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Closed Supply Chain Loops in the Context of Disruptions and Shocks

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Abstract:

Purpose: *The aim of the following considerations is to bring closer the issues related to closed loops in supply chains. The author notes a research gap in this area of knowledge and decides to address this topic against the background of logistical problems.*
Design/Methodology/Approach: *The theoretical basis of this study is an analysis of the existing scientific work dedicated to closed supply chains (CLSCM) – an area that has become one of the key and most developing trends in management sciences and logistics in recent years. The literature review aims not only to synthetically compile existing research findings but primarily to accurately reconstruct the conceptual transformation pathway. This shows the transition from reverse logistics, focused on disposal operations and cost optimization, towards advanced, circular systems aimed at proactive, dynamic capturing of residual value from products withdrawn from use. Through this approach, the phenomena analysed are permanently embedded within the strategic paradigm of the circular economy (CE) and the concept of building resilience in logistics systems in response to global market shocks.*
Findings: *The recent consolidation of research efforts around the idea of the circular economy (CE) demonstrates that this concept – along with its theoretical and operational subsystems – has become a central reference point in modern logistics and management sciences. The dynamics of this trend suggest that it will remain a key determinant of the research agenda in the coming decade. The ongoing transformation of modern, mature economies is increasingly reorienting them towards the circular paradigm (CE), which is based on replacing products and components at the end of their life cycle with secondary raw materials obtained from recycling or broadly understood recovery. In these realities, at the microeconomic level – determined by the product range structure, market mechanisms, consumer preferences, and strategic orientation of companies – closed-loop supply chains (CLSC) prove to be highly effective operational management tools.*
Practical implications: *The considerations presented can serve as an interesting source of knowledge for both researchers dealing with closed loops in supply chains and for analysts, managerial staff, and entrepreneurs. The perspective on the issues discussed in this study can form an important foundation for their understanding.*
Originality value: *This study constitutes an interesting contribution to the scientific literature by presenting and analysing issues related to closed loops in supply chains within a unified logistical framework. The work allows for comprehensive synthesis of theoretical*

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and empirical observations, identification of significant research gaps, and proposing directions for future research, especially in the context of developing logistics.

Keywords: *Closed Loop Supply Chain, Logistic Management.*

JEL Classification: *O30, O39, Q20.*

Paper type: *General review, viewpoint.*

1. Introduction

The concept of the Circular Economy (CE) is based on the mechanism of closing resource loops, which aims to establish sustainable patterns of production and consumption. These patterns are defined by high raw material efficiency, minimisation of waste streams, and the capacity for resource regeneration (Murray *et al.,* 2017; Kalmykova *et al.,* 2018). From a supply chain management (SCM) perspective, the implementation of CE principles involves creating and consolidating resilient supply chain structures that are deliberately fed and supported by autocatalytic (self-reinforcing) process loops (Genovese *et al.,* 2017; Geissdoerfer *et al.,* 2018).

The evolution of interest in reverse logistics (RL) and closed-loop supply chains (CLSC) began with a growing social awareness, as extensively described by Dowlatshahi (2000). In the subsequent phase, strict legal regulations became the key driver of change, imposing responsibility on manufacturers for the management of end-of-life (EOL) products.

A flagship example of such measures in Europe was the 2003 directive concerning waste electrical and electronic equipment (WEEE, 2002/96/EC), which introduced mandatory standards for collection, recycling, and recovery of devices at a minimum level of 4 kg per inhabitant annually (Georgiadis and Besiou, 2010). Similar legislative initiatives were also implemented in Canada, Japan, China, and in certain US states (Quariguasi Frota Neto *et al.,* 2010). Today, the perception of RL/CLSC has undergone a fundamental transformation – instead of being strategies that generate only costs, these concepts are now viewed as opportunities to create additional revenue streams (Guide and Van Wassenhove, 2009).

