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Improving the Effectivity of Urban Freight Transport by Means of Cellular Automata Simulations

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ABSTRACT

Unloading bays are one of the most popular and simple to implement solutions to support development of sustainable urban freight transport systems. The solution is aimed at reducing congestion on busy city streets, which is often caused by freight vehicles that, in an attempt to load or unload their cargoes, park directly in traffic lanes. Where dedicated unloading bays are in place, the traffic is undisturbed, which helps to prevent extra consumption of energy and fuel, and thus extra pollution, and which also makes it possible to avoid wasting time in traffic jams and ensuing costs. Therefore, the major benefit derived from this solution is its contribution to reduction of traffic congestion, followed by a perceptible decrease in pollutant emissions. This article aims at developing an algorithm for recommended distribution of unloading bays based on the reported locations of delivery points and parameters related to varied quantities of goods and the number of available parking spaces in the vicinity of unloading bays. Additionally, it addresses the issue of using unloading bays as EV charging stations. The proposed solution was implemented on the basis of a dedicated road traffic simulator based on the original cellular automaton model..

KEYWORDS: urban freight transport, loading/unloading bay, computer simulation, cellular automata

1. Introduction

According to the latest findings of the Central Statistical Office, the number of retail outlets in Poland has been rising steadily by ca. 1.7% per year. Also, the average sales space of a retail outlet has increased by 3.5%. Along with the growing number of shops as well as the increasing sales space of retail outlets, the demand for merchandise is also on the rise. While large-format retail outlets (hypermarkets) are provided with separated loading and unloading zones, the smaller shops in city centres face serious problems in that respect. Due to the fact that food, everyday use items and even some less vital products must be delivered to retail outlets on a daily basis, the question is how to plan the traffic in the area so as to optimise the distribution of unloading bays [1-3].

This article is focused on studying the effectiveness of urban freight transport and on development of solutions to streamline it [4-8], also those aimed at improving the road traffic security [9-16].

This article is aimed at developing and examining a method for effective distribution of unloading bays.

It is divided into the following parts. Chapter 2 contains the literature review. The next chapter presents information regarding the discussed process of computer simulation. The remaining part describes the findings of experimental studies and the final conclusions.

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2 Related works

Unloading bays are one of the most popular and simple to implement solutions to support development of sustainable urban freight transport systems. The solution is aimed at reducing congestion on busy city streets, which is often caused by freight vehicles that, in an attempt to load or unload their cargoes, park directly in traffic lanes. Where dedicated unloading bays are in place, the traffic is undisturbed, which helps to prevent extra consumption of energy and fuel, and thus extra pollution, and which also makes it possible to avoid wasting time in traffic jams and ensuing costs. Therefore, the major benefit derived from this solution is its contribution to reduction of traffic congestion, followed by a perceptible decrease in pollutant emissions. The research studies conducted in the French city of Bordeaux have shown that implementation of unloading bays reduced CO2 emissions by up to 40 kg per day. The analyses completed in Szczecin (Poland) and in Oslo (Norway) have revealed that freight vehicle drivers have to drive on for ca. 1.8 – 2 km (on average) in order to find a parking space to unload their cargo [17]. Gatta and Marcussi [18] studied the impact of the quantity of unloading bays, the probability of finding an unoccupied bay and charges for using the bays on the opinions of retail suppliers and transport operators. A need to provide unloading bays was also addressed in studies conducted in Shanghai – a metropolis that is much larger than any major European city. The authors in [19] presented a discrete model for estimating the demand for unloading bays.

[20] presents the study of congestion via the proposed methods of determining the optimum size and location of loading/unloading bays. The earlier studies [21] also confirmed the pertinence of unloading bays, particularly in the context of the limited time that any freight vehicle drivers have at their disposal. [22] shows a model for determining the optimal location of unloading bays in terms of abiding by availability and delivery times for individual unloading bays, taking into account the purposefulness of deliveries both from the point of view of freight vehicle drivers and other road users [23]. Based on survey studies and data obtained from GPS systems it was found that unloading bays were used by various vehicles, not only freight vehicles [24]. The unloading bays were also used by taxis (8%), private cars (18%) and other, such as municipal service vehicles (17%). The studies showed that the unloading bays were occupied by freight vehicles for ca. 50% of the time. Among all the freight vehicles, the study distinguished between large, medium and small freight vehicles. The studies described in [25] pertained to the methodology of optimising the FURBOT system operation on the basis of the actual demand for cargo.

There are many studies regarding the effectiveness of urban transport [26-32].

This is a proof that the issue is still important and shows the potential of using unloading bays as additional spaces for electric vehicle charging [33].

