Cargo Delivery Systems in Agglomeration Areas

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Transport constitutes a key component of any city or agglomeration's functioning and development. It is indispensable for the functioning of business entities (deliveries of raw materials and components, internal flows, distribution of finished products, provision of services) and public institutions (public services, administrative functions, regulatory and inspection activities), as well as for the functioning of the city and agglomeration's residents and users (meeting the transport needs of the public—moving about to meet their work, education, entertainment, healthcare, and other needs).

energy transition | zero-emission transport | electromobility | sustainable urban freight transport | transport | Cargo Delivery Systems

1. Introduction

Transport constitutes a key component of any city or agglomeration's functioning and development [1]. It is indispensable for the functioning of business entities (deliveries of raw materials and components, internal flows, distribution of finished products, provision of services) and public institutions (public services, administrative functions, regulatory and inspection activities), as well as for the functioning of the city and agglomeration's residents and users (meeting the transport needs of the public—moving about to meet their work, education, entertainment, healthcare, and other needs).

Unfortunately, in addition to its positive effects, transport generates a number of negative impacts on the environment. The environmental impacts include degradation of air quality, greenhouse gases (GHG) emissions, increased threat of global climate change, degradation of water resources, noise, and habitat loss and fragmentation [2]; and the adverse impacts on society include respiratory, nervous, and circulatory system diseases, decreased safety on the roads and side-walks, and the extended time and cost of travel to the destination as a result of road congestion [3][4][5][6]. Due to the abovementioned aspects, transport in cities constitutes a particular challenge for urban logistics [7], as it requires searching for innovative solutions to make cities less polluted and easier to access, and to make the street traffic more fluent [8].

The European cities' response to the abovementioned challenges is an irreversible shift to low-emission mobility. Pursuant to A European Strategy for Low-Emission Mobility adopted by the EU, it is to be implemented via three major areas of actions: the achievement of higher efficiency of the transport system, utilisation of low-emission alternative energy for transport, and application of low-/zero emission vehicles [9]. The implementation is to cover both freight and passenger transport.

2. The Effects of Applying Cargo Delivery Systems to Support Energy Transition in Agglomeration Areas

A transport system constitutes a vital element of any human environment. It provides mobility to residents, supports logistics processes, and moreover it is an indispensable factor of regional competitiveness and development. In this respect, intensively developing TSs gains particular importance in cities and agglomerations [10]. Their development is a direct outcome of demographic changes, including the progressing global urbanisation trend. According to United Nations Department of Economic and Social Affairs [11], the urban population between 2018 and 2030 is to increase from 55% to over 60% of the global population. The forecasts show that by 2050, the value will reach as much as 66–68% [12][13][14].

When analysing the processes connected with city development, it is possible to notice that TSs play a key role in those processes. It is hard to imagine a contemporary city without appropriately developed systems of:

- Linear and nodal transport infrastructure;
- Passenger (private and public) transport;
- Urban deliveries.

As it is these systems that are responsible for meeting the transport needs found in urbanised areas, it is also hard to imagine future cities without well-developed TSs; even more so as the forecast large rise in the population of urbanised areas may significantly increase the needs related to passenger and cargo flows.

However, when analysing any TSs it is also necessary to account for the accompanying phenomena that may influence the city residents' health and life quality. Domagała et al. [15], Kijewska et al. [16], and Davidich et al. [17] pointed out that in addition to its positive aspects, a transport system may also be a source of hazards. This is also confirmed by Gao et al. [18] who indicated that the cities where the TS is mainly based on road transport experience various negative consequences. As noted by Lah [19] and Waquas et al. [20], said hazards result mainly from the fact that most vehicles are still powered with fossil fuels. This leads to considerable emissions of harmful substances, including: CO, CO_2, SO_2, NO_X, PM_{10}, $PM_{2.5}$. There are numerous studies on transport-related emissions, including those authored by, e.g., Łapko et al. [21], Strulak-Wójcikiewicz et al. [22], Mikulski et al. [23], Połom et al. [24], Jereb et al. [25], and Urrutia-Mosquera et al. [26].