In the traditional view, a forward supply chain constitutes a sequence of processes aimed at satisfying customer needs, involving participants such as suppliers, manufacturers, freight forwarders, warehouse operators, distributors, and end consumers (Chopra and Meindl, 2010). Conversely, the American Council for Logistics Management defines reverse logistics as the process of planning, implementing, and controlling the efficient and cost-effective flow of raw materials, semi-finished products, finished goods, and related data, directed towards the transfer from the point of consumption back to the original point in order to recover residual value or properly dispose of the items (Rogers and Tibben-Lembke, 1998).

In practice, operations within reverse logistics are initiated at the end-user level. After receiving end-of-life (EOL) products, a decision-making process takes place, involving alternative courses of action: recycling (aimed at raw material or component recovery), regeneration (enabling resale on primary or secondary markets), repair (servicing for distribution on secondary markets), and final disposal of elements that have lost their utilitarian value.

The aim of the following considerations is to bring closer the issues related to the area of knowledge concerning closed loops in supply chains within logistics management. A review of the literature revealed a research gap in this field, which prompted the writing of this study. An analysis of the available research material allowed the formulation of the following research questions:

RQ1 – Do closed loops in supply chains have a significant impact on management in logistics?
RQ2 – What factors influence the difficulties in managing closed loops in supply chains?

2. Literature Review

The modern logistics sector is facing unprecedented structural challenges. Market pressure manifests in the increasing demand for customised products (Requelme, 2018; Krowas and Riedel, 2019), drastic shortening of product life cycles, and the acceleration of innovation processes (Werner-Lewandowska and Kosacka-Olejnik, 2019; Winkelhaus and Grosse, 2020; Schmidtke *et al.,* 2018; Wrobel-Lachowska and Wisniewski, 2017).

Additionally, customer expectations for higher service standards and faster order fulfilment (Winkelhaus and Grosse, 2020; Schmidtke *et al.,* 2018), combined with the geographical dispersion of supply chains, reduction in batch sizes (Lee *et al.,* 2018), and the constant variability of the market environment (Cimini *et al.,* 2019; Torbacki and Kijewska, 2019; Lagorio *et al.,* 2020), drive a sharp increase in the complexity of information and material flows (Kostrzewski *et al.,* 2019; Hofmann and Rüsch, 2017).

Traditional logistics approaches and instruments prove insufficient to generate the level of agility and flexibility necessary for immediate responses to these fluctuations (Baretto *et al.,* 2017). A strategic alternative, aimed at optimising operational efficiency in supply chains, is seen in the implementation of closed-loop economy principles.

The traditional approach to closed-loop supply chains (CLSCM), defined by Asif *et al.* (2012) as logistical structures in which products return to the original manufacturer for regeneration to a standard of a fully functional substitute in the primary market, has proven to be too restrictive in the course of literature development. The evolution of theory has necessitated an expansion of the conceptual framework, allowing for the analysis of product-material cycles and segments of secondary markets, which previously extended beyond the boundaries of closed systems.

As Guide and Van Wassenhove (2009) note, moving away from an orthodox focus on the final product has opened the way for exploring recovery at the module, component, and raw material levels. The parallel broadening of the perspective beyond the original manufacturer has enabled the inclusion of independent entities, including external integrators (3PR – Third-Party Remanufacturers) operating as cooperators (Atasu *et al.,* 2008).

Furthermore, the removal of the requirement for full integration of distribution and reverse logistics processes has allowed for the establishment of autonomous reverse chains, as exemplified by the recycling sector (Mesjasz-Lech *et al.,* 2024). In such open systems, the justification lies in the reduction of supply limits for new goods, bringing these systems closer in character to classical models with unlimited supply (Guide and Van Wassenhove, 2009).

Additionally, revising the dogma of perfect substitutability has gained importance in light of market differentiation between new and consumer-regenerated goods (Akçali and Çetinkaya, 2011), as well as in the context of distributing refurbished products on dedicated secondary markets (Asif *et al.,* 2012).

Discussing supply chain management, it is impossible to overlook a very important issue concerning the occurrence of shocks. The analysis of disruption management processes has clearly gained significance over the past fifteen years. Importantly, although this topic naturally fits within the realm of operations research and management sciences (OR/MS) (Rameshwar *et al.,* 2019), the literature still reveals a deficit of studies dedicated to operations in the face of macroeconomic or mass dysfunctions.

