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Smart Sustainable City Manufacturing and Logistics: A Framework for City Logistics Node 4.0 Operations

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Abstract: The location of smart sustainable city multi-floor manufacturing (CMFM) directly in the residential area of a megapolis reduces the delivery time of goods to consumers, has a favorable effect on urban traffic and the environment, and contributes to the rational use of land resources. An important factor in the transformation of a smart city is the development of CMFM clusters and their city logistics nodes (CLNs); the key elements of the logistics system of a megapolis. The primary goal of this study was to examine the role of the CLN4.0, as a lead sustainability and smart service provider of a CMFM cluster within the Industry 4.0 paradigm, as well as its value in the system of logistics facilities and networks of a megalopolis. This paper presents an innovative model of a CLN4.0 under supply uncertainty using a material flow analysis (MFA) methodology, which allows for specific parameters of throughput capacity within the CMFM cluster and the management of supply chains (SCs) under uncertainty. The model was verified based on a case study (7th scenario) for various frameworks of a multi-floor CLN4.0. The validity of using a group of virtual CLNs4.0 to support the balanced operation of these framework operations under uncertainty, due to an uneven production workload of CMFM clusters, is discussed. The results may be useful for the decision-making and planning processes associated with supply chain management (SCM) within CMFM clusters in a megapolis.

Keywords: smart sustainable city; city multi-floor manufacturing; city logistics node 4.0; supply chain management

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1. Introduction

The large smart city and megapolis provide a wide range of digital services and technologies with which to meet the needs of the population and the sustainable development of the agglomeration. Instant information support in the day-to-day decision making by the population cannot always be quickly implemented when purchasing products and goods in high demand, due to logistical and transport problems [1–3]. The situation is complicated by the fact that the population is forced to purchase many goods and services for everyday needs, not from local manufacturers, but from far beyond the megapolis, which leads to expectations of supplies and unjustified interregional or international freight traffic of consumer goods, from manufacturer to consumer. The approach of manufacturing enterprises supplying consumers by being placed outside the large city, in the so-called industrial zones or industrial technology parks (ITPs), has led to new problems associated with traffic jams during rush hours, increased urban traffic, and difficulties in finding parking spaces for both passenger and freight vehicles [4–6]. It is obvious that the timely satisfaction of the needs of the population, the reduction of harmful emissions into the atmosphere, and the reduction of energy demand, due to such freight transportation, are associated with the placement of sustainable manufacturing directly in residential areas [7–9].

In this case, the localization of city multi-floor manufacturing (CMFM) directly in the residential area of a large city is due to limited land resources and a modular approach to manufactured products and technological equipment [10–12]. Such CMFM reduces the distance between the manufacturer and consumer, as much as possible, but has led to the need to solve the logistical problems of freight transportation for production needs. Joining a group of CMFM buildings into a cluster, with its own city logistics node (CLN), is aimed at optimizing freight transportation, both within the cluster, and in the urban environment [13].

The issue of CLNs 4.0, as well as regarding improving their efficiency, is not well known in the literature [13–15]. This article attempts to classify, hierarchize, and organize the definition of megapolis logistics facilities. The interactions of logical objects through freight transport logistics networks were identified, and CLN4.0 is shown to be the leading provider of sustainable and intelligent services within the CMFM cluster, the large city, and the megapolis, under conditions of uncertainty. This paper proposes a new model of final CLN4.0 throughput in a CMFM cluster, using a material flow analysis (MFA) methodology. The results obtained from the proposed model confirm the adopted thesis, that the efficiency of CLN4.0 determines the functioning of CMFM production clusters in conditions of uncertainty regarding supply chains (SCs), due to the uneven production load of CMFM clusters.

2. Literature Review

2.1. Smart Sustainable City Manufacturing and Logistics

In the literature [16–21], we observe an increasing interest in the issues of sustainable city manufacturing and logistics using industry 4.0 technology. The sustainable development of city manufacturing and logistics in a smart city has been evaluated using a triple bottom line (TBL), which considers environmental, economic, and social aspects simultaneously [1,16,22]. A range of sustainable performance indicators have been used to assess city manufacturing and logistics across these three dimensions, during a predetermined time period [16,23,24]. The complexity of the sustainability assessment of city manufacturing and logistics with a three-dimensional approach has led to the development of indicators and reporting on certain aspects of their sustainability, related, for instance, to ensuring the supply of environmentally friendly materials, products, and technical equipment in a circular economy using electric vehicles, to minimize the harmful effects of transport activities on the environment [5,16,22].

Smart manufacturing or manufacturing 4.0 is a product of modern digital technologies that automatically collect and process data using artificial intelligence (AI) at all stages of the product lifecycle, in order to quickly adapt production and logistics processes to emerging uncertainties, in the framework of the stringent and dynamic requirements of consumers and a competitive environment [25–27].

According to Kusiak [26], the essence of smart manufacturing is captured in six pillars: advanced technologies and manufacturing processes; innovative materials; big data and data mining; technological assessment at the design stage of manufacturing and transport systems; sustainability of city manufacturing based on the TBL; and creation of manufacturing and logistics networks and resource sharing, which agree well with the results of other studies [1,16,22]. The analysis of the six pillars of smart manufacturing shows that all of them are somehow aimed at ensuring the sustainability of production and logistical services in real time [28].

In recent years, the integrated consideration of smart sustainable city manufacturing and logistics has been increasingly recognized and become widely adopted, due to the holistic approach to planning and use of production and transport resources within a smart city [16,29,30]. Cutting-edge smart sustainable city manufacturing and logistics technologies are common to the following: cyber-physical systems (CPS), cloud-based design and manufacturing (CBDM), cloud-based materials handling systems (CBMHS), internet of things (IoT), digital twins, big data and data mining, AI, blockchain, and additive manufacturing [16,18,31,32]. These technologies embody the relationship between industrial AI, IoT-based real-time manufacturing logistics, and cyber-physical process monitoring systems in city logistics-based sustainable smart manufacturing [33–35]. Thus, it is assumed that smart sustainable city manufacturing and logistics will use smart technologies based on intelligent systems and AI to identify and implement the (single) optimal sustainable solution in real time in every case of uncertainty [18,30,32].

Manufacturing enterprises in a CMFM cluster, differing in terms of their form of ownership, size (mainly small and medium-sized enterprises), and production focus, determine a wide range of production services in the cluster and the metropolis. The technical equipment used by cluster enterprises is driven by market needs and the organization of production and distribution networks, while competitive conditions contribute to the balance of production services and pricing policies, as well as the reengineering of business processes [1,36,37]. CMFM cluster enterprises are focused on various types of production organization, from unit to mass production. In the latter case, single- or multifloor production lines are used [38].

Smart sustainable city logistics are particularly important in view of heavy urban traffic and supply uncertainty. Cutting-edge technologies, additionally, embody the relationship between smart sustainable urban transport systems, intelligent transportation planning and engineering, and big geospatial data analytics, as they eliminate the need for transport, by locating intelligent production directly in cities [39,40]. Therefore, to assess smart sustainable city logistics in a CMFM cluster and megapolis, indicators such as the compatibility of freight, transport throughput, empty runs, gas emissions, and environmentally friendly transport infrastructure are used in real time [4,5,21]. Smart sustainable city logistics form a link between the CMFM and smart city, and represents an important tool for cooperation between partners and customers, a for as well as risk management under supply uncertainty; supporting decision-making based on the objective information received from monitoring systems [41]. The implementation of smart sustainable city logistics within a megalopolis entails the use of CLNs4.0 in CMFM clusters, which are designed to solve urban logistics problems by dividing internal (inside the cluster) and external (outside the cluster) material flows. Within a CMFM cluster, materials only flow through theCLN4.0, where freight is sorted by delivery direction and distributed to internal and external material flows [13].

Smart sustainable city logistics within a CMFM cluster are delivered by the transport system, the main elements of which are intelligent reconfigurable trolleys (IRTs), the freight elevators of CMFM buildings and the cluster's CLN4.0, automated guided vehicles (AGVs), autonomous mobile robots (AMRs), light e-tracks [4,42,43], and the delivery service platform (DSP) of the megapolis [44–46]. The main function of the DSP is to provide a link between urban IoTs systems and data-driven planning and logistics technologies in smart sustainable city governance and management [28,47,48]. Intelligent reconfigurable trolleys (IRT), designed for the temporary storage and transportation of a wide range of freights and goods from manufacturer to customers through the cluster's CLN and within the megapolis, are a key element of the CMFM transport system [5,43]. The design of the IRT enables quick changeovers, to adapt to different freights; picking a group of IRTs for a city container (CC), to enable unimodal, multimodal, and intermodal transportation; adopting the Kanban philosophy and the concept of smart sustainable SCM, owing to the presence of a recording and transmitting device that contains the necessary real-time information about the IRT and its freight [4,43,49].

2.2. CLN4.0 within the Smart Sustainable CMFM Cluster and Megapolis

The location of city manufacturing in the area of the customer's life and functioning significantly reduces the length of transport routes of the product to the customer. However, such a solution can generate serious logistical problems in a megapolis, as well as in the internal logistics of the plant. The key element influencing the effectiveness of this solution is the efficiency of CLN4.0, and in the case of the city logistics cluster 4.0 (CLC4.0).

The essence of smart manufacturing is captured in the following six pillars: advanced technologies and manufacturing processes; innovative materials; big data and data mining; technology assessment at the design stage of manufacturing and transport systems; the sustainability of city manufacturing based on the TBL (triple bottom line: social, environmental, and financial); and the creation of manufacturing and logistics networks and resource sharing [26], which correspond with [17,21]. Choosing the location of city manufacturing and logistics facilities is the subject of many studies [50–57]; however, attention should be paid to certain aspects (e.g., historical buildings), regarding their location in the megalopolis.

The proper location of logistics facilities in the megapolis is an important determinant, in addition to CLN4.0 throughput and achieving a sustainable SC effect in the megapolis. For the optimal selection of CMFM locations, a megapolis can be divided into three concentric zones [5,14]: central and historical; a large city without a historical part; and a megalopolis without a large city. It is obvious that the second zone of the megapolis (the large city without a historical part) is the most densely-populated part, with the greatest needs for the supply of everyday goods [45]. Reducing the distance between the producer and the consumer makes this zone of the megapolis (the large city without a historical part) the most attractive for CMFM cluster placement [5]. The use of warehouses and logistics centers on the outskirts of a large city to serve CMFM clusters creates a number of problems regarding the supply of materials and components for production and for the distribution of finished products and goods, due to the increased intensity of urban traffic within the cluster and beyond, the need to find parking spaces for freight transport, and the increased energy demand for transport purposes [3]. In order to ensure the proper operation of the SC in the megapolis, the logistics facilities inside the megapolis must be connected to the logistics facilities outside it. The elements that connect logistics inside the megapolis to the outside are the logistics nodes.

