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Supply Chain 4.0: what the supply chains of the future might look like

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ABSTRACT

The article mainly aims to try and create a new concept for developing logistics and supply chains in the era of Industry 4.0. Analyses of development trends in logistics and production management were used to create the new logistics and supply chain concept. Conclusions were used from the analyses of how the modern concepts of Industry 4.0, Logistics 4.0, Supply Chain 4.0, and 5.0 work. Analyses of the benefits of applying modern management concepts in these areas were carried out and criticised because of their inadequacies, which became apparent during the recent crises in the world. Although the sources of the crises were different, they could be eliminated by reconfiguring logistics systems and supply chains. The results aim to answer three questions: (1) Has the time come to change the current way of looking at logistics and supply chains? (2) What could Supply Chain 4.0 look like using Industry 4.0 tools? (3) How should Supply Chain 4.0 address the logistics and supply chain challenges? The presented answers do not exhaust the topic but rather open up a discussion on logistics and supply chains of the future. The presented concept allows for a completely new global and local view of logistics chains. The structure of the presented model can be subjected to scenario analysis using agent-based simulation modelling due to the structure's emergent nature. The new approach can significantly benefit the development of local production centres and global supply networks. The benefits mainly come from reducing the environmental impact of manufacturing and logistics processes from the moment the new product idea is conceived.

KEY WORDS
Supply Chain 4.0, Industry 4.0, agent-based modelling

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Introduction

Business management issues got complicated during the twenties of the 21st century to an even greater extent than in previous decades. Globalisation, mass personalisation, hyper-competition, and consumerism, referred to as chaos by Kotler and Caslione even before 2008 (Kotler & Caslione, 2009), have been made more complex by natural disasters. Natural disasters are mainly caused by an environment increasingly degraded by industry, pandemics,

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armed conflicts in industrialised countries, and cyber-attacks (Chopra & Sodhi, 2004, p. 54).

Meanwhile, Germany's industrial development strategy (Industry 4.0 — I 4.0), announced in 2011, has been providing striking solutions, especially in the technological and IT spheres (Kagermann, Wahlster, & Helbig, 2013, pp. 13–15; Magruk, 2016). Cyber-physical systems, additive manufacturing, the Internet of Things, Internet of Services, augmented and virtual reality, big data, business analytics, cloud computing, etc., are opening up possibilities for organisations to create solutions limited only by human imagination (Rojko, 2017).

The development of logistics and supply chain management coincided with the development of manufacturing management. Where it was necessary to produce more efficiently, concepts such as Lean Manufacturing (Womack, Jones, & Roos, 1990) appeared, which soon received its logistical counterpart, Lean Logistics (Golsby & Martichenko, 2005, p. 65).

Where flexibility and agility had to be maintained, Agile Supply Chain concepts emerged (Towill & Christopher, 2010, p. 301), and where the broader environment had to be taken care of, Green-type concepts (Shi et al., 2012) or Corporate Social Responsibility (CSR) concepts emerged (Hopkins, 2014). Were it not for environmental changes (progressive destruction of the environment), the COVID-19 pandemic, and escalating armed conflicts in 2022 (e.g., armed conflict in Ukraine), these concepts would have developed in the industry faster, more effectively, and more efficiently.

Globalisation has made logistics and supply chains one of the most important elements of business competitiveness (Humphrey, 2003). Searching for suppliers that can offer raw materials, materials, parts, components, and finished goods has become a major challenge for many companies. When choosing purchasing sources, companies must consider such issues as cost, time, quality, and cooperation terms. Increasingly, it is also necessary to consider cultural diversity, fighting stereotypes relating to given countries or regions, operating within different time zones, and the lack of homogeneity of business ethics on a global scale (Bielecki, 2022). In addition, there are new civilisational, economic, social, and similar challenges, which include:

- dynamic and adverse environmental changes;
- new or known disruptions to economies and businesses, such as pandemics, wars, and economic crises;
- development of new Industry 4.0 technologies, including information technology finding its way into the industry;
- social changes, such as the entry of Generation Z into the labour market — iGeneration (iGen — iGeneration) — the generation of adult users of the Internet, smartphones and social media (Twenge, 2017) or the emergence of the concept of Society 5.0 — S 5.0 (Pereira, Lima, & Charrua-Santos, 2020).

All these "signs of the times" in the context of logistics and supply chains necessitate a scientific discussion on this article's topic. This discussion should address the redefinition of current business rules. The authors endeavoured to initiate a focused discussion on such a redefinition as the main research objective of this article. The result of the deliberations is to be an initiative for a new logistics and supply chain concept.

The model proposed in this article is based on a review of the issues in the literature and an analysis of the gaps identified in the referenced studies. Assumptions have been prepared from the evolution of existing logistics concepts and provide a starting point for developing a new logistics and supply chain paradigm.

The insights are also based on an analysis of the operation of actual logistics solutions. Preliminary considerations of the presented concept are included in "Total Logistics Management. Logistics and Supply Chains 4.0" (Bielecki, 2022). The article shows the conclusions of the desk research. An analysis shows interdependencies between the various subsystems, their couplings, synergy effects and other interdependencies.

Let this be an introduction to the discussion of developing a new concept. This new concept is based on the layers of customer needs, product-added value, physical flows, and digital data flows and can be, in its current version, a good start for criticism and discussion by the scientific community. This way of presenting the model may not be complete, but it will arouse curiosity.

The paper presents a literature analysis of the evolution of various supply chain concepts and their interpretation to develop the systemic, territorial and flow aspects of the concept of logistics and supply chain model 4.0. Section 3.1 is devoted to presenting the systemic aspect; Section 3.2 shows the logic of spatial operation of the logistics and supply chain model 4.0. The next section presents the key issue of the new supply chain concept of information flow.

Section 3.4 presents the determinants of the model, while Section 3.5 is devoted to presenting how to model the development of the system. An approach is proposed here that can be used to create simulation models to test various configurations of the new model.

1. Literature review — challenges of 21st-century supply chains

Negative environmental changes have continued for a long time and are not slowing down despite emerging demands and management concepts. Protecting the environment and ensuring people's right to a clean and healthy environment should be one of the priority areas of law, economics, management, and policy (Perkumienė et al., 2020, p. 2). However, regardless of existing regulatory solutions, climate change risks are growing, significantly impacting business performance (Ghadge, Wurtmann, & Seuring, 2019, p. 44). The Sustainable Development Goals set by the UN Commission on Environment and Development (2015) was one of the responses to the changes.