3 Proposed approach

The basic version of the simulation system and the description of the model based on cellular automata were presented in [17, 34, 35] and the model was further developed in [27]. This chapter presents the additional functions developed for the purposes of this article and implemented in the simulator, to enable studies pertaining to optimal distribution of unloading bays.

3.1 Limitations affecting distribution of unloading bays

An important factor for optimising the distribution of unloading bays is information regarding the population of a given area and its demand for parking spaces.

In order to compute the minimum quantity of needed parking spaces, the following formula was applied:

$$FPS = (rl \bullet 2) - (\frac{P}{ac}) \quad \textbf{(1)}$$

where: *rl* – length of the examined road segment, *P* – population living within the said road segment, *ac* – average number of people per passenger car. On that basis, it was possible to develop an algorithm for automatic recommendations regarding distribution of unloading bays, while taking into account e.g. the needed number of parking spaces.

An additional factor that was decisive for establishing an unloading bay is information regarding the quantity of merchandise units transported by a single freight or delivery vehicle to a specific retail outlet, and the potential unloading time. The factors affect the time needed for unloading, and consequently the risk of congestion (particularly when freight vehicles stop in a traffic lane to make a delivery) or occupancy of the vehicle charging facility in case the unloading bay is also used as an EV charging station. This is reflected by the formula:

$$uT = \frac{mc}{up} \quad \textbf{(2)}$$

where: *mc* – quantity of goods in the freight vehicle, *up* – quantity of goods unloaded within one operation cycle of the simulator.

3.2 Validation of the prepared software

Due to the specific nature of discrete simulation, particularly in the aspect of examining the probable traffic behaviours, results generated for specific input data may sometimes vary. This is connected with the stochastic nature of the road traffic dynamics in individual simulations. For a simulator to be a reliable tool, the differences in computations for the same data should not be too significant. Therefore, the measurement error was computed by means of the following formula:

$$\delta = \frac{\Delta x}{x} \cdot 100\% \quad \textbf{(3)}$$

where: Δx – absolute error of measurement, x – the actual value of the measurand.

100 sets of test data were prepared for the purposes of the simulator validation, taking the following assumptions: on the examined road segment the traffic is intensive, vehicles move with the average velocity of ca. 30 km per hour, the probability of a new vehicle joining the traffic is 0.9, during each of the simulations 100,000 vehicles drive along the examined road segment. 100 simulations were run for each data set, and the results being the mean for all the data sets are presented in Fig. 1.

The mean error difference for each measurement in the set of 100 simulations was 0.0004%. This is a very good result which proves that the developed simulator is a reliable tool for road traffic simulation in the aspect of unloading bays.

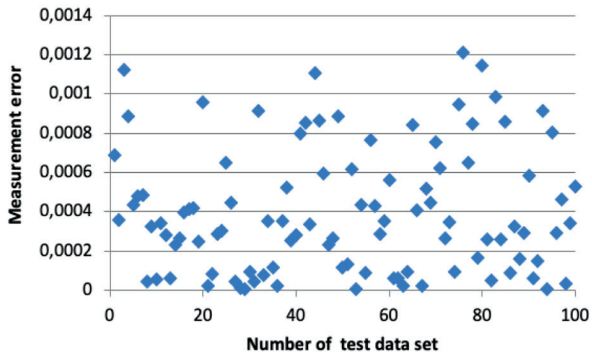

Fig. 1. Measurement differences (%) for 100 simulations based on the same measurement data [own study]

3.3 Algorithm for optimising the distribution of unloading bays

The developed simulator is based on a cellular automaton model. A fragment of the cellular automaton grid is presented in Fig. 2. Along the road being used by vehicles there is a space where unloading bays may be located, which are also used as EV charging stations. Unloading bays are between the road space and the space where retail outlets may be located.

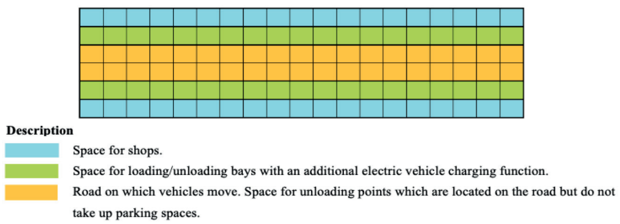

Fig. 2. Cellular automaton grid [own study]

One of the major criteria for correct distribution of unloading bays is eliminating their redundancy. As long as there are several retail outlets in the vicinity, it becomes more reasonable to locate an unloading bay. Therefore, one of the parameters of the presented algorithm for optimising the distribution of unloading bays is the optimisation area, understood as an area covered by a specific unloading bay. If there already is an unloading bay within the assumed optimisation area, the optimisation algorithm will not be generating another unloading bay in that area. An additional parameter is the probability of setting up an unloading bay. On the basis of the described probability, the algorithm selects at random whether unloading bays should be set up in the car park space (along the road), or on the road. Additionally, the road traffic capacity in that area is checked in the numeric experiment process, and in the case of excessive congestion the unloading bays are moved to other places. As a result, the algorithm displays a list of possible locations for unloading bays, along with information on the road traffic capacity.

