-to-consumer approaches, allowing for a more flexible and efficient supply chain. The HD is particularly beneficial for managing perishable goods, as it can adapt to varying demand patterns and logistical challenges.

The structure of the HD typically involves a combination of centralized and decentralized distribution points (Figure 4). Centralized warehouses may be used for bulk storage and distribution, while decentralized nodes, such as local distribution centres or direct delivery systems, facilitate quicker access to consumers (Tan et al., 2022). This dual approach allows for the efficient handling of a diverse range of products, from non-perishable items to fresh produce, ensuring that inventory levels are optimized across the supply chain (Ubud, 2024).

Material flows in the HD model are characterized by a combination of bulk shipments to central warehouses and smaller, more frequent deliveries to retail outlets or directly to consumers. This structure allows for better inventory management and reduces the risk of spoilage for perishable items (Gomez et al., 2021). Information flows are equally critical in the HD model, as real-time data sharing between suppliers, distributors, and retailers enables better demand forecasting and inventory control (Tan et al., 2022).

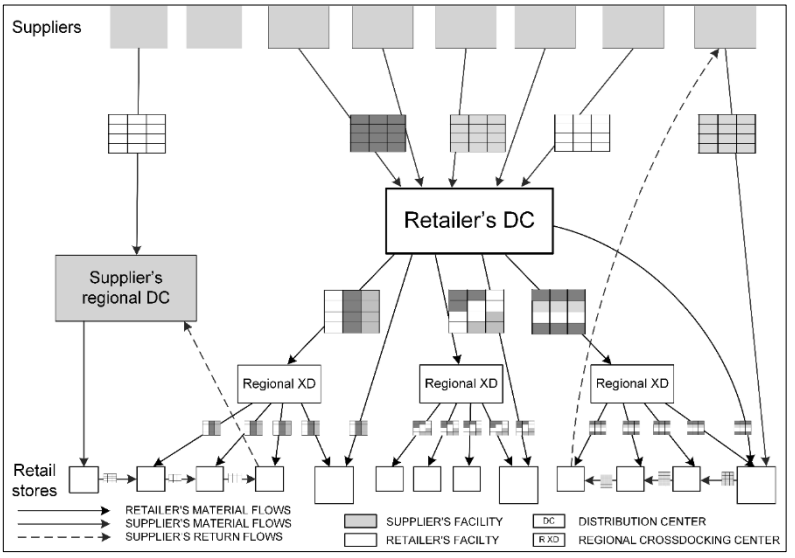

Figure 4 Hybrid distribution system in food supply chain

Source: author.

HD model allows for greater flexibility in logistics, enabling suppliers to respond quickly to market changes and consumer preferences. By utilizing both

centralized and decentralized distribution methods, suppliers can optimize their inventory levels and reduce waste, particularly for perishable goods (Tan et al., 2022). This model also facilitates collaboration among different stakeholders, which can lead to improved supply chain performance and reduced costs (Gomez et al., 2021). For retailers, the HD model enhances operational efficiency. Retailers benefit from a more responsive supply chain that can adapt to fluctuations in demand, ensuring that shelves are stocked with fresh products (Ubud, 2024). Additionally, the integration of various distribution methods can lead to cost savings, as retailers can choose the most efficient delivery options based on their specific needs (Tan et al., 2022). This flexibility can also improve customer satisfaction by ensuring product availability and freshness (Gomez et al., 2021). The responsiveness of the supply chain means that consumers are more likely to find products available when they shop, enhancing their overall experience (Ubud, 2024). Furthermore, the reduction of food waste through optimized logistics can contribute to more sustainable consumption practices (Tan et al., 2022).

Limitations of the HD both for retailers and for suppliers arises from complex and resource-intensive managing of an HD network. Coordinating logistics across multiple distribution channels requires sophisticated planning and execution, which can strain resources, particularly for smaller suppliers (Gomez et al., 2021). Additionally, the reliance on technology for information sharing and inventory management can pose risks if systems fail or are not properly integrated (Tan et al., 2022).