According to K. Rimienė and D. Grundey (2007), the logistic nodes are ‘points that gather and connect different transport modes and give an opportunity to serve cargoes that flow from different directions. Nodes include major seaports and other large-scale terminals that are seen as complementary to inland logistics centers’ [58]. The structural foundation of a unit load for the logistics node is an intermodal container. Considering that the logistics facility of the CMFM cluster is located in a residential area of a large city and performs a spectrum of operations similar to the logistics node and uses the CC as the structural foundation of a unit load, by analogy it is proposed that the term ‘CLN’ is used for it. The close location of the CLNs to adjacent CMFM clusters allows them to integrate their activities into a CLC. In this case, it is also possible to join these CMFM clusters, to from a CMFM mega cluster [13].

The main activity of the CLN 4.0 is related to traditional logistics operations: the receiving, storage, sorting, and shipment of freight in the appropriate directions using modern technologies such as CPS, CBMHS, IoT, digital twins, big data, and data mining, blockchain, and AMR [13,31,49]. According to V. Yavas and Y.D. Ozkan-Ozen (2020), for manufacturing 4.0, it is necessary to implement the four main logistics facility (center) activities: handling, information, transportation, and warehouse management, while including 12 critical criteria [14]: smart handling, zero emission, smart mobility, freight exchange platforms, digital information platforms, intelligent transportation systems, information security, real time locating systems, autonomous vehicles, smart warehouses, logistics center alliances, and digital connectivity. At the same time, according to experts, the most important criteria for logistics facilities 4.0 are the following [14]: digital information platforms, intelligent transportation systems, and smart mobility.

In terms of improving the logistics of megapolis transport, in addition to the already existing clean terminologies in the field of external logistics, it is necessary to implement a uniform terminology of megapolis logistics facilities.

The classification of the logistics facilities of a megapolis is the first step towards their definition. Obviously, such a classification should consider future needs, in accordance with a suitable city manufacturing 4.0 paradigm [14,59,60]. One of the key factors of effective megapolis logistics is CLN4.0, which determines the efficiency of the CMFM cluster and determines its throughput model.

3. Materials and Methods

The correct identification of megapolis logistics facilities and knowledge of their fencing in urban logistics is the basis for developing optimal and effective load handling scenarios. One of the key logistics facilities are CLNs4.0. They are the logistics facilities of the CMFM clusters within the large city and interact with other facilities in it: advanced technology and educational parks (ATEPs), with a city logistics center (CLCE); city waste transfer stations (CWTSs); while in megapolises outside the large city: energy parks; industrial and technology parks (ITPs); recycling, treatment and energy parks (RTEPs); megapolis logistics nodes 4.0 (MLNs4.0), megapolis distribution logistics hubs 4.0 (MDLHs4.0), megapolis transportation logistics hubs 4.0 (MTLHs4.0), megapolis waste transfer stations (MWTSs), etc. These facilities are the nodal points of the freight transportation networks of a large city and megapolis (Figure 1).

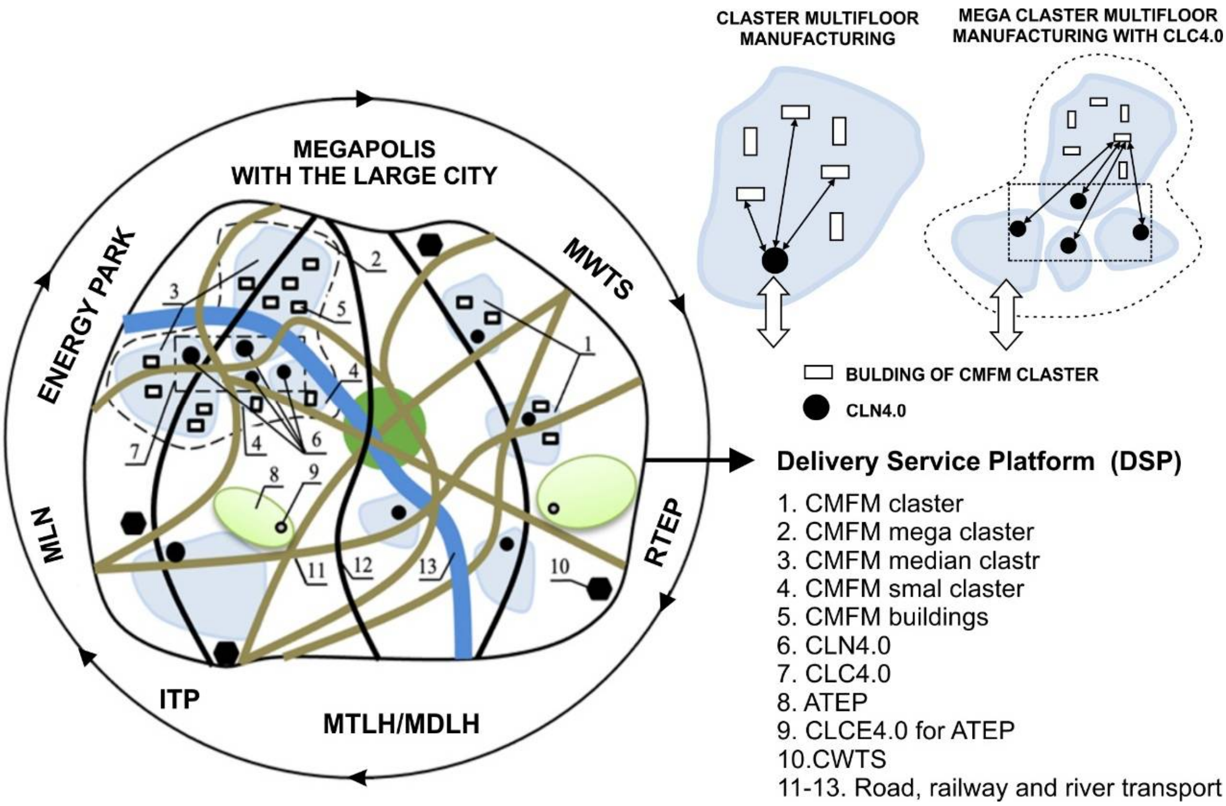

Figure 1. CMFM clusters with CLN4.0 in the structure of a large city and megapolis.

A CLN4.0, which is designed to serve the CMFM cluster, is a multi-floor logistics facility with its own infrastructure and is located in the residential zone of a large city [13]. The CMFN cluster's material flow passes through this logistics facility, where all IRTs and their freight are sorted for further shipment to consumers via CCs. The CLNs4.0 also interact with other logistics facilities in the megapolis. The literature presents classifications and definitions of various logistics facilities and considers the issues of their optimal location and their interaction with other logistics facilities [61–68]. However, there has, so far, been no such classification of logistics facilities located in the residential part of a large city within the CMFM clusters, and their interaction with other logistics facilities of the megalopolis through freight logistics networks has not been sufficiently studied.

The CLN4.0 is a multi-floor building located within the large city. In order to ensure the high efficiency of a CLN4.0 functioning in a CMFM cluster, it is necessary to learn the optimal structure and features that will ensure its durability and functionality.

It is necessary to consider in more detail its structure and characteristics, which have an impact on the sustainability of its operation. It is also advisable to consider the types of CLNs4.0 and the organizational forms of the loading–unloading operations, considering the prevailing type of production in the CMFM cluster, material flows, and its role as a leading sustainability and smart service provider within a large city and megapolis. Finally, it is necessary to develop a finite throughput capacity model of the CLN4.0, in order to define its ability to serve the CMFM cluster under supply uncertainty, to prevent its overstocking and overloading and make of its operation smarter and more sustainable.

The development of a finite throughput capacity model of a CLN4.0 within the CMFM cluster is based on the fundamental principle of MFA, i.e., material balance: the inflow to the CLN4.0 operating floors is equal to the out-flow [69] and throughput of freight elevators, as well as on the method of calculation of the actual capacity requirement planning (CRP) of the CMFM cluster [70]. The finite throughput capacity model of the CLN4.0 can be implemented, with the efficient use of vehicles based on a smart sustainable approach to SCM [49].

Indicators of full, quasi-full, and partial handling of freight are used to evaluate the efficiency of vehicle use [5,49]. With full freight handling, all empty runs of vehicles are excluded. In cases of quasi-full freight handling, empty runs of vehicles are possible in some sections of traffic, but the freights are delivered in both directions as full freights. In the case of partial freight handling, full delivery is carried out only in one direction [5]. This means that a vehicle (e.g., an e-truck) arrives at the CLN4.0 empty and leaves with a fully loaded CC, or vice versa. It is important to note that the arrival and/or departure of a vehicle with a partially filled CC also refers to the partial handling of the CLN4.0 floor. It is obvious that partial handling of freight, with empty vehicle runs, is an unacceptable scenario from the point of view of ensuring the finite throughput capacity of the CLN4.0 [49].

The choice of the best freight handling scenario is associated with the sustainable-smart approach to SCM, in which the planning of the SCs and their implementation in real time are provided by the DSP of the megapolis server and the current information about the transported freights. The smart sustainable SCM is based on information coming in real time from IRT recording and transmitting devices and includes CCs selected from IRTs, considering the compatibility and safety of the freight for its subsequent transportation; monitoring in real time the loading–unloading operations; the supervision of the cross-border transport of materials, products and production waste; and their storage, handling, delivery, and disposal [5,71].

4. Identification and Hierarchy of Megapolis Logistics Facilities: Results

4.1. Concept of Megapolis Logistics Facilities: Classification, Hierarchy, and Definitions

The conducted literature research from recent years (e.g., [62–68]) allowed us to identify and distinguish five types of megapolis logistical objects: CLN4.0, CLC4.0, MLN4.0, MDLH4.0, and MTLH4.0, which serves as a leading provider of sustainable development and intelligent services. The smallest identified logistics facility of a megalopolis is CLCE4.0, located within the corresponding ATEP. Its size and throughput capacity depends on the research and production possibility of the ATEP and its spatial location in a large city [5]. The structural foundation of the unit loads of the CLCE4.0 are the pallet, IRT, and CC [49].

At the first level among the megapolis logistics facilities is the CLN4.0, located within the corresponding CMFM cluster. Its size and throughput capacity depends on its spatial location in a large city. It is obvious that the closer the central historical part of the large city is to CLN4.0, the smaller its size and throughput capacity. The structural foundation of a unit load of the CLN4.0 is a CC [13,49].

At the second level, in terms of size and throughput capacity is the CLC4.0, which is two or more closely located CLNs4.0 joined in a cluster. A special feature of the CLC4.0

is the use of a common server for managing their activities. The CLN4.0 and CLC4.0 are unimodal or multimodal logistics facilities, while the structural foundation of a unit load is a CC [13,49].

At the third and fourth levels are the multimodal MLN4.0 and MDLH4.0. The structural foundation of a unit load of the MLN4.0 and MDLH4.0 are city and intermodal containers. The common feature of these megapolis logistics facilities is the use of multi-floor intermodal terminals, and the difference is in the storage time of the freights. The MDLH4.0 is designed for longer storage of freights, so its size is large [57,62].