Some goals fit the logistics and supply chains issue, but not all. Goals directly related to supply chains include Goal 9: "industry, innovation, and infrastructure". This objective is strongly linked to logistics and supply chains. This goal, however, must be correlated with a group of intermediate goals that create specific boundaries for the development of logistics and supply chains or indicate the directions of development while emphasising its sustainability. Among the intermediate goals that logistics should consider in its development Transforming Our World: The 2030 Agenda for Sustainable Development are Goal 6: "clean water and sanitation", Goal 7: "affordable and clean energy", Goal 8: "decent work and economic growth", Goal 11: "sustainable cities and communities", and Goal 13: "climate action". Logistics development should, therefore, consider the following:

- dignity of work and wages;
- clean energy;
- minimising the impact of logistics processes on water resources by protecting them and reducing their consumption;
- minimising the negative impact of logistics processes on the climate (Bielecki, 2022, p. 15).

The new determinants of logistics development are ascertained by these goals and the overarching goal of Goal 17: "partnership for goals".

A new concept that must fit into sustainable development is that of the circular economy (CE). Kirchherr, Reike and Hekkert (2017, p. 221) collected 114 definitions of the circular economy, which were then examined in the context of 17 dimensions, which included such elements as the 4R model (4R — Reduce, Reuse, Recycle, and Recover). In their research, the authors found that the circular economy is most often portrayed as a combination of reducing, reusing and recycling. They also noted that the literature often overlooks the fact that the circular economy requires systemic change, which is an important paradigm gap. In addition, they found that definitions show few clear links between the circular economy concept and sustainable development. The CE concept itself needs to be given coherence and a framework defined so that it is not scattered by overinterpretation and extreme ideas from different authors.

When discussing sustainability and the circular economy, the issue of carbon footprint cannot be ignored. Based on a literature review, Wiedmann (2008) defined the carbon footprint as a measure of the exclusive total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or as the cumulative value created over the life cycle of a product or service. The definition of carbon footprint indicates that the measure only considers carbon dioxide. However, it should be borne in mind that there are also other substances that cause the greenhouse effect, such as methane; however, there is a problem in obtaining data to calculate such a measure. In the case of having comprehensive information on the emissions of all greenhouse gases, a measure called "climate footprint" could be created. In the case of the carbon footprint, the most practical and transparent solution was chosen considering only CO2 (Wiedmann & Minx, 2008, pp. 4–5).

Until 2019, the world of logistics and supply chains was characterised by a high level of resilience to numerous disruptions. However, it should be noted that the reality of the beginning of the third decade of the 21st century is somewhat different and shows increasing uncertainty. Between 1996 and 2022, humanity has witnessed many types of unpredictable disasters, such as:

- terrorist attacks (e.g., World Trade Center and Pentagon 2001),

- wars (e.g., in Syria since 2011, in Ukraine since 2014),
- earthquakes and tsunamis (e.g., Sumatra 2012, Japan 2011, Chile 2010),
- economic crises, (e.g., USA 2009),
- pandemics (Swine flu 2009–2010, SARS-CoV-2 2020),
- strikes (examples are too numerous to cite),
- cybercrime (attack on British and Delta Airlines in 2004, attack on German steel mill in 2014),
- human errors (container ship Ever Given 2021) and others.

Tang (2007) reports that according to two independent studies, one conducted by the Centre for Research on the Epidemiology of Disasters (www.cred.be) and the other by the world's largest reinsurer, Munich Re (www.munichre.com), historical data shows that the total number of natural and artificial disasters between 1996 and 2006 increased dramatically. The average cost of these disasters has increased tenfold (Tang, 2007, p. 33) since the 1960s.

However, the COVID-19 pandemic appears to have been one of the biggest problems for logistics and supply chains in the 21st century. A Deloitte report titled Governments' Response to COVID-19 — From Pandemic Crisis to a Better Future (Eggers et al., 2020) identified three primary factors that differentiate the SARS-CoV-2 pandemic from ordinary disasters. These included:

- the development of an emergency over a long time horizon, which is in contrast to natural disasters that sometimes last seconds, minutes or hours; COVID-19 is a "slow motion" disaster that develops over weeks and months;
- COVID-19 is a global disaster, with every region of the world infected, making it impossible to move a variety of resources from unaffected locations to those affected by the pandemic (fortunately, lessons learned in one region can be applied to those regions where the virus emerged later);
- a new RNA virus (COVID-19), has a high degree of uncertainty about its timing, spread and ultimate impact; much is yet unknown, and official estimates of the virus' impact, duration and potential for recurrence vary (Eggers et al., 2020, p. 7).

This shows that global supply chains are not as resilient as they seem.

The emergence of unusual global disruptive events that slow down and hinder economic development has coincided with the development of new development concepts. Presented in Germany in 2012, the Industry 4.0 (I 4.0) concept opens up completely new horizons for logistics and supply chains (Kagermann et al., 2013). It consists of four basic concepts (Rojko, 2017), appearing most often in the literature, i.e.:

- Cyber-Physical Systems (CPS),
- Internet of Things (IoT),
- Internet of Services (IoS),
- Smart Factory (SF).

The most spectacular solution is the Smart Factory (SF) as defined by the German Research Foundation (Deutsche Forschungsgemeinschaft — DFG). It is a factory that offers previously unknown opportunities to contextually help people and machines perform their tasks (Lucke, Constantinescu, & Westkämper, 2008, pp. 115–116). Solutions proposed by I 4.0 that will affect (or are already affecting) logistics and supply chains include (Skobelev & Borovik, 2017, pp. 307–311):

- cyber-physical systems,
- virtual and augmented reality,
- artificial intelligence,
- Internet of Things, services, everything,
- big data and cloud computing,
- cyber security,
- S 5.0 operating determinants,
- evergetics.

The literature also contains attempts to combine these issues. The topic of sustainability in I 4.0 and Supply Chain 4.0 (SC 4.0) was addressed by Canas, Mula and Campuzano-Bolarin (2020, pp. 13–14). Through their research based on a literature review, they showed that most scientific work focuses mainly on enabling technologies with the overriding goal of reducing costs and increasing the effectiveness of systems control (monitoring). Thus, they concluded that there is a need to refer to a sustainable and standardised I 4.0 framework. The authors also noted that the articles often overlooked the social aspect of I 4.0.