Additionally, the complexity of the supply chain may not always translate to lower prices for consumers, as the costs associated with managing a hybrid model may be passed on to them (Tan et al., 2022).

5. DND MODELS IN EUROPEAN AND CROATIAN FOOD SUPPLY CHAIN

The European food distribution sector is experiencing significant transformation driven by various factors, including economic pressures, competitive dynamics, and changing consumer preferences. The market is largely dominated by a few key retailers, with discounters like Lidl and Aldi (Schwarz Group) leading the charge in growth and market share. As of 2024, the grocery market in Europe is projected to be valued at approximately €3.26 trillion, reflecting resilience amid inflation and shifting consumer behaviour (McKinsey & Company, 2024; GourmetPro, 2024). According to recent study (McKinsey & Company, 2024), the biggest trend that will characterize the European grocery retail market is *cost and margin pressure*. There are various ways how to achieve this, but efficiency of distribution network and choosing the right DND model are one of most important.

The European food distribution landscape is characterized by a diverse range of grocery retailers employing various DND models. The complexity of these networks is influenced by factors such as market size, consumer preferences, and

technological advancements. The top ten grocery retailers in Europe utilize distinct models tailored to their operational strategies and market demands.

This paper analyzes DND models in the European and Croatian grocery sector, i.e. in the food supply chain. Analysis begins with the situation in the European food distribution sector where main players are analyzed. Table 1 presents Top 10 European grocery retailers in 2023 by their turnovers in billions of euros, country of origin, number of stores and employees, and prevailing DND model used.

Table 1 Top 10 European grocery retailers in 2023: main characteristics and their prevailing DND model

Rank	Retailer	Turnover (in billions of €)	Country	Number of Stores	Employee Count	DND Model
1	Schwarz Group	167.2	Germany	13900	575000	CD
2	Aldi	111.6	Germany	12728	288302	CD
3	REWE Group	92.31	Germany	15718	390000	Hybrid (CD & DSD)
4	Edeka	70.7	Germany	11048	410700	Hybrid (CD & DSD)
5	Tesco	69.5	UK	4859	336,926	CD
6	Carrefour	94.1	France	14000	305300	CD
7	E.Leclerc	61.8	France	1500	150000	CD
8	Les Mousquetaires	39.9	France	2650	N/A	Hybrid (CD & DSD)
9	Sainsbury's	43.7	UK	2200	148000	Hybrid (CD & DSD)
10	Auchan	32.9	France	2354	153965	Hybrid (CD & DSD)

Source: author based on publicly available data and reports (retailer's corporate web pages).

The European grocery sector is characterized by a blend of centralized, hybrid, and direct store delivery distribution models, reflecting the diverse operational strategies and logistical needs of its leading retailers.

CD is the prevailing model among the largest European grocery retailers, including Schwarz Group (Lidl and Kaufland), Aldi, Tesco, Carrefour, and E.Leclerc. According to Tesco (2024), "*Over 2bn cases is moved through the network each year, 95% of this is distributed centrally and 5% is delivered directly to stores*". These retailers leverage centralized warehouses to consolidate inventory, optimize logistics, and achieve economies of scale. Key benefits of this approach include cost efficiency, consistency of uniform product availability across stores, and sustainability (through fewer kilometers travelled, logistics networks minimize carbon emissions and waste).

Hybrid distribution models (combining CD and DSD) are increasingly popular among retailers such as REWE Group, Edeka, Les Mousquetaires, Sainsbury's, and Auchan. This model balances the strengths of both approaches: non-perishable goods are distributed via centralized hubs for cost savings (centralized efficiency), and perishable items, such as fresh produce and dairy, are delivered directly to stores, ensuring freshness and responsiveness to local demand (DSD Flexibility). For example, REWE Group and Edeka in Germany employ hybrid models to cater to regional preferences and the high demand for fresh, local products. This approach also supports independent store owners in cooperatives like Edeka, allowing for tailored inventory.