Zhang et al. [27], Matz et al. [28], and Boogaard et al. [29] pointed to the existing correlation between TS and life and health of people living in cities and agglomerations. The identified and studied diseases that derive directly from TS functioning include: cardiovascular diseases [30], asthma and COPD/chronic bronchitis [31][32][33], and acute changes in blood pressure [34][35].

Also, a significant environmental hazard ensuing from TS-related emissions is the global warming. This fact is emphasised in the studies authored by Giannakis et al. [36], Abraham et al. [37], and Zhang et al. [38]. According to the literature, the industry related to the transport sector is responsible for ca. a quarter of the global GHG emissions [39][40], and unless adequate measures are taken, in the future the transport sector will have an even greater share in GHG emissions. Very interesting insights in this respect are presented by Gelete et al. [41], Regmi et al. [42], and Koetse et al. [43]. They pointed out that the global warming caused by TSs, in addition to the negative impacts on the natural environment and human life and health, may also hinder and constrain the functioning of TSs themselves. The rising average air temperatures and the increasingly frequent extreme weather events (floods, hurricanes, torrential rain) can lead to accelerated wear and tear of vehicles and transportation infrastructures, as well as to increased costs of constructing new infrastructure elements. They may also periodically disrupt the possibility of providing transport services.

Aminzadegan et al. [44] pointed out that within the EU area, the TS was the second largest source of GHG emissions. According to Pomianowski [45], the TS constitutes the main source of air pollution in cities. The tangible aspects of the measures taken by the EU to mitigate the impact of TSs on the natural environment and human health and life are, e.g., the numerous changes within the scope of its transport policy [46]. The policy promotes all activities to support the development of low- and zero-emission forms of transport [47]. The aspect of particular importance in this respect is the development of electromobility [48], that is, the totality of issues related to the use of electric vehicles [49] applied in passenger and freight transport. The process of electromobility development in transport encompasses both the implementation of low- and zero-emission means of transport along with the necessary infrastructure and making specific urban spaces available exclusively for them—low-emission zones (LEZs) [50][51][52] and zero-emission zones (ZEZs) [53].

In the case of urban passenger transport, it is possible to identify several areas of activity in that regard. The first of them is the development and promotion of public transport (PT). It is aimed at increasing the PT share in the overall number of passenger trips in cities and agglomerations. There are numerous studies that have proved the effectiveness of those measures [54][55][56][57][58][59][60], where the authors indicate that PT may constitute the basis for the development and functioning of sustainable transport in cities and agglomerations. Cheng et al. [61] pointed to the considerable potential of PT in GHG emissions' reduction, which results from the possibility of carrying a large number of passengers in a short time compared to individual transport; this was also confirmed by Ranceva et al. [62]. For the past several years, it is possible to notice that many cities have been developing their existing TSs. They place particular emphasis on enhancing the role of PT, or even prioritising it over other forms of movement. In this case, the particularly relevant solutions seem to be the ones that are independent of or moderately dependent on road congestion—trams, metro, light rail, and trolleybuses [63][64][65][66][67][68].

The second area of activity regarding passenger transport, which in some terms supplements the first one, is the development and application of alternative sources of energy for public means of transport. As Guzik et al. [69] were right to say, vehicles such as trams, metro, light rail, and trolleybuses may be excluded from this process. Due to the fact that they are electrically-powered, they have been meeting the electromobility criteria for many years. However, there is still an issue connected with the use of buses in the city public transportation system, as many of them are still internal combustion engine vehicles (ICEVs). Therefore, it is important to develop and implement alternative drives for this type of means of transport. The application of compressed natural gas (CNG) and liquefied natural gas (LNG) buses, as well as hybrid vehicles at the initial stage, brought tangible benefits in terms of noise and GHG emissions' reductions [70][71][72][73][74][75]. However, this was only a beginning of further activities in that respect. A kind of revolution was the introduction of electric buses to the market. The benefits of replacing ICEVs with electric buses were demonstrated in the studies authored by Konečný et al. [76] and Dalla Chiara et al. [77]. They stressed that the use of electric buses may bring significant savings in social costs.

