

Logistics of smart cities

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Abstract

Growing economic, sociopolitical, and environmental challenges encourage or force cities, their administrations, companies, and population to review existing and rethink new ways of functioning of urban environments, lifestyles, business models and processes, supply and reverse logistics systems, etc. Efforts to overcome such challenges and improve the quality of life in the city gave rise to the concept of smart cities, which implies the application of various innovative solutions, concepts, and technologies in urban areas. Given that logistics represents one of the most important functions of cities, a smart city also implies smart city logistics, and smart city logistics is the implementation of logistics flows and operations using smart technologies and processes. Improving efficiency, increasing visual attractiveness, reducing the costs and negative environmental impacts caused by logistics processes and activities is achieved by applying technologies such as the Internet of Things, artificial intelligence, blockchain, cloud computing, autonomous vehicles, etc. In this paper, various possibilities, advantages and challenges of applying the mentioned and other technologies in certain activities, subsystems, and aspects of city logistics are analyzed.

Keywords: Smart city, City logistics, Smart technologies, Industry 4.0

1 Introduction

Today's time is marked by smartphones, smart watches, smart cars, and even smart cities and smart logistics. The term "smart" indicates that the entities it describes have the ability to intelligently, efficiently, and purposefully implement various processes. With it, through the projection of advanced human cognitive features, a kind of personification of those entities is carried out. Therefore, man is the "measure of all things" and in the creation of language, perhaps precisely because the goals of various smart concepts are aimed at man, his environment, and activities.

Logistics is one of the most important functions of cities since it enables all other urban functions [1], [2]. Therefore, an indispensable element of a smart city is smart city logistics. Moreover, it is the basis for its development [3]. On the other hand, it is not possible to achieve the goals of smart logistics without optimizing other components and aspects of the smart city concept. Achieving the goals of smart cities and smart

logistics requires logical, innovative, and technologically advanced planning, design and functioning of urban systems and processes. Advanced, smart technologies that are the carriers of Industry 4.0 play an essential role in achieving these goals.

The literature discusses the application of various smart technologies in city logistics: internet of things [4], autonomous vehicles [5], drones [6], artificial intelligence [7], big data [8], blockchain [9], cloud computing [10], 3D printing [11], etc. Taniguchi et al. [12] modeled city logistics in the context of the application of some innovative technologies. Evaluations of city logistics concepts based on some smart technologies were also performed [13], [14]. Although the applicability of smart, i.e., Industry 4.0 technologies in logistics [15], i.e., some of its areas: logistics centers [16], return logistics [17], home delivery [18], etc., has been discussed so far, a comprehensive analysis of the application of these technologies in city logistics has not yet been completed. So far, the most comprehensive research in this direction was carried out by

Büyüközkan & Ilıcak [19]. However, although it contains an extensive review of the relevant literature, this paper does not sufficiently thoroughly describe the areas, methods, experiences, and perspectives of the application of certain technologies in city logistics.

This paper provides a comprehensive overview and description of the current and potential application of smart technologies in city logistics. This achieved the main goal and contribution of the paper.

The paper is organized as follows. After the introduction, the second section describes the concepts of smart city and smart logistics. In the third section, the application of smart technologies in city logistics is analyzed. At the end, concluding considerations and directions for future research are given.

2 Smart city and smart logistics concepts

There are numerous definitions of smart cities. According to Angelido [20], smart cities represent a conceptual model of urban development based on the use of human, collective, and technological capital to promote development and prosperity in urban agglomerations. According to Komninos [21], smart cities are territories with a high capacity for learning and innovation, which is embedded in the creativity of their population, institutions for education and research, and digital infrastructure for communication and knowledge management. However, no definition is generally accepted, which leaves room for changes and expansions in the understanding and meaning of the term. The architecture of smart cities consists of [22]: users, services, infrastructure, and data. The components of a smart city and the aspects of urban life with which they are connected are [23]: smart economy (economy, industry), smart people (education), smart governance (e-democracy), smart mobility (logistics and infrastructure), smart environment (efficiency and sustainability), smart living (safety and quality).