Cross-sectional studies in this area have been published by, among others, Altay and Green (2006), Galindo and Batta (2013), and Farahani *et al.* (2020). However, the state of knowledge appears to be particularly limited when research questions concern the implications of these phenomena for closed-loop supply chain (CLSC) structures. This is probably due to the fact that the detailed mechanisms of how crises impact CLSC efficiency remain largely unrecognised (Ivanov, 2020a; 2020b; Ivanov and Dolgui, 2020b; Dolgui *et al.,* 2020; Holguín-Veras *et al.,* 2012).

Additionally, as pointed out accurately by Borja *et al.* (2019), the scientific contribution dedicated to the dynamic behaviours of CLSC systems remains strongly limited.

Potential system states can, however, be effectively explored using models that map the interactions between individual components of the structure. Under conditions where unknown effects occur, these relationships become nonlinear, and the prediction of models depends directly on the ability to reflect feedback loops, implement adaptive control mechanisms, and account for time delays (Surana *et al.,* 2005).

This necessitates the use of a dynamic modelling approach. Tools for multi-criteria analysis and optimisation of CLSC under uncertainty include, among others: the theory of complex adaptive systems (Surana *et al.,* 2005; Hwarng and Yuan, 2014; Li *et al.,* 2010), chaos theory (Hwarng and Xie, 2008; Wu and Zhang, 2007), disturbance theory (Helbing *et al.,* 2006), as well as concepts based on crisis risk (Peterson, 2002), operational recovery (John Kwesi-Buor *et al.,* 2019), and nonlinear dynamics (Mosekilde and Laugesen, 2008; Wu and Zhang, 2007; Chang *et al.,* 2007).

Nevertheless, the application of these advanced mathematical approaches is usually associated with a high degree of algorithmic complexity and restrictive limitations regarding the permissible number of state variables and the complexity of cost structures.

3. Research Methodology

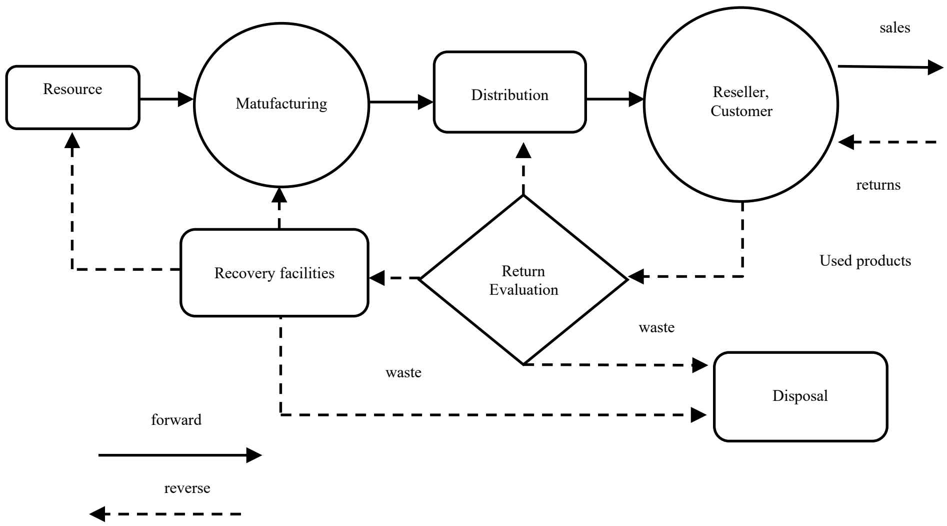
The development is based on a review of the existing scientific achievements concerning closed loops in supply chains within the broadly understood field of logistics. Such an approach constitutes one of the most dynamic research areas in contemporary logistics.

The main aim of this theoretical retrospection is not only to organise the existing body of knowledge but also, most importantly, to identify the conceptual evolution — from traditionally understood reverse logistics, focused on disposal and cost reduction, to modern, integrated circular networks aimed at the dynamic recovery of residual product value.