Regional trends in distribution are expected to lean towards biggest and economically strongest countries. With four of the top 10 retailers based in Germany (Schwarz Group, Aldi, REWE Group, Edeka), the country demonstrates a strong reliance on both centralized and hybrid models. The choice is influenced by the large market size and high demand for cost efficiency and fresh products. France based retailers such as Carrefour, E.Leclerc, and Les Mousquetaires employ a mix of centralized and hybrid models, reflecting the need to balance cost efficiency with responsiveness in a competitive grocery market. Finally, retailers from United Kingdom (Tesco and Sainsbury's) highlight the importance of hybrid models, particularly for online order fulfilment, leveraging both centralized warehouses and local store networks.

The distribution model choice is influenced by store formats and operational scale as well. Retailers with extensive store networks, such as Schwarz Group (13,900 stores) and REWE Group (15,718 stores), benefit from centralized models for cost-effective supply to a vast number of outlets. Retailers with smaller networks like E.Leclerc (1,500 stores) and Sainsbury's (2,200 stores) leverage hybrid models to provide tailored solutions for regional markets, enhancing flexibility.

The rise of e-commerce is shaping the evolution of distribution networks. CD is effective for managing bulk online orders, with warehouses dedicated to fulfilment. Hybrid models offer agility for last-mile delivery and click-and-collect services, combining traditional store supply with direct consumer delivery. Retailers like Tesco and Sainsbury's are leaders in integrating e-commerce capabilities into their distribution systems, leveraging hybrid models for omnichannel retailing.

None of major European food (grocery) retailers use DSD as their predominant DND model. This does not mean that this model is not used at all in the European food supply chain (i.e. food distribution), but rather indicates that it is primarily intended for and used by smaller retailers who, due to limited turnover, cannot realize significant benefits from the economies of scale that a centralized model enables.

While Croatian academic community extensively study different topics partly of fully connected to logistics and supply chain (according to Sajter (2024), in Croatian economic science, branch *Organisation and management*, most relevant terms are “logistics” and “supply chain”), still there is a significant lack of

researches on DND models. When it comes to Croatian food distribution in practice, table 2 presents Top 10 Croatian grocery retailers, highlighting their market share and prevailing DND model they use in Croatia.

Table 2 Top 10 Croatian grocery retailers in 2023 and their prevailing DND model

No.	Retailer	Market Share (2023)	Number of Stores	Employee Count	Key Features of DND Model
1	Konzum	[20 – 30] %	630	10812	CD - Operates major logistics centres, including the 85,000 m² LDC Dalmatina in Dugopolje and expanded Zagreb facility; supports over 600 stores across Croatia.
2	Lidl Croatia	[10 – 20] %	109	3200	CD - Centralized network with major facilities in Križ (64,000 m², 39,000 pallets), Jastrebarsko, and Perušić; advanced automation and sustainability features.
3	Plodine	[10 – 20] %	140	4295	CD - Centralized distribution at Kukuljanovo near Rijeka; supplies over 140 supermarkets nationwide with optimized logistics operations.
4	SPAR Croatia	[10 – 20] %	137	4600	CD - Central logistics centre in Donja Zdenčina (75,000 m²), serving 140 stores across 55 cities; storage capacity of 100,000+ pallets, 170+ loading ramps.
5	Kaufland	[5 – 10] %	49	3500	CD - Distribution centre in Jastrebarsko (expanded to 92,000 m² in 2024); supplies an expanding retail network of 50+ stores; utilizes automation for efficiency.
6	Studenac	[5 – 10] %	1265	6509	CD - Central DC in Dugopolje and regional cross-dock facilities; plans to open a new DC near Zagreb.
7	Tommy	[5 – 10] %	230	4400	CD - Logistics centre in Dugopolje, near Split, serves over 230 retail outlets across nine counties and Zagreb; supports efficient inventory and delivery.
8	KTC	[0-5] %	70	1600	CD - Centralized distribution system located in Križevci, supports 80+ retail outlets nationwide; optimizes inventory and delivery operations.
9	NTL	[0-5] %	346	1121	DSD - Cooperative network of 7 regional companies; no centralized DC but collaborative logistics structure for procurement and supply.
10	Trgovina Krk	[0-5] %	440	2000	HD - Hybrid distribution model ensures efficient local supply chain. Centralized warehouse in Malinska for most of food product distribution across retail outlets on the island of Krk, but also use direct-to-store delivery.
First 10 grocery retailers in Croatia (CR_{10}):		**86,7 %**			2 CD models, 1 DSD model, and 1 HD model of DND

CD = Centralized Distribution model; DSD = Direct Store Delivery model; HD = Hybrid Distribution model.

