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Considering IT Trends for Modelling Investments in Supply Chains by Prioritising Digital Twins

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Abstract: Supply chain disruptions and challenges have and will always exist, but preparing in advance and improving resilience for the upcoming consequences should be the utmost important goal. This paper explores trends that affect innovation in the technological sphere of supply chain systems. More precisely, the research is focused on Digital Twin technology applicability through other logistics IT trends and aims to research the pressing issue of ensuring the visibility and resilience of future supply chain systems. The paper's objective is to produce a conceptual model enabling the investment assessment of the necessary IT resources. Initially, a theoretical confirmation of logistics IT trends' relevance to supply chain systems was established. After, propositions of Digital Twin technology applications to other logistics IT trends were made, which were divided into corresponding constant multitudes of supply chain systems. Lastly, the conceptual model for the investment assessment of the necessary IT resources was derived in the form of a matrix. It considers 16 parameters for investment assessment and applicability to all companies, regardless of their specifics. It also supports the notion of digital IT competencies' fundamental importance to the continuous operation of supply chain systems.

Keywords: supply chain management; logistics; process optimisation; visibility; resilience; Digital Twin

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1. Introduction

Although a technologically developed world, the latter is facing major unpredictable challenges due to vigorous technological development, global economic and environmental changes, and demanding fluctuating consumer changes. Individuals struggle to adapt to the consequences brought by external disturbances; it is even more difficult for companies, which tend towards greater consumption, where they must constantly and successfully adapt to not only consumers' demands, but their expectations. In addition to the latter, companies are also faced with emerging economic, sociological, and political influences [1]. These influences have the power to disrupt daily operations and performance, limiting their business effectiveness and causing strains in global supply chain systems, also referred to as supply bottlenecks [2]. The events of the last three years have severely affected supply chains, highlighting the importance of stability, flexibility, and resilience to the disruptions' negative impacts on the entire world. The COVID-19 pandemic was and still is one of the most severe supply chain disruptions that has challenged companies to improve their supply chain resilience [1,3–5]. To respond to these disruptions and changes, which have a domino effect on everyone in the supply chain system, companies must quickly adapt to the new "normal" to provide visibility, resilience, and continuity of their supply chains. The latter can be accomplished by the use of modern technology, which "is a primary catalyst for change in the world" [6], where technology advances and trends enable vast possibilities for greater productivity and efficiency and the invention and re-invention of products and services and contribute to the well-being of environments. Disruptions in the supply chain can be anticipated and verified, especially with Digital Twin technology, which allows the exploration, prediction, and preparation to innovatively respond appropriately and adequately to the unknown [7]. This paper touches upon the pressing issue through the eyes of Digital Twins and their implementation through other logistics IT trends to resolve the supply chain visibility and resilience issue.

1.1. Background

One of the key Industry 4.0 concepts, technologies, and fundamental enablers of digital transformation [8] are Digital Twins [9–14]. A Digital Twin is a virtual representation of its real-world counterpart [15,16]—a product, service, system [17–19] or process [20]. A Digital Twin can also be presented as a form of cyber-physical device which uses Internet of Things (IoT) sensors and produces a high-fidelity visualisation of a physical resource [21] enabled by near real-time synchronisation between cyberspace and physical space [22]. The obtained data by the Digital Twin are aggregated and analysed through machine-learning algorithms to promote strategic and organisational decision-making [23]. Another definition of a Digital Twin is "a set of realistic models that can simulate an object's behaviour in the deployed environment. The Digital Twin represents and reflects its physical twin and remains its virtual counterpart across the object's entire lifecycle" [24]. The most concise yet detailed description of Digital Twins' capabilities is: "a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level" [25]. Specifically, Digital Twins (a) include fundamental elements as geometrical components of the considered object and its material properties; (b) they can accurately and realistically simulate relevant processes throughout the objects' life cycle; and (c) Digital Twins can be connected to the real-world object [26] by sensor data, which are continuously updated in real-time [15]. A Digital Twin can be used independently—it is not necessarily connected to the physical, real-time existing object that it represents [8].

Digital Twins are used: (a) to improve the existing theory and knowledge in building virtual models; (b) in virtual model simulation technology to explore and predict the unknown world; and (c) to find better ways to stimulate innovative ideas to pursue and achieve optimal progress. Hence, Digital Twins are essential utensils to support innovation in every industry [7]. Related to the latter, Digital Twins are being increasingly adapted into a variety of areas and industries, including aerospace [27], healthcare [28], biopharmacy [29,30], the food industry [31,32], manufacturing [33], agriculture [34], education [35], the process industry [36–38], logistics [21], and, likewise, supply chains [7,39–41].

Supply chain management (SCM) presents a fundamental and integral part of the business—it has the capability to boost customer service and, consequentially, their level of satisfaction, reduce operating costs while improving the company's financial position [8], and has an essential role in the economy [40]. The continuous adaptation of SCM is necessary, which can present a challenge due to the lack of real-time data availability and responsiveness of planning systems [42]. The competitiveness of individual supply chains and SCM will increasingly depend on analytics algorithms combined with optimisation and simulation modelling [43,44]. Consequently, the continuous improvement of SCM systems has fuelled the development of various digital tools to automate business [42]. Thus, supply chains are shifting from traditional hierarchical structures to "value webs", characterised by complex, interconnected, and interdependent relationships. Here, knowledge flows, learning, and collaboration are almost as important as the better-known product flows, controls, and coordination [39]. The latter is considered a critical strategic goal of the Industry 4.0 paradigm, expressed as "the transformation of existing manufacturing supply chain systems into more digitally connected and agile ones" [45].

1.2. Visibility and Resilience of Supply Chain Systems

Supply chain agility, visibility, and resilience are fundamental factors of companies' success in their attempt to respond to dynamic and complex changes [39]. Real-time supply chain optimisation and visibility have proven to be the key factors that can reduce inventory costs by 20–50% [46]. Further, the urgency for resilience is critical. Given the last few years, supply chains must find a way to respond to various circumstances by adapting the whole model and ensuring flexibility to cope with changes [39]. The global megatrends towards globalisation have created several challenges in organisations' management of current supply chains as they grow more complex, parallel to consumer requirements [47,48]. In essence, supply chain visibility depends on ensuring the provision of access to reliable and up-to-date knowledge relating to internal and external processes [49,50].

The four main visibility processes, which enable a company to reorganise its supply chain according to its internal and external demands [51,52], are (a) visibility for learning; (b) visibility for sensing; (c) visibility for integrating; and (d) visibility for coordinating [50]. Therefore, visibility requires a cross-divisional platform that (proactively) enables end-to-end SCM in real-time. A high visibility level is possible solely when the core elements (people, processes, and technology) work cohesively and holistically [21]. While supply chain visibility is essential, achieving and maintaining complete visibility in an international supply chain system is a challenge, bordering on the impossible without using recent developments in digital technology [53,54]. The desire and demand for ensuring manufacturing and materials flow call for new approaches with real-time information sharing, collaboration, simulation, and optimisation models to evaluate alternative network setups for this specific purpose [39]. With the latest technologies, such as artificial intelligence (AI), IoT, Robotic Process Automation, and Digital Twins, more automation in the industry is now possible for end-to-end supply chain management operations [21].