The largest logistics facility in a megapolis is the multimodal MTLH4.0, the structural foundation of a unit load of which is an intermodal container. Unlike the MDLH4.0, it is not intended for long-term storage of intermodal containers, only for their transit or redirection [62]. The MDLH4.0 and MTLH4.0 of the megapolis are located close to regional, national, or international highways and railways, and near airports. In addition, the MTLH4.0 can be located at a seaport [57,62].

Table 1 presents the author's classification, hierarchy, and definitions of megapolis logistics facilities: CLCE4.0, CLN4.0, CLC4.0, MLN4.0, MDLH4.0, and MTLH4.0.

Table 1. Classification, hierarchy, and definitions of megapolis logistics facilities.

Logistics Facilities	Size Logistics Facilities	Structural Foundation of a Unit Load	Definition
MTLH4.0	5 level (largest size)	Intermodal Container	A MTLH4.0 is intermodal and consists of synchromodality transportation logistics facilities within the megapolis outside the large city for intermodal container handling; they are located at the extreme points of the megapolis freight logistics networks and perform the role of a lead sustainability and smart service provider.
MDLH4.0	4 level	Intermodal Container and CC	MDLHs4.0 are multimodal, intermodal, and synchromodality distribution logistics facilities within the megapolis outside the large city, for city and intermodal container handling; they are located at the extreme points of the megapolis freight logistics networks and perform the role of a lead sustainability and smart service provider.
MLN4.0	3 level	Intermodal Container and CC	A MLN4.0 is a multimodal and synchromodality logistics facility within the megapolis, outside the large city for city and intermodal container handling; they are located at the nodal points of the megapolis freight logistics networks and perform the role of a lead sustainability and smart service provider.
CLC4.0	2 level	CC	A CLC4.0 consists of CLNs4.0 located in a CMFM mega cluster.
CLN4.0	1 level	CC	A CLN4.0 is a unimodal or multimodal and synchromodality logistics facility within the CMFM cluster for CC handling; it is located at the nodal points of the megapolis freight logistics networks and performs the role of a lead sustainability and smart service provider.
CLCE4.0	0 level (smallest size)	Pallet, IRT and CC	A city logistics center is a unimodal or multimodal and synchromodality logistics facility for pallets, IRTs, and city container handling, which is located at the nodal points of the freight logistics networks and provides sustainability and smart services.

4.2. CLNs 4.0 within Megapolis Freight Logistics Networks

The conducted research allowed for the identification and classification of material flows between logistic facilities. Logistics facilities were classified into three groups.

Group 1. Freight transportation in a megalopolis outside the large city, between MLNs4.0, MLNs4.0, MDLHs4.0 or MTLHs4.0, MWTSs, and other recipients of large volumes of freight, is only carried out using intermodal containers [62] and multimodal transport. The delivery of intermodal containers to MDLHs4.0 or MTLHs4.0 is carried out by road, rail, sea, river, or air vehicles [55,57,62].

Group 2. Freight transportation in a large city between CLNs4.0, CLNs4.0, MLNs4.0, MDLHs4.0 or MTLHs4.0, CWTSs, MWTSs, and other recipients of large volumes of freight (for example, CMFM buildings with freight elevators for CC transportation, shopping centers, trade fairs, exhibitions, etc.) is only carried out by CCs [49]. Recipients of medium volumes of freight (where the freight volume is more than an IRT but less than a CC) within the megapolis receive their IRTs from the CC placed in a vehicle, in exchange for loaded or empty IRTs. The recipients of medium volumes of freights also include points for last-mile delivery: shops, postal offices, pick-up points, parcel lockers, and drone delivery servers [72–74]. Recipients of small volumes of freight (where the freight volume is less than an IRT) within the megapolis receive CLNs4.0 by delivery services, couriers, and relocation services, using ground, underground, and air vehicles: bicycles, motorcycles, light e-trucks, subways, and drones [68,72,74].

Group 3. Freight transportation in the central and historical part of a large city and in tourist and recreational areas can also be carried out by CCs, for servicing shopping centers, trade fairs, exhibitions, etc. Despite the absence of CMFM clusters in this part of the smart city, small and medium-sized manufacturing enterprises with sustainable technologies and products operate within it. However, due to the restrictions on the entry of e-trucks and trucks into this green part of the large city, in most cases, freight-transportation bicycles and the individual vehicles of local residents are used [3,75].

Figure 2 shows the megapolis freight logistics networks for ground, underground, or air transportation vehicles and freight flows between CLNs4.0, CLNs4.0 of ATEPs, CWTSs, MLNs4.0, MTLHs4.0, MDLHs4.0, and MWTSs.

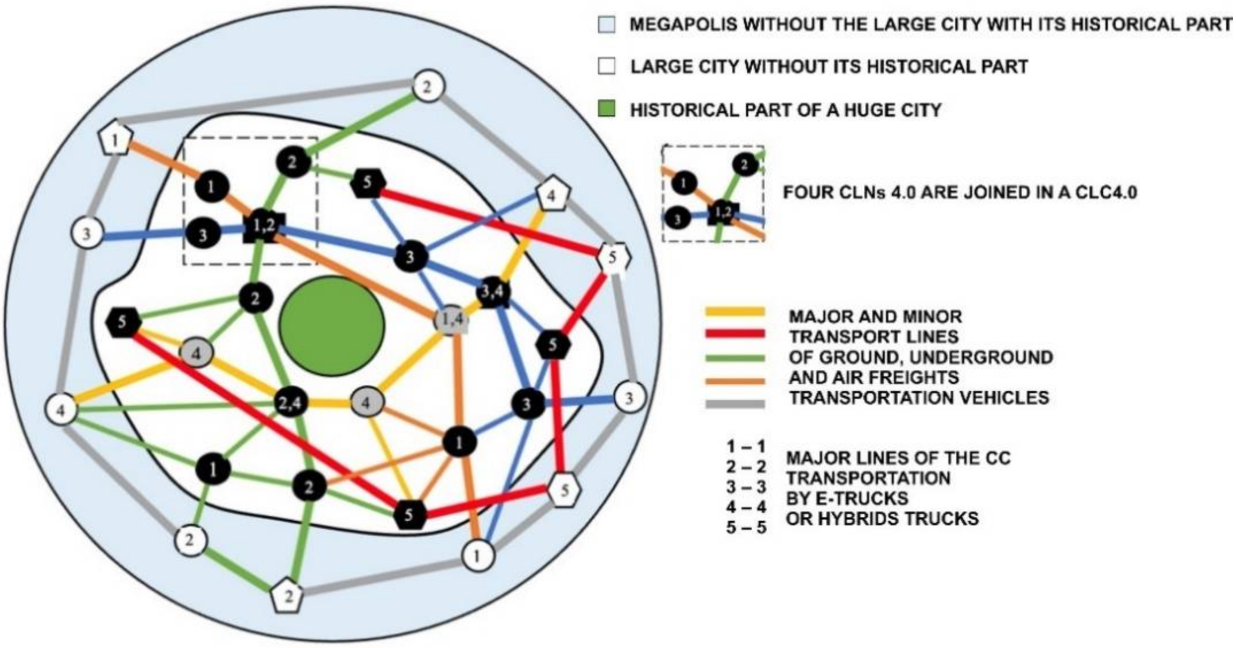

Figure 2. CLNs4.0 within a megapolis freight logistics networks for ground, underground, or air transportation vehicles: freight flows between CLNs4.0, CLNs4.0 of ATEPs, CWTSs, MLNs4.0, MTLHs4.0, MDLHs4.0, and MWTSs.

4.3. The Role of CLN4.0 in the Concept of a Smart City

The analysis of the logistic functions of the megapolises, and of their mutual dependence, showed that the CLN 4.0 is a key logistics facility in the urban structure, in terms of a smart sustainable approach within the framework of the smart city concept.

The CLN4.0 is located in the CMFM cluster area within a large city, outside its historical, central, tourist, and recreational areas, and is usually adjacent to a shopping center with parking, a subway and/or, a local train station [13,56,74]. The CLN4.0 is a nodal point of the megapolis freight logistics networks (Figure 2).

The CLN4.0 is a unimodal or multimodal and synchromodality logistics facility [4,49,76]. Unimodal vehicles, such as light e-trucks, are mainly used for CC transportation [4]. Other types of vehicles can also be used for multimodal transportation of CCs: subways, local trains, and drones [56,72,74].

The CLN 4.0 is a multi-floor building (Figure 3). On the lower operating floors of the CLN4.0 there are enterprises that carry out the acceptance and shipment of the CCs; their unpicking and picking; short-term and long-term storage; the sorting of IRTs and their freights, including separate IRTs and their freights; and the delivery of IRTs and their freights to the shopping center, pick-up points, parcel lockers, and drone delivery servers for the subsequent receipt of goods by customers. The administration of the CMFM cluster, as well as the main and supporting enterprises, is located on the upper floors of the CLN4.0 and performs the role of a lead sustainability and smart service provider; not only within the cluster, but also within the megapolis as a whole [13].

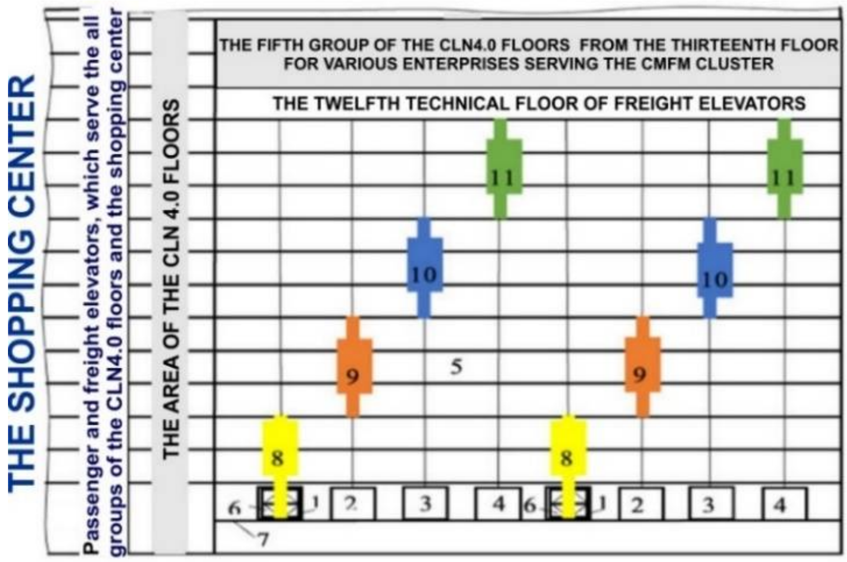

Figure 3. Multi-floor CLN4.0 (front view): 1, 2, 3, 4—freight elevators; 5—multi-floor CLN4.0 building; 6—CCs (multi-IRTs); 7—overpass; 8—the first group of CLNs4.0 floors (highlighted in yellow) from the ground floor to the second floor, which are served by the distributed pair(s) of freight elevators 1; 9—the second group of CLN4.0 floors (highlighted in orange) from the third floor to the fifth, which are served by the distributed pair(s) of freight elevators 2; 10—the third group of CLN4.0 floors (highlighted in blue) from the sixth floor to the eighth, which are served by the distributed pair(s) of freight elevators 3; 11—the fourth group of CLN4.0 floors (highlighted in green) from the ninth floor to the eleventh, which are served by the distributed pair(s) of freight elevators 4.