Alicke, Rexhausen and Seyfert (2017, pp. 2–4) stated that through digitisation and new customer demands, supply chains should become

- faster; "predictive shipments" are already appearing in practice, which are shipped before a customer places an order and then matches a specific order;
- more flexible; real-time, ad hoc planning under SC 4.0 allows organisations to respond flexibly to changes in demand or supply;
- more detailed, as customers expect increasing customisation of products;
- more accurate; next-generation performance management systems provide real-time visibility across the supply chain;

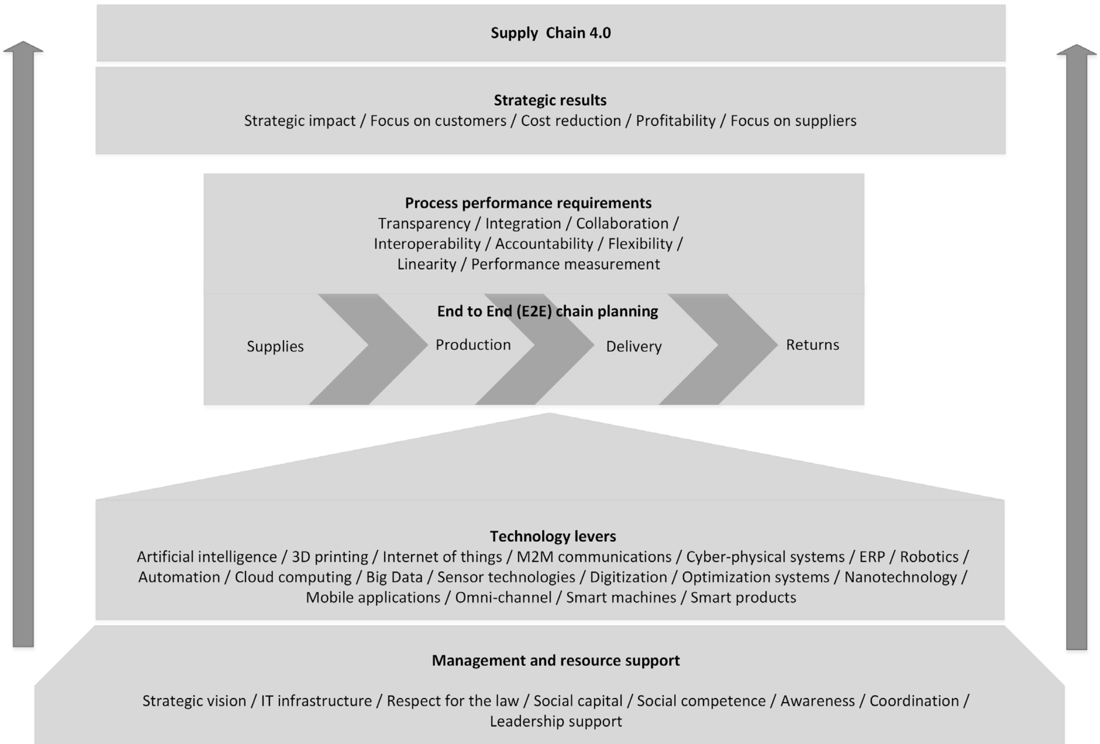

Fig. 1. Theoretical structure of the Supply Chain 4.0 concept

Source: elaborated by the author based on (Frederico, 2021, p. 18).

- more efficient; automation of physical and planning tasks increases supply chain efficiency (Alicke et al., 2017).

An interesting theoretical structure of the SC 4.0 concept was presented by Frederico, Garza-Reves, Anosike, and Kumar (2016) (Fig. 1). They based the entire concept on two basic pillars:

- management and resource support;
- technological leverage based primarily on I 4.0 solutions.

The listed elements support a phased logistics arrangement that is based on specific principles, which are requirements for process performance. All this aims to achieve strategic results that complement the SC 4.0 concept.

Although SC 4.0 is a topic on which academic work has begun, Frederico (2021, pp. 15–16) has already proposed transitioning from SC 4.0 to Supply Chain 5.0 (SC 5.0). During a systematic literature review, the author managed to identify forty-one articles related to the SC 5.0 topic. Analysis of these articles using the VOSviewer software made it possible to extract nineteen keywords forming four main conceptual constructs: industrial strategy, innovation and technology, society and sustainability, and transition issues. According to Federico, SC 5.0 encompasses an industrial strategy that seeks to create a sustainable human-technological environment and a sustainable and intelligent society. It is supported by technology and innovation, which includes I 4.0 technologies and an innovation ecosystem. The SC 5.0 strategy also involves some transitional issues arising from I 4.0 paradigms and other issues such as psychology, employee safety, social, ethical, legal and regulatory issues. The main goal of SC 5.0, in social and sustainability terms, is to create a more sustainable, intelligent society. It also creates mass personalisation of products and services in supply chains.

Based on the presented conditions and the challenges facing logistics and supply chains presented in the presented work, and considering the existing assumptions and concepts of Industry 4.0, Logistics 4.0, Supply Chain 4.0, Supply Chain 5.0, Society 5.0 in the literature, a conceptual model of logistics and Supply Chains 4.0 (L&SC 4.0) was proposed, which could become a vision of SC 4.0 dedicated especially to industrial products[1].

[1] The model's assumptions apply strictly to industrial products since the possibilities for their design and, above all, the possibilities for recovery from used finished products of materials, raw materials, and components have a much higher potential than in the case of food products, where packaging can be recovered in the main.

2. Methodology

Based on the above review of issues and the analysis of gaps identified in the referenced studies, assumptions have emerged from the evolution of existing logistics concepts and can serve as a starting point for developing a new paradigm for logistics and supply chains. The concept was prepared based on the following methods:

- literature analysis — research and analysis of scientific publications, reports, books and other literature;
- descriptive method describing the phenomenon, concept and situation without deep quantitative study;
- interpretive method focusing on understanding the meaning, significance and interpretation of social phenomena based on qualitative and conceptual data analysis;
- conceptual method analysing and developing concepts, theories, ideas, or models to enrich understanding of an issue.

A discernment of the issue was carried out based on a literature study. Then, the concepts of logistics and supply chain logistics development known and operating now and in the past were described. The conclusions became the basis for interpreting the identified concepts in the context of the changing economic environment and incidental challenges on a global scale. A posteriori knowledge of the evolution of logistics solutions in a rapidly changing environment was used.