The transition to visible, agile, resilient, and connected supply chains immensely depends on digital transformation. In contrast, various information–communication technology solutions enable information to be monitored through digital models. However, they must be more cohesive and offer complete supply chain visibility and interoperability [39]. The latter is achievable through a more holistic and "digitally smart" approach, using the application of a virtual yet realistic digital equivalent to physical entities—the Digital Twin [55], which is slowly taking the lead amidst digital transformation [56]. Digital Twins will significantly increase supply chain visibility [57] and resilience. With implementation capability to products, services, machines, processes, and even whole business ecosystems, Digital Twins can enable insight from the past, the optimisation of the present, and predictions of future performance [22].

1.3. Digital Supply Chain Twins

Adapting digital solutions into extant business models enables an increase in product quality, a decrease in waste, cost reduction, and improvements in efficiency and market share [58]. Diminished product life cycles [39], technological changes, and interconnected economies represent fierce business competitors, where their SCM has to be supported by technological innovations such as Digital Twins [8]. Digital Twins present a solution for challenges such as obtaining real-time dynamic information [7,42]; the enablement of real-time digital monitoring [26,40]; the enablement of automatic decision-making with higher efficiency and accuracy [8] through the entire supply chain [59–61]; creating a continuous cycle of improvement and adjustment of the whole supply chain in near-real-time [42]; the creation of real-time synchronisation [8]; the enablement of cost reduction [42]; the composition of virtual models [7,10], simulations [8,9,43], and estimations [12] of virtual or physical products; the enablement of virtual product design and physical production [12]; the development of products, services [8], processes, or systems [40]; the enablement of simulation-based engineering, optimisation, and control [9]; and the implementation of risk management [62].

Versatile simulations with analytical optimisations present two of the most dominant technologies for supply chain risk management that enable stability and reliability if disruptions occur [63]. The Digital Twin concept in supply chains empowers the creation of a mirror-simulation model of all processes within supply chains [42], facilitating networking and the automation of complex value-added chains [9]. They entail the capability to solve optimisation problems, increasing the supply chain's resilience and mitigating its disruptions at any point in the system [8]. The connection of Digital Twins with supply chains is what many authors call the Digital Supply Chain Twins (DSCTs) [64–67]. DSCTs represent the physical supply chain and can be exploited for real-time planning and control decisions based on inventory, transportation, capacity, and demand [68]. DSCTs represent the condition of a network at any point in time, enabling complete end-to-end supply chain visibility, which can help increase resilience and contingency plans. The core technology that allows the relatively accurate development of a DSCT is a combination of simulation, optimisation, and data analytics [62]. The goal of developing any Digital Twin is to increase the risk management of supply chains, thus enabling them to become more dependable and resilient in the potential case of disruptions [63].

1.4. Objective, Aim and Research Questions

Technological advancements enable businesses, organisations, and institutions to be more productive and efficient, to re-invent or invent new products and services, and to contribute to environmental well-being [6]. In a technologically advanced world, it is difficult to predict even near-term events; accurately planning the future, paved based on future trends, presents an eminently more complex task. To understand the future, it is necessary to begin in the present. This research explores trends that affect innovation in technological waters. More precisely, it examines the impact of Digital Twin technology in correlation with other IT trends and its significance for increasing the visibility and resilience of future supply chain systems.

Simulations of supply chains and their optimisation enable the generation of new information regarding challenges, issues, disruptions, and their impact on the supply chain systems by procuring a multitude of various scenarios, their critical points, duration, and even recovery policies [63]. Due to the predictability factor provided by Digital Twin technology, appropriate preparation and response tactics can be established. Disruptions in supply chain systems have and will always exist but being prepared in advance and improving responsiveness for the upcoming consequences should be the utmost important goal.

This research is premised on the impact of logistics IT trends, their relevance in sectors, and the examination of Digital Twins' applicability to individual technology trends in supply chains. Logistics IT trends were obtained from the Logistics Trend Radar from DHL, which is the world's leading contract logistics provider, with 380,000 professionals in over 220 countries and territories, delivering 1,818,000.000 parcels per year [69]. Based on the latter, a conceptual model shall be produced, which will enable the assessment of investments in the necessary information technology (IT) resources—the objective of this paper. This paper aims to research the pressing issue of ensuring supply chain visibility and resilience, which is possible with the implementation of Digital Twins through logistics IT trends, enabling the assessment of needed investments. The research questions are as stated:

1. How can Digital Twin technology benefit the constant multitudes of supply chain systems?
2. What are the parameters to consider for a conceptual model for assessing investments in supply chain systems?
3. How to pose the conceptual model so that it will be applicable, regardless of the company's specifics and requirements?
4. Will the conceptual model support the notion that digital IT competencies should develop according to new IT trends to enable supply chain resilience?

2. Methodology

The research was divided into three parts for better transparency, as shown in Figure 1. The first part covers the theoretical introduction of future supply chain challenges, presented with information about specified IT trends. Consequently, 14 IT trends were chosen as the basis of this research. They were obtained from the DHL Logistics Trend Radar [70] due to their recognition as one of the most important logistics companies. Following short descriptions, the studied trends have assigned sectors for which they are most relevant. Based on [70], IT trends' impact and time relevancy on supply chains were derived. This part provided theoretical confirmation of technology trends' relevance for supply chains and a basis for further research.

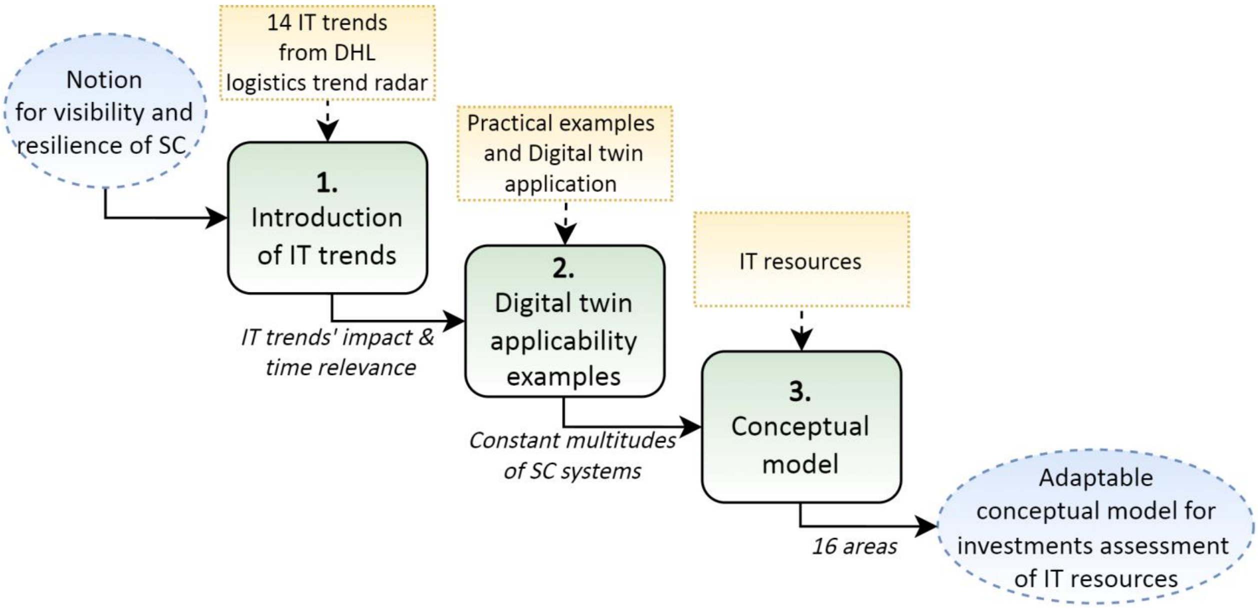

Figure 1. Research methodology process—stages of conceptual model development.