The freight elevators of the CLN4.0 accept and ship the CCs to the appropriate groups of operating floors, with the possibility of changing them in the case of such a need (Figure 3). The acceptance and shipment of freights in the form of CCs contributes to the increase in the throughput capacity of the CLN 4.0 and the reduction of empty runs of freight elevators [5]. Each group of operating floors of the CLN4.0 can have the same number of freight elevators, and, in this case, loading–unloading operations when servicing vehicles (e-truck) in these groups are carried out without using of takt time. The group of low-level floors have the shortest loading–unloading operations cycle, while the group of high-level floors have the longest loading–unloading operation cycle. It is possible to organize the loading–unloading operations using takt time, by changing the number of freight elevators in the indicated groups of the CLN4.0 operating floors. The loading–unloading operations in the CLN4.0, using takt time and without using takt time, are associated with different approaches to the handling of CCs (Table 2).

Table 2. Organization of loading–unloading operations in the CLN4.0, without using of takt time and using of takt time.

The Organizational Form of Loading–Unloading Operations	The Groups of Operations Floors		
	Lower	Middle	Upper
Without using takt time	Sorting of IRTs	Sorting of IRTs and their freights	Deep sorting of IRTs and their freights
Using takt time	Partial sorting of IRTs	Partial sorting of IRTs	Partial sorting of IRTs

The organization of loading–unloading operations of the CLN4.0 depends on the production type in the CMFM cluster. The operations using takt time are appropriate for mass or large-scale production in the CMFM cluster [38]. With a single, small-, or medium-scale production, the organization of operations without using takt time is performed. Changing the organizational forms of loading–unloading operations in the CLN4.0 (with or without a takt cycle) is possible in a very short period, which increases the flexibility of the servicing cluster enterprises. The widespread use of flexible production, aimed at mass personalization [17,77,78], defines the requirement of organizing loading–unloading operations in a CLN4.0 without a takt. The operating floors of CLN4.0 are equipped with freight elevators for the delivery of CCs and with freight elevators for IRT post-deliveries to the shopping center, pick-up points, parcel lockers, drone delivery servers, couriers, customers, passenger elevators and staircases servicing all floors of the building, and sanitary facilities. The ability to ship freight and goods from the CLN4.0 allows customers to receive products quickly, using individual transport methods (e–transport or bicycles may be preferred). It is also possible to utilize IRT transportation by bicycles using appropriate devices, if the weight of the freight does not exceed the accepted norm.

The operating floors of the CLN4.0 include (Figure 4) the input zone of the CCs; the buffer and unpicking zone for the CCs; the freight sorting zone of the IRTs; the mobile storage for freight distributed in sections, considering the destination or major lines of transportation (Figure 3; and the sorting, picking, and buffer zone for the CCs. IRTs to the CC are also selected considering the compatibility of the transported freights [13,49]. The types of CLN4.0 are as follows (Figure 4): one-sided with a non-direct flow of CCs, two-sided with a direct flow, and two-sided with a non-direct flow. AMRs are also used for the transportation of CCs, IRTs, and the unloading, loading, and sorting of the freight of IRTs and mobile storage [42,75,79]. AMRs not only replace human labor on the operating floors but, also promote SCM within the freight logistics networks, implementing the synchromodality concept.

The main enterprises of the CLN4.0 organize and manage the activities of its operating floors using the DSP of the megapolis server (Figures 4 and 5). The SC planning and SCM in the main enterprises of the CLN4.0 are implemented by the DSP, which connects all the information and logistics facilities of the megalopolis for the implementation of their main activities: handling, information, storage, and transportation, using cutting-edge technologies: CPS, CBDM, CBMH, RFID (Radio-Frequency Identification), Wi-Fi, GPS (Global Positioning System) Systems, IoT, big data and data mining, digitals twins, and blockchain technologies [13,14,31,49]. The key characteristic of the CLN4.0 is its throughput capacity, which defines the size of the CMFM cluster and its operational performance. A common feature of CMFM and logistics facilities is that their finite production capacity, or finite throughput capacity, is defined by the throughput of freight elevators in the case of full handling of the floors. Thus, there is a need to create a finite throughput capacity model of the CLN4.0, considering the fact that freight elevators in a multi-floor building are its bottleneck, the effective use of which is associated with the distribution of the share of full, quasi-full, and partial handling of freight transportation [5].

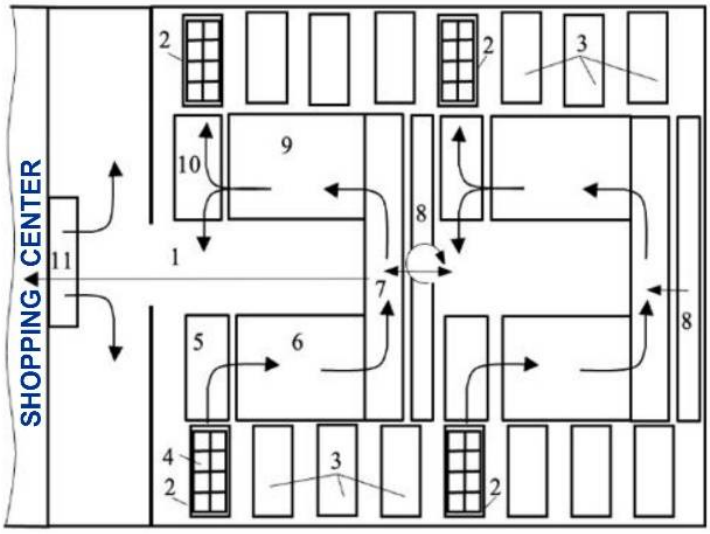

Figure 4. Spatial plan of loading–unloading operations of the CCs on the CLN4.0 floor, with four freight elevators for servicing: 1—operation floor of the CLN4.0, 2—four freight elevators for floor servicing, 3—freight elevators for servicing other floors of CLN4.0, 4—CCs, 5—the input zone of the CCs on the CLN4.0 floor, 6—buffer and unpicking zone of the CCs on the CLN4.0 floor, 7—freight sorting zone of the IRTs on the CLN4.0 floor, 8—mobile storage for freights distributed in sections, 9—sorting, picking, and buffer zone of the CCs on the CLN4.0 floor, 10—output zone of the CCs on the CLN4.0 floor; 11—passenger and freight elevators, which serve all groups of the CLN4.0 floors and shopping center.

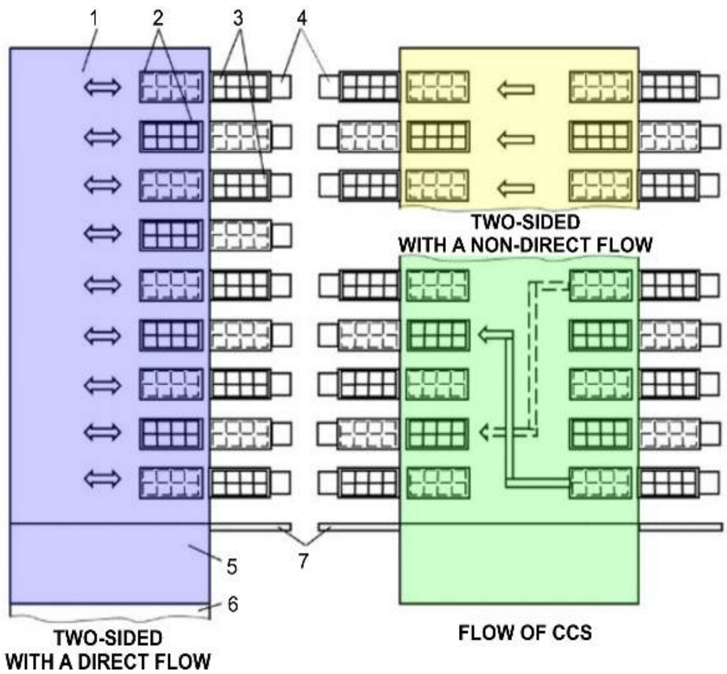

Figure 5. Type of CLN4.0 (top view): 1—CLN4.0, 2 – freight elevators, 3—CCs, 4—e-trucks, 5—area of the CLN4.0 for the placement of sanitary facilities, staircases, and passenger elevators, 6—shopping center with parking, 7—parcel lockers.

4.4. A Finite Throughput Capacity Model of CLN4.0

Information about the operating limitations of a CLN4.0 is based on the development of a finite throughput capacity model. This model allows establishing the production potential of the CMFM cluster and understanding the operating conditions of the CLN4.0, which exclude the possibility of overstocking and overloading under uncertainty, due to a more sustainable and smarter process of operation.

The following assumptions were made for the development of the model:

- It is advisable to measure the finite throughput capacity of the CLN4.0, using the number of CCs per unit of time, for example, an hour, day, month, or year.
- The area of each operation floor of the CLN4.0 is the same.
- The number of floors of the CLN4.0 building for each group of operating floors is determined, without considering the ground floor using Equation (1).
- The finite throughput capacity of each group of the operating floors of the CLN 4.0 is determined by the throughput capacity of their freight elevators [4,49] using Equation (2).
- The throughput efficiency of the CLN's4.0 over a specified period (e.g., month or year) is determined by the throughput capacity utilization indicator, which depends on the proportion of full, quasi-full, and partial handling on operating floors [49] Equation (3).

$$F_k = \sum_{i=1}^{k} F_{O.i} - 1. \quad (1)$$

$$L_{F.i} = \varepsilon_i F_i Q_i / T_{R.i}. \quad (2)$$

$$E_i = \frac{\sum_{i=1}^{k} J_{F.i} + 0.75 J_{Q.i} + 0.5 J_{P.i}}{\sum_{i=1}^{k} J_{F.i} + J_{Q.i} + J_{P.i}} \quad (3)$$

$$L_{F.1} = \frac{E_1 F_{O.1} \varepsilon_1 Q_1}{\lambda_1 [M_{R.1} F_1 (F_1 + 1) + 2K_{EF.1} K_{E.1} (2t_{E.1} + t_{O.1} + t_{C.1})/3600]}; \quad (4)$$

$$L_{F.2} = \frac{E_2 F_{O.2} \varepsilon_2 Q_2}{\lambda_2 M_{R.2} \left[F_2 (F_2 + 1) - F_1 (F_1 + 1)\right]}; \quad (5)$$

$$L_{F.k} = \frac{E_k F_{O.k} \varepsilon_2 \varepsilon_k Q_k}{\lambda_k M_{R.k} \left[F_k (F_k + 1) - F_{k-1} (F_{k-1} + 1)\right]}, \quad (6)$$

were:

$$M_{R.i} = \frac{K_{C.i} f_i}{3600 K_{EFi} K_{E.i} \nu_i}; \quad (7)$$

$$K_{C.i} = 1 + \frac{\nu_i \left[4\lambda_i t_{E.i} + 2\left(2t_{f.i} + t_{o,i} + t_{C.i} + t_{p.i}\right)\right]}{f_i (1 + F_i)}. \quad (8)$$