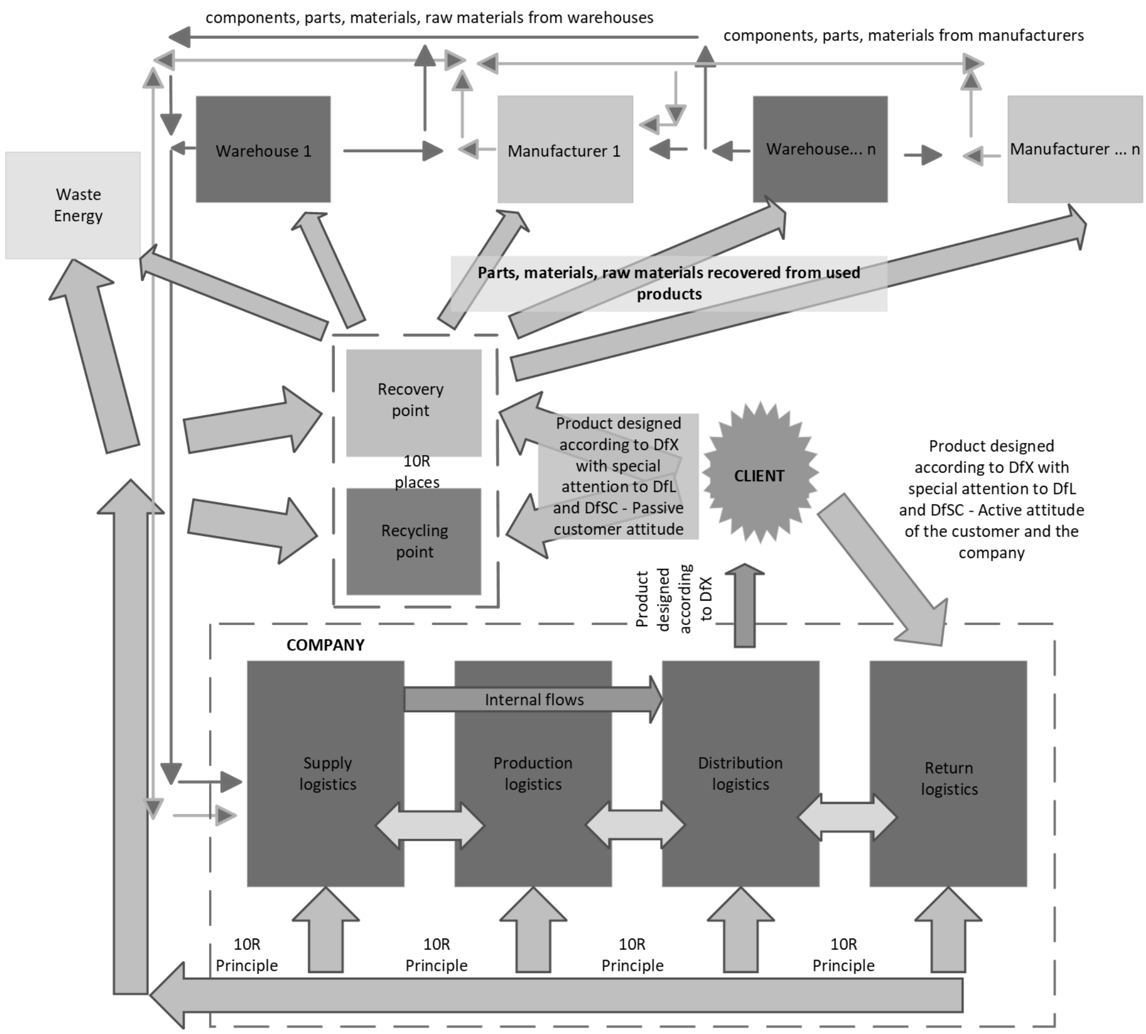

Fig. 2. Concept of collaboration among participants in the L&SC 4.0 model (the 10R Principle includes Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Re-use, Reduce, Rethink, and Refuse)

Abbreviations used: DfX — Design for Excellence, DfL — Design for Logistics, DfSC — design for Supply Chain

Source: elaborated by the author based on (Bielecki, Galińska, & Polak-Sopińska, 2021).

Following the interpretive analysis, an analysis and synthesis of the new concept of the supply chain logistics development model was performed.

3. Results and discussion — a conceptual model of Logistics and Supply Chain 4.0

The authors' proposed concept of the Logistics and Supply Chains 4.0 model will be considered from three basic aspects:

1. systemic,
2. territorial,
3. flow-based.

The flow aspect welds together the system and territory aspects; it considers physical flows (Fig. 2) and information flows (Figs. 4 and 5).

3.1. Systemic aspect

The systemic aspect distinguishes five basic types of L&SC 4.0 participants:

- customers using applications in product design and, upon approval, sending their design to the cloud based on the ERP systems of a single enterprise;
- single organisations, often single-station artisans with high specialisation using digital additive manufacturing, are served by hubs, recovery points and recycling points;
- warehouses, which are hubs where new and used raw materials, materials, parts, components and other items are available;
- recovery points that are specialised units recovering parts and components from used products, which are also warehouses for used raw materials, materials, parts and components, or transferring recovered components to specific warehouses (hubs);
- recycling points, i.e., specialised units recovering raw materials and materials from used facilities, also constituting warehouses for used raw materials, materials or transferring recovered elements to specific warehouses (hubs).

Fig. 2 presents the idea of cooperation between the participants in the conceptual L&SC 4.0 model and the aspect of physical flows. The time and routes by which the physical flow of used products is carried out depend on what attitude the customer takes towards them, i.e., passive or active. The active attitude of the customer makes it possible to give used products directly to the company, which uses the selected components in the company's internal processes in the following phases:

- distribution (e.g., packaging),
- production (e.g., screws, washers, other universal components),
- procurement (e.g., structural components).

The components of the used product that the enterprise could not use are transferred to recovery or recycling points, which put the selected components on the market.

The customer's passive attitude involves leaving used products in specially designated places, from where they can be transferred to recovery and recycling centres.

3.2. Territorial aspect

The territorial aspect demonstrates the logic of spatial functioning and cooperation among L&SC 4.0 participants. In a sense, it contradicts existing concepts of long (global) supply chains and promotes cluster solutions. These solutions can take the form of global supply chains only in extreme cases, e.g., in the absence of components recovered from the market at the company's site. This context presented in Fig. 3. is divided into five layers, which include the following spheres:

- nano: customers, individual organisations, hubs, recovery and recycling points – model participants;
- micro (micro cluster): cities, agglomerations, collections of towns and villages;
- mini (cluster): collections of several or more micro territorial units (equivalent to a province, state, and canton), cluster organisations: hubs, recovery and recycling points;
- meso: collections of provinces, a country or collection of countries (depending on their size and population), international organisations: hubs and recovery and recycling points;
- macro (global): global area, continent, world, global organisations: hubs and recovery and recycling points.

L&SC 4.0 participants and the territorial context of the system are supported by technological advances of the Fourth Industrial Revolution, which mainly include:

- extensive digitisation of products and processes;
- cyber-physical systems;