The second part derives from scientific research literature starting points, premised on which the implementation examples of practical orientations and the application of Digital Twins through other logistics IT trends within supply chains were selected. These examples were obtained from scientific research articles. The methodology of searching for these articles was to enter the desired keywords in combination with the keywords "Digital Twin" and "Supply chain" into a database of published scientific papers, where, among the resulting articles, the suitable ones were derived. The latter were related to the practical application of IT trends within supply chains. The keywords used for attaining scientific articles with practical implementation examples were: "Digital Twin", "Supply chain", "Augmented reality", "Virtual reality", "Bionic enhancement", "5G", "Blockchain", "Quantum computing", "Drone", "3D", "Big data", "Cloud", "Internet of Things", "Automation", "Robotics", "Artificial Intelligence", "Self-driving vehicle", and "Wireless".

There are several divisions of the supply chain, from components of supply chain management [71,72], elements of SCM [73–75], to types of supply chain segments [76,77] and others. Digital Twins are a digital representation of a unique product, service, system [17], or process that imitates almost every aspect of the latter [20]. Consequentially, for the purposes of this research, the following division of IT trends was the most suitable: products, services, processes, and systems—which have been referred to as "constant multitudes of supply chain systems" by the authors of this paper. The explanation for such a designation lies in the fact that a product, service, process, and system are a consistent part of any and every supply chain system; likewise, they themselves form a multitude of other products, services, processes, or systems that are or can be interconnected and combined. Derived from the latter, the main results of the second part of this research are the propositions of Digital Twin technology applicability to every single implementation example of the chosen technology trend, which are divided into corresponding constant multitudes of supply chain systems.

The third and last part presents the conceptual model for assessing investments in the necessary IT resources, derived from the applicability of Digital Twin technology through individual technology trends and the corresponding constant multitude of the supply chain system. The essential information for the conceptual model realisation was obtained from the second part of this research: (a) implementation examples of practical orientations and the application of IT trends within supply chains (named: Example); (b) the division of the implementation examples of practical orientations into four defined sets (named: Constant multitudes of supply chain systems); and (c) the propositions of Digital Twin technology applicability for each implementation example of the chosen technology trend (named: Applicability of DT technology). Another integral part of the conceptual model is the parameters by which the investment can be assessed. For these parameters, IT resources were determined, without which the supply chain systems cannot operate or function smoothly and were defined premised on the scientific literature. This newly obtained conceptual model was developed based on the idea of the matrix that we ultimately obtained for assessing investments in the necessary IT resources, which is presented in detail in the next chapter.

Digital Twin technology enables companies to optimise their business processes through various forms of implementation. Furthermore, Digital Twins can support the notion of the visibility and resilience of a company's supply chain system, which is crucial in effective business operation. The emphasis on theory is due to the complex implementation of the Digital Twin technology itself, and because many articles talk about theoretical applications, but few touch on practical implementation, especially in such a broad field as supply chains. Thus, this paper presents a conceptual model that encompasses four constant multitudes of supply chain systems (products, services, processes, systems), which enables companies to assess their investment levels into necessary IT resources (information, applications, infrastructures, intangible assets, and people) for the implementation of desired IT trends.

3. Results

This chapter is divided into three sub-chapters. The first one provides theoretical content on IT trends, representing the basis of this research and the following two sub-chapters. The second sub-chapter encompasses examples of IT trend implementation premised on a theoretical starting point obtained through the scientific research literature. The main result of this research is presented in the third sub-chapter, where the conceptual model for assessing investments in the necessary IT resources is produced.

3.1. Information Technology Trends' Risk Assessment

This sub-chapter presents IT trends already intertwined into supply chain operations and can either benefit them or represent a missed opportunity for success.

Table 1 encompasses a verbal description of 14 IT trends that will be encountered in future supply chains. The data and information on these trends were adapted from the DHL website [70] and are publicly available. The IT trends are classified sequentially based on their impact on supply chains, which has three stages: low, medium, and high. Each trend is connected to sectors that are most relevant to the trend, based on feedback from logistics experts [70]. The sectors are [70]:

- Auto-Mobility;
- Engineering and Manufacturing;
- Technology;
- Energy;
- Life Sciences and Healthcare;
- E-Retail and Fashion.

In the final column, IT trends' degree of relevance within supply chains is presented, premised on time intervals:

- Short-term (up to 1 year);
- Medium-term (up to 5 years);
- Long-term (from 5 to 10 years).

Table 1. IT trends' risk assessment, adapted from [70].

IT Trend	Description	Sectors	Impact	Relevance
1. Augmented and Virtual Reality (AR and VR)	AR can amplify logistics quality and productivity, providing employees with the correct information at the right time and place. VR enables the design, experience, and evaluation of environments in the digital world for logistics providers to optimise material flows and training processes.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy; Life Sciences and Healthcare; e-Retail and Fashion.	LOW	Medium-term
2. Bionic Enhancement	Bionic enhancements (such as advanced wearables and exoskeletons) are supporting systems worn near or within the human body that augment the body and mind's capabilities. Bionic enhancements enable support for logistics workforces in training, communication, process execution, and optimisation.	Auto-Mobility; Engineering and Manufacturing; Life Sciences and Healthcare.	LOW	Long-term
3. Digital Twins	Digital Twins enable the design, visualisation, monitoring, management, and maintenance of the company's assets more effectively through virtual representations of potential or actual physical objects or services. The simulated replicas, derived from Digital Twins, help achieve new service-based business models built on valuable insights from operational data.	Auto-Mobility; Engineering and Manufacturing; Energy.	MEDIUM	Medium-term
4. Next-Generation Wireless	Next-generation wireless technologies are enabling the next communication revolution, which proceeds today's goal of connecting everyone to everything and everywhere.	Auto-Mobility; Technology; Energy; e-Retail and Fashion.	MEDIUM	Medium-term
5. Blockchain	Blockchain and other distributed ledger technologies facilitate a higher level of trust and transparency among stakeholders and customers and support administrative and commercial process automation.	Auto-Mobility; Technology; Energy; Life Sciences and Healthcare.	MEDIUM	Medium-term
6. Quantum Computing	Quantum computers enable unprecedented levels of calculating power, capable of processing highly complex logistics algorithms in real-time, rapid simulations, and the iteration of product and service models for more efficient supply chains.	Engineering and Manufacturing; Technology; Life Sciences and Healthcare.	MEDIUM	Long-term
7. Unmanned Aerial Vehicles	Unmanned Aerial Vehicles (UAVs) or drones can be used for the first- and last-mile delivery of products, intralogistics, and surveillance operations.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy.	MEDIUM	Long-term
8. Three-dimensional Printing	Three-dimensional printing encourages opportunities for greater customisation, less waste, and more localised and diverse manufacturing and delivery.	Auto-Mobility; Engineering and Manufacturing; Technology; Life Sciences and Healthcare.	MEDIUM	Long-term