Source: author's creation based on Croatian Competition Agency's report for 2023 (AZTN, 2024), publicly available data (retailer's corporate web pages), and interviews with retail logistics experts about DND models.

First thing that needs to be highlighted is high market concentration in Croatian market. According to Papatheodorou (2016), concentration ratio (CR) *measures the joint output of a number of firms ranked in descending order of*

significance as a percentage of total market production (Papatheodorou, 2016). CR_{10} measures the market share of the ten largest companies, and in Croatia it is 86,7% (CR_{10} = 86,7). Even CR_5 is very high, CR_5=66,4 (AZTN, 2024). This indicates that leading retailers in the Republic of Croatia generate large turnover, and it is not surprising that they have chosen the CD model as the prevailing DND model. Reasons for CD use are similar to on European food market - enabling efficient scaling and supply chain control. Additionally, retailers like Lidl Croatia and Kaufland integrate advanced automation and sustainability practices into their logistics centers, aligning with modern operational standards and enabling even higher efficiency (Kaufland Croatia, 2024). Of course, certain small number of products is delivered to stores using DSD method as well. But those are mostly highly perishable and fresh products like bakery products, beverages or some dairy products, local products that are only locally distributed and sold, or products that have completely different logistics requirements and need to be delivered separately from other products (e.g. frozen products, fresh meet).

As Lopez (2023) stated, larger retailers scale up their operations, they often employ sophisticated distribution networks that leverage economies of scale, while smaller retailers may focus on niche markets and personalized service to differentiate themselves. NTL is a notable exception in Top10 of Croatian grocery sector, employing a decentralized cooperative structure (DSD) instead of a centralized model. The reason lies in a fact that NTL as national retail chain is established to allow procurement benefits to its members (smaller regional retail chains). Therefore, regional companies within the NTL cooperative manage their logistics independently while sharing procurement resources. Decentralized systems allow NTL to better cater to localized demands without the need for expansive central facilities. While this model supports smaller retailers and cooperatives, it may face challenges in scalability and cost efficiency compared to centralized networks.

Trgovina Krk uses a hybrid distribution model, combining centralized warehousing with direct-to-store delivery (DSD). This model supports local market focus (the central warehouse in Malinska handles most food distribution, while DSD ensures flexibility for unique supply needs on the island of Krk), and enables balancing operational efficiency with the need to meet regional variations in demand.

Croatia's relatively small market size and regional disparities influence the choice of distribution models. Leading retailers such as Konzum and SPAR (SPAR International, 2024) have invested in large, strategically located logistics centers to serve their networks efficiently. Others are in the process of building their new DCs. Smaller retailers like Trgovina Krk adapt their models to specific geographic or logistical constraints, such as serving islands or rural areas.

5.1. Comparative analysis of the basic DND models in food supply chain

The quantitative analysis of DND models in the food industry - specifically CD, DSD, and HD models - provides valuable insights into their performance, efficiency, and adaptability. Each model presents unique characteristics that can be evaluated through various metrics, including cost efficiency, responsiveness, and operational flexibility. This analysis will draw upon not only previous research in the field, but also upon analysis of European and Croatian food supply chain and aiming to quantify the advantages and disadvantages of each model. Concise analysis is presented in table 3, followed by detailed explanation.