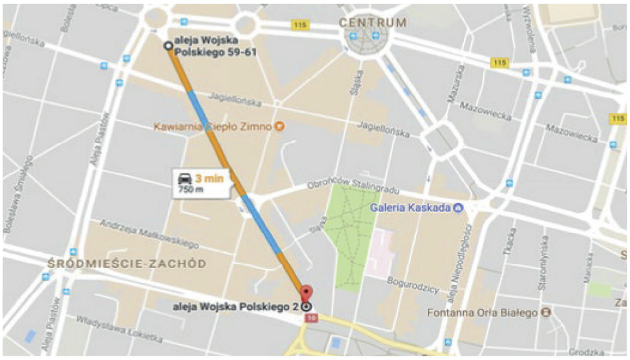

Fig. 3. The examined road segment [own study]

The simulations were run for many various configurations so as to verify the optimisation algorithm for different road traffic behaviours. The parking spaces are located in parallel to the examined road segment. The Polish road traffic regulations stipulate that thus situated parking spaces for passenger cars may not be smaller than 5 m in length and 2.5 m in width [36]. Assuming that such a parking space may be converted into an unloading bay for freight vehicles with the GVW of up to 3.5 T, the length of each parking space was defined as 7.5 m.

All the simulations were run for a single quantity configuration, i.e. 26 retail outlets that need to be delivered their merchandise. The space covered by the study was modelled in the developed simulator along with the traffic parameters and the retail outlets locations (Fig. 4).

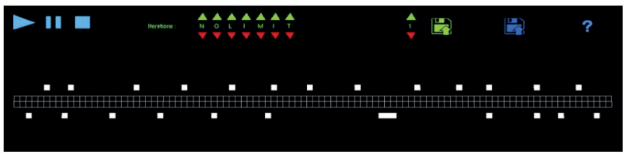

Fig. 4. Distribution of service outlets (white rectangles) along the analysed road [own study]

The first criterion for evaluation of the proposed algorithm is the number of free parking spaces after distributing the unloading bays. Another possibility is that a delivery point may be located in the traffic lane instead of an unloading bay located on the roadside. It was assumed that parking spaces are found all over the length of the analysed road, on both sides. This means that on the given

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750 m stretch of the road segment (100 CA cells in the simulator) there are 200 parking spaces.

Parking spaces located along the road are scarce in city centres and this can considerably disturb the traffic [27]. It is important that unloading bays should be distributed in such a way so as to take up the fewest parking spaces. In terms of this criterion, the best distribution of unloading bays is when none of them is located on the roadside. Obviously, such distribution of unloading bays will lead to deterioration of the road traffic capacity.

The road traffic capacity is the second major criterion of optimising the effectiveness of the examined solution. Thus, the person making use of the simulator is able to estimate whether within a given area there will be increased congestion. Road traffic capacity is calculated as follows: the more computational cycles (iterations) the simulator performs, the greater the congestion for the given setting. This means that in order to decrease the congestion, the simulator searches for a solution resulting in the smallest number of operation cycles (iterations).

The comparison of the effects of the algorithm for distribution of unloading bays involved three sets of data: data on the unloading bays which were entered manually by the user, data on the unloading bays distribution which were generated at random on the basis of the previously discussed criteria (parking spaces, road traffic capacity, area covered by an unloading bay, etc.), and locations of unloading bays generated by the optimisation algorithm.

The results of the first study aimed at comparing the effectiveness of unloading bays distribution in the aspect of supplying varied quantities of goods are shown in Fig. 5-6. The optimisation algorithm operated on the basis of the following values: probability of locating an unloading bay on the road – 0.5, optimisation area – 4.

The study reflects the expectations. The more time it takes to unload the goods, the more intensive congestion is observed, so it becomes more important to properly distribute unloading bays. In both analysed cases, the effectiveness of the unloading bays distribution is the greatest when the locations are determined by the optimisation algorithm. The worst effect was obtained via generating data at random, which confirms that locating unloading bays at random without taking into account the specific features of the area is ineffective. Consequently, one might expect that decision-makers should make use of analyses performed by researchers in order to increase the effectiveness of cargo flows in cities.