Table 1. *Cont.*

IT Trend	Description	Sectors	Impact	Relevance
9. Big Data Analytics	With the help of big data analytics, unprecedented amounts of data can be obtained from various supply chain sources. It offers enormous potential to increase operational efficiency, improve customer experience, reduce risks, and create new business models.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy; Life Sciences and Healthcare; e-Retail and Fashion.	HIGH	Short-term
10. Cloud and Application Programming Interfaces	Application programming interfaces (APIs) present the basis of on-demand logistics services and real-time data processing. The latter enables the integration and scaling of software services via centralised cloud-based platforms, replacing existing electronic data interchange solutions for carriers and 3PL providers.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy; Life Sciences and Healthcare; e-Retail and Fashion.	HIGH	Medium-term
11. Internet of Things (IoT)	IoT potential presents virtual connectivity amongst anything and the acceleration of data-driven logistics. Objects can send, receive, process, and store information, thus actively participating in self-steering, event-driven logistics processes.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy; Life Sciences and Healthcare; e-Retail and Fashion.	HIGH	Medium-term
12. Robotics and Automation	Due to rapid technological progress and affordability, intelligent robotics solutions support zero-defect processes and increase productivity. Mobile or stationary robots will assist employees in warehousing, transportation, or even last-mile delivery activities.	Auto-Mobility; Engineering and Manufacturing; Technology; Life Sciences and Healthcare; e-Retail and Fashion.	HIGH	Medium-term
13. Artificial Intelligence	AI aims to improve supply chain efficiency through its predictive and vision recognition capabilities by driving intelligent workflow automation and delivering new user experiences.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy; Life Sciences and Healthcare; e-Retail and Fashion.	HIGH	Medium-term
14. Self-Driving Vehicles	Self-driving capabilities have fundamentally transformed the way vehicles are assembled, operated, utilised, and serviced. From long-haul trucks to last-mile rovers, self-driving vehicles will upgrade logistics by enabling new levels of safety, efficiency, and quality.	Auto-Mobility; Engineering and Manufacturing; Technology; Energy.	HIGH	Long-term

Based on Table 1, it was established that two IT trends have a low impact on supply chains (Augmented and Virtual Reality and bionic enhancement). Six have a medium impact (Digital Twins, next-generation wireless, blockchain, quantum computing, Unmanned Aerial Vehicles, and 3D printing) and six have a high impact (big data analytics, cloud and APIs, IoT, robotics and automation, AI, and self-driving vehicles).

Regarding IT trends' degree of relevance within supply chains, one of them has short-term relevance (big data analytics), eight of them have medium-term relevance (Augmented and Virtual Reality, Digital Twins, next-generation wireless, blockchain, cloud and APIs, IoT, robotics and automation, and AI), and five of them have long-term relevance (bionic enhancement, quantum computing, Unmanned Aerial Vehicles, 3D printing, and self-driving vehicles).

Digital Twin technology has progressed in two years from being a semi-trend, with a low impact on supply chains and long-term relevancy [78], to being a whole trend, with a medium impact on supply chains, while maintaining long-term relevance [70]. This fact only reinforces Digital Twin technology's critical role and relevancy for supply chains.

3.2. Practical Applicability of Digital Twin Technology through Individual IT Trends

Due to its versatile relevancy, the aforementioned Digital Twin technology has been "removed" from other trends, as it will be used in a more detailed study of its applicability. Premised on the scientific research literature, implementation examples of the remaining IT trends within supply chains were collected. Each of the examples has been segmented into constant multitudes of the supply chain system. The division into constant multitudes is possible in different ways. For instance, IT trends can be considered from the point of view of one multitude or several, since trends can consist of activities intended for products, services, processes, and systems. The proposed division into constant multitudes could also be regarding the IT trends and (a) their direct applicability or what they are related to, or (b) the impact of said trends on defined multitudes. In this case, the first division was chosen since IT trends could indirectly affect just about any constant multitude, depending on how they are studied. IT trends are supported by the benefits and challenges they pose within supply chains or logistics. Table 2 presents:

1. IT trend implementation examples (which are classified sequentially, as in the previous table) in the first column;
2. Corresponding sources in the second column;
3. The division into constant multitudes of supply chain systems in the third column;
4. Up to three benefits and challenges that arise from this implementation example in the fourth and fifth columns, although many more can be found;
5. The last column is reserved for the proposals of Digital Twin technology applicability on the remaining 13 IT trends, to increase the resilience and flexibility of future supply chain systems.

Table 2. Implementation examples of practical orientations and the applicability of Digital Twins through individual technology trends within supply chains.

Example	Source	Constant Multitudes of SC Systems	Benefits	Challenges	Applicability of DT Technology
1. AR in logistics	[79]	Product, Service, Process, System.	(1) Optimisation of processes, planning, an increase in operational efficiency; (2) Optimisation of transportation activities.	(1) Complex manipulation of 3D models; (2) Defining the right AR device for the specific issue.	Smart manufacturing, supply chains, and logistics processes based on AR and VR.
2. VR for logistics and SCM training	[80]	Product, Service, Process, System.	(1) Enhancement of human capacities; (2) Preparation, development, and evaluation of logistics and SCM stakeholders' skill acquisition and professional readiness.	(1) Delays in movement recognition and image visualisation cause nausea or disorientation; (2) Extraction of data.	

Table 2. *Cont.*

Example	Source	Constant Multitudes of SC Systems	Benefits	Challenges	Applicability of DT Technology
3. Bionic enhancement in transport and logistics	[81,82]	Service.	(1) Reduction or elimination of injuries; (2) Increased efficiency and mobility; (3) Power-assisted leg exoskeletons to take loads off the wearer.	(1) Cost indicators are challenging and unclear; (2) Legal, ethical, and policy challenges; (3) Modification or development of new laws.	Bionic enhancements for efficient performance.
4. Fifth-generation technology for future SCM and wireless IT competency	[83,84]	Products, Service, Process, System.	(1) Enables a unified platform for massive device connectivity, improving real-time data access; (2) Low latency, higher data speed and Wi-Fi capacity, reduced energy consumption, and on-demand service-oriented resource allocation.	(1) Complex implementation with high financial investments; (2) Necessity to overcome current bottlenecks of information exchange; (3) Security issues.	Fifth-generation technology for intelligent, flexible, and customisable manufacturing.
5. Blockchain-based SCM and security and issues in smart logistics	[85,86]	Service, Process, System.	(1) Higher levels of transparency enable process optimisation and better visibility; (2) Cryptocurrencies as potential payment forms for logistics products and services; (3) Cargo and vehicle tracking.	(1) Lack of strong correspondence between physical exchanges and digital information; (2) Industry-wide adaptation is not supported due to competitiveness.	Blockchain for improved data processing and comprehensive data security.
6. Quantum computing in SCM	[87,88]	Service, Process, System.	(1) More possibilities are verified simultaneously; (2) Quantum prediction anticipates and can solve disruptions to supply chain traceability and transparency to enhance performance; (3) Pre-existing algorithms for many issue types.	(1) Error correction and fault tolerance management of quantum devices; (2) Requirements for quantum mechanics knowledge; (3) Completely new technology.	Quantum computing for acquired data from sensors.
7. Drones for SCM and logistics	[89]	Product, Service.	(1) Reduced delivery time in SCM and logistics; (2) Improvement of SCM and logistics flexibility; (3) Increase SCM and logistics sustainability.	(1) Limited payload capacity, inability to fly for long periods; (3) Potential to harm the environment.	Path simulation for better SCM performance.
8. Impact of 3D innovations on logistics and SCM	[90,91]	Product.	(1) Manufacturing of low-volume, customised products with high-resource-efficiency production; (2) Reduction in orders and delivery time; (3) Cost-effective production.	(1) Studies focused on 3D adoption impacts only by manufacturers; (2) Three-dimensional printing customisation process will increase due to the high costs of printing equipment and material.	Cost predictions of customisable products.