With the increase in the number of large cities and the number of inhabitants, the number and volume of streams in urban areas and the complexity of their planning, organization, and performing are increasing. Given that it is necessary to ensure the efficient implementation of passenger, as well as logistics flows of goods, materials, and cargo, research and solutions in the areas of urban mobility and city logistics play an

increasingly important role, especially in the context of the development of smart cities. A smart city also requires smart logistics. Analogous to smart cities, the concept of smart logistics can be understood and interpreted in different ways. However, in most definitions it is stated that it is based on the application of (new) technologies (e.g. [24], [25]). Smart logistics means planning, managing, and controlling logistics operations in a more intelligent way than in the case of conventional solutions [26]. It represents an effective way to respond to the challenges of rapidly changing customer expectations, take advantage of the opportunities brought by new technologies and enable new business models. Although the basic characteristics of smart logistics can be viewed in other ways, Uckelmann [24] points out that some of the most important are: it includes smart services and smart products, it is based on technology and therefore subject to change, it frees people from (control) activities that can delegate to smart products and services, transparency, connectivity (communicates and possibly interacts with its environment), enables state-of-the-art data processing, integrates existing logistics technologies and enables them to react and act appropriately, includes state-of-the-art invoicing, payment or licensing as an integral component. Likewise, the functions of smart logistics may be different, but Song et al. [25] see as basic: sensing/perception/detection, i.e. information gathering, data integration and standardization, intelligent problem analysis, optimization decision-making, system support, automatic error correction and timely feedback.

3 Application of smart technologies in city logistics

Taniguchi and Thompson [27] state that intelligent transportation systems, information and communication technologies, the Internet of Things, big data technologies, and artificial intelligence are key technologies for performing the goals of smart logistics. In addition to these technologies, Song et al. [25] also emphasize the importance of cloud computing. However, numerous other technologies can also be significant for achieving the goals of smart cities and smart logistics: blockchain, augmented reality, autonomous and automated guided vehicles, drones, 3D printing, etc. These solutions are applied both in the processes of goods delivery [18], [28], [29], and in operations in logistics centers [15], [16], [30].

Internet of Things (IoT) is a communication paradigm that assumes that various objects are equipped with microcontrollers, transceivers for digital communication and the appropriate protocol, which allows them to communicate with each other and with users, becoming an integral part of the Internet [31], [32]. The goal of IoT is to connect everything and everyone, anytime and anywhere [33]. IoT technology is most widely applied in the logistics system [26], and in all its subsystems [15]: ordering [34], transportation [35], storage [36], inventory management [37] and packaging [38]. In this sense, it has a significant role in city logistics, as well as the potential for further application, especially in combination with other technologies such as big data technologies, blockchain, GPS and TMS, autonomous vehicles, etc. Some of the areas and ways of applying IoT in city logistics are: route planning [39], tracking of drivers, vehicles [40], [41], cargo status and/or environmental conditions in real time (e.g. temperature, humidity, etc.) [42], [43] (real-time track and trace), delivery assurance [44], virtual user addressing [45], connection of CDPs (collection and delivery points) with the system of the company making the delivery [46] etc.

One of the technologies applied in integration with IoT is **cloud computing (CC)** [40]. CC implies broad and readily available access to a network that enables the use of shared computing resources (e.g. servers, storage capacities, applications, services, software, etc.) that can be quickly occupied and released with minimal involvement of service providers [47]. The key characteristics of CC are [25]: service provision on user demand, wide network access, pooling of resources, system elasticity and measurable service. There is a great potential for applying CC in city logistics, especially transport. The CC concept provides a unique opportunity to design city logistics infrastructure so that it can be easily adapted to changing transport requirements [10]. CC provides the possibility of using various IT (information technology) services via the Internet, whereby users do not have to manage hardware and software (Transport Management System, Warehouse Management System, Enterprise Resource Planning, etc.), but acquire them on demand and then pay. The application of CC in city logistics enables the integration and sharing of resources, as well as improving the efficiency of the logistics system and the quality of services [25].

Big data is the process of collecting a large amount of data from heterogeneous and autonomous sources, with distributed and decentralized control, to find complex and changing connections between them [48]. Ghosh [49] identified logistics as one of the main areas of application of big data. It is applied in all subsystems of logistics, i.e. wherever data can be collected that can be used to improve logistics services [15]. Big data is increasingly applied in city logistics, for demand forecasting, predictive maintenance of equipment and vehicles, risk management in the supply chain, etc. [25], [50], and it is of particular importance in the performing of the last mile, where it is used in the optimization of delivery real time vehicle routing, as well as in the processes of planning and performing of crowd delivery [18].

Blockchain is a computer technology that represents a record of transactions, which are performed and recorded in a decentralized manner. Transactions are recorded in blocks, which form a linear, chronologically ordered chain. The functioning of the blockchain technology is based on the consensus of the participants in the computer network on the performing of transactions and editing of the blockchain. The blockchain is constantly growing, because none of the recorded transactions can be modified or deleted. Transactions are confirmed by nodes, i.e. computers in the network that own a copy of the chain. Once a record of a new transaction is verified and added to the blockchain, multiple copies are created in a decentralized manner to create a chain of trust [51]. The goal of blockchain technology is to provide users with anonymity, security, privacy, transparency, and data integrity [52]. Blockchain technology can be applied in all subsystems of logistics in the city, but for now it is applied in the following areas: document processing and supply chain management [15], goods data collection and security monitoring [42], delivery assurance [44], horizontal carrier cooperation in the context of micro-hubs [53], etc.