The throughput capacity of the CLN4.0 is defined using the following equation:

$$L_F = \sum_{i=1}^{k} L_{F.i}. \quad (9)$$

The organizational form of the loading–unloading operations with a takt is achieved by selecting the number of operating floors and freight elevators in each group of operating floors of the CLN4.0, to fulfill the following condition:

$$L_{F.1} \approxeq L_{F.2} \approxeq \ldots \approxeq L_{F.j}. \quad (10)$$

The finite production capacity of the CMFM buildings of the cluster, and their boundaries, can be chosen if the following condition is met:

$$L_F \geq C_F. \quad (11)$$

The finite throughput capacity of the CLN4.0, and the transport fleet to support it, define the input for the implementation of smart sustainable SCM within the CMFM cluster, under uncertainty. The developed model of finite throughput capacity of the CLN4.0, taking into account the used organizational form of loading–unloading operations, allows one to make calculations that define the production capabilities of the CMFM cluster and its size in accordance with the proposed classification [13,49]: up to 15 CCs/h: a small cluster; up to 30 CCs/h: a medium cluster; more than 200 CCs/h: a large cluster. An operational and SCM performance indicator can be used to evaluate the effectiveness of the smart sustainable SCM within the CMFM clusters and megapolis.

The following section presents the recommendations and principles for implementing smart sustainable SCM within the CMFM cluster and megapolis, under uncertainty.

As a case study, consider a one-sided CLN4.0 (Figures 3 and 5) with the following initial data (with a ground floor): f = 3 m; $Q_1 = Q_2 = Q_3 = Q_4 = 1\ CC$; $\lambda_j = 1$; $K_{EF} = 0.9$; $K_E = 0.95$; v = 0.63 m/s; t_E = 60 s; t_f = 2 s; $t_O = t_C$ = 5 s; t_p = 92 s and five options for freight elevators locations and of operation floors:

1. $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_4 = 2$; $F_{O.1} = F_{O.2} = F_{O.3} = F_{O.4} = 3$; Sc 1–7 (Scenario 1–7).
2. $\varepsilon_1 = 1$; $\varepsilon_2 = 3$; $\varepsilon_3 = \varepsilon_4 = 2$; $F_{O.1} = F_{O.2} = F_{O.3} = F_{O.4} = 3$; Sc 1–7 (Scenario 1–7).
3. $\varepsilon_1 = 1$; $\varepsilon_2 = \varepsilon_3 = 2$; $\varepsilon_4 = 3$; $F_{O.1} = F_{O.2} = F_{O.3} = F_{O.4} = 3$; Sc 1–7 (Scenario 1–7).
4. $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_4 = 2$; $F_{O.1} = F_{O.2} = F_{O.3} = F_{O.4} = 2$; Sc 1–7 (Scenario 1–7).
5. $\varepsilon_1 = 1$; $\varepsilon_2 = \varepsilon_3 = 2$; $\varepsilon_4 = 3$; $F_{O.1} = F_{O.2} = F_{O.3} = 2$; $F_{O.4} = 3$; Sc 1–7 (Scenario 1–7).

Seven scenarios for the handling of operating floors of the CLN4.0 are considered [5]: Scenario 1 (Sc 1) involves 100% partial handling of all the operation floors of the CLN4.0, E_i = 0.5; Scenario 2 (Sc 2) involves 60% partial, 20% quasi-full, and 20% full handling of all operation floors of the CLN4.0, E_i = 0.65; Scenario 3 (Sc 3) involves 40% partial, 40% quasi-full, and 20% full handling of all the operation floors of the CLN4.0 E_i = 0.70; Scenario 4 (Sc 4) involves 100% quasi-full handling of all the operation floors of the CLN4.0 E_i = 0.75; Scenario 5 (Sc 5) involves 20% partial, 40% quasi-full, and 40% full handling of all the operation floors of the CLN4.0 E_i = 0.80; Scenario 6 (Sc 6) involves 20% partial, 20% quasi-full, and 60% full handling of all the operation floors of the CLN4.0 E_i = 0.85; Scenario 7 (Sc 7) includes 100% full handling of all the operation floors of the CLN4.0 E_i = 1.0.

Table 3 shows the final throughput of the operating floor groups and the total final throughput of CLN4.0 for the five options of the initial data, taking into account the possible handling scenarios for the operating floors.

Table 3. The finite throughput capacity of groups of operational floors and total finite throughput capacity of CLNs4.0.

Option	F_k	Finite Throughput Capacity of a Group of Operational Floors, CC/h				Finite Throughput Capacity of CLN4.0, CC/h						
		$L_{F.1}$	$L_{F.2}$	$L_{F.3}$	$L_{F.4}$	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7; L_F
1	11	16.5	9.6	8.0	7.2	20.7	26.8	28.9	31.0	33.0	35.1	41.3
2	11	8.3	14.3	8.0	7.2	18.9	24.6	26.5	28.4	30.2	32.1	37.8
3	11	8.3	9.6	8.0	10.8	18.4	23.9	25.7	27.5	29.4	31.2	36.7
4	7	18.8	13.8	12.1	11.3	28.0	36.4	39.2	42.0	44.8	47.6	56.0
5	8	9.9	13.8	12.1	15.4	25.6	33.3	35.8	38.4	41.0	43.5	51.2

The obtained values of the parameters of the final throughput of groups of operating floors and the total final throughput of CLN4.0 allow one to simulate various options with the number of freight elevators and operating floors, so as to implement the necessary organization of the loading–unloading operations. The results obtained in this study show that the finite throughput capacity of a CLN4.0 with a higher number of floors is low. By selecting the number of freight elevators and operating floors in the corresponding groups, it is possible to align the finite throughput capacity of each group of operating floors and implement an organizational form of loading–unloading operations with a takt (Option 3).

Considering the lower finite throughput capacity of the higher operating floors, it is advisable to use them in cases of deep sorting of city containers, IRTs, and their freights. In the first group of operating floors, it is possible to use more operating floors or reduce the number of freight elevators. In addition, the first floor of the first group of operating floors of the CLN4.0 should be used for CCs, IRTs, and their freights, which require longer storage.

The location and number of the groups of operational floors in the CLN4.0, as well as the number of operating floors and freight elevators in each group may vary, depending on logistical needs. It should be noted that relocation of the groups of operating floors within the CLN4.0, all other things being equal, does not affect the calculation of the finite throughput capacity or the CLN4.0 as a whole, but may be useful for its activities. For example, in Option 1 (Table 3), the arrangement of groups of operating floors, in terms of number of floors, is as follows: $F_1 = 2$, $F_2 = 5$, $F_3 = 8$, and $F_4 = 11$. They can be arranged in any other arbitrary order, e.g., $F_1 = 11$, $F_2 = 8$, $F_3 = 5$, and $F_4 =2$ or $F_1 = 5$, $F_2 = 2$, $F_3 = 11$, and $F_4 = 8$.

The analysis of the considered scenarios of CLN4.0 handling shows that one of the main factors for increasing its finite throughput capacity is an increase in the share of full and quasi-full handling of operating floors of the total volume of operations, by increasing the efficiency of SCM. Therefore, the managerial implications of the choice of handling scenarios of operating floors are decisive for the high-throughput capacity of the CLN4.0 operations.

4.5. Managerial Implications

A smart sustainable approach within the CMFM cluster's activities covers a wide range of economic, social, and environmental issues, including the reduction of lead times; overstocking of cluster enterprises and CLN4.0; freight traffic flows under supply uncertainty by the CCs, which are selected in accordance with their delivery points; the compatibility of the transported freights; and their full handling [5,49,80]. The implementation of such a smart sustainable approach in the framework of these problems is associated with the use of integrated production and SC planning and scheduling [81–83] and smart SCM technologies [40,48,76], as well as smart city technologies and indicators for city manufacturing and freight logistics [3,24,46]. Initially, the integrated production and SC planning of the CMFM cluster's enterprises are carried out, considering the compatibility with already planned SCs, both within the cluster and its CLN4.0, and within the megalopolis. Information about planned and actual SCs is available on the DSP of CLNs4.0 and megapolis server in real time. Monitoring of these deliveries through the use of the recording and transmitting devices of IRTs allows one to quickly obtain the necessary information under uncertainty to adjust of SC's plans considering the principles of freight compatibility and full/quasi-full handling [5,49]. The conducted research and the results obtained from the analysis of scenarios 1–7, as well as the literature research, made it possible to formulate recommendations/good practices for sustainable-smart SCM. These recommendations are designed to help managers of CLN4.0 organize smart management, within and outside the CMFM cluster. The most important identified recommendations/good practices are:

- The freight delivery from the manufacturing enterprises located in the CMFM cluster to the recipients should be considered. Similarly, the delivery of freights from external suppliers to the manufacturing enterprises of the CMFM cluster through the CLN4.0 should be carried out [5].
- The distribution of input IRTs in the production enterprises of the CMFM cluster, considering the planned shipments of freight, the determination of a need for additional IRTs, including buffer IRTs, for production lines, and an assurance that their delivery occurs within the required time should be carried out [49].
- RFID tags on shipped freights should be used to automatically identify and track the IRTs, as well as mobile storage of the CLN4.0 to sort and deliver them to the consumer by means of CCs [5,21,46].
- Freights should be certified with registration on a blockchain and recording device in IRTs. Necessary information about the transported freights in the recording/transmitting devices of the IRTs, and sorting and placing them in the IRTs, should be recorded, along with considering the recommendations received in real time from the DSP, in order to simplify their subsequent sorting in the CLN4.0. The sorting and placing of freights in the IRTs can be performed automatically by the AMR [5,42,46].