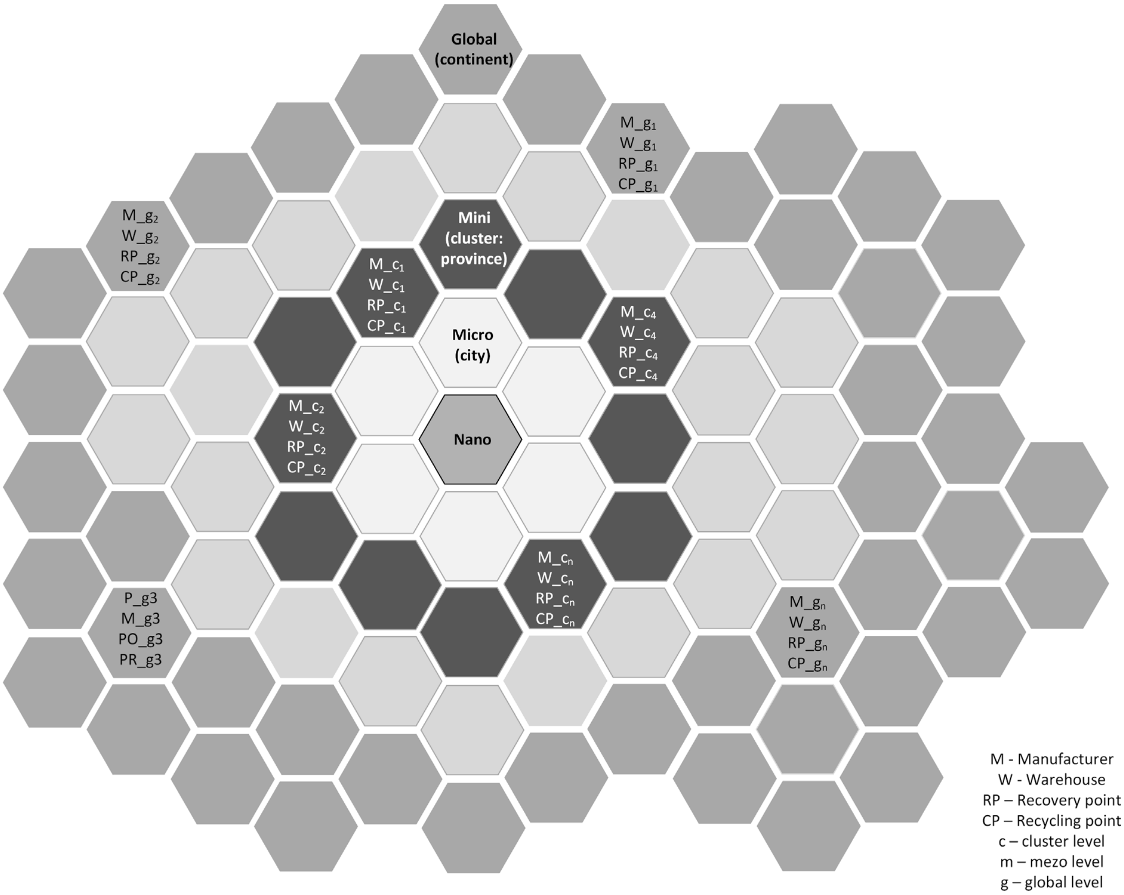

Fig. 3. Territorial structure of the L&SC 4.0 model

- applications (App) and mobile applications (MA);
- cloud computing (CC) and Big Data analytics;
- extensive Cluster Resource Planning (CRP) and ERP systems operating in enterprises;
- Forecasting and Simulation (F&S);
- Business Intelligence (BI);
- Internet of Things (IoT) with a focus on machine-to-machine (M2M) communications;
- Internet of Services (IoS);
- virtual and augmented reality;
- cyber security (CS);
- blockchain technology.

The presented layout will form a logistics system using intra-cluster cooperation on the one hand, and on the other hand, it will be open to external clusters and the meso and macro spheres. The smoothly operating intra-cluster reverse logistics of each enterprise, combined with recovery points and recycling points, allow the recovery of most of the components and parts for reuse in manufacturing processes, and the recycling points deliver recovered raw materials and materials to enterprises.

The remaining discussion focuses on the operation of the meso and global spheres, which do not differ much from the operation of the cluster. Material flows would occur within the mini-warehouses located in the cluster, which would be systematically replenished through regional, national, continental or global warehouses. In the event of changes in demand or the emergence of demand for new products, the rapidly reconfigurable warehouses would become warehouses for other than existing goods.

The meso and macro spheres are the second and subsequent warehousing hubs of L&SC 4.0. They also group manufacturers who produce their products in provinces, regions, countries, continents and globally. Distributed logistics hubs of various raw materials, materials and subassemblies or parts that, due to the nature of their production processes, cannot be produced in "artisanal factories" or clusters are supplied through Milk Run systems. These logistics trains travel the same route constantly, replenishing the same locations on a meso and macro scale. Transportation and warehousing processes are far smaller in scale than current global logistics systems. This is due to the principle of Design for Excellence (DfX), or Design for Circular Economy (DfCE). According to these concepts, most components and parts are reused to make new products.

3.3. Information flow

The key issue of the whole system becomes the sphere of information flow, i.e., digital data. Available and unified applications (home appliance and construction industries) allow customers to design and personalise their products. Once a product has been accepted by the customer and paid for to some extent through electronic flows, a bill of materials (BOM) goes to the ERP information systems of enterprises, from where it is directed to the CRP (Cluster Resource Planning) information systems in the first place. In the case of problems with the availability of materials or resources within the cluster, the CRP system shifts information about missing resources to the meso level (CRPM system — Cluster Resource Planning in the Meso Zone) or the global sphere (CRPG system — Cluster Resource Planning in the Global Zone), (Fig. 4).

The lack of resource availability at different levels necessitates their search at higher levels or involves their replenishing (if possible) at the base level. Forecasting and simulation algorithms reserve a resource by analysing its temporal and spatial availability. Based on this, feedback is returned to the company and the customer related to the timing of the order. An important aspect of this model is that the information is provided online in real time already during the customer's personalisation of the product, so they