The last area of activity regarding passenger transport is the development of environmentally-friendly vehicles that may be jointly referred to as non-motorised transport (NMT), along with the infrastructure that is indispensable for their functioning. The literature also refers to this kind of movement as "active transportation" or "human powered transportation" [78][79]. NMT encompasses bicycling and other kinds of vehicles: skates, skateboards, or push scooters, which may be categorised as small-wheeled transport [80]. As shown by Maciorowski et al. [81], NMT has been gaining popularity due to its low external costs, but also the significant benefits to the physical and mental health of its users. Risimiati et al. [82] on the basis of studies carried out in Johannesburg pointed to the possibility of integrating NMT with the infrastructure dedicated for PT and the ensuing benefits. NMT can be used in the initial and final stages of multimodal passenger travel, e.g., where the PT network is not adequately developed (city outskirts) or where there are restrictions for motorised traffic (city centres, old towns). The appropriate integration of NMT with PT makes it possible to build all-inclusive transportation chains in city TSs. In fact, the suggested integration relies on the construction of an appropriate nodal infrastructure (e.g., B&R); however, as Rietveld [83] emphasised, due to the small size of NMT vehicles it does not require considerable space as in the case of P&R facilities.

Grzelak et al. [84] argued that the relevant aspects of measures taken to reduce TS-related CO_2 emissions were also those aiming at the promotion of the purchase and use of private electric vehicles (to replace the currently used ICEVs). These include systems of subsidies for the purchase of vehicles or the application of various kinds of preferences in using the city car parks, or access to special, designated traffic lanes. Gerboni et al. [85] are of a similar opinion and they stress that an increased share of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) in the total number of individual vehicles may bring the desired effects. This, however, depends on the improved availability of public charging infrastructures, among other things.

In the case of urban freight transport (UFT), the implementation of solutions aimed at mitigating TSs' impact on the natural environment and human health and life pertains predominantly to the first- and last-mile (FM and LM) operations. These are usually light, small-size cargoes—mainly parcels and courier consignments. Deliveries of this kind may be made using electric freight vehicles (EFVs) whose parameters correspond to the diesel-powered light commercial vehicles (LCVs) used thus far with a carrying capacity of up to 1.5 tonnes. The practical aspects of the possibilities of making deliveries with the use of EFVs, as well as the potential barriers to that process, were investigated by Dong et al. [86], Wątróbski et al. [87], Iwan et al. [88], Taefi et al. [89], and Malander et al. [90]. Importantly, the application of EFVs may bring tangible benefits in terms of mitigating the TS's impacts on the natural environment and human life and health (reduced levels of emissions and noise); nonetheless, it does not eliminate all the nuisances caused by UFT. For example, it does not reduce congestion and does not improve pedestrians' and cyclists' safety [91].

Where the entry of ICEVs is constrained or prohibited [92], and also in the case of the numerous spatial limitations found especially in city centres, cargo deliveries supporting energy transition may also be made using the vehicles categorised as light electric freight vehicles (LEFVs). According to Balm et al. [93], LEFVs are electrically powered or electrically assisted vehicles that are smaller than a van and have a maximum loading capacity of 750 kg. Moolenburgh et al. [94] enumerated the following LEFVs: electric cargo bikes (loading capacity up to 350 kg), electric cargo mopeds (loading capacity up to 500 kg), and small electric distribution vehicles (loading capacity up to 750 kg). LEFVs take up much less space than EFVs; therefore, they are much easier to manoeuvre in city centres, and it is also easier to find an appropriate place for un/loading them. The utilisation of LEFVs may bring considerable effects in terms of processes related to energy transition in UFT. The study carried out by Diaz-Ramirez et al. in Bogota [95] has shown that the utilisation of LEFVs in urban distribution may reduce GHG emissions by more than 95%. Such a large reduction may be the result of synergy encompassing the abandonment of fossil fuels and replacing them with electric energy, at the same time reducing the demand for energy due to the reduced vehicle weight.