Table 2. *Cont.*

Example	Source	Constant Multitudes of SC Systems	Benefits	Challenges	Applicability of DT Technology
9. Big-data-driven SCM and smart manufacturing	[92,93]	Service, Process, System.	(1) Refinement and algorithmic process of data, enabling large-scale sensing and modelling of (near-)real-time digital replicas of processes and systems; (2) Traceability of information.	(1) Real-time access to accurate and open data; (2) Small percentage of big data have been utilised for decision-making in SCM.	Dig data support quantum computing of Digital Twin data.
10. Cloud supply chain	[94,95]	Service, Process, System.	(1) Development of integrated systems; (2) Reduction in investment costs; (3) Provision of web services with scalability, availability, security, and serverless computing for distributing, sharing, and storing large amounts of data.	(1) Challenges of big data processing, analytics, and scalability; (2) Lack of research on cloud supply chains; (3) Necessity for high availability, performance, scalability, and security.	Real-time cloud-based Digital Twins to acquire information and data sharing.
11. Impacts of IoT on SCM	[83,86,96]	Service, Process, System.	(1) Smart communication between machines and data-driven intelligence on manufacturing; (2) Ability to integrate various logistics processes internally and externally with suppliers and customers.	(1) Issues with vulnerability, reliability, robustness, complexity, compatibility, storing, discovering, and sharing data, scalability, and interoperability; (2) Cyber-attacks.	
12. Robotics and automation in SCM	[97,98]	Product, Service, Process, System.	(1) Monitoring, maintaining, preserving product quality, facilitating quality decision-making; (2) Customisable grasping and manipulation; (3) Omissions of manual processing in SCM.	(1) Discovering and analysing appropriate processes for automation; (2) Issues of integration, information interchange, and validation of solutions.	Manufacturing process automation and robotisation.
13. Building SC resilience with AI	[99,100]	Service, Process, System.	(1) Machines think, react, and behave rationally; (2) Ability to handle large amounts of heterogeneous data of varying quality; (3) Identification of complex patterns.	(1) Requirements of implementation and appropriate control mechanisms; (2) Scalability of complex problems with high computing requirements.	Optimised warehouse process operations.
14. Self-driving vehicles for supply chain operations	[96,97]	Product, Service, Process, System.	(1) Autonomous and unmanned mobile robots react to their surroundings, follow required trajectories based on facility maps, dynamically respond, navigate around obstacles, move at desired speeds, and haul varying payloads; (2) Automated storage and retrieval systems.	(1) Automated guided vehicles can navigate through fixed trajectories and react to obstacles by halting; (2) Ethics and safety difficulties of dividing the workspace with machines, replacement of workforce, and fear of using intelligent applications in SCs.	

AR in logistics poses many benefits, such as process optimisation due to the merger of real and virtual objects and higher flexibility in logistics systems' planning [79]. On the other hand, VR enables the analysis of manufacturing and logistics systems options with simulations and experiments without costs (except software costs) and the optimisation of every logistics system [101]. Digital simulations and prototypes can reduce the failure of physical prototypes [10]. The correlation between AR, VR, and Digital Twin technology would enable virtual simulations of the physical manufacturing, supply chain, and logistics processes, converting them into smart systems. Their operations performance could be assessed in the beginning stages, enabling agile responses, increased effectiveness and reduced adversity of prototype design, consistent information exchange, and reduced costs of composing smart systems' prototypes [10,102]. Smart manufacturing, supply chains, and logistics processes are attributed to all constant multitudes—manufacturing is related to products. In contrast, supply chains and logistics represent the services offered, have processes that define them, and also symbolise their own systems.

Bionic enhancements are still entirely unregulated, although they are an increasing part of today's life [103]. Bionic enhancements encompass robots and smart support sensors (smart glasses) used for locating, tracking, and recognising the gestures of those who carry or wear them. Intelligent clothing enables the improvement of work routines, safety, and health. Like Digital Twin technology, bionic enhancements use sensors in warehouses, on employees' clothes, and even vehicles, enabling the provision of information between employees (the driver knows that the worker is behind his vehicle) [104]. The use of bionic enhancement could be supported by Digital Twin technology, which is beneficial to the performance of supply chain systems. Human augmentations could be required due to health issues or their prevention—using a bionic leg or arm [103]. With Digital Twin technology, simulations could be performed based on an employee's physique to determine what or which kind of bionic enhancement is suitable for them. Thus, employees would have the right equipment for more efficient performance, such as increased motion and mobility, while preventing potential health issues. Consequentially, this IT trend is attributed to only bionic enhancements since it is directly applied to enhance services performed by the employees.

The evolution of cloud-based supply chains, prompted by wireless IT, has hastened the momentum of innovations and increased competition [84]. The application of wireless IT within SCM enables companies to merge the competencies of their supply chain partners [105,106] whilst expediting innovations in real-time and with remote solutions [107]. Employees possessing wireless IT competency can improve supply chain operations by real-time access to crucial information or authentic customer services [84]. Fifth-generation communications provide much-needed performance improvements [108], and considering the demand from companies, 5G could be implemented in smart manufacturing—flexible and customisable production, enabling quality control, tracing, and tracking. This trend, correlated with other technologies, can even change the e-business market [83]. Next-generation wireless could present a support system for AR, VR, and Digital Twin technology for smart, flexible, and customisable manufacturing, where requirements for products, services, processes, and even systems could be simulated in the digital world, preventing unwanted outcomes.

In the desire to strengthen supply chain systems, future smart supply chains have to be composed of intertwining traceability, resilience, sustainability, traceability, security, and efficiency. To implement the latter into smart supply chain systems, blockchain technology could be the perfect solution. Manual processes would be redundant, shipped products could be tracked, and data sharing between companies and their stakeholders would be secure [86]. Visibility is another feature that can improve through process optimisation [85]. Digital Twin technology can prosper with the implementation of blockchain technology through the enablement of better security, visibility, and efficiency. This correlation enables the refinement of both technologies, thus revolutionising SCM [40]. The symbiosis of these technologies would improve data processing and comprehensive information security in supply chain systems, facilitating better visibility and resilience. The corresponding constant multitudes, in this case, are services, processes, and systems in which operations can be optimised through strongly supported real-time information sharing.

Supply chain systems are constantly exposed to unpredictable occurrences, impacting their performance and the achievement of their objectives. This is where quantum computing could play a crucial part by providing a stable environment for unstable events [87]. Quantum predictions are significant in enhancing SCM, where companies could anticipate statistical conclusions and calculate demand forecasting, leading to superior business decision-making processes. Although quantum computing algorithms are complex to create, present a time-consuming task, and require specialised knowledge, various algorithms for many different issue types already exist [109]. Digital Twin replicas can be based on multiple sensors that collect data for further analysis, which would be inclined to quantum computing and predictions. This would further support Digital Twin simulations, considering that a "non-deterministic and computationally intense process, with a large set of variables, is a candidate for improvement by quantum computing" [109]. The data could be acquired for various services, processes, and systems within supply chain systems and logistics.