This analysis allows for situating the studied phenomena within the broader context of the circular economy (CE) paradigm and the building of resilience in logistics systems in the face of global market disruptions.

Simultaneous consideration of traditional and return logistics streams allows for the formulation of a closed supply chain (CLSC) structure. The model process layout for forward and reverse logistics is presented in Figure 1, where classical connections are illustrated with a solid line, while return flows are shown with a dashed line. A key element of this architecture is the verification and assessment stage, where decisions are made that determine the further handling of returned products (see the alternative general model in: Beamon, 1999).

Figure 1. *Forward/Reverse Logistics Overview.*



Source: *Own work based on Tonanont et al., 2008.*

In the context of the contemporary conceptual evolution of CLSC, particular attention should be paid to the definition formulated by Guide and Van Wassenhove (2009).

According to this modernised approach, managing a closed supply chain involves designing, controlling, and operationalising a system aimed at maximising value creation throughout the entire product lifecycle, while simultaneously dynamically recovering this value from diverse reverse streams in terms of volume and structure.

The essence of this redefinition lies in prioritising the business perspective over purely legislative, social, or technical details. This allows business practitioners to reorient their objectives—from traditional cost minimisation to profit generation and value building within RL/CLSC.

In the era of new market realities, which reflect updated paradigms, it becomes crucial to identify the threats present in supply chains, as this will facilitate researchers in pinpointing future, promising directions for the development of this field.

4. Results of the Research and Discussion

The analysis begins with a presentation of the framework model of a closed-loop logistics system. The general diagram of the studied CLSC system is illustrated in Figure 2. The analysis covers a single-product, multi-level supply chain integrated with regeneration (remanufacturing) and recycling processes. The direct distribution channel (forward supply chain) consists of five levels: raw material supplier, component manufacturer, finished product manufacturer, wholesaler, and retailer.

The raw material supplier sources directly from the external market. The component manufacturer produces based on two independent supply streams: primary raw materials and recovered materials from recycling, with the latter being prioritised. The final manufacturer assembles the final product, which consists of n = 1, 2, ..., N parts, sourcing them both from the component manufacturer and from the regeneration process, which has a higher allocation priority.

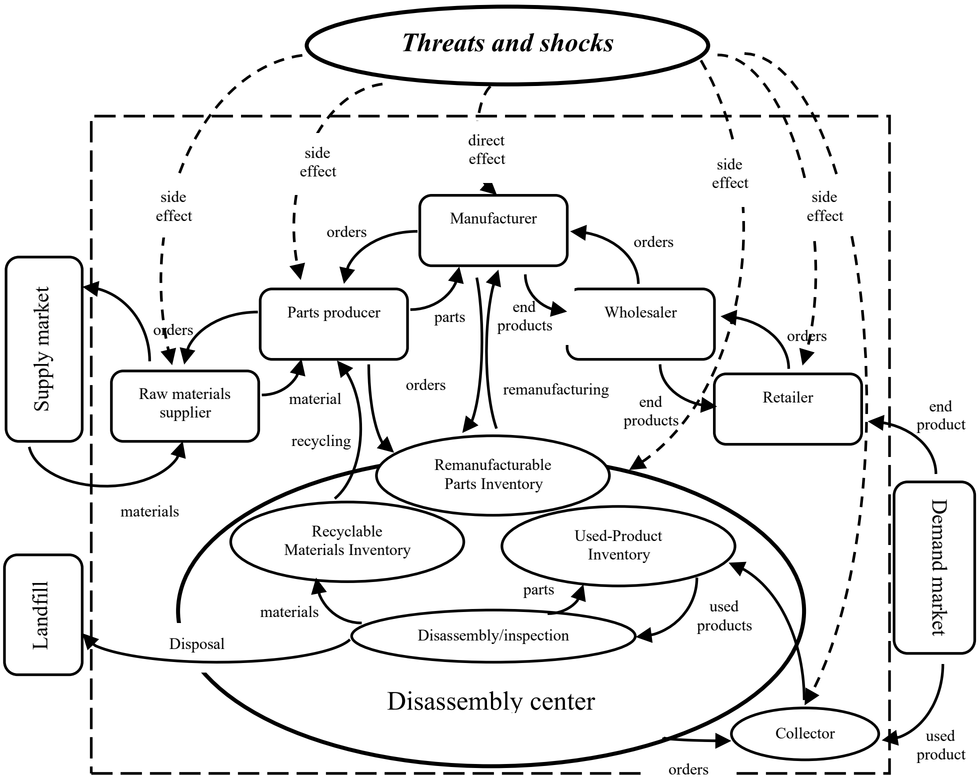
The distribution of finished products to the target market (demand market) occurs sequentially through the wholesaler and retailer. An important assumption for the direct channel is that any unfulfilled orders from the retailer and wholesaler, as well as unmet consumer demand, create backlogs that must be fulfilled in the next time horizon. The reverse logistics subsystem consolidates collection operations (carried out by the collector), disassembly (conducted at the disassembly centre), as well as regeneration, recycling, and final waste disposal. Used products are collected from users by the collector and then resold to the disassembly centre.

There, components obtained from disassembly undergo strict quality verification regarding their suitability for regeneration. Disqualified parts at this stage are assessed for material recycling potential. Parts that do not meet recycling criteria are ultimately disposed of (landfilled as waste).

The outcome of the regeneration process is high-quality components (as-new class) intended for the finished goods manufacturer, while recycling produces substitutes for primary raw materials, which are returned to the component producer. Regarding trade relations within the network, a single sourcing strategy is adopted in both channels, meaning each entity has exactly one dedicated supplier and customer at each level of the structure.

The modelling of the impact of disturbance on the manufacturing efficiency of the producer is presented in Figure 3, which illustrates the probability distribution of the production rate during the pre-conflict/pre-crisis phase, the recovery period, and the stabilisation phase after the occurrence of an anomaly. In this model, the variable tD defines the unknown moment of the crisis event, while hD indicates the indefinite duration of the restitution (restoration of efficiency) process. This approach is based on the concept of resilience (resistance) triangle, originally formulated by Bruneau *et al.* (2003), and further developed in the works of Zobel and Khansa (2014).

Figure 2. *Threats and shocks in the Closed Loop Supply Chain.*



Source: *Own work based on Tonanont et al., 2008.*

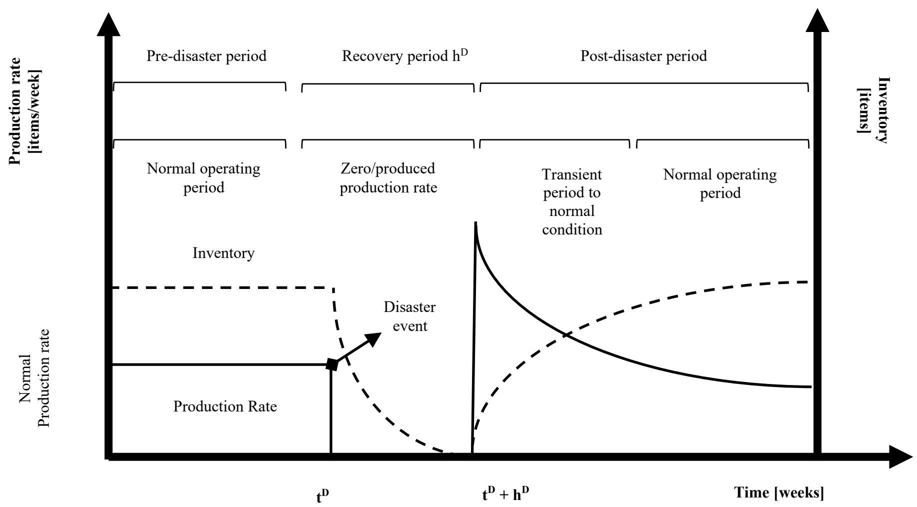
According to the model specification shown in Figure 3, it is assumed that during the recovery phase, the continuity of supply at the producer–wholesaler level is maintained provided that warehouse stocks are available. During this period, two alternative scenarios of production potential reduction caused by the shock are analysed: complete production stoppage (zero dynamics) or limited operational efficiency (reduced dynamics).