- The real-time monitoring of the IRT's location using a GPS system by means of video cameras, weight sensors, the IRT's recording/transmitting device, Wi-Fi systems, and drones should be carried out to predict the time of its shipment and for indirect assessment of the freight's condition during its transport [5,47,49]. The received information can be recorded on the blockchain for the information support of smart SCM [84–86]. Blockchain technology promotes economic, social, and environmental sustainability and, in particular, promotes sustainable-smart SCM using IoT technology [48,87,88].
- Information about filling the IRT with freight (finished products or municipal production waste, etc.) should be sent to the DSP before the stage of waiting for its shipment begins. During this period, the buffer IRT should be filled with freight. The freight elevator can then come to unload an IRT with freight and pick up the full IRTs. The time of arrival of the freight elevator to the floor behind the filled IRT can be determined based on the following seven principles [5,49]: the just-in-time principle (there may be a slight deviation from the graphics within the specified limits); the full or quasi-full handling of the production floor of the CMFM building; the shipments of the CCs using of the given takt time; the predetermined location of the IRT in the CC, to facilitate its sorting in the CLN4.0; the compatibility of transported freights in the CC, for example, in terms of temperature parameters (determined based on information about the transported freights from the IRT recording/transmitting device); the uniformity of the IRTs in the CC, to deliver it to the corresponding group of operating floors of the CLN4.0 (for example, for the group of upper operating floors of the CLN4.0, for the deep sorting of IRTs and their freights); the occupancy of CCs with freight in the delivery directions (the selection of a floor from the group of operating floors, on which there are freights in other IRTs or in the mobile storage, to follow the principle of full handling of transported freights) [5,46,49].
- The IRT from the production floor of the CMFM building can be transported by the freight elevator to the ground floor, where a CC is collected and loaded into a light e-truck for delivery to the CLN4.0. The IRT from the production floor of the CMFM building can be transported by the freight elevator to the ground floor, where a CC can be collected and loaded into a light e-truck for delivery to the CLN4.0. At the same time, the CC can be unloaded from the same truck and individual carts can be loaded into the freight elevators in a certain sequence, based on the recommendation of the DSP. The AMRs can also be used to transport and load IRTs on the ground floor of the CMFM building. The freight elevators can read delivery addresses from the IRT recording device and deliver to the corresponding floor of the CMFM building [49]. If the building has freight elevators designed to transport the CC, it is possible to produce large-scale or mass products, using single-floor or multi-floor production lines [38].
- The recommended time of a light e-truck arrival to the CMFM building or CLN4.0, the best route of delivery, and the designated parking place for loading–unloading operations can be sent to the driver or operator of the vehicle from the DSP. The freight vehicle management within the CMFM cluster and the megapolis should be aimed at reducing the need to find parking places outside the buildings and the CLN4.0, guided by the principle of just-in-time, which positively affects urban traffic [3,4].

After loading the CC into the freight elevator of the CLN4.0, it arrives at the operating (or storage) floor, where it is unpacked and sorted by IRTs together with freights from other IRTs, and/or mobile storage, using AMRs and freight identification systems. The sorting of IRTs and their freights and the subsequent selection of the CC are carried out along the delivery lines, with the choice of a destination CLN4.0 (see Figure 4). The CC is then shipped to the appropriate CLN4.0, in compliance with the principle of full handling. In the destination CLN4.0 of the CC, most of the IRTs and their freights are delivered to consumers, through the various channels discussed above. The separate IRTs and their freights, from the received CC, can be resorted at this CLN4.0 and sent to the final CLN4.0

for receipt by consumers. When picking the CC in the source CLN4.0, the possibility of an intermediate CLN4.0 on the route of the CC is assumed [5,13,46].

5. Discussion

In this paper, a novel model of finite throughput capacity of a CLN4.0 serving a CMFM cluster is proposed, which complements the similar already existing models of logistics facilities [13,23,54,65]. The distinctive features of the proposed model are the multi-floor layout of the CLN4.0, with operating floors located on different levels in each of the operating groups, as well as the number of freight elevators and their characteristics, and the efficiency of the vehicles used in various scenarios of loading–unloading operations. The key concepts in the development of a finite throughput model for the CLN4.0 are as follows: (i) the finite throughput capacity of the CLN4.0 should not be less than the actual capacity arising from capacity requirements planning (CRP) for the CMFM cluster; (ii) the multi-floor layout of the CLN4.0 should help increase the finite throughput capacity of the CLN4.0 in the conditions of limited land resources in a megapolis; (iii) the division of the CLN4.0 into groups, with operating floors located on different levels, contributes to a more complete use of the area of the operating floors for the organization of the handling of CCs and freight; (iv) the throughput capacity of the CLN4.0 depends on the throughput and efficiency of use of the freight elevators; (v) the throughput capacity of operating groups of the CLN4.0 can be adjusted to the production needs of the CMFM cluster by changing the number of freight elevators in use, the number of operating floors, and the conditions for CC and freight sorting [13,49]. The methodological criteria for the proposed model rely on certain fundamental principles: the balance of material flows through the operating floors of the CLN4.0, the actual capacity requirement planning (CRP) method of the CMFM cluster, and the use of an efficiency indicator for transport facilities [49,69,70]. The disadvantage of the proposed model is that it does not take into account the material flow through shopping centers, postal offices, pick-up points, parcel lockers, drone delivery servers, parking lots; being an integral part of the city complex, which also includes a CLN4.0.

The adequacy of the proposed model was verified using a case study. The results showed that the throughput capacity of the CLN4.0 also depends on the efficiency of the CCs and freight handling (full and quasi-full freights handling is preferred), addressing the uncertainty of supply and production problems by adopting a smart sustainable approach to SCM, vehicle synchromodality, and using virtual CLCs4.0.

The timely implementation of SCs to support operations in a cluster depends on vehicle synchromodality, which provides 'real-time information management, service flexibility, stakeholders cooperation and coordination, and synchronization of the operations' [76]. The synchromodality also allows for a more efficient use of internal and external vehicles, in terms of reducing their downtime and empty runs, as well as CO_2 emissions [49,76,89]. The implementation of vehicle synchromodality under uncertainty of SCs depends on the planning of logistics operations, the efficiency and smooth functioning of the DSP, and the timeliness of receiving information about the freights and their location from the IRTs in real time. The DSP is a municipal tool that determines, not only the operation of the entire logistics infrastructure of the megapolis, but also the operational management and monitoring of SCs and the assessment of the operations sustainability, etc. The smooth and uninterrupted operation of the platform is one of the main factors affecting the throughput capacity of logistics facilities in the megapolis. The need for CLC4.0 formation is associated with the uneven development of the production and logistics infrastructure of the CMFM clusters and their CLNs4.0, the fixed assets of the production and logistics enterprises of the CMFM clusters, and their workload in accordance with the operational and short-term plan of their activities.t Temporarily formed CLCs4.0 can be represented as virtual logistics facilities. The virtual CLC4.0 is a group of closely located CLNs4.0 that are temporarily inter-connected, to ensure the efficient functioning of their associated production enterprises in the CMFM clusters [49]. The main elements (satellite) of the virtual CLC4.0 are the most loaded CLN4.0, which coordinates business processes associated with the redistribution of SCs through the other auxiliary CLNs4.0. At the same time, auxiliary CLNs4.0 of the CLC4.0 can also participate in other virtual CLCs4.0. The virtual CLC4.0 is created temporarily, based on the mutual business interests of the CLNs4.0, to eliminate emerging bottlenecks in the busiest CLN4.0 of a CMFM cluster. In this case, any busy CLN4.0, regardless of its finite throughput capacity, can become the main element of the CLC4.0.

Based on the conducted research and literature research, it was possible to define the main objectives of the CLC4.0 in various stages of its life cycle in a megapolis. The main objectives of the CLC4.0 are [5,46,49]:

- Reducing the negative impact of the uneven development of the industrial, logistics, and social infrastructure of the metropolis on the activities of CLN4.0.
- The creation of business models for the virtual CLC4.0 allows for the application of new approaches to the design principles of the CMFM clusters and CMFM mega clusters, in order to increase corporate profitability.
- The economic alignment of manufacturing and logistics infrastructure within the megapolis promotes CMFM cluster development.
- The rational distribution of human resources and jobs contributes to an enhancement of the social welfare of the megapolis population.
- A smart sustainable approach in an urban environment improves the management of risk and safety in SCs, increases their flexibility and agility, and promotes the development of environmental responsibility of the personnel, under uncertainty.
- The rational distribution of energy resources within the virtual cluster helps to reduce peak loads on the power grid.
- The load leveling of the CLNs4.0 and freight vehicles within the CLC4.0 contributes to their more efficient use.
- The rational redistribution of freight traffic flows and, as a result, the improvement of urban traffic contributes to the reduction of carbon dioxide emissions and the timely delivery of freight.
- Reduced lead time is a consequence of a decrease in the intensity of cargo turnover in the CLNs4.0.

6. Conclusions

This study focused on the design of a framework for the operations of the CLN4.0, its role as a lead sustainability and smart service provider within a CMFM cluster and megapolis, as well as links to other city logistic facilities from the proposed nomenclature.

A novel model of finite throughput capacity of the CLN4.0 was proposed, considering the framework and the organizational forms of loading–unloading operations, which enable the determination and adjustment of the production potential of the CMFM cluster. The findings provide an insight into the throughput capacity of a multi-floor CLN4.0 and the possibilities of increasing and adjusting this capacity using smart sustainable technologies for SCM. The proposed structure of the CLN4.0 is aimed intensifying its operations in conditions of limited urban land resources and heavy traffic. As a limitation, this paper focuses only on examining the throughput capacity of the CLN4.0, considering its operating framework and SCM based on a smart sustainable approach.

The proposed framework for the CLN4.0 reflects the critical concerns of the adaptation of city logistics facilities in the urban environment, and is the first ever framework to include the assessment of throughput capacity. Recommended good practices for smart sustainable SCM were proposed. However, several key issues were not adequately examined, such as the economic efficiency of operation of the CLN4.0, in view of the predefined TBL assessment criteria [1,22,56] and the material flow from the CLN4.0 through shopping centers, postal offices, pick-up points, parcel lockers, drone delivery servers, and parking lots in the city complex, which are also of interest for further research.

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Nomenclature

I	number of groups of the operating floors of the CLM4.0, i = 1, .., k.
C_F	finite production capacity of the CMFM cluster (CC/h);
Q_i	carrying capacity of the freight elevators of item i (CC);
L_F	finite throughput capacity of the CLN4.0 (CC/h);
$L_{F.i}$	finite throughput capacity of the CLN4.0 of the CMFM cluster of item i (CC/h);
ν_i	rate speed of the freight elevators of item i (m/s);
f_i	inter-floor distance of item i (m);
ε_i	number of freight elevators of item i (unit);
$T_{R.i}$	freight elevator round trip time of item i (h);
$M_{R.i}$	time indicator for the freight elevator operation of item i (h);
$t_{E.i}$	CC loading/unloading time of item i (s);
$t_{f.i}$	single floor flight time, representing the time of acceleration and deceleration of item (s);
$t_{O.i}$	the door opening time of freight elevators of item i (s);
$t_{C.i}$	the door closing time of freight elevators of item i (s);
$t_{p.i}$	the time of the CC picking-unpicking operations of item i (s);
F_i	number of floors of item i;
$F_{O.i}$	number of operating floors of item i;
λ_i	number of the CCs in the freight elevator of item i (unit);
$K_{C.i}$	coefficient of operation time cycle losses for the freight elevators of item i;
$K_{EF.i}$	coefficient of the freight elevator occupancy rate of item i;
$K_{E.i}$	coefficient taking into account the average month downtime of freight elevators falling within their round trip time of item i;
E_i	throughput capacity utilization indicator of the CLN4.0 during a predetermined time period of item i;
$J_{F.i}$	number of cases of the full handling of the operating floors of the CLN4.0 during a predetermined time period of item i;
$J_{Q.i}$	number of cases of the quasi-full handling of the operating floors of the CLN4.0 during a predetermined time period of item i;
$J_{P.i}$	number of cases of the partial handling of the operating floors of the CLN4.0 during a predetermined time period of item i.