Transport routes can be affected and impassable due to various disasters, where drones can easily access the remote parts unreachable by standard modes of transportation [110]. Drones can transport lightweight cargo to rural, inaccessible regions [111], considering that pre-existing flight paths are not required [110]. In SCM and logistics, drones enable reductions in delivery time [112,113], costs [114,115], improved flexibility [116], and increased sustainability [112,117]. Unmanned Aerial Vehicles would benefit from Digital Twin technology by the calculation of their maximum payload capacity and the path length they have to complete in a particular (perhaps critical) time interval, which would allow the overall optimisation of both. Hence, this technology has a direct impact on and applicability potential for product delivery services.

Three-dimensional or 3D printing technology can manufacture complex components, elements, and products in short manufacturing cycles, enabling portable manufacturing with space, material, cost, ordering, and delivery time savings [90,91]. Three-dimensional printing is widely used in manufacturing industrial supplies' parts, exhibiting comparable performance levels between printed and standardly manufactured products while providing the potential to develop remanufactured products [91]. Additionally, logistics suppliers could potentially use 3D printing as a competitive advantage, interfering with the costs of traditional manufacturing processes [90]. Digital Twin technology integration would, among other things, benefit cost predictions of customisable products, where multiple iterations would calculate the preferred number of variants of one product, which would allow for a prosperous financial goal. Derived from this proposal, 3D printing technology directly applies to the constant multitude of products.

The emergence of big data supports data-driven smart manufacturing, presenting numerous opportunities for supply chain systems. IT-supported manufacturing companies' development in tracing intangible data and information flows evolved parallelly with material flows [92]. Big data analytics present an opportunity to provide the fundamentals of decision-making support systems, allowing SCM professionals the much-needed insight into potential resource optimisations [93]. As previously mentioned, quantum computing and predictions would enhance Digital Twin simulations. If big data functions were implemented within this correlation, the supply chain systems would become immensely data-driven, which is vital to accomplishing intelligent, agile, resilient, and visible supply chain systems. Correspondingly to quantum computing, directly affected constant multitudes would be services, processes, and systems from which the data would be acquired.

Cloud-based supply chains are transforming traditional, static supply chain systems into dynamic supply chain services, correlating flexible and reconfigurable compositions supported by outsourcing. The cloud-based platform integrates digital manufacturing and logistics processes, comprising flows of materials, finances, and information [95]. Cloud technology can intertwine with quantum computing [94], wireless, big data, and blockchain technology [118], enabling investment and cost savings while enhancing service extensibility [119]. Cloud infrastructure encompasses availability, scalability, and serverless computing and enables the secure features necessary for web services. Concerning the distribution, sharing, and storage of immense information amounts, all is facilitated by secure and private web networks [86,94]. The utility of IoT can also be highlighted here since it presents a foundation of smart logistic systems, encouraging the development of the Internet of Everything (IoE) in smart systems and correlating people and IoT nodes [120]. IoT technology also allows smart communication among machines and promotes the intelligent, data-driven manufacturing of products [121]. IoT service benefits include sensors everywhere and in everything, wireless networks, data capturing, the internal integration of logistics and supply chain processes, and external integration for suppliers and customers [122]. IoT integration in supply chain systems will enable data capturing, storage, and sharing [83]. Many companies suffer due to non-up-to-date or distorted information, received potentially at the improper time. Cloud technology would allow for secure, real-time, Digital Twin-acquired information and data sharing among individual departments, subsidiaries, and stakeholders, preventing inadequate information sharing and decision-making with adverse consequences. Adhering to the latter, suitable constant multitudes for Cloud and IoT applicability with Digital Twin technology comprises services, processes, and systems premised on which the information and data would be obtained and used.

SCM's persistence, sustainability and superior results depend on automated activities [98]. Multidimensional and complex systems integrate the cyber world with the dynamic physical world [56], providing real-time information feedback from sensors and effective control [123,124]. With the implementation of software robots, manual processes become redundant, downtime can be excluded, and repeatably structured activities can be undertaken [98]. Real-time interactions and cyber-physical integration are hence achievable for monitoring and controlling physical entities in a collaborative, dependable, secure, and efficient way [124]. Manufacturing processes would benefit from faster cycles, improved process consistency, reduced manual labour, refined data accuracy and quality, flexible resource planning, and resilience [98,125]. Automation utilities have expanded the use of software platforms for monitoring and control, specifically through Digital Twin technology [126]. Firstly, Digital Twin technology would enable the prediction of the best-suited automation of manufacturing processes with the implementation of robotics, which would allow for autonomous warehouse and storage retrieval and its reorganisation [97]. The first directly impacted constant multitude would be products because of their automated retrieval, then services, processes, and systems, based on more efficient operations.

AI-based technologies provide solutions for more resilient supply chain systems [99], considering their flexible and self-learning techniques, fostering the capability of machines to think and react akin to humans [127,128]. AI enables the supported dynamic capabilities of perception, seizing, and transformation to alleviate and avert potential challenges and their consequences [129]. Supply chain systems would benefit from the integration of AI in terms of higher capacity of self-adaptation and flexibility, resulting in increased resilience [129,130]. Autonomous or self-driving vehicles are premised on this technology. They can react and navigate according to the surroundings and obstacles, following the required previously mapped trajectory at the desired speed whilst transporting altering cargo [97]. These vehicles provide safe cargo movement [131] while being economical, environmentally friendly, and socially sustainable [96]. The optimisation of warehouse process operations could benefit from Digital Twin technology and self-driving vehicles, which could be managed remotely based on wireless communication, managing various tasks while being guided via radio frequency by the program. The latter would be supported with data acquired from Digital Twin sensors. This collaboration would directly affect products' internal transport while optimising the execution of services, processes, and systems.

It is necessary to emphasise that these proposals do not support the notion that these modifications and improvements can be implemented immediately or that significant investments are not required (financial, materialistic, infrastructural, human, etc.). Premised on the revised literature and examples, it can definitely be argued that implementing Digital Twin technology is not pointless but must be considered and thought out.

3.3. Conceptual Model

In this sub-chapter, the premises of the conceptual model for the assessment of investments in the necessary IT resources will be presented, derived from the applicability of Digital Twin technology through individual logistics IT trends and the corresponding constant multitude of the supply chain system (shown in the previous sub-chapter). The first parameter set, necessary for the conceptual model realisation, was obtained from the second part of this research, based on (a) implementation examples of practical orientations and the application of IT trends within supply chains, and consequently from (b) the division of the implementation examples of practical orientations into four defined constant multitudes of supply chain systems. The second parameter set also presents an integral part of the conceptual model by which the investment can be assessed. For these parameters, IT resources were determined.

The four primary logistics resources, without which logistics processes and supply chain systems cannot operate or function smoothly, are resources available to implement into IT processes [132]. Further, it is stated that they can be perceived as investments in IT processes and need to be ultimately protected [133]. Any technology is comprised of "four interdependent, codetermining, and equally important components" [134], called IT resources, which are [133,135–137]:

1. Information—represented by databases, files, system documentation, manuals, instructions, and training materials, describing the logic for using the IT in a precise way;
2. Applications—represented by essential software and resources, solutions, support programs, and development tools for providing knowledge on how to perform the required activities and tasks;
3. Infrastructures—represented also as hardware, physical assets such as communication, computer, and technical equipment, which are used to perform the required activities and tasks;
4. Intangible assets and people—represented by confidential information, computer processing and communication services, passwords, and human resources.