As noted by Iwan et al. [96], at the moment electric vehicles are still much more expensive than ICEVs; moreover, they have other limitations. The most significant ones include a limited travel range, long charging time (considerably longer than the time needed to refuel ICEVs), and the still-small number of public charging stations. This was also confirmed in the studies carried out by Skrúcaný et al. [97], Macioszek [49], and Anosike et al. [98]. The above indicated features effectively curb the applicability of electric vehicles in heavy cargo or long-distance transport; however, they do not negatively affect the provision of transport services in urban conditions. An interesting study in this respect was carried out by Settey et al. [99]. According to the study, it is in urban cycles characterised by frequent stopping and low velocity that EFVs are the most effective in terms of energy consumption. The advantage of EFVs over ICEVs can be particularly noticeable in limited speed zones (e.g., 30 km/h zones) or areas prone to congestion. The discussed results were also confirmed by Melo et al. [100] who pointed out that EV effectiveness depends on the cargo weight and size as well as the route length. In the authors' opinion, the use of electric vehicles is particularly effective in urban logistics, which deals predominantly with small and light consignments that are carried over small distances. The EV travel range, which depends on the amount of electric power stored in the vehicle batteries, imposes additional constraints on distribution routes' design [101], may require recharging while the vehicles are in operation [102], and also imposes the need to support the delivery systems by cargo consolidation centres.

The completed literature review has shown that the issue of energy transition in UFT is addressed primarily in relation to typical urban and agglomeration delivery systems, mainly in FM and LM deliveries. This derives directly from the constraints and properties of electric vehicles. It is in urban traffic that it is possible to charge the vehicles on a current basis or recover energy as a result of frequent braking, and the travel range of this type of vehicle does not constitute a significant barrier to making deliveries over short distances.

Nevertheless, it should be noted that many cities and agglomerations still have an issue with delivery systems for heavy weight cargoes, such as bulk, oversized, hazardous cargoes or containers. The problem affects mainly port, trading, tourist, and industrial cities and agglomerations, where deliveries are made often without a possibility of consolidation/deconsolidation and determine the use of the transport infrastructure connecting specific points or entities (e.g., trading ports, industrial enterprises). Deliveries of this kind are made over long distances with the use of high-carrying-capacity vehicles.

Unfortunately, the literature does not sufficiently address cargo delivery systems supporting energy transition with respect to the abovementioned cargo group. This is mainly due to the very limited possibility of applying electric road vehicles that are capable of making such deliveries. Even though it is possible to apply electric drive in heavy goods vehicles (HGVs), this requires very capacious batteries which would considerably reduce the vehicle's loading capacity, in terms of both volume and weight. As indicated by Olovsson et al. [103], given the current battery efficiency, long-distance HGVs would need a battery with a capacity in the range of 600–800 kWh, which would necessitate a battery package weighing several tonnes.

In an attempt to solve this problem, some solutions are being tested in several countries, to make it possible to charge HGVs while they are in motion. The electric road system (ERS) program [104][105], also called dynamic power transfer (DPT), which is currently being tested, e.g., in Sweden, Norway, and Germany, consists of constructing traction power networks above selected roads to supply road vehicles in motion, on a similar principle as in the case of trains or trams. Schwerdfeger et al. [106] noted that the implementation of this type of solution to a larger extent may be costly and time-consuming. Moreover, according to Börjesson et al. [107], the potential benefits of the ERS system may be limited in the long term as a result of the further development of batteries and hydrogen fuel cells. A substantial limitation of this solution may also be the fact that a traction power network located above the road may restrict or even block the transport of oversized cargoes.

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