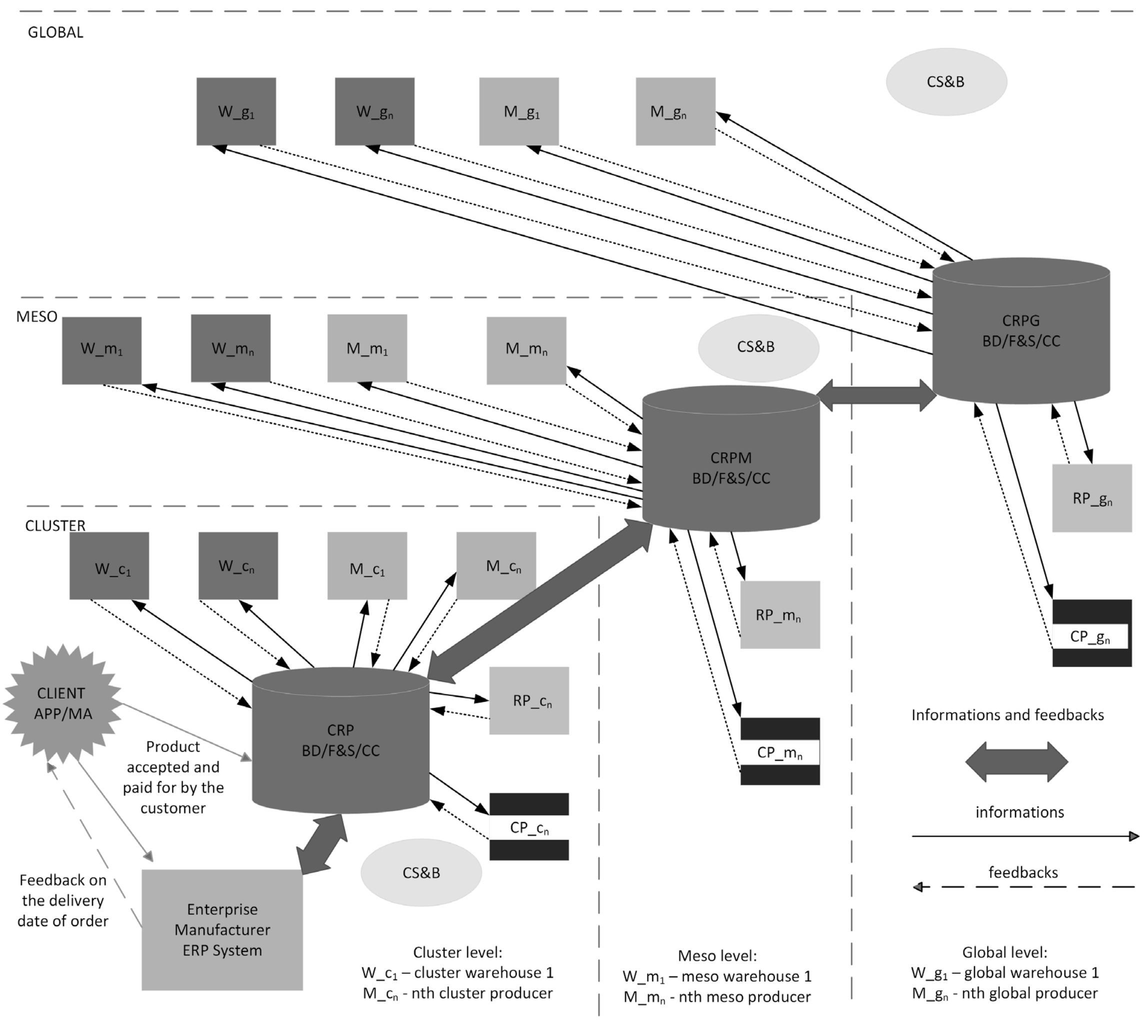

Fig. 4. Information flow between customer, organisation and cluster in the L&SC model. 4.0 — layer No.1 of the digital data flow — analysis of resource availability

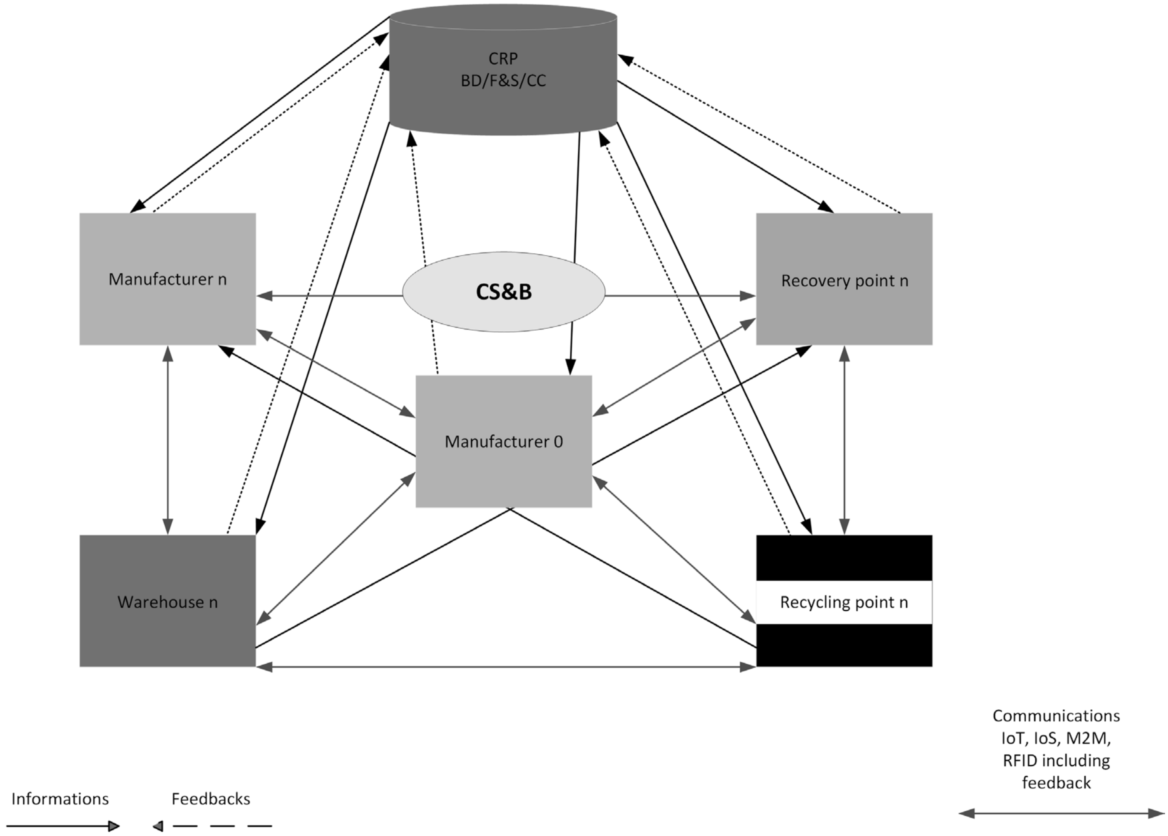

Fig. 5. Launch of manufacturing in the L&SC model. 4.0 using IoT, IoS and M2M communication technologies — Layer 2 digital data flow — launching manufacturing and physical flows

have a direct influence on the optimisation of the ordered goods in terms of the availability criterion. All this is subject to cybersecurity assurance processes while using blockchain architecture (CS&B) and other forms of Blockchain use in supply chain management (Dujak & Sajter, 2019).

The acceptance of an order with its payment or promise of payment generates the activation of cyber-physical systems (physical flow layer) in the organisations, warehouses, recovery points and recycling points included in the project implementation. Internet is used to activate technological IoS and IoT tools, generating their effects through the start of M2M communication (Fig. 5).

When all the necessary components for a product are available within the micro or mini (cluster) realm, Big Data analytics, business intelligence (BI), as well as forecasting and simulation algorithms running on cloud computing and ERP, CRP, CRPM and CRPG systems trigger M2M communications using IoT and IoS technologies. This triggers parallel processes for manufacturing or preparing necessary components. Of course, as in the previous case, the whole thing is secured by CS&B.

Necessary raw materials or materials, or manufactured spare parts go to the company, which is responsible for the final assembly of the final product. For this purpose, e.g., drones or autonomous delivery vehicles operating in tunnels located under cities can be used[2]. According to the principles of Just-in-Time and Just-in-Sequence, which form the basis of the CRP algorithms and are optimised by them, delivery of the necessary components takes place to subcontractors and the last point in the supply chain before the end customer (Fig. 2).