Now that the importance of IT resources has been established, the significance of investments should be emphasised. Supply chain investment decisions are essential undertakings [138]. However, implementing an innovative culture requires investments in resources and the constant introduction of modern supply chain processes [139]. Such investments can be introduced for technology improvements, employee education, safety, and health [140]. The authors of [141] presented a model that provides a general framework for companies to evaluate the short and long-term impacts of investments in sustainable operations in supply chain systems [140]. To optimise and successfully re-engineer supply chain systems, the processes' harmonisation is required within the company's objectives, scope, and complexity [137]. Certainly, companies want to make revenue, but with outdated techniques, they will not be competitive for long [140]. They have to be the ones in charge of determining the investment quota [138]. Companies should be interested in maximising revenues and profits, premised on identified optimal product path flow, together with necessary investments [140], innovations, and optimisation. Improvements in the performance and policies of supply chain systems require investments in sustainable operations, which are beneficial to results in multiple periods [141]. In contrast, it is necessary to be aware that the results may not be immediately evident [139]. Optimisation with consequent investments in IT solutions for supply chain operations support should be directed onto IT resources, considering the latter represents "the essential capacity for accomplishing mundane business operations" [137], thus making modern technology investments crucial for competitiveness and optimised supply chain management.

The conceptual model in the form of a matrix (Figure 2) is produced to assess investments in the necessary IT resources. The long-term objective is to facilitate the visibility and resilience of the supply chain systems of any company. In this specific case, 14 IT trends were obtained based on the literature and then classified due to their benefits and challenges, impact on supply chain systems, and connection to sectors that are most relevant to them. The Digital Twin trend applicability was then correlated to the remaining 13 IT trends' adoption examples within supply chains and logistics. The latter were accordingly divided into constant multitudes of supply chain systems. Based on the literature, essential IT resources were established, representing the pivotal content of any functional supply chain operation. The conceptual model proposes the implementation of the just-described segmentation of logistics IT trends that are a prerequisite for the operations of any (logistics) company. Premised on this segmentation, a matrix with 16 areas is provided (in this case) where investments are evaluated for IT resource (information, applications, infrastructures, intangible assets, and people) acquirement, depending on the necessary implementation within the constant multitude of the supply chain system (products, services, processes, systems).

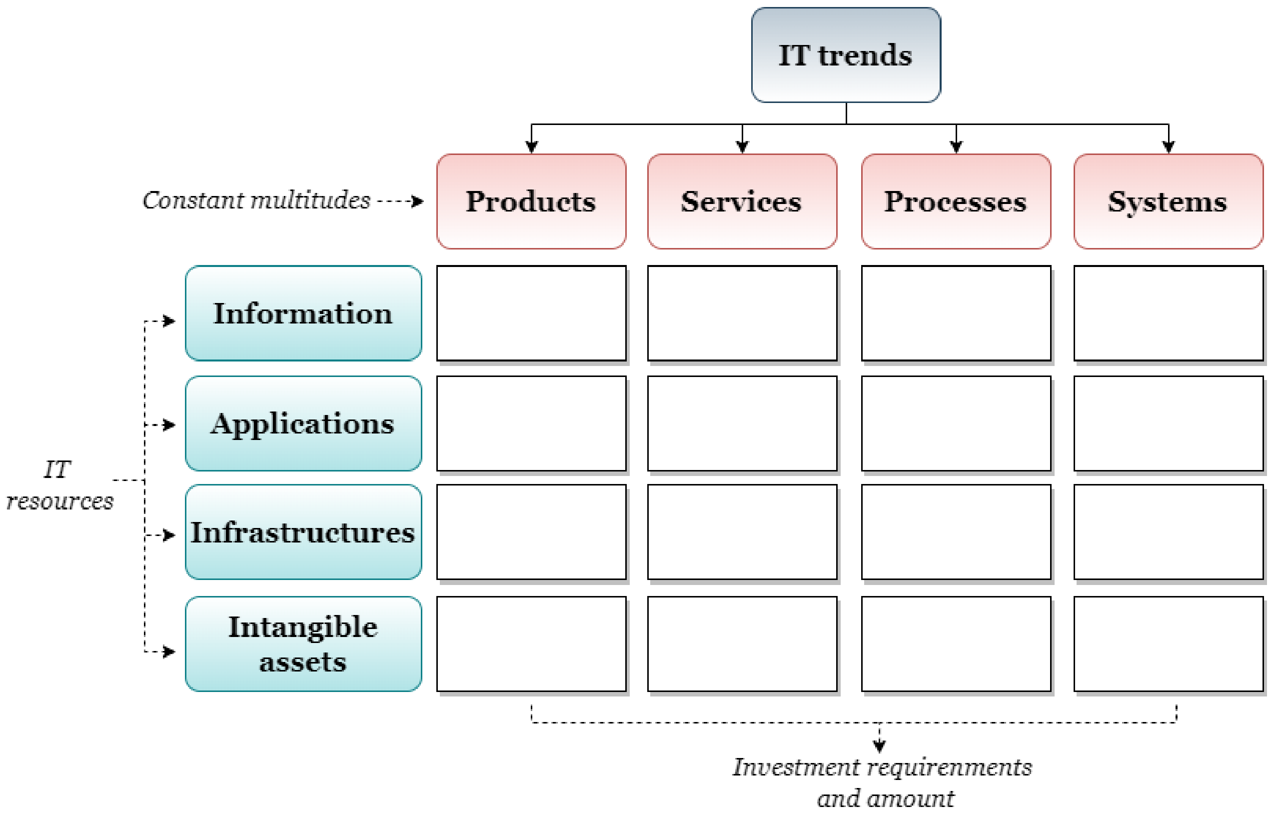

Figure 2. The conceptual model (matrix) for assessing the investments in the necessary IT resources.

The conceptual model was produced with the aspiration to enable the assessment of investments in the necessary IT resources for process digitalisation and optimisation whilst facilitating the visibility and resilience of the supply chain systems of any company, regardless of their specifics and requirements. The produced conceptual model in the form of a matrix provides 16 areas, where the assessment of investments for IT resource acquirement is evaluated depending on the desired implementation within the constant multitude of supply chain systems. The conceptual model is agile and inclined to different IT trend divisions; the consideration of other trends (e.g., business trends) and enabling adaptation to them; and enabling the narrowing-down of individual supply chain parts or even company departments and of expansion to other business fields. The model can also differ from case to case—from company to company—and according to its requirements for providing digital innovations, IT resources, and investment levels. Thus, the conceptual model can delve into one logistics IT trend from different perspectives, depending on the election of the corresponding constant multitude of an individual company. Consequently, diverse and various assessments of investments are obtained for a single IT trend. This was precisely the aspiration when creating the conceptual model: its implementation is flexible according to the needs and requirements of different, individual companies, while the parameters for investment assessment in IT resources are provided.

4. Discussion and Conclusions

To increase the visibility and resilience of future supply chain systems, it is significant to provide the functional integration of Digital Twin technology within logistics processes [142] and supply chains. Precisely the latter was sought to be achieved premised on the production of this conceptual model for investment assessment, which would support operation optimisation and contribute to the visibility and resilience of any supply chain system. Digital Twin technology enables tremendous positive impacts on business operations, such as designing an overview of the company's processes, which could be problematic [143–145], to optimise them for better functioning of the entire supply chain system. Ensuring adequate visibility and resilience in a supply chain system has several beneficial consequences, such as process optimisation, predictions, preparation, innovation implementation [51,52], and the reconfiguration of the supply chain system [146]. Although, it is necessary to be aware that the implementation of Digital Twin technology is complex, requires extensive resource investment, and does not provide an absolute state of visibility and resilience of the supply chain system [21].