References

1. Sarkis, J.; Zhu, Q. Environmental sustainability and production: Taking the road less travelled. *Int. J. Prod. Res.* **2018**, *56*, 743–759. [CrossRef]
2. Kutty, A.; Abdella, G.M.; Kucukvar, M.; Onat, N.C.; Bulu, M. A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations Sustainable Development Goals. *Sustain. Dev.* **2020**, *28*, 1347–1365. [CrossRef]
3. Pan, S.; Zhou, W.; Piramuthu, S.; Giannikas, V.; Chen, C. Smart city for sustainable urban freight logistics. *Int. J. Prod. Res.* **2021**, *59*, 2079–2089. [CrossRef]
4. Wiśnicki, B.; Dzhuguryan, T. Integrated sustainable freight transport system for city multi-floor manufacturing clusters. *Multidiscip. Asp. Prod. Eng.* **2019**, *2*, 151–160. [CrossRef]
5. Dzhuguryan, T.; Deja, A.; Wiśnićki, B.; Jóźwiak, Z. The Design of Sustainable City Multi-Floor Manufacturing Processes under Uncertainty in Supply Chains. *Sustainability* **2020**, *12*, 9439. [CrossRef]
6. Rauch, E.; Ciano, M.P.; Matt, D.T. Distributed manufacturing network models of smart and agile mini-factories. *Int. J. Agil. Syst. Manag.* **2017**, *10*, 185. [CrossRef]

7. Tiep, N.C.; Oanh, T.T.K.; Thuan, T.D.; Tien, D.V.; Ha, T.V. Industry 4.0, lean management and organizational support: A case of supply chain operations. *Pol. J. Manag. Stud.* **2020**, *22*, 583–594. [CrossRef]
8. Tutak, M.; Brodny, J.; Siwiec, D.; Ulewicz, R.; Bindzár, P. Studying the level of sustainable energy development of the European union countries and their similarity based on the economic and demographic potential. *Energies* **2020**, *13*, 6643. [CrossRef]
9. Ulewicz, R.; Siwiec, D.; Pacana, A.; Tutak, M.; Brodny, J. Multi-criteria method for the selection of renewable energy sources in the polish industrial sector. *Energies* **2021**, *14*, 2386. [CrossRef]
10. Dzhuguryan, T.; Jóźwiak, Z. Specific Approach to Assessment of Technologies for Multi-Floor Manufacturing System. *Autobusy Tech. Eksploat. Syst. Transp.* **2017**, *6*, 1656–1659.
11. Dzhuguryan, T.; Wiśnicki, B.; Jóźwiak, Z. Modular Loading Units for Facilitating Multi-Floor Manufacturing and City Logistics. *Sci. J. Marit. Univ. Szczec.* **2018**, *55*, 73–78.
12. Ghobakhloo, M. Industry 4.0, digitization, and opportunities for sustainability. *J. Clean. Prod.* **2020**, *252*, 119869. [CrossRef]
13. Dzhuguryan, T.; Jóźwiak, Z.; Deja, A.; Semenova, A. Infrastructure and Functions of a City Logistics Node for Multi-Floor Manufacturing Cluster. In Proceedings of the 8th International Scientific Conference CMDTUR 2018, Žilina, Slovakia, 4–5 October 2018; pp. 196–201.
14. Yavas, V.; Ozkan-Ozen, Y.D. Logistics centers in the new industrial era: A proposed framework for logistics center 4.0. *Transp. Res. Part E* **2020**, *135*, 101864. [CrossRef]
15. Zhang, G.; Chen, C.-H.; Zheng, P.; Ray YZhong, R.Y. An integrated framework for active discovery and optimal allocation of smart manufacturing services. *J. Clean. Prod.* **2020**, *273*, 123144. [CrossRef]
16. Jabbour, A.B.L.D.S.; Jabbour, C.J.C.; Foropon, C.; Filho, M.G. When titans meet—Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. *Technol. Soc. Chang.* **2018**, *132*, 18–25. [CrossRef]
17. Hyers, D. Big data-driven decision-making processes, Industry 4.0 wireless networks, and digitized mass production in cyber-physical system-based smart factories. *Econ. Manag. Financ. Mark.* **2020**, *15*, 19–28. [CrossRef]
18. Abubakr, M.; Abbas, A.T.; Tomaz, I.; Soliman, M.S.; Luqman, M.; Hegab, H. Sustainable and Smart Manufacturing: An Integrated Approach. *Sustainability* **2020**, *12*, 2280. [CrossRef]
19. Andronie, M.; Lăzăroiu, G.; Ștefănescu, R.; Uță, C.; Dijmărescu, I. Sustainable, Smart, and Sensing Technologies for Cyber-Physical Manufacturing Systems: A Systematic Literature Review. *Sustainability* **2021**, *13*, 5495. [CrossRef]
20. Ingaldi, M.; Ulewicz, R. Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector. *Sustainability* **2020**, *12*, 217. [CrossRef]
21. Ullah, M.; Sarkar, B. Smart and sustainable supply chain management: A proposal to use RFID to improve electronic waste management. In Proceedings of the International Conference on Computers and Industrial Engineering, Auckland, New Zealand, 2–5 December 2018; pp. 1–15.
22. Jemai, J.; Chung, B.D.; Sarkar, B. Environmental effect for a complex green supply-chain management to control waste: A sustainable approach. *J. Clean. Prod.* **2020**, *277*, 122919. [CrossRef]
23. Nantee, N.; Sureeyatanapas, P. The impact of Logistics 4.0 on corporate sustainability: A performance assessment of automated warehouse operations. *Benchmarking Int. J.* **2021**, *28*, 2865–2895. [CrossRef]
24. Sharifi, A. A typology of smart city assessment tools and indicator sets. *Sustain. Cities Soc.* **2020**, *53*, 101936. [CrossRef]
25. Frazzon, E.M.; Agostino, I.R.S.; Broda, E.; Freitag, M. Manufacturing networks in the era of digital production and operations: A socio-cyber-physical perspective. *Annu. Rev. Control.* **2020**, *49*, 288–294. [CrossRef]
26. Kusiak, A. Smart manufacturing. *Int. J. Prod. Res.* **2018**, *56*, 508–517. [CrossRef]
27. Ivanov, D.; Dolgui, A.; Sokolov, B. The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *Int. J. Prod. Res.* **2019**, *57*, 829–846. [CrossRef]
28. Nica, E. Urban Big Data analytics and sustainable governance networks in integrated smart city planning and management. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 93–106. [CrossRef]
29. Ulewicz, R.; Jelonek, D.; Mazur, M. Implementation of logic flow in planning and production control. *Manag. Prod. Eng. Rev.* **2016**, *7*, 89–94. [CrossRef]
30. Keane, E.; Zvarikova, K.; Rowland, Z. Cognitive automation, big data-driven manufacturing, and sustainable industrial value creation in Internet of Things-based real-time production logistics. *Econ. Manag. Financ. Mark.* **2020**, *15*, 39–48. [CrossRef]
31. Sgarbossa, F.; Peron, M.; Fragapane, G. Cloud Material Handling Systems: Conceptual Model and Cloud-Based Scheduling of Handling Activities. In *Scheduling in Industry 4.0 and Cloud Manufacturing*; International Series in Operations Research & Management, Science; Sokolov, B., Ivanov, D., Dolgui, A., Eds.; Springer: Cham, Switzerland, 2020; Volume 289, pp. 87–101. [CrossRef]
32. Nica, E.; Stan, C.I.; Luțan (Petre), A.C.; Oașa (Geambazi), R.-Ș. Internet of Things-based Real-Time Production Logistics, Sustainable Industrial Value Creation, and Artificial Intelligence-driven Big Data Analytics in Cyber-Physical Smart Manufacturing Systems. *Econ. Manag. Financ. Mark.* **2021**, *16*, 52–62. [CrossRef]
33. Cohen, S.; Macek, J. Cyber-physical process monitoring systems, real-time big data analytics, and industrial artificial intelligence in sustainable smart manufacturing. *Econ. Manag. Financ. Mark.* **2021**, *16*, 55–67. [CrossRef]