Table 3 Quantitative and qualitative characteristics of main DND models in food supply chain

Characteristic of the DND model	**Centralized Distribution model**	**Direct Store Delivery model**	**Hybrid Distribution model**
Average Delivery Time	+20-30% longer than DSD	Reduced by ~30%	Moderate, depending on model mix
Transportation Cost	Reduced by ~20%	Increased by 10-25%	Reduced by 15-20%
Inventory Levels	Up to 25% higher, but lower in-store inventories	Lower due to direct delivery	Balanced, optimized for perishables
Spoilage Rate	10-15% higher	~5%	Reduced by ~25%
OOS level	Lower	Higher	Moderate to high
Operational Efficiency	Moderate	High	Improved by 10-15%
Food Waste Reduction	Limited	Limited	~25% reduction
Flexibility	Low	High	High
Resilience	Low	Moderate	High
Number of stores in network / Demand size	High number of stores with huge demand	Low number of stores with low to moderate demand	Can be adjusted to the number of stores and the size of demand
Sustainability	High	Low	Moderate

Source: author's analysis based on (Gupta et al., 2021; Kaipia et al., 2013; Vittersø et al., 2019; Pincheira et al., 2018; Katsikouli et al., 2020; Wang, 2022; Almena et al., 2019; Do et al., 2021; PMC, 2022; Dujak, 2019).

CD models are designed to consolidate inventory and logistics operations within a limited number of distribution centres (DCs). While this approach can optimize costs, it often results in longer delivery times for perishable items. Research indicates that average delivery times in centralized systems can extend

by 20-30% compared to direct-to-store delivery (DSD) models, particularly for products that require rapid turnover (Gupta et al., 2021). This delay can contribute to increased spoilage rates, which are estimated to be around 10-15% higher in centralized systems due to the longer transit times (Ibrahim et al., 2023). Furthermore, centralized models can lead to increased inventory levels, with studies showing that they may necessitate up to 25% more inventory to compensate for fluctuations in demand, especially for perishable goods (Kaipia et al., 2013).

In contrast, direct-to-store delivery (DSD) models streamline the transportation of products by facilitating direct shipments from suppliers to retail outlets, effectively bypassing traditional distribution centres. This model presents several key quantitative aspects. For instance, while DSD can increase transportation costs by 10-25% due to the need for more frequent deliveries and a more complex logistics network (Vittersø et al., 2019), it also significantly enhances delivery speed. Studies indicate that DSD can reduce handling and storage times by approximately 30% (Malak-Rawlikowska et al., 2019). This efficiency is particularly beneficial for perishable items, ensuring that products reach consumers quickly and in optimal condition, thereby reducing spoilage rates to about 5% (Pincheira et al., 2018). Additionally, DSD systems are more responsive to local demand fluctuations, allowing for rapid adjustments to delivery schedules. Research shows that DSD can improve service levels by up to 20% compared to centralized models, especially in urban areas where consumer preferences can shift rapidly (Katsikouli et al., 2020).

Hybrid distribution models offer a flexible approach by combining elements of both CD and DSD systems. This integration allows organizations to achieve a balance between cost efficiency and responsiveness. Quantitative evaluations reveal that hybrid models can reduce overall logistics costs by 15-20% compared to purely CD or DSD approaches (Wang, 2022). This is accomplished by centralizing non-perishable items while utilizing DSD for perishables. Moreover, the flexibility inherent in hybrid models facilitates better inventory management, leading to a reduction in food waste by approximately 25% (Almena et al., 2019). This reduction is particularly crucial in the food industry, where spoilage can significantly impact profitability. Additionally, hybrid models enhance operational efficiency by enabling real-time decision-making and optimization through the integration of digital technologies. Research indicates that organizations employing hybrid models can improve operational efficiency by 10-15% through better resource allocation and demand forecasting (Do et al., 2021).

Recent studies have explored the resilience of food supply chains concerning their structure. While centralized systems can be economically advantageous due to lower operational costs, distributed systems tend to be more resilient against disruptions. For instance, during the COVID-19 pandemic, localized food systems demonstrated greater adaptability when faced with supply chain shocks (PMC, 2022). Research indicates that decentralizing certain aspects of food production can enhance resilience without significantly increasing costs. A

study assessing food system resilience found that decentralized networks could better withstand disruptions related to energy and water supply shortages (PMC, 2022).

Retailers with higher number of stores and higher demand and output, will more easily take advantage of centralized model.

One significant trend in DND is the emphasis on resilience, particularly in the context of perishable goods. Research indicates that grocery retailers are adopting two-stage models that incorporate dynamic competition and resilient strategies to optimize their supply chains. This approach allows retailers to determine optimal inventory periods while simultaneously enhancing their ability to respond to market fluctuations and disruptions (Alikhani, 2021).

The rise of e-commerce has also significantly influenced distribution strategies among grocery retailers. The shift towards online shopping necessitates a redesign of traditional distribution networks to accommodate direct-to-consumer models. Retailers are increasingly leveraging multi-channel distribution strategies that include both physical stores and online platforms, allowing for better inventory sharing and reduced transaction costs. This omnichannel approach not only enhances customer experience but also improves supply chain performance by integrating various sales channels. Moreover, studies have shown that the pandemic has accelerated the adoption of online grocery shopping, which means that retailers need to adapt their logistics and distribution strategies accordingly (De Canio et al., 2023). The working model of consumers (working from home or from the office) has also influenced consumer habits in food retailing (Mesić et al., 2024).

The level of cooperation between retailer and its suppliers significantly influence success of certain DND model. Examples include CD models of different maturity and cooperation level. 'Younger', recently implemented CD models usually result in lowering the level of product availability and increasing the level of out-of-stock (OOS) in retail stores. As CD model progress and logistical synchronization and overall cooperation between retailer and its suppliers improves, CD results in lower OOS levels and higher product availability then DSD model. A study analysing the impact of various distribution models on stock availability found that CD generally results in lower OOS rates compared to DSD, particularly in environments with high variability in consumer demand. The centralized model's ability to aggregate demand data and optimize inventory levels across multiple locations is a significant factor contributing to its effectiveness in minimizing stock-outs (Yao et al., 2020; Ulrich et al., 2021). Conversely, while DSD can provide agility and responsiveness (especially on local markets), it often struggles with maintaining consistent inventory levels, especially in larger retail chains where demand can vary significantly from one location to another (Milioti et al., 2020).

6. CONCLUSION

The grocery retail sector in Europe is undergoing significant transformation, driven by evolving consumer demands, technological advancements, and the ongoing challenges posed by global events such as the COVID-19 pandemic. This paper has explored the DND models employed by the top grocery retailers in Europe, highlighting the critical role these models play in operational efficiency, cost management, and customer satisfaction.

The evolution of food DND models demonstrates the ongoing balancing act between efficiency, responsiveness, and sustainability in modern supply chains. CD, DSD, and HD models each cater to specific operational and logistical needs, offering distinct advantages. CD models are effective for cost efficiency and economies of scale, while DSD prioritizes rapid delivery and freshness for perishable goods. HD models bridge these approaches, providing flexibility and adaptability to meet diverse market demands.

Study results point out that CD models remain prevalent among major European grocery retailers like Schwarz Group and Aldi, offering advantages in terms of economies of scale and streamlined logistics. However, as consumer preferences shift towards freshness, convenience, and sustainability, many retailers are increasingly adopting hybrid distribution models. These models combine elements of CD and DSD systems, allowing for greater flexibility and responsiveness to local market demands. Retailers such as REWE Group and Edeka exemplify this approach, utilizing both centralized warehouses for non-perishable items and direct delivery methods for perishable goods.

Technological advancements, including real-time data analytics, automation, and the Internet of Things (IoT), have further optimized these models, enabling better demand forecasting, inventory management, and resilience against supply chain disruptions. Simultaneously, sustainability considerations are reshaping food distribution, with greater emphasis on minimizing environmental impact, reducing food waste, and integrating local sourcing practices.

The European grocery sector demonstrates a strategic use of CD and HD models to meet operational demands and market-specific challenges. While centralized systems dominate due to their cost-efficiency and scalability, hybrid models are gaining traction for their flexibility and ability to address perishability and regional preferences. The exclusive DSD was used primarily by small retailers, which are the majority on the market, but achieve significantly smaller market shares.