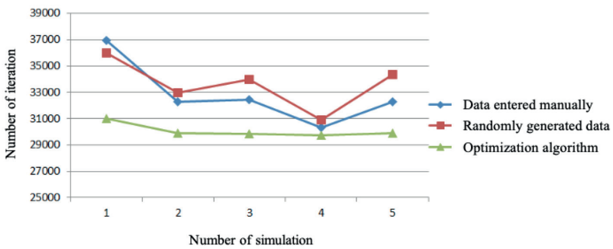

Fig. 5. Examining the effectiveness of unloading bays distribution for three sets of data for freight vehicles with the max. loading capacity of 500 cargo units [own study]

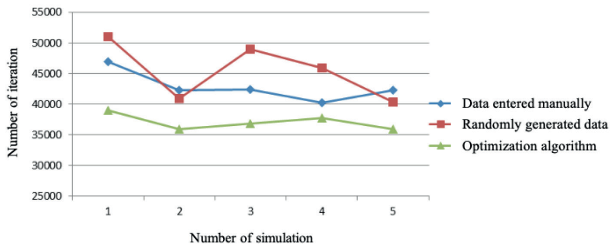

Fig. 6. Examining the effectiveness of unloading bays distribution for three sets of data for freight vehicles with the max loading capacity of 1000 cargo units [own study]

The subsequent study regarded an emergency situation (extended road repairs). The question was: should the distribution of the unloading bays be verified in the course of such works? The said situation was modelled in the simulation system as per Fig. 7 (the red rectangle stands for roadworks). If a freight vehicle stops in the same place (but on the other traffic lane), the traffic on the road will be stopped. It seems reasonable to locate delivery points directly ahead of or behind the roadworks area.

The simulations were run for various road traffic loads, i.e. low road traffic intensity (Fig. 8) and high road traffic intensity (Fig. 9). In this case, the results obtained by the developed algorithm are much better when the traffic intensity is higher. This means that appropriate shifting of delivery points may to large degree contribute to increasing the road traffic capacity in the area where roadworks are underway.

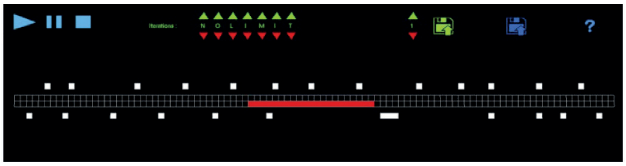

Fig. 7. The road segment with roadworks underway (red rectangle) [own study]

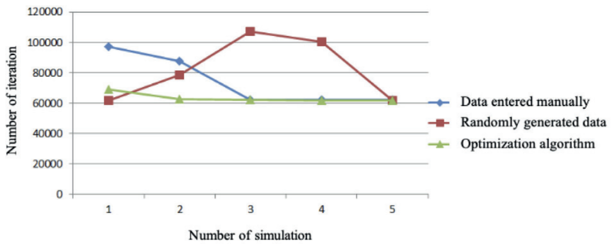

Fig. 8. Examining the road traffic capacity with roadworks underway and low traffic intensity [own study]

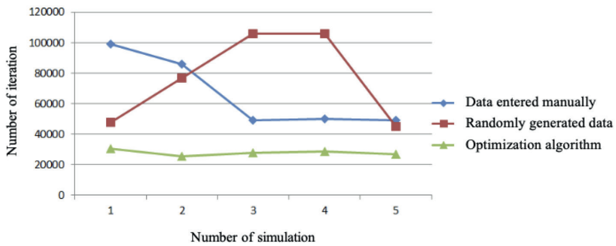

Fig. 9. Examining the road traffic capacity with roadworks underway and high traffic intensity [own study]

5. Conclusion

The main objective of this article was to address the problem of distribution of unloading bays in the aspect of the effectiveness of cargo flows in the city. Distribution of unloading bays and examining the effectiveness of this process were based on the original traffic micro-simulator operating on the basis of the developed cellular automata models.

The authors of this article developed an algorithm for automatic distribution of unloading bays, and the effectiveness of the algorithm was verified in the process of experimental studies. The obtained results made it possible to organise the places for unloading the goods in such a way so as to optimally save parking spaces and not to deteriorate the road traffic capacity. Both parameters seem to be in conflict with one another, however, the studies have shown that appropriate and automatic distribution of places for unloading is possible and produces better results than locating any unloading bays at random.

An additional, important idea presented in the article is simultaneous use of unloading bays as electric vehicle charging stations. In that context, it is necessary to perform further analyses in order to find out about the related needs and risks.

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