These variants, combined with a restrictive single sourcing strategy, generate cascading disruptions throughout the entire supply chain structure (both in the direct and reverse channels – see Figure 2), leading to the following implications: (i) complete halt or significant reduction in the volume of purchases of primary components between the parts manufacturer and the end producer; (ii) reduction or complete disappearance of regeneration and recycling processes at the dismantling centre; and (iii) a decrease in the contracting dynamics of used products between the dismantling centre and the collector, which is a direct consequence of regression in the secondary processing sphere.

To capture the dynamics of the CLSC system's response to the mentioned disturbances, it is necessary to apply a dynamic model illustrating the structure of inventories and flow streams. This methodology derives from the system dynamics (SD) model developed by Gu and Gao (2012), which utilises adaptive control mechanisms that, through regulation of resource inflow, adjust the actual inventory levels to the desired level.

The extension of this model, aimed at increasing the system's resilience, is based on the work of Kastoras and Georgiadis (2022), who introduced additional adaptive mechanisms for the manufacturer, parts producer, dismantling centre, and collector. For the remaining links in the chain (raw material suppliers, wholesaler, and retailer), standard solutions proposed by Gu and Gao (2012) were retained. However, the author of this paper will not provide a detailed description of these issues.

Figure 3. *Likelihood pattern for production rate and end-products inventory under shock effect at manufacturer level.*



Source: *Own work based on Kastoras and Georgiadis, 2022.*

The intensification of research processes in recent years clearly demonstrates that the issue of the circular economy (CE) – along with its related sub-disciplines, theoretical frameworks, and application areas (Winans *et al.,* 2017) – constitutes a key, highly current scientific trend that will maintain its priority status in the coming decade. Although the historical roots of the circular concept date back to literature from the mid-twentieth century (Boulding, 1966), its definitional frameworks are subject to ongoing evolution and revision (Geisendorf and Pietrulla, 2018).

Based on a semantic analysis, Homrich *et al.* (2018) characterised CE as a strategy aimed at breaking the paradigm of conventional, linear production systems. Its goal is to neutralise resource scarcity and waste generation issues through the implementation of a win-win approach, based on the optimisation of economic criteria and the creation of new value.

This conceptual dichotomy, which in the realm of production systems and logistics is referred to as closed loops (CL – Closed-Loop), currently attracts particular attention from both academic circles and business practitioners.

As a specific configuration of logistics systems, closed-loop supply chains (CL) implement the principles of sustainable development through the collection of products withdrawn from use or operation (EoL/U), referred to as cores, for recovery, regeneration, renewal, reuse, or recycling processes. CL integrate material, financial, and informational flows, linking downstream (customers) and upstream (suppliers) market links into a coherent, unique system structure; empirical examples of such solutions in economic practice are presented by Mishra *et al.* (2018).

In general terms, CLSC (Closed-Loop Supply Chain) represent an extension of traditional forward logistics flows with reverse logistics (backward). Consequently, they are characterised by a much broader range of operational processes and usually involve a greater number of entities than conventional, linear supply chains.

The identification of key process determinants provides a structural foundation that accelerates the transformation and transition from the linear economy paradigm to a circular model.

Previous research trends have focused on identifying significant factors in the areas of sustainable development, ecological supply chains (Björklund *et al.,* 2012; Hervani *et al.,* 2005), and the circular economy (Ghisellini *et al.,* 2016; Kalmykova *et al.,* 2018; Pieroni *et al.,* 2019).

Due to the multifaceted structure of CLSC models, precisely defining and classifying their distinctive features facilitates researchers in designing innovative theoretical frameworks (Souza, 2013; Govindan et al., 2015) and reorienting existing processes towards methods with higher operational efficiency. In this context, operationalising CLSC indicators allows for the identification of key catalysts that stimulate the development of the circular economy.