3.4. Determinants of the model

The presented model also assumes the existence of four basic areas influencing it, e.g.:

- customer needs and product-added value (resulting from the challenges facing logistics and sup-

[2] The second of the scenarios described by Ehrhart (2012, pp. 25–26).

ply chains and societal changes, e.g., the iGen generation entering adulthood);
- physical flows (considering the technological levers of I 4.0 — Hofmann's 4.0 model (2017, pp. 25–26);
- digital data flows (layer No. 1 — analysis of resource availability, layer No. 2 — activation of generation and physical flows) discussed above;
- necessary requirements of process operation — SC 4.0 model by Frederico, Garza-Reyes, Anosike, Kumar (2021, pp. 17–18).

The layer of customer needs and added value of the product should consider the current trends of order fulfilment showing:
- a high degree of personalisation (product customisation);
- high degree of product availability;
- fast order processing time (one click and one day — one click and day);
- use of virtual space in shopping;
- security and pragmatics of products and transactions;
- optimal price/quality ratio (Twenge, 2017, pp. 221–228);
- product compliance with the tenets of sustainability and the circular economy;
- confidence that during a crisis, the product will not run out of the market;
- use of the product for a long time with the possibility of modification — a long product lifecycle.

It should be noted that a key element of the entire model is an enterprise that uses information technology to design products and packaging that are not only logistically efficient but also incorporate several tenets of the Design for Excellence (DfX) concept. Manufacturing is not deliberately mentioned here since the enterprise's core competence becomes product design, along with managing its entire supply chain and logistics from the microsphere to the macrosphere. The sphere of product design should, therefore, consider the layer of customer needs and added value (e.g., a high degree of personalisation), but also the current standards that allow efficient and effective manufacturing or assembly, which include the following guidelines:
- a high degree of product personalisation, mainly through the realm of "software", e.g., changes in colour, functionality or other attributes that occur by activating a particular product module or incorporating optional add-ons into products;
- product designs have their application (digital) translation into programs that allow them to be designed by customers (according to the design guidelines assumed by a given company), e.g., mobile applications;
- a high degree of standardisation, modularity and multifunctionality of components resulting from careful analysis of their availability in the market;
- use of standard, intelligent materials susceptible to personalisation;
- the ability to use raw materials, supplies, spare parts, packaging and other finished product components from used finished goods and packaging subject to reverse logistics;
- accurate preparation and digitisation of technology sheets in the form of batch programs (e.g., for additive machine tools, allowing to make individual components of the finished product in a given CPS), operating instructions and service manuals.

An important model of L&SC 4.0 is product design. As a result of the thoughtful action of designers, using the concept of DfX, with special attention to DfL and DfSC, efficient reverse logistics, and inter-cluster cooperation, makes it possible to achieve closed cluster circulation. This generates little demand for raw materials, materials, and components from outside the cluster and, therefore, from the meso and global spheres.

The operation of the L&SC 4.0 model is, therefore, based on four basic phases:
1. design and analysis of resources. Based on the application or mobile applications of the enterprise in question, the customer designs their product, and at the time of acceptance, payment or generation of its promise, the enterprise with an ERP system launches the Cluster Information System (of CRP) tasked to:
    a. analyse the availability of resources within the cluster at other enterprises, hubs, recovery points and recycling points;
    b. in the absence of resource availability within the cluster, analysing resource availability at the meso and global levels;
    c. prioritisation of resources;
    d. resource reservation;
    e. estimation of lead times;
2. launch of manufacturing and physical flows, i.e., generated order of components to enterprises within the cluster or outside the cluster to the closest functioning enterprises, which, using IoT,

IoS and M2M communication technologies, can start executing orders, minimising human impact on order execution;
3. final assembly and distribution create the finished product and distribute it within the cluster using automated, autonomous transportation technologies (using IoT, IoS and M2M);
4. reverse logistics focuses on closing the product flow inside the cluster.

The presented concept of the supply chain 4.0 model still needs to be clarified, but its framework seems to provide a fairly good starting point for discussions on supply chains 4.0.

3.5. System development modelling

The concept of the L&SC 4.0 model presented in the previous chapter is somewhat complex and multilayered. The individual components that make up the relationships in this model already exist, but their configuration is novel. Developing such a complex concept and testing its effectiveness cannot be done by investing in unique solutions on a trial basis and seeing what results this will produce. This model is complex because it involves entities with an extensive territorial scope and uniquely combines entities operating in other configurations. The entire system's efficiency will depend on how effectively and efficiently processes are carried out in this new configuration.

This raises a major difficulty as the effects can only be examined after many cycles of process execution in this structure. Hence, the following questions arise: What is the probability that the proposed method of implementing logistics and supply chains will be good? What are the chances that such a model will evolve in the right direction and resist disruptions and unexpected situations? Remember that it was created as a response to problems in previous logistics and supply chain models when unexpected situations of global scope and catastrophic dimensions arose. Is it possible, then, that it will be a solution making logistics immune to large-scale disruptions? Is it possible that the model will reduce the risks of negative environmental impacts of the logistics processes themselves and the manufacturing processes to the point where the manufacturing processes and logistics processes become completely environmentally unobtrusive? Is it possible that this solution will reduce the amount of resources consumed and increase the evenness of profit allocation? Such questions can be multiplied, and many questions will be associated with each small element of such a structure.

Based on experience with the operation of logistics structures and concepts, an attempt can be made to answer such questions. The answers will concern local aspects and the current relationships between system elements. How these matters will look in a completely new configuration is unknown. Therefore, a way must be found to provide answers with an acceptably high probability of being correct. However, it must be kept in mind that once obtained, the answers are not and will never be conclusive. This is because such complex structures are dynamic and evolutionary in nature, as individual attributes and configuration relationships can change to suit current requirements and situations. Thus, it is impossible to obtain unambiguous answers that can be used as arguments for accepting or rejecting a particular solution. This is largely because the concept presented in its conception is a multi-variant solution. It is based on multiple elements, and each is described by an extensive structure of attributes, with each element related to many other objects, and together they form a system. Describing such a structure deterministically is unreasonable and inefficient, and the description would become outdated immediately after its formulation.

Modern approaches to designing highly complex structures are based not only on a deterministic approach, in which a precise description of each component at the micro-scale and all the interrelationships up to the macro scale is required. There are alternative approaches to object modelling where, due to the structures' complexity and the descriptions' mathematical complexity, it is impossible to obtain satisfactory results in an efficient time. In such cases, simulation modelling is used. It makes it possible to create a model of a given system with the accuracy determined by the adopted level of abstraction. Such a model can be extended in subsequent iterations. Simulation models make it possible to perform simulations in which both the configuration of the model and the parameters defining its operation can be changed in any way.