Artificial intelligence (AI) in the broadest sense implies the ability of a computer to perform tasks that are usually performed by intelligent beings, primarily perception, reasoning, problem solving, learning and communication [54]. It can be used in various areas of city logistics [15], [18]: order processing, performing of transshipment operations, storage/warehousing, locating/allocating goods and handling

equipment, loading and unloading transport units/means, order picking, management, and control of warehouse processes, demand forecasting, inventory level optimization, goods and vehicle status tracking in fleet management systems, vehicle routing, vehicle navigation, delivery time forecasting, driving skills improvement, transportation safety, etc. AI methods, such as artificial neural networks, genetic algorithms, simulated annealing, artificial immune system, the ant colony optimiser, bee colony optimization, and the fuzzy logic model, have a special importance in reforming and redefining urban transport (for vehicles, infrastructure, drivers, users, etc.) [55].

Augmented reality (AR) is a combination of the physical and digital world, i.e. the addition of virtual elements, objects or information to the physical world in real time [56]. There is great potential for the application of this technology in city logistics, both in logistics centers and in the processes of goods delivery. It can be applied in the reception, storage, order picking, and dispatch of goods in logistics centers [56], warehouse planning [57], and work related to documentation. It can contribute to the efficiency of transport and other distribution operations, providing, if necessary, visibility to the driver of additional information about the drive (speed, time, navigation, etc.), the goods (type of goods, weight, specific logistics requirements, etc.), and the customer (address, security identification of the person etc.).

In recent years, **automated guided vehicles (AGVs), autonomous vehicles (AVs), and drones** have played a more significant role in city logistics. Their application is particularly significant in last-mile delivery and home delivery, but they can also be used for operations in logistics centers. AGVs are remotely controlled or self-driving vehicles following a predefined path, using radio waves, cameras, magnets, lasers, etc. for guidance. [58]. AGVs are predominantly used in logistics centers in storage, transshipment, and internal transport subsystems [15]. In home delivery, AGVs with lockers can be used, which receive goods at the initial location and transport them to locations near the user [59]. AVs are adaptive and self-learning vehicles that are capable of "sensing" the environment and navigating it safely with little or no human assistance [60]. They can independently carry out a complete delivery to a home address or be an auxiliary tool when walking the delivery person

in the "last yard" of the delivery [28]. Drones are one of the most promising technologies for application in city logistics. There are numerous possibilities (deliveries to users, application in logistics centers) and advantages (independence from transport infrastructure, speed, economy, etc.), but also barriers in the application of drones in city logistics, which need to be overcome in the future [61], [62].

3D printing involves the production of three-dimensional objects by adding multiple layers of material based on virtual representations. Campbell et al. [63] believe that 3D printing can lead to changes equal to those caused by the advent of personal computers and the Internet. There will be a change in the structure of logistics chains, both globally and locally [64], and especially in the characteristics of last mile deliveries (starting point, type of goods, return flows, etc.) [65]. McKinnon [11] states that a particularly significant impact on city logistics and deliveries in the last mile could have 3D printing that users perform independently. Mass adoption of this concept could eliminate the need to ship anything other than the raw materials (fibers, resins, and polymers) used in the printing process, as well as the 3D printers themselves, as well as the collection of materials for recycling [65]. Therefore, Taniguchi and Thompson [27] recognize that 3D printing and similar innovative technologies could reduce the demand for goods movement.

4 Conclusion

Various modern challenges, scientific-technological, and socio-cultural development gave rise to the concept of smart cities and smart technologies. Logistics as one of the basic functions of the city is also changing in the direction of innovation and advanced technological solutions. Technologies such as the IoT, drones, automated and autonomous vehicles, AI and 3D printing, in different ways accelerate, facilitate and/or improve the efficiency and attractiveness of various logistics processes and subsystems or have significant potential to achieve such effects.

This paper provides a comprehensive description of the current and potential application of smart technologies in city logistics, i.e. the logistics of smart cities, which achieved the main goal and contribution of the paper. The focus of future research can be the analysis of possibilities, needs, problems, but also the

potential dangers of applying certain technologies. Also, mathematical models (e.g. multi-criteria decision-making model, fuzzy systems, etc.) should be defined for the evaluation of smart technologies and the selection of the most favorable among them for city logistics. Finally, it is necessary to investigate the applicability of these technologies in other areas of logistics (e.g. humanitarian logistics, household logistics, etc.).

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