5. Conclusions

All kinds of shocks (epidemics, warfare, disasters) cause disruptions in supply chains. Such a state of affairs is contributed to by the introduction of restrictive measures (e.g., complete lockdowns) implemented in most countries worldwide, even in economically developed nations (Suborna, 2020). The global consequences of the COVID-19 pandemic for logistics structures can be classified as catastrophic events with unpredictable, unknown effects (Pawson *et al.,* 2020).

The specific nature of this phenomenon has generated deep uncertainty and multi-level disturbances, requiring the implementation of effective management strategies to restore stability in transport systems (Maureen *et al.,* 2020), and subsequently – in financial terms. Although the literature commonly uses defined disruption scenarios to evaluate supply chain resilience, analyses that account for extreme uncertainty, including phenomena of the 'unknown-unknown' type, are still rare.

This is due to the fact that most studies are limited solely to network structures, neglecting the associated components of the systemic environment, which creates a significant knowledge gap (Maureen *et al.,* 2020). The response to these challenges is the proposed paradigm of the Vital Supply Chain (VSC) by Ivanova (2020a; 2020b). It defines the key properties of logistics networks through three complementary perspectives: flexibility, resilience, and sustainable development, providing strategic support for enterprises in restructuring processes and rebuilding market position after prolonged economic crises, such as pandemics or armed conflicts.

Referring to the research questions posed at the beginning of the article, it can be stated that the analysed content allows for answers to be provided. In relation to the first research question RQ1 – Do closed loops in supply chains have a significant impact on management in logistics? – it can be confirmed that closed loops in supply chains have a substantial influence on logistics management.

At the current stage of socio-economic development, managing a circular economy is becoming increasingly important. Conversely, regarding the second research question RQ2 – What factors influence the difficulties in managing closed loops in supply chains? – it is important to emphasise the significance of all kinds of disruptions that occur during the supply process. These include acts of war, epidemics (COVID-19), as well as broadly understood economic crises.

The results presented in this article certainly do not exhaust all aspects of crisis management in CLSC. Coordinated actions among supply chain participants and optimisation of emergency supply chain operations to ensure a rapid response to demand uncertainty may be open issues requiring the formulation of appropriate policies.

The emergence of threats and shocks is often highly dynamic and interdisciplinary, which means that their degree of repeatability can vary significantly depending on the nature and level of innovativeness, as well as the uniqueness of the activities undertaken.

Contemporary, highly developed macroeconomic systems are increasingly evolving towards a circular economy (CE), whose fundamental assumption is the substitution of products and components withdrawn from exploitation with secondary raw materials, recovered or recycled. In this paradigm, at the microeconomic level – encompassing the sphere of goods, markets, consumer behaviours, and corporate strategies – closed-loop supply chains (CLSC) constitute a highly effective operational tool.

Systemic identification of the characteristic features of CLSC stimulates and accelerates the transformation of the linear structure into a circular one. This process facilitates the conversion of modern, inefficient economic models into an integrated circular system, which, alongside the optimisation of financial objectives, generates significant environmental synergy.

In the scientific literature, there are also concepts concerning open loops in supply chains (OLSC). Two approaches to this issue have emerged. Goltsos et al. (2019) perceive OLSC as a progressive supply chain system in a linear economy, whereas Gou *et al.* (2008) see OLSC as a supply chain system for the recovery of products, components, and/or materials by entities other than the OEM manufacturer.

The knowledge about CLSC indicates a preference in the literature to adhere to a narrow definition of the CLSC concept. Considering the narrow definition, this concept is suitable for studying an integrated forward and backward recovery system (SC), controlled by the OEM manufacturer, with the reintroduction of regenerated products as ideal substitutes in the primary market.

However, this narrow definition of CLSC has over time been expanded to capture features of both product and material flows, as well as target markets, which would otherwise fall outside the boundaries of a closed system. The results of the OLSC review show that there are various views in the literature regarding how this concept is utilised. In particular, the view that OLSC is a configuration of SC where entities other than the OEM manufacturer handle product and material recovery aligns well with the idea of OLSC as a complement to the CLSC concept.

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