Consumers' expectations dictate the need for optimised material flows, the customisation of products and services, and rapid and agile responses, while governments and organisations strive towards circular economy business processes. All of these trends require supply chain systems to transform into a foresight-capable network of organisations that can predict challenges, be flexible in dynamic environments, and ensure optimised performance [39]. While it is difficult to predict tomorrow's events, challenges could be anticipated with Digital Twin technology, which allows preparation to respond adequately and appropriately. This paper presented research about Digital Twin technology and its implementation through other logistics IT trends for the purpose of resolving the issue of the visibility and resilience of supply chain systems. The objective of this research was resolved by presenting the conceptual model in the form of a matrix for assessing investments in the necessary IT resources. Ensuring supply chain visibility and resilience was researched through Digital Twin implementation through logistics IT trends. The conceptual model was created with the thought of logistics companies, but it is applicable to other companies as well, premised on its agile concept of assessing the investment levels into necessary IT resources (information, applications, infrastructures, intangible assets, and people) for the implementation of desired IT trends through the four constant multitudes of supply chain systems (products, services, processes, systems). Regarding the research questions:

1. Digital Twin technology can benefit the constant multitudes of supply chain systems through its implementation into business operations, consequently leading to better performance of said constant multitudes, remaining and/or connecting multitudes, and their sub-multitudes.
2. The parameters, considered for the conceptual model for the assessment of investments in supply chain systems, are constant multitudes due to their continuous presence in the supply chains and IT resources, without which supply chains' operations would be impossible.

3. The conceptual model was posed with the ability to decide between a selected constant multitude and the required IT resource, which presents a necessity for the investment assessment for the company in question.
4. The notion of digital IT competency development according to new IT trends to enable supply chain resilience is supported through the presented conceptual model. This has been confirmed based on the literature background and partial results, which testify to the importance and essentialness of IT-related knowledge and relevant competencies.

4.1. State of the Art

Various researchers have focused on both theoretical and applied features of Digital Twin technology. There are lists of features based on personal studies and findings from scientific research [22,23,147,148] that encompass a proposed description of the characteristics of why Digital Twins act as a foundation for future scientific endeavours. The authors of [21] state that these features can be used for the comprehensive coverage of Digital Twin technology implementation from something as small as a fraction of manufacturing or something as considerable as an entire city. The authors of [42] mention the Digital Twin of an organisation (DTO). Considering applicability, Digital Twins are especially suitable for production planning, predictive maintenance, and control optimisation, while broad applicability can be found in manufacturing, general planning, and supply chains, increasing their resilience and mitigating disruptions and challenges [8]. The technology can automate monotonous manual activities, which are prone to human error [143].The authors of [8] mention one study showing utility in an example of a smart factory cell, evaluating the applicability of Digital Twins for a production system. Directly related research on Digital Twins and remanufacturing is limited, according to [149]. However, research about the digitalisation of services and manufacturing is becoming a trend. A Digital Twin-based remanufacturing paradigm is proposed by [150], composed of theoretical concepts with the possibility of applicability in companies for the management and tracing of product-remanufacturing processes. Another study presents a Digital Twin application in supply chains, introducing the concept of Digital Supply Chain Twins (DSCTs) [64]. The authors of [43] state that the combination of simulations, data analytics, and optimisation represents fundamental elements for the creation of DSCTs. This model can observe processes in real-time, allowing for the possibility of planning and decision-making in real-time [151]. DSCTs present the condition of a network at any point in time, enabling whole end-to-end supply chain visibility, which can help increase resilience [62]. Digital Twin technology can hence be applied to observe present systems, predict, and assess future conditions of the latter, allowing for more efficient and optimised operations [58]. This technology can apprehend large amounts of data, typically complex to calculate [21]. Premised on these data, decision-making processes and suggestions can be provided to maximise assets [143]. The authors of [152] carried out a case study on how Digital Twin technology could be applied in the logistics field and used for predicting supply chain risks. The customisation of supply chain systems imposes the latter to be more connected through sharing knowledge [39]. In this desire, acquiring correct data and information is a prerequisite, which can conversely present a challenge [101]. The foremost opportunity for technologies such as Digital Twin is to utilise statistical analysis, data retrieval, the production of predictions about system performance, and their application to process control [8].

However, the authors of [23] point out the disjointed definitions or understanding of Digital Twin technology, which could beguile organisations to characterise their current 3D-modeling system with asset-tracking technology as a Digital Twin. The definition of Digital Twin technology is presented by [153] in three different categories, depending on the level of data integration [154]: digital model, digital shadow, and Digital Twin.

The preeminent challenge is "to design and operate a system with the capacity to produce a high variety of customised products efficiently and as quickly as possible, dealing with uncertainties and many risks that can break up at any point of the network" [8]. Challenges also arise with the integration of Digital Twin technology in the fields of education, data quality and digital security, costs, and interoperability [21]. Nonetheless, there is still a lack of research on Digital Twin applicability for supply chain remanufacturing [7]. Digital Twin technology applicability has not been fully realised yet [39], presenting an immense opportunity for further investigation [8] due to the fact that studies concerning Digital Twins are "still in their infancy, the available literature is mostly conceptual, whilst research areas are still lacking concrete case studies" [153]. This leaves monumental room for future research [62].

4.2. Future Research

In the future, there will be extensive opportunities for additional and various research. The first suggestion for further research is to enhance the current research by applying trends from other sources, such as Gartner (which distinguishes different and various trends, from IT and supply chain to logistics trends) or even pillars of European strategy. Further, examining the benefits, challenges, and impact of Digital Twin technology implementation in supply chains and logistics would be remarkable for the mentioned fields. The latter can be accomplished only if the definition of Digital Twin technology is crystal clear. Thus, detailed research on the aforementioned three categories of Digital Twin technology is preferred. Another suggestion would touch upon meticulous research and investigation about the implementation of Digital Twin technology in each individual constant multitude (products, services, processes, and systems) presented in this paper—this would represent very comprehensive and exhaustive research, which is substantially considerable for the field of supply chains and logistics. Furthermore, the conceptual model will be tested in the future on a pilot model, where the conceptual model's matrix will be implemented on selected organisations in different supply chain systems with the help of their employees. From this, possible modifications of the model would be enabled, premised on attained knowledge from practical implementation. It should be emphasised that this is more professional-oriented work than scientific research. Conducting research about technology's impact on other fields would also be advisable, such as education or medicine. Lastly, the story could be taken into human resource management. It would be highly alluring to research how many companies have suitably selected people to work in IT and with Digital Twin technology or whether these employees possess suitable digital IT competencies.

Some authors believe it is necessary to start with small steps regarding Digital Twin technology—the application should be limited in scope and extent [112]. The latter means that the results are also limited [155]. Nevertheless, the first version or application of the said technology should be treated as an opportunity to learn about the procedures to apply Digital Twins into organisations' processes on account of the need to re-create or re-develop the introductory version of Digital Twin technology [156]. Despite the long-standing awareness of Digital Twin technology's existence, the latter's implementation is relatively new to the spheres of logistics [21] and supply chain systems. Thus, further research and developments are undoubtedly on the rapidly approaching horizon.

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