34. Durana, P.; Perkins, N.; Valaskova, K. Artificial Intelligence Data-driven Internet of Things Systems, Real-Time Advanced Analytics, and Cyber-Physical Production Networks in Sustainable Smart Manufacturing. *Econ. Manag. Financ. Mark.* **2021**, *16*, 20–30. [CrossRef]
35. Kovacova, M.; Lewis, E. Smart Factory Performance, Cognitive Automation, and Industrial Big Data Analytics in Sustainable Manufacturing Internet of Things. *J. Self-Gov. Manag. Econ.* **2021**, *9*, 9–21. [CrossRef]
36. Dzhuguryan, T.; Jóźwiak, Z. Infrastructure for Multi-Floor Virtual Enterprises System. *Syst. Wspomagania W Inżynierii Prod.* **2016**, *3*, 70–78.
37. Dudek, T.; Dzhuguryan, T.; Lemke, J. Sustainable production network design for city multi-floor manufacturing cluster. *Procedia Comput. Sci.* **2019**, *159*, 2081–2090. [CrossRef]
38. Dzhuguryan, T.; Jóźwiak, Z. The transport providing of works of the multi-floor flexible production line. *Autobusy: Tech. Eksploat. Syst. Transp.* **2016**, *6*, 1311–1314.
39. Wallace, S.; Lăzăroiu, G. Predictive Control Algorithms, Real-World Connected Vehicle Data, and Smart Mobility Technologies in Intelligent Transportation Planning and Engineering. *Contemp. Read. Law Soc. Justice* **2021**, *13*, 79–92. [CrossRef]
40. Blackburn, E.; Pera, A. Autonomous Vehicle Interaction Control Software, Big Geospatial Data Analytics, and Networked Driverless Technologies in Smart Sustainable Urban Transport Systems. *Contemp. Read. Law Soc. Justice* **2021**, *13*, 121–134. [CrossRef]
41. Shaoa, X.-F.; Liu, W.; Lia, Y.; Chaudhry, H.R.; Yuec, X.-G. Multistage implementation framework for smart supply chain management under industry 4.0. *Technol. Forecast. Soc. Chang.* **2021**, *162*, 120354. [CrossRef] [PubMed]
42. Fragapane, G.; De Koster, R.; Sgarbossa, F.; Strandhagen, J.O. Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. *Eur. J. Oper. Res.* **2021**, *294*, 405–426. [CrossRef]
43. Dzhuguryan, T.; Wiśnicki, B.; Dudek, T. Concept of Intelligent Reconfigurable Trolleys for City Multi-Floor Manufacturing and Logistics System. In Proceedings of the 8th Carpathian Logistics Congress (CLC2018), Prague, Czech Republic, 3–5 December 2018; pp. 254–259.
44. Barenji, A.V.; Wang, W.M.; Li, Z.; Guerra-Zubiaga, D.A. Intelligent E-Commerce Logistics Platform Using Hybrid Agent Based Approach. *Transp. Res. Part E-Logist. Transp. Rev.* **2019**, *126*, 15–31. [CrossRef]
45. Crainic, T.G.; Montreuil, B. Physical internet enabled Hyperconnected City logistics. *Transp. Res. Procedia* **2016**, *12*, 383–398. [CrossRef]
46. Qi, L.; Guo, J. Development of smart city community service integrated management platform. *Int. J. Distrib. Sens. Netw.* **2019**, *15*, 64. [CrossRef]
47. Burke, S.; Zvarikova, K. Urban Internet of Things Systems and Data Monitoring Algorithms in Smart and Environmentally Sustainable Cities. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 135–148. [CrossRef]
48. Lăzăroiu, G.; Harrison, A. Internet of Things Sensing Infrastructures and Data-driven Planning Technologies in Smart Sustainable City Governance and Management. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 23–36. [CrossRef]
49. Dzhuguryan, T.; Deja, A. Sustainable waste management for a city multifloor manufacturing cluster: A framework for designing a smart supply chain. *Sustainability* **2021**, *13*, 1540. [CrossRef]
50. Khaksar-Haghani, F.; Kia, R.; Mahdavi, I.; Javadian, N.; Kazemi, M. Multi-floor layout design of cellular manufacturing systems. *Int. J. Manag. Sci. Eng. Manag.* **2011**, *6*, 356–365. [CrossRef]
51. Fechner, I. Location conditionings of logistics centers as central units of national logistics network. *Logist. Transp.* **2011**, *1*, 23–32.
52. Campbell, J.F.; O'Kelly, M.E. Twenty-Five Years of Hub Location Research. *Transp. Sci.* **2012**, *46*, 153–169. [CrossRef]
53. Rao, C.; Goh, M.; Zhao, Y.; Zheng, J. Location selection of city logistics centers under sustainability. *Transp. Res. Part D* **2015**, *36*, 29–44. [CrossRef]
54. Farahani, R.Z.; Hekmatfar, M.; Arabani, A.B.; Nikbakhsh, E. Hub location problems: A review of models, classification, solution techniques, and applications. *Comput. Ind. Eng.* **2013**, *64*, 1096–1109. [CrossRef]
55. Essaadi, I.; Grabot, B.; Fénies, P. Location of logistics hubs at national and subnational level with consideration of the structure of the location choice. *IFAC-PapersOnLine* **2016**, *49*, 155–160. [CrossRef]
56. Zhao, L.; Li, H.; Li, M.; Sun, Y.; Hu, Q.; Mao, S.; Li, J.; Xue, J. Location selection of intra-city distribution hubs in the metro-integrated logistics system. *Tunn. Undergr. Space Technol.* **2018**, *80*, 246–256. [CrossRef]
57. Vieira, C.L.S.; Luna, M.M.M. Models and methods for logistics hub location: A review towards transportation networks design. *Pesqui. Oper.* **2016**, *36*, 375–397. [CrossRef]
58. Rimienė, K.; Grundey, D. Logistics Centre Concept through Evolution and Definition. *Eng. Econ.* **2007**, *4*, 87–95.
59. Barreto, L.; Amaral, A.; Pereira, T. Industry 4.0 implications in logistics: An overview. *Procedia Manuf.* **2017**, *13*, 1245–1252. [CrossRef]
60. Szymańska, O.; Adamczak, M.; Cyplik, P. Logistics 4.0—A New Paradigm or Set of Known Solutions? *Res. Logist. Prod.* **2017**, *7*, 299–310. [CrossRef]
61. Higgins, C.; Ferguson, M.; Kanaroglou, P. Varieties of logistics centers: Developing standardized typology and hierarchy. *Transp. Res. Rec. J. Transp. Res. Board* **2012**, *2288*, 9–18. [CrossRef]
62. Huber, S.; Klauenberg, J.; Thaller, C. Consideration of transport logistics hubs in freight transport demand models. *Eur. Transp. Res. Rev.* **2015**, *7*, 32. [CrossRef]

63. Yang, C.; Lan, S.; Lin, T.; Wang, L.; Zhuang, Z.; Huang, G.Q. Transforming Hong Kong's warehousing industry with a novel business model: A game-theory analysis. *Robot. Comput.-Integr. Manuf.* **2021**, *68*, 102073. [CrossRef]
64. Cho, G.S. A study on establishment of smart logistics center based on logistics 4.0. *J. Multimed. Informat. Syst.* **2018**, *5*, 265–272. [CrossRef]
65. Ishizaka, A.; Khan, S.A.; Simonov Kusi-Sarpong, S.; Naim, I. Sustainable warehouse evaluation with AHPSort traffic light visualisation and post-optimal analysis method. *J. Oper. Res. Soc.* **2020**. [CrossRef]
66. Montwiłł, A.; Pietrzak, O.; Pietrzak, K. The role of Integrated Logistics Centers (ILCs) in modelling the flows of goods in urban areas based on the example of Italy. *Sustain. Cities Soc.* **2021**, *69*, 102851. [CrossRef]
67. Dembińska, I. Smart logistics in the evolution of the logistics. *Eur. J. Serv. Manag.* **2018**, *3*, 123–133. [CrossRef]
68. Gruchmann, T.; Melkonyan, A.; Krumme, K. Logistics business transformation for sustainability: Assessing the role of the lead sustainability service provider (6PL). *Logistics* **2018**, *2*, 25. [CrossRef]
69. Allesch, A.; Brunner, P.H. Material Flow Analysis as a Decision Support Tool for Waste Management: A Literature Review. *J. Ind. Ecol.* **2015**, *19*, 753–764. [CrossRef]
70. Jodlbauer, H.; Reitner, S. Material and capacity requirements planning with dynamic lead times. *Int. J. Prod. Res.* **2012**, *50*, 4477–4492. [CrossRef]
71. Deja, A.; Dzhuguryan, T. Environmental Sustainable Waste Management for a City Multi-Floor Manufacturing Cluster. *Syst. Safety Hum. Tech. Facil. Environ.* **2019**, *1*, 457–464. [CrossRef]
72. Park, J.; Kim, S.; Suh, K. A Comparative Analysis of the Environmental Benefits of Drone-Based Delivery Services in Urban and Rural Areas. *Sustainability* **2018**, *10*, 888. [CrossRef]
73. Wagner, N.; Strulak-Wójcikiewicz, R. Exploring opportunities of using the sharing economy in sustainable urban freight transport. *Sustain. Cities Soc.* **2021**, *68*, 2–11.
74. Lesmini, L.; Rahmat Hidayat, R.D.; Firdaus, M.I.; Liew, J.K. The role of railway integrated distribution centers in industrial zones to improve logistics competitiveness. In Proceedings of the Conference on Global Research on Sustainable Transport (GROST 2017), Jakarta, Indonesia, 22–23 November 2017. [CrossRef]
75. Bechtsis, D.; Tsolakis, N.; Vlachos, D.; Srai, J.S. Intelligent Autonomous Vehicles in digital supply chains: A framework for integrating innovations towards sustainable value networks. *J. Clean. Prod.* **2018**, *181*, 60–71. [CrossRef]
76. Giusti, R.; Manerba, D.; Tadei, R. Smart Steaming: A New Flexible Paradigm for Synchromodal Logistics. *Sustainability* **2021**, *13*, 4635. [CrossRef]
77. Wang, F.; Shang, X.; Qin, R.; Xiong, G.; Nyberg, T.R. Social Manufacturing: A Paradigm Shift for Smart Prosumers in the Era of Societies 5.0. *IEEE Trans Comp. Social Syst.* **2019**, *6*, 822–829. [CrossRef]
78. Wang, Y.; Ma, H.-S.; Yang, J.-H.; Wang, K. Industry 4.0: A way from mass customization to mass personalization production. *Adv. Manuf.* **2017**, *5*, 311–320. [CrossRef]
79. Fragapane, G.; Ivanov, D.; Peron, M.; Sgarbossa, F.; Strandhagen, J.O. Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. *Ann. Oper. Res.* **2020**, 1–19. [CrossRef]
80. Dadi VNikhil, S.R.; Mor, R.S.; Agarwal, T.; Arora, S. Agri-Food 4.0 and Innovations: Revamping the Supply Chain Operations. *Prod. Eng. Arch.* **2021**, *27*, 75–89. [CrossRef]
81. Bilotta, E.; Bertacchini, F.; Gabriele, L.; Giglio, S.; Pantano, P.S.; Romita, T. Industry 4.0 technologies in tourism education: Nurturing students to think with technology, Journal of Hospitality. *Leis. Sport Tour. Educ.* **2020**, *29*, 100275. [CrossRef]
82. Touzout, F.A.; Benyoucef, L. Multi-objective sustainable process plan generation in a reconfigurable manufacturing environment: Exact and adapted evolutionary approaches. *Int. J. Prod. Res.* **2018**, *57*, 2531–2547. [CrossRef]
83. Krynke, M. Management optimizing the costs and duration time of the process in the production system. *Prod. Eng. Arch.* **2021**, *27*, 163–170. [CrossRef]
84. Issaoui, Y.; Khiat, A.; Bahnasse, A.; Ouajji, H. Smart Logistics: Blockchain Trends and Applications. *J. Ubiquitous Syst. Pervasive Netw.* **2020**, *12*, 9–15. [CrossRef]
85. Dolgui, A.; Ivanov, D.; Potryasaev, S.; Sokolov, B.; Ivanova, M.; Werner, F. Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain. *Int. J. Prod. Res.* **2019**, *58*, 2184–2199. [CrossRef]
86. Zhao, J.; Ji, M.; Feng, B. Smarter supply chain: A literature review and practices. *J. Data Inf. Manag.* **2020**, *2*, 95–110. [CrossRef]
87. Esmaeilian, B.; Sarkis, J.; Lewis, K.; Behdad, S. Blockchain for the future of sustainable supply chain management in Industry 4.0. Resources. *Conserv. Recycl.* **2020**, *163*, 105064. [CrossRef]
88. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain technology and its relationships to sustainable supply chain management. *Int. J. Prod. Res.* **2019**, *57*, 2117–2135. [CrossRef]
89. Wang, J.; Lim, M.K.; Tseng, M.-L.; Yang, Y. Promoting low carbon agenda in the urban logistics network distribution system. *J. Clean. Prod.* **2019**, *211*, 146–160. [CrossRef]