Simulation experiments are performed before decisions are made on the construction or expansion of individual system components. Therefore, it is proposed to create simulation models for the model structure to study how the concept works without involving real resources.

It seems that the most appropriate method for modelling the system from the perspective of its territorial structure (Fig. 3) will be the agent-based modelling method (Golroudbary et al., 2019; Hu et al., 2022). Agent-based simulation modelling (ABM) is a computational modelling technique that involves the creation of autonomous agents, representing individual entities that interact with each other and their environment to simulate real-world phenomena (Lange et al., 2021; Ruiz et al., 2011). Applications of ABM include:

- social science: to study such complex social phenomena as the emergence of norms and conventions, the spread of disease, the formation of crowds and social networks, and the dynamics of conflict and cooperation;
- economics: for modelling economic systems, such as markets and supply chains, to understand how individual components interact to determine the overall behaviour of the system;
- environmental science: to model the behaviour of complex environmental systems, such as ecosystems and climate systems;
- engineering and infrastructure: to model infrastructure systems, such as transportation networks, power grids and communication networks, to assess the impact of new policies or technological innovations;
- ABM is a powerful tool for modelling complex systems that involve a large number of interacting agents, where traditional mathematical models may be insufficient to capture system dynamics.

Therefore, it is necessary for the presented concept to undergo simulation studies and identify potential risks and develop scenarios for different conditions. The described L&SC 4.0 structures are emergent in nature, so agent-based modelling will be the most appropriate (Lange et al., 2021). Once the modes of behaviour, responses, and relationships between individual elementary objects have been designed, it will be possible to get a picture of the behaviour of the entire system and its individual components.

Conclusions

In building the L&SC 4.0 concept within the mini, meso and macro spheres, it was assumed at selected points to challenge the existing paradigms regarding the functional areas of logistics, production and quality that shape the current industry while creating additional considerations. These include:

- the logistics sphere:
  - moving away from global supply chains — maximising the shortening of supply chains to neighbourhoods, cities and county equivalents called clusters;
  - decreasing warehouse space in favour of increasing the number of small-area, quick-reconfigure warehouses — placing a large number of small warehouses of raw materials, materials, and semi-finished goods in clusters or on the border of clusters, maintaining low inventory levels for clusters; for specific raw materials, materials and parts, creating highly specialised warehouses with somewhat smaller reconfiguration capabilities;
  - creation of national warehouses for raw materials, materials and parts replenished through global traditional supply chains from which goods are delivered in an optimised manner to clusters (an element of resilient logistics to disruptions such as the COVID-19 pandemic);
  - changing the rules of reverse logistics — placing in clusters, or at the border of clusters, a large number of facilities for recovering components and raw materials from used products; creating a reverse logistics system that does not allow used products to leave the cluster in which they are located;
  - a departure from the current form of transportation — the use of underground tunnels or airways for transportation processes inside the clusters, in which autonomous "green" vehicles such as drones will move; this eliminates the negative impact of logistics processes on residents and the environment as the existing transportation is reduced to the meso and global sphere;
  - full cooperation and transparency governed by international law — cooperation among clusters in inventory management, making them available to balance supply and demand;
  - simultaneous maintenance of the concepts of Just-in-Time and Just-in-Sequence as a key element determining the effectiveness of the entire system using Milk Run systems to optimise logistics processes;

- production and quality sphere:
    - product design supporting excellence (DfX) with an emphasis on circular economy issues, quality, logistics, and manufacturing and assembly under cyber-physical systems and additive manufacturing;
    - moving away from mass production to highly personalised unit production in small "artisan" plants specialised in given technologies and operating within clusters;
    - reducing the time of making one finished product to a maximum of one day, assuming maximum use of standardisation, modularity, and multifunctionality of raw materials, materials, subassemblies and parts;
    - considering the need to use components from used products in new products — establishing a rate of used parts in the product, which would be legally changed in selected periods;
    - extending the life cycle of products by including the possibility of repairing them while improving their quality;
    - returning to the implementation of TQM principles supporting TLM, especially in the issue of synergetic cooperation of enterprises.

The presented L&SC 4.0 model seems to address many of the challenges facing today's logistics and supply chains. The arrangement of clusters globally shortens supply chains; reverse logistics makes it possible to incorporate used materials or components into re-circulation, thus closing the environmental loop while increasing the resilience of supply chains. The use of I 4.0 technologies and the principles of "green logistics" helps reduce the negative impact on the environment, while the digitisation and unification of product design processes using smart materials reduces the risk of the collapse of global supply chains.

However, it should be noted that at the present time, the presented L&SC 4.0 model has at least a few key limitations, which include not so much the problems of the development of technologies available on the market but the existing mental limitations that have remained unchanged for centuries in individual economies and societies. These include:

- pervasive selfishness and "business Machiavellianism";
- the desire of businesses and states to monopolise or oligopolise;
- low awareness and responsibility of societies resulting from education systems, e.g., environmental protection; emphasis is placed on increasing specialisation of education, while general education, which is necessary for understanding many phenomena, is overlooked;
- politics and the desire for power.

Egoism and "business Machiavellianism" are nothing more than the implementation by a large number of entrepreneurs of the vision "the end (profit) justifies the means". The effect of following such an approach is that the search for universal solutions and the strategic view of entrepreneurship other than through the lens of profit ceases in most cases (Skobelev & Borovik, 2017, pp. 308–309). This, of course, is aimed at gaining a competitive advantage, which is supposed to take the shape of an oligopoly or monopoly while failing to realistically assess the negative consequences of these actions.

If this is compounded by the low awareness and responsibility of societies, translating environmental issues to the next generation or looking to environmental issues to improve competitiveness and profit, a grim picture emerges of the destructive industry's impact on the environment. The lack of general education does not allow employees and managers to look at processes and the sphere of product design in a broader, systemic way, as they are often very elaborate and multidimensional. Of course, the vision of Society 5.0, or Long Life Learning, assumes that enlightened societies will eventually emerge, but the changes and differences taking shape in the younger generation, unfortunately, predict no illusions that the S 5.0 trend will not dominate for too long.

The presented L&SC 4.0 model considers the latest trends and presents an idea about the future of logistics and supply chain. It also shows the direction for changes in logistics and supply chains. It is a good contribution to open the discussion on logistics and supply chains of the future.

This new concept could not be practically tested because all the shown connections do not exist. However, it should be noted that individual aspects of the model have their own practical version, and in such cases, the behaviour of the system has been observed, and the conclusions of these observations are included in this model.

As a suggestion for further research, the proposed model should be evaluated periodically in response to ever-changing situations in contemporary supply chains. Three main aspects should be considered:

new relationship-based changes between supply chain members, new and emerging technologies enabling more efficient and reliable information flow and overcoming territorial demands of supply chains based on novelties in the first two aspects.

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