The Croatian grocery sector exhibits a diverse landscape of DND models that reflect both local market dynamics and broader trends observed across Europe. The dominance of CD models among larger retailers strengthens their market positions by enabling efficient scaling and supply chain control. Smaller players employing decentralized or hybrid models may struggle to compete on cost but can maintain a niche presence by focusing on regional responsiveness and customer proximity. The ongoing investments in technology and infrastructure will be

critical for enhancing the resilience and sustainability of food distribution networks in Croatia, ultimately benefiting both retailers and consumers alike.

In Europe and Croatia, the use of these models varies according to regional characteristics, with large retailers leveraging centralized systems for efficiency and hybrid models emerging to address local logistical complexities. As e-commerce continues to grow in importance, retailers are also exploring omnichannel strategies that seamlessly integrate online and offline sales channels. Despite the advancements in DND, challenges remain. Addressing these challenges requires ongoing investment in infrastructure, technology, and sustainable practices to ensure that food supply chains can adapt to changing conditions while minimizing waste and maximizing efficiency.

Research limitations: While this study provides a comprehensive analysis of food distribution models, certain limitations should be noted. The study relies heavily on secondary data and case studies, which may not fully capture the operational nuances of all retailers, especially smaller or emerging players (although they account for under 20% of European food distribution, and under 13 % of Croatian food distribution). The focus of study on European and Croatian supply chains may limit the generalizability of findings to other geographic contexts with differing market conditions, regulatory environments, or consumer preferences. While sustainability is discussed broadly, specific quantitative metrics on environmental and social impacts are limited, hindering a deeper evaluation of green supply chain initiatives.

Future research suggestion: Future research should focus on the long-term impacts of these distribution strategies on sustainability and resilience within food supply chains, as well as the potential for emerging technologies to further transform the industry. Furthermore, researchers could conduct empirical studies to quantify the performance metrics of CD, DSD, and HD models across different regions – to extend the analysis to include food distribution networks in non-European markets, such as Asia, Africa, and the Americas, to uncover regional adaptations and innovations.

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KOMPARATIVNA ANALIZA MODELA DIZAJNA DISTRIBUCIJSKE MREŽE U EUROPSKOM I HRVATSKOM SEKTORU TRGOVINE MJEŠOVITOM ROBOM

Sažetak

Ovo istraživanje bavi se razvojem i primjenom modela dizajna distribucijske mreže u europskim i hrvatskim lancima opskrbe mješovitom robom, vodeći računa o operativnoj učinkovitosti, zadovoljstvu potrošača i održivosti. Unatoč opsežnim istraživanjima o upravljanju opskrbnim lancem, nedostaje komparativna analiza centraliziranih, izravnih prodajnih i hibridnih modela distribucije u ovim kontekstima. Koristeći se pristupom mješovitih metoda, u istraživanju se kombinira pregled literature, studije slučaja i prikupljanje sekundarnih podataka za procjenu djelotvornosti ovih modela na temelju troškovne učinkovitosti, odaziva i prilagodljivosti. Nalazi pokazuju da centralizirani modeli dominiraju zbog troškovne učinkovitosti i skalabilnosti, dok su hibridni modeli sve više prihvaćeni zbog svoje fleksibilnosti i sposobnosti rješavanja kvarljivosti namirnica. Hrvatski trgovci mješovitom robom pretežno se koriste centraliziranim sustavima s ograničenim primjerima hibridnih i kooperativnih modela. U ovom radu ističe se potreba za budućim istraživanjima o integriranju novih tehnologija i održivih praksi kako bi se odgovorilo na rastuće zahtjeve tržišta i izazove opskrbnog lanca.

Ključne riječi: dizajn distribucijske mreže, lanac opskrbe hranom, centralizirana distribucija, hibridni modeli distribucije, izravna dostava u trgovine, europska i hrvatska maloprodaja mješovitom robom.

JEL klasifikacija: F36, F61, L23, L66, Q11.