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EXAMINATION OF LOGISTICS SYSTEMS OF CONCENTRATED SETS OF URBAN DELIVERY POINTS BY SIMULATION

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ABSTRACT

In the field of logistics, the examination of urban concentrated sets of delivery points (e.g. shopping malls or markets) is an important, new area. In these sets, there is a relatively large number of stores with significant goods traffic, which generate significant customer traffic, air and noise pollution, while their logistics systems are not properly designed. Despite all this, city logistics research does not specifically target this field, there are no models that can be used to examine any kind of urban concentrated sets of delivery points. Earlier, only few subsystems have been examined, so we started to study and model the concentrated sets of delivery points generally. As a first step in our research project, we collected data about concentrated sets of delivery points, and this data made it possible to start the simulation modelling and to develop new solutions.

Keywords: logistics, city logistics, modelling, simulation

1. INTRODUCTION

Earlier, several researchers worked in the field of simulation modelling of urban logistics systems. In a paper from 2015, 31 city logistics models were examined and evaluated (Anand, Van Duin, Quak and Tavasszy, 2015). The results of this study gave us a useful input for modelling. In the review, the selected models were evaluated based on four factors of the review framework: stakeholders, descriptors, objectives, and solution approach. Based on the conclusions of this paper, there are several possibilities to develop the examined city logistics models. They note that the dynamic nature of urban freight systems and the variation of the presented problems make it difficult to create a standard framework for urban freight transportation modelling, so we need to develop a new model for the actual problems.

Since the area under study is complex, its different subsystems should be examined by simulation modelling separately. For example, we can examine only the restaurants, whose goods should be handled in a separated logistics system, like in the case of a research project from Vienna, Austria (Fikar and Gronalt, 2018). Another possible research field is the urban supply system of fruits and vegetables. In the case of Teheran, Iran, this system was examined and redesigned by use of modelling methods (Saeedi, Teimoury and Makui, 2018). We have chosen a bigger urban logistics subsystem for our research topic: we examine the current and possible future city logistics system of concentrated sets of urban delivery points with use of mathematical and simulation models. *This research field is very important because of the possible significant savings and due to the lack of the general mathematical and simulation models which could be used generally for examination of these sets.* We started this research projects in 2015.

1.1. Urban concentrated sets of delivery points

The urban delivery points can be divided into two main groups for our research (see on Figure 1). There are single delivery points and concentrated sets of delivery points (referring to CSDP). *The concentrated sets of delivery points are sets including multiple single delivery points grouped together according to some given aspect.* In the case of them the density of the delivery points is very high in a relatively small area.

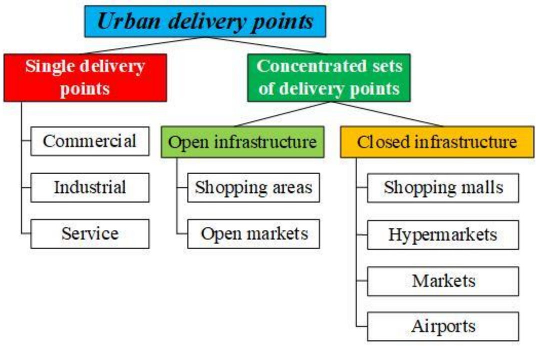

Figure 1: Groups of urban delivery points

The examined sets can be characterized by two main types of concentrations.There are concentrated sets of delivery points with open and closed infrastructure. *In case of open infrastructure, the road transportation infrastructure (roads, squares) provides the borders of the examined concentrated set of delivery points.* This can be noticed in case of a shopping area bordered by roads or a market bordered by a square. *In case of closed infrastructure a given building provides clearly defined boundaries of the examined concentrated set of delivery points.* This can be noticed in case of shopping malls or in case of the duty free area of airports.

As it can be seen on Figure 1, there are several subgroups in the two main group of CSDPs. The shopping areas have the most opened infrastructure, in their case, there are densely located single delivery points in an open urban area, and we can assign them to a CSDP based on their proximity. In a similar, but more compact way can we assign delivery points to a set in case of open markets. The stores of shopping malls, markets in buildings, hypermarkets and airports can be assigned to a set based on their connection to a given building and to its owner.
In our research project, we primarily examined Budapest, where we can notice all the subgroups. There are several shopping malls (see on Figure 2, with borders of the city and the main roadsó), hypermarkets, markets (both with open and closed infrastructure), a significant shopping area and an international airport.

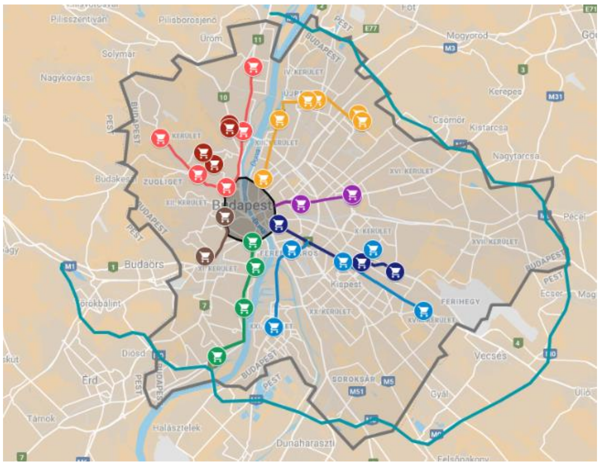

Figure 2: Shopping malls in Budapest on Google Maps

Despite the significant goods traffic of these concentrated sets of delivery points, few research projects have examined their complex city logistics systems directly. Indeed, in their design phase the sizing, optimization and simulation of their logistics systems are neglected, they deal primarily with the aspects of shopping flow, so to develop models for the sizing and simulation is going to be a very important task. Research in this field mostly deals with some given elements of these logistics systems, and not with whole complex system. One of these studies examines the common optimization of the location of shopping malls and logistics centres (Yang and Moodie, 2011), omitting the shopping areas or markets from the model. Another known study also deals only with the shopping malls, highlighting the use of their loading bays and evaluating the impacts of new solutions (Chiara and Cheah, 2017). City logistics issues related to airports were also specifically examined in a research project (Boloukian and Siegmann, 2015), and several studies analysed consolidation centres or cross docks alone.
In some European cities, there are urban logistics systems that serve given CSDPs, mostly shopping areas. For example, in Bristol, Great Britain, the Broadmead Freight Consolidation Scheme system serves 63 stores of the shopping area in the city center. By implementing this new system, the number of delivery transactions was reduced by 75% and in the examiend period the CO_2 emission was reduced by 22.5 tons (Hapgood, 2009). Similar systems are operating in Padova and Lucca in Italy, and in Nijmegen and Utrecht in the Netherlands.
In the case of CSDPs with closed infrastructure, we can only examine some existing and documented systems. A city logistics project serves the processes of Heathrow Airport in London, Great Britain, where this gateway-concept based city logistics system is a significant element of their sustainable transportation plan (Matthews, 2014). We would like to highligt the Franprix system from Paris, France, where the shops of a supermarket chain are served by cargo ships. In this system, the cargo ships deliver the goods in containers from a consolidation center to the supermarkets in the city center (Janjevic and Ndiaye, 2014). The delivery points in this system are not CSDPs (according to our definition), but it is possible to implement this solution for CSDPs as well.
Since only a few subsystems of this complex logistics system have been studied in the past, we chose to study the concentrated sets of delivery points generally. This is a very important task to make the examination and the simulation of the city logistics systems of CSDPs possible for future projects. Our main purpose was to develop general mathematical and simulation models, which can help us to examine any type of CSDPs, and to show the possible savings and emission reductions in multi-stage logistics systems.

1.2. Characteristics of the examined CSDPs

In the first phase of our research project, we needed to collect data about the logistics characteristics of the examined CSDPs to provide input data for the simulation. Previously, we assumed that the examined stores handle relatively large amounts of goods arriving in mostly smaller quantities and vehicles. Between 2015 and 2018, we collected data about 490 stores from four CSDPs (3 shopping malls and 1 shopping area). For the data collection, we used our own research methodology with an exploratory and a descriptive research part. In the exploratory part, we performed a field study, an expert interview and the examination of the bylaws. In the descriptive part, there was a complex questionnaire with 31 questions about the general properties of the stores, the delivery parameters, storage parameters, properties of inverse logistics and home deliveries, IT system and their main aspects for joining to a new, gateway-concept based city logistics system (Mészáros, Sárdi and Bóna, 2017).
Based on our results, in the current logistics system the delivery transactions are not synchronized (except in case when multiple stores use the same logistics provider), and this results that the sizable amount of goods is delivered in small parts and the utilization of the vehicles (which are mostly passenger cars and lorries) is low, so our earlier assumptions were proven right. For 420 stores of 4 CSDPs, this means 0.67 daily delivery transactions (244 yearly delivery/store and 119,568

delivery/420 store). In these deliveries, the stores handle nearly 3,000 boxes daily, approximately 200 pallet unit loads, 2,700 clothes hanger units and 1,000 other units (N=330). This means 60 t of goods per day (24,000 t per year) for them, and now we examined only responder stores from 4 CSDPs. Based on these results, the amount of goods is significant, but we assume that t the logistics processes could be more effective with new organizational solutions.
It was also important to collect information about the main aspects of the storeowners for joining to a new system and these results of the questionnaire showed us a direction for the next steps of the research. It can be seen on Figure 3 that stores who would like to join to a new system considered the emission reduction to be of higher importance than the financial and reliability aspects. In a five-point rating scale this means a willingness of 3.15, which is nearly equal to the medium value of 3. In case of urban transport this value is 3.04 and all the other aspects are under 3, reliability is the less important aspect for the responding storeowners (average value 2.51). On the figure dark green means that the given store definitely would like to join, in case of yellow the given aspect is neutral for the responding storeowner and red means that the completion of the given aspect absolutely won't make them to join to a new system.

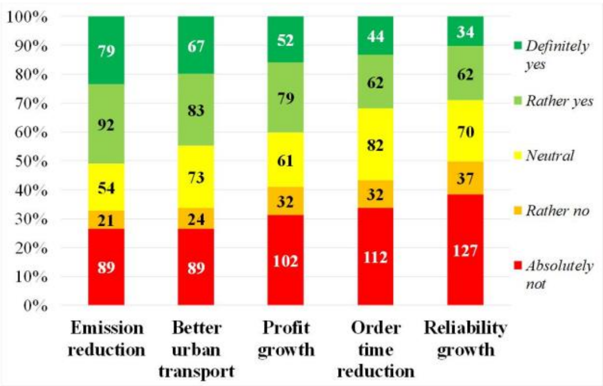

Figure 3: The importance of different aspects of examined stores (N=336)

The described results of the data collection showed us that the suspected problems in the examined city logistics system are real, but green logistics aspects are important for a significant share of the stakeholders. In case of new systems, it is going to be significant to reduce the emissions and make the city logistics processes more sustainable, because it seems to be also important for the storeowners.
In the next steps of our research, we needed to fix the structure of the current system based on the collected data and to develop new system concepts too.

2. THE EXAMINED LOGISTICS SYSTEMS

For the modelling, we had to specify the structure of the current logistics system, and to develop the structure of the possible future system concepts, to be the basis of developing the mathematical and the simulation model. We developed two main, gateway-concept based new concepts to model and simulate, and some other concepts as well.

2.1. Current city logistics system

We created the structure of the current city logistics system of the concentrated sets of delivery points based on the processes of the earlier examined 4 CSDPs (3 shopping malls and 1 shopping area in Budapest). The current structure can be seen on Figure 4 (this structure was desribed in our simulation model). To desricbe, model and simulate the current logistics system was an important task in our project, because of the validation of the models of the new concepts and in the evaluation phase it is generally a better solution to compare models with models.

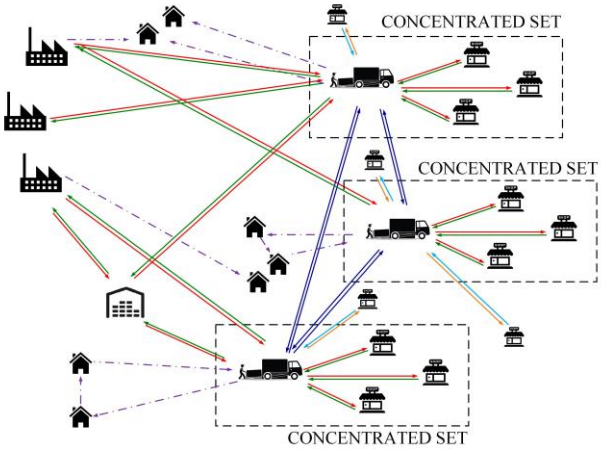

Figure 4: Current city logistics system of CSDPs

As we can see, in case of CSDPs, we have several stakeholders. The goods are delivered from the suppliers to the logistics area (or common loading area in case of open infrastructure) of the CSDP directly or via a logistics centre. The deliveries are mostly FTL organized because of the bigger amounts, but in some cases (e.g. in case of logistics providers) there are LTL organized transactions too. From the loading area, the employees of the suppliers or the stores move the goods to the store or to its storage. On the inverse way, they handle the empties (e.g. empty pallets), the return goods, and the goods, which must be delivered to service. We have in this system home deliveries from the suppliers and from the stores of the CSDPs too, and we have deliveries between stores of different CSDPs or between single delivery points and stores of CSDPs too (Sárdi and Bóna, 2017).

2.2. New city logistics system concepts

In our research project, we developed gateway-concept based, multistage city logistics systems. In the basic concept, we place a consolidation centre (referring to CC) between the suppliers and the CSDPs (this is the first gateway), where we can consolidate the delivery transactions. Suppliers can deliver directly to the CC, and it can have also an inventory handling role, which makes it possible for the suppliers to have less delivery transactions with bigger amounts. At the CSDPs, we replace the logistics and loading areas with cross-docks (these are the second gateways, referring to CD). We can organize this system even in more stages with having second and third gateways too, e.g. in the case of shopping areas with use of CDs and common loading bays. In this concept, we deliver from the CC bigger amounts in bigger vehicles to the CDs, where we have cross docking (short term storage, e.g. to make night deliveries easier). For these consolidated deliveries, green lorries or cargo trams could be used in the same structure (see on Figure 5). In the second case, naturally we need side-tracks to the CSDPs (Sárdi and Bóna, 2017). In this new structure, we can organize home deliveries from the CDs in round trips. In this case, the goods to be delivered are prepared in the CC to special units; they can be directly delivered to the customers from the CDs after transshipment, so the number of tasks of store workers will be also reduced.

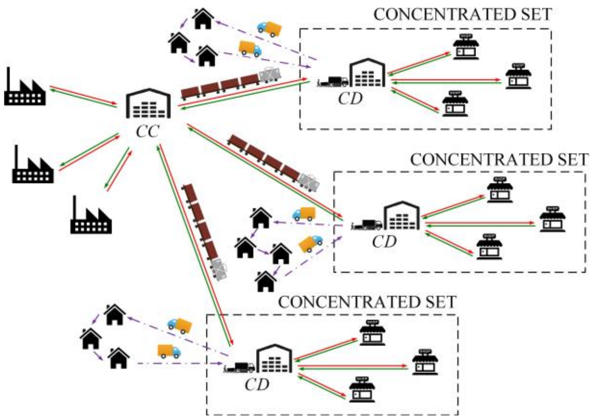

Figure 5: New city logistics system concept by use of cargo trams for CSDPs

We developed some other system concepts in our research, which are not modelled yet, but it is an important future challenge to examine them by simulation as well. For example, we can use cargo ships in a similar structure, where we deliver from the CC to transshipment points at the river, and from them we deliver by road vehicles (cargo bikes, lorries) to the CDs of the CSDPs, as it can be seen on Figure 6. In this system, we can load the road vehicles of the last mile deliveries in the CC and deliver them by ship to the transhipment points. In these gateway-concept based solutions we can combine the use of cargo bikes even with lorries, cargo trams or cargo ships too, e.g. for the deliveries between stores of CSDPs or for home deliveries. It is also possible to use them for delivery transactions with smaller amounts (for example if they get the goods from lorries at a transshipment point). In this solution, the transshipment point could be on an inner ring of the city in a radial city structure, and the cargo bikes could serve the CSDPs via the "rays" of the city (Sárdi and Bóna, 2018). It is also imaginable to use the metro lines or drones in similar city logistics concepts.

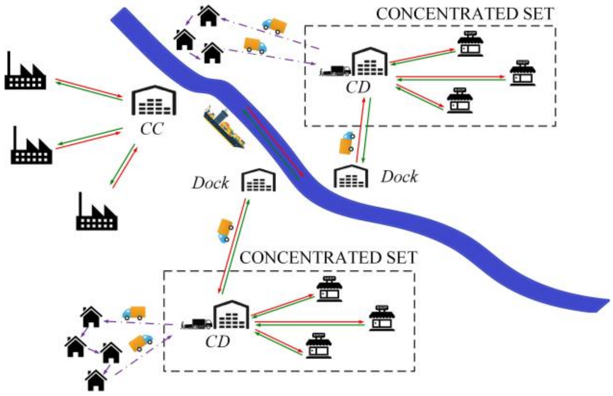

Figure 6: New city logistics system concept by use of cargo ships for CSDPs

3. MATHEMATICAL AND SIMULATION MODELLING

After describing the examined system structures, we modelled the current system and the two basic future concepts (the concepts where we deliver from the CC to the CDs in lorries or in cargo trams). The first step of the modelling was to develop the mathematical model of the logistics processes and the cost structure, both for the current system and the two new concepts. This was followed by developing a mesoscopic level simulation model in MS Excel for all examined solutions, based on the mathematical models. After all this, we developed the topological model of the shopping areas because of their specialties, to make it possible to examine the open infrastructure CSDPs. In our models, 30-day long periods are handled.

3.1. Mathematical modelling

The mathematical model was developed based on the presented results of the data collection phase and the described system structures (Sárdi and Bóna, 2019). The resulting mathematical model describes all main properties of the examined city logistics processes for a one-month period and describes exactly the operation of the simulation model. In this section, we are presenting the main components of the mathematical model both for the model of the current and the new system. In the mathematical formulas, "i" means the examined delivery transaction, "j" is the given day, and "l" is the given hour of the given day.

The basis of the model (both in the model of the current system and in the model of the new concepts) is the delivery generator, which specifies the actual delivery time on the actual day, if the given delivery transaction is realized. In the current system, we have one generator at the suppliers and for the new concept, in addition to this, there is another generator at the consolidation centre, which generates the deliveries to the CDs (according to the demands of the stores). The first component of the generator in the current system can be seen in Equation (1). Here, $x_{i,j}$ is the variable, which shows us whether the given transaction is realized on day no. „j" or not (this belongs to a given store, but to one store more transactions and variables can belong).

$N_i^{sup\_day}$ gives us in this formula the maximum number of monthly delivery days, $r_{i,j}$ is a random number between 0 and 1 with uniform distribution, and q_i is the probability parameter of the examined transaction.

$$x_{i,j} = \begin{Bmatrix} 0, \text{if } \sum_{k=1}^{j-1} x_{i,k} = N_i^{sup\_day} \\ 0, \text{if } x_{i,j} - 1 = 1 \text{ and } N_i^{sup\_day} < 7 \\ 0, \text{if } \sum_{k=1}^{j-1} x_{i,k} < N_i^{sup\_day} \text{ and } r_{i,j} \geq q_i \\ 1, \text{if } \sum_{k=1}^{j-1} x_{i,k} < N_i^{sup\_day} \text{ and } r_{i,j} < q_i \end{Bmatrix} \quad (1)$$

The second component of the delivery generator gives us the specific times of the transactions (more than one transaction per day is possible in the model) in the given day, if $x_{i,j}$ has the correct value, as it can be seen in Equation (2). Here, $R_{i,j}^l$ is a random number between 0 and 1 with uniform distribution, Q_i is another probability parameter of the examined transaction, $N_i^{max(day)}$ and $N_i^{max(month)}$ are the daily and monthly maximum number of transactions, $TW_i^{SH(LL)}$ and $TW_i^{SH(UL)}$ are the lower and upper limit of the time window of the examined store.

$$x_{i,j}^l = \begin{Bmatrix} 1, \text{if} \begin{Bmatrix} x_{i,j} = 1 \\ TW_i^{SM(UL)} \leq k \\ TW_i^{SM(LL)} \geq k \\ \sum_{k=1}^{l-1} x_{i,j}^k < N_i^{max(day)} \\ \begin{bmatrix} \sum_{h=1}^{j-1} \sum_{g=1}^{24} x_{i,h}^g + \\ + \sum_{k=1}^{l-1} x_{i,j}^k < N_i^{max(month)} \end{bmatrix} \\ R_{i,j}^l < Q_i \end{Bmatrix} \\ 0, \text{otherwise} \end{Bmatrix} \quad (2)$$

After generating the variables of the delivery transactions, the model generates the goods amount (weight and volume), calculates the sum delivery distance, the delivery performance, the fuel consumption (and electric energy consumption in case of cargo trams), and the emission (for five examined pollutants: CO, CO_2, NO_X, PM, HC). We calculate the performances and the emissions linearly from the distance. In Equation (3), the distance between the suppliers and the CC can be seen, where we handle so called "merged transactions", because of the inventory-handling role of the centre. As it can be seen in Equation (3) adjacent, the distance between the two examined points is given as input data. From this calculated distance, we can linearly calculate the delivery performance based on the goods weights. This indicator can be seen in Equation (4). The consumptions and emissions can be calculated from the distance in a similar way, from given specific parameters.

$$S_{i,j}^{land,CC} = \begin{Bmatrix} s_i^{land(l)}, \text{if } x_{i,j}^{CC} = 1 \\ 0, \text{otherwise} \end{Bmatrix} \quad (3)$$

$$Q_{i,j}^{land,CC} = S_{i,j}^{land,CC} \cdot M_{i,j}^{CC} \quad (4)$$

In our research, we modelled the empties handling as the inverse of the deliveries. In these processes, the vehicle, which performs the delivery transaction, delivers the empties (e.g. empty pallets, empty compartments) back to the supplier. After analysing the data we collected earlier, we concluded that the return goods deliveries and the service deliveries are rather sporadic processes with small amounts. Therefore, in a mesoscopic level for a one-month long period we don't need to integrate them to our model, and we can assume there is capacity for handling them in the empties handling process because of the small amounts.

At modelling the home delivery transactions, we use VRP (Vehicle Routing Problem) estimation formulas for calculating the number of round trips and the sum distance. We chose the Clarke&Wright formulas for a circle area, because of the approximately round shape of the primarily examined Budapest and other big cities. We modelled the home deliveries both in the current and in the new system with lorries, assuming an LTL organized system. Then (in the new system, for one given CSDP), the sum estimated distance of the home deliveries in one day can be seen in Equation (5). Here, $J_j^{hd\_CSDP}$ is the minimum number of home delivery round trips from a CSDP, $L_j^{in\_out}$ is the distance from the CD to the served area and back, and L_j^{area} is the sum distance inside the served area, between the home delivery points.

$$S_j^{hd\_CSDP} = J_j^{hd\_CSDP} \cdot \left(L_j^{in\_out} + L_j^{area}\right) \quad (5)$$

These two distance parameters are given by the Clarke&Wright VRP estimation formulas, based on different conditions about the maximum number of home delivery points per trip. For example, if the empirical condition is met (in case of a circle area), Equation (6) gives us the sum distance inside the examined territory. Here, $A_j^{hd\_CSDP}$ is the surface of the served area (in km^2), , $N_j^{hd\_CSDP}$ is the sum number of requested home delivery transactions of the CSDP, and $C_j^{hd\_CSDP}$ is the average number of home delivery points to be served in one round trip.

$$L_j^{area} = 0{,}680 \cdot \sqrt{A_j^{hd\_CSDP} \cdot N_j^{hd\_CSDP}} \cdot \frac{C_j^{hd\_CSDP}}{N_j^{hd\_CSDP}} \quad (6)$$

At the home delivery processes, the mathematical model also describes the fuel consumption and the emissions, and with this all, we realized the mathematical model for all delivery processes.

In the new system, for the model of the consolidated deliveries, we needed to define the necessary number of consolidated deliveries per CSDP in the examined day. This is given by Equation (7) for road vehicles, and it is similar for cargo trams. Here, $C^{sup\_CC\_road(m)}$ and $C^{sup\_CC\_road(m)}$ are the capacity parameters of the delivery vehicle in weight and volume, M_j^{CSDP}, and V_j^{CSDP} are the sum demand of the examined set for examined day in weight and volume, and r^{road} is an average utilization factor for the vehicle.

$$N_j^{CSDP} = \left\lceil \max \left\{ \frac{C^{sup\_CC\_road(m)} \cdot r^{road}}{M_j^{CSDP}} ; \frac{C^{sup\_CC\_road(V)} \cdot r^{road}}{V_j^{CSDP}} \right\} \right\rceil \quad (7)$$

The mathematical model also describes the main inventory points of the system; these are the supplier sites, the consolidation centre and the stores (and their storages). We modelled backlog handling only in case of the CC, while in all other cases the unsatisfied demands were lost. In all inventory points, the model generates for every delivery transaction an opening stock and a safety stock. As an example, Equation (8) gives us the stock at the supplier site, for delivery transaction no. "i" on day "j". In this model, the stored goods amount is added to the closing stock of the last day, and the amount of delivered goods in the given day is subtracted. The stock amount is not allowed to be less than zero in the model.

$$K_{i,j}^{SUP} = \max\{K_{i,j-1}^{SUP} + M_{i,j+1} - M_{i,j}; 0\} \quad (8)$$

The opening stock for the supplier sites is given by Equation (9), based on the basic safety stock-model, where U_i^{SUP} is the safety factor of the given supplier (calculated based on the distribution and generally with 95% reliability), and $D(M_{i,j})$ is the standard deviation of the goods to be delivered. Over the safety stock, the opening stock covers the demands of the first three days (this is an experimentally set parameter) and the lead times (delivery times) are constant 1 days with 0 standard deviation.

$$K_{i,0}^{SUP} = U_i^{SUP} \cdot \sqrt{D(M_{i,j})} + \sum_{k=1}^{3} M_{i,k} \quad (9)$$

In addition to all of these, the mathematical model describes the necessary loading time at the suppliers, in the CC, in the CDs (logistics areas) and in the stores. It also generates the customer demands and the home delivery share (in percentage of the customer demands), based on the expected demands and the expected share. With this all, we developed the full mathematical model of the current and the new city logistics system of the CSDPs of delivery points (Sárdi and Bóna, 2019).
For the examination of all significant parameters, the mathematical model of the cost structure of the examined systems was needed to be developed. This cost model was prepared in a former phase of our research project, where we described the costs in linear structure, grouped by cost centres and process types (Bóna, Róka and Sárdi, 2018). In the examined logistics system, the cost centres are the supplier sites, the delivery routes, the cross docks (logistics and loading areas in the current system), the internal material handling routes and the stores (with their storages). In the current system there are delivery routes between the suppliers and the CSDPs, while in the new system separately between the suppliers and CC and between the CC and the CDs of the CSDPs.
In the examined cost centres, there are five main process types: loading, storage, delivery, intralogistics operation and administration processes. Based on this structure, the cost parameters can be represented and simulated in a three-dimensional structure. As an example, on Figure 7 the simulated monthly logistics costs of five companies from three CSDPs can be seen. On the figure, dark green means the lowest and red means the highest cost values, and we can see the costs of given companies, in given processes and in given cost centres.

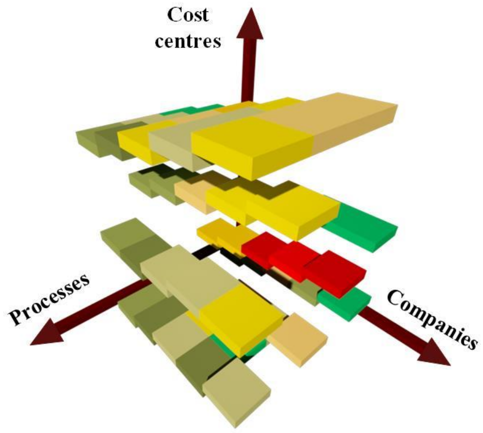

Figure 7: Representing logistics costs of the stores of a CSDP in a 3D structure

After developing the mathematical model of the processes and the cost structure, we developed the simulation model.

3.2. Simulation modelling

The mesoscopic simulation model of the examined city logistics systems was developed based on the presented mathematical model, in MS Excel (Sárdi and Bóna, 2017). We have chosen Excel for the modelling, because as a first step we could build the current and the new systems relatively simply, by use of functions (mainly random generators) and visual basic-based macros. This MS Excel-based simulation model is a discrete event simulator, where the departure and arrival of the delivery transactions and the appearance of demand give us the discrete events to be handled.
The simulation model maps the entire mathematical model for the current system and for the new system concepts. Its basics are random number generators, which are generating the parameters of the transactions (customer demands, deliveries, empty handling, home deliveries) based on the statistical properties of the distributions.

3.2.1. Simulation model of the current system

The simulation model has two main components. The first component (an Excel-workbook) describes the current logistics system and it generates the different parameters on different worksheets, the second (another

Excel-workbook) examines the processes of the new system concepts.

In the tables of the given worksheets one transaction belongs to one row, which is defined by a CSDP ID (on Figure 8 it is a shopping mall ID), a supplier ID, a store ID and an SKU ID. The columns are given by properties of the transactions and the days of the examined month, as you can see it on Figure 8.

	A	B	C	E	F	G	H
1	Transport informations						
2	Mall ID	Supplier ID	Shop ID	Opening stock	1	2	3
3	SM001	SUP0001	SH0001	4,8	4,8	4,8	4,8
4	SM001	SUP0002	SH0002	43,1	17,1	17,1	33,1
5	SM001	SUP0003	SH0003	47,1	47,1	47,1	44,1
6	SM001	SUP0004	SH0004	264,1	298,1	308,1	275,1
7	SM001	SUP0005	SH0005	69,4	69,4	21,4	71,4
8	SM001	SUP0006	SH0006	849,6	849,6	72,6	72,6
9	SM001	SUP0007	SH0007	374,4	60,4	=MAX(0;I	60,4
10	SM001	SUP0008	SH0008	361,7	366,7	391,7	388,7
11	SM001	SUP0009	SH0009	23,4	20,4	20,4	10,4
12	SM001	SUP0010	SH0010	140,9	43,9	43,9	43,9
13	SM001	SUP0011	SH0011	2542,1	2778,1	2869,1	2203,1
14	SM001	SUP0012	SH0012	663,6	844,6	1075,6	992,6
15	SM001	SUP0013	SH0013	44,1	193,1	416,1	416,1

DAILY WEIGHT | DAILY VOLUME | SUP MAT HAND (T) | SUP STOCK (W) | STARTING POINT | DISTANCE (C) | DISTANCE (L) | PERFORMANCE (C)

Figure 8: Calculation of the suppliers' stock parameters in the simulation model of the current system

In the case of some parameters (delivery transactions, goods amount, performances) in the current system, the processes needed to be handled per hour, as it was possible to have the same delivery transaction more than once in a day, with different parameters.

3.2.2. Simulation model of the new system concepts

The second component of the simulation model (its other workbook) describes the processes of the new system concepts. Between the suppliers and the CC, it handles the processes similarly to the current system, the different transactions can be found in different rows. It generates all parameters by stores, suppliers and days on different worksheets, and it generates the actual demands of the stores and the amount to be delivered in the same way.

In the case of the consolidated deliveries from the consolidation centre, the simulation model handles all processes consolidated by CSDP and SKU ID, so we can see the processes by the examined CSDPs and days, still on different worksheets, as it can be seen on Figure 9.

	A	B	N	O	P	Q	R	S	T	U
1			Daily deliveries/shopping mall [kg]							
2			12	13	14	15	16	17	18	
3	SM001	SKU001	28485,3	28102,3	27232,9	28942,5	20341,3	26250,0	31589,1	2540
4	SM006	SKU001	11520,3	21571,4	8108,9	21077,4	8060,7	23252,3	5494,2	545
5	SM018	SKU001	6836,2	10018,4	13606,2	12309,7	13004,7	14163,4	12472,7	11071
6										
7			Daily deliveries/shopping mall [m³]							
8			12	13	14	15	16	17	18	
9	SM001	SKU001	112,7	135,7	102,1	115,5	79,7	112,3	142,2	121
10	SM006	SKU001	72,6	95,4	76,4	88,2	56,5	79,7	39,9	48
11	SM018	SKU001	57,9	83,2	99,5	80,0	113,8	121,2	110,1	10
12										
13			Count of deliveries/shopping mall/day (road vehicle)							
14			12	13	14	15	16	17	18	
15	SM001	SKU001	4	4	4	=KEREK	3	4	5	
16	SM006	SKU001	3	3	3	3	2	3	2	

HOME DEL DEM (W) | HOME DEL CC-SM (W) | CC-SM DELIVERIES | DISTANCE (C) | PERFORMANCE (C) | CONSUMPTION (C) | EMISSION (C)

Figure 9: Calculation of the number of consolidated deliveries in the simulation model of the new system

To calculate the number of deliveries for each CSDP is one of the most important components of the simulation model of the new system concepts. The simulation model handles the same time (on the same worksheets) the deliveries by lorries and by trams and generates the parameters for each of them.

3.2.3. The simulation process

After developing the simulation model in MS Excel both for the current system and for the new concepts, it was validated and verified based on the goods amounts in the delivery, empty handling, and home delivery processes, and the experiment design and simulation runs were automated. The simplified process of the simulation runs can be seen on Figure 10.

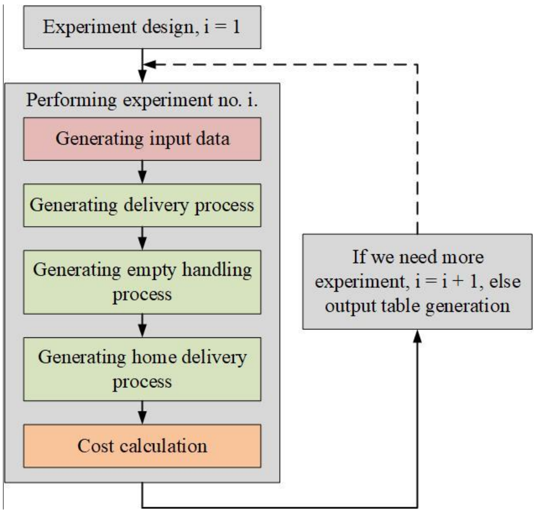

Figure 10: The simplified simulation process

We can declare that the developed mathematical model and the simulation model structure are general, we can examine all types of the CSDPs by use of them. In former city logistics projects, this kind of general device was gravely missing.

3.3. Modelling specialties of shopping areas

In case of the CSDPs with closed infrastructure, the floor map of the given building gives us the area where the processes can be examined; the internal routes can provide the material handling distances, the time values etc. In the case of open infrastructure, primarily at shopping areas, a more extensive area must be examined, where there are lots of stores, loading areas, cross docks, there are several special road traffic regulations and more external connections with the transportation infrastructure. Because of these, we need a different approach to the modelling, and the topological model of the examined area is needed to be developed, in addition to the existing mathematical and simulation model. This can make it possible to examine the routes, distances and time values, and in the future, it is going to help to integrate e.g. location search algorithms into our simulation model.

The first step of the topological modelling was to develop the data structure, which can provide the city logistical

topological model of shopping area after appropriate data collection. The frame of this data structure is defined by the graph of streets and nodes in the area. The edges of the graphs are the urban roads (so the road infrastructure) and the nodes are the contact points or breakpoints of the roads. In this model, several objects and their attributes had to be defined with considering both the current and possible future logistics solutions. In the topological model of a shopping area, the following objects are handled: roads, nodes, urban railways, railway nodes, bus stops, waterway docking points, commercial and service stores, accommodations, store-groups, brownfield lands, parking areas, connecting points of the transportation subsectors and barriers. They have several properties, e.g. size, capacity and coordinates. In this data structure, the roads are in the centre of the model and the other objects are assigned to them.
After developing the topological model, we performed data collection for a shopping area in Budapest. For this, several public online databases were used, and on-site data collection was performed too. The results of the data collection can be seen on Figure 11. This topological model makes it possible to implement the models for shopping areas, therefore this is a critical element for our future research.

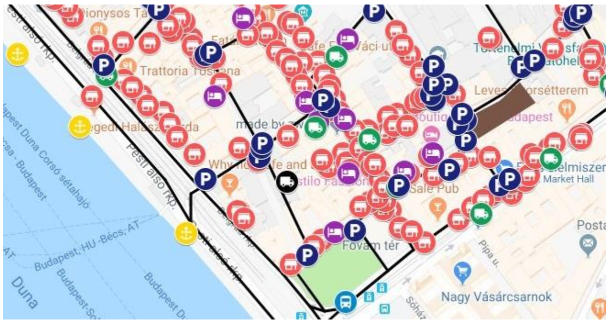

Figure 11: Topological model of a shopping area in Budapest, on Google Maps

In the next section, we are going to present the results of the simulation runs for three shopping malls, but we started to examine with this model shopping areas too.

4. RESULTS OF THE SIMULATION

In the simulation, the processes of 178 stores from three shopping malls were examined; their data (from the data collection phase of the project) was the most detailed and most exact (Sárdi and Bóna, 2017). After experiment design, we performed 100 experiments for all system concepts. This number of experiments proved to be sufficient to make conclusions about the examined parameters with 95% reliability.

4.1. Performance and emission in the current system

Based on the results of the simulation, in the current system in one month (for 178 stores of three malls in Budapest), the sum amount of goods is 1,346.1 t (st. dev. 31.8 t, min. 1,275.7 t, max. 1,427.1 t). This generates 44.8 t of empties to be handled (st. dev. 0.4 t), and 54.1 t of all the good must be delivered to homes (st. dev. 2.3 t) from the shopping malls. So, in the current system there are monthly 3,396.7 delivery transactions to the malls (st. dev 16.5, min. 3,360, max. 3,451) and all of them have an inverse version (with or without empties to be handled). In addition, there are monthly 4,097 home delivery transactions in the examined system (st. dev. 72.8, min. 3,952, max. 4,250).
During these transactions, the vehicles need to go 635,385 km, which generates monthly 3,132.2 l petrol, and 37,253.1 l fuel oil consumption. This consumption generates high emissions. As an example, the CO_2-emission is 7.11 t monthly and the NO_x-consumption over a month 14.3 kg for 178 stores. During the delivery and empties handling tasks, the sum delivery performance is 152,851.7 tkm in the current logistics system.

4.2. Performance and emission in the new system

The current system can be compared with the two examined, gateway-concept based solutions based on the results of the simulation runs.
In the new concepts (based on the experiments), the modelled goods amount is 1,356.2 t between the suppliers and the consolidation centre (st. dev. 77 t, min. 1,173.4 t, max. 1,611.0 t). Between the CC and the stores, 1,338.1 t goods are delivered (st. dev. 41.5 t, min. 1,241.2 t, max. 1,435.2 t), based on the experiments. The difference between the expected values comes from the independent experiments and from the independent random number generation. In case of empties, we deliver 43.9 t (st. dev. 2.7 t) and 47.4 t (st. dev. 1.6 t) on the two main section of the delivery routes, and there is monthly 49.8 t (st. dev. 3.7 t) of home delivery goods in the modelled new system.
These amounts are generating 1,338.9 delivery transactions per month between the suppliers and the CC (st. dev. 16.7, min. 1,305, max. 1,380). Between the CC and the CSDPs, there are monthly 268.7 consolidated transactions by lorries (st. dev. 6, min. 255, max. 283) or monthly 123.1 transactions by trams (st. dev. 3, min. 115, max. 130), if 90% average utilization rate is expected. The comparison of the number of transactions can be seen on Figure 12.

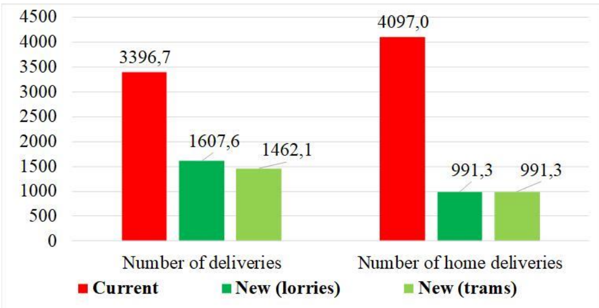

Figure 12: The number of delivery transactions

To perform these transactions in the new system, the vehicles need to travel 316,109 km, if we use lorries (so the sum distance is reduced by 50.2%), which generates 1,729.2 l petrol consumption (reduced by 44.8%) and

17,473.8 l fuel oil consumption (reduced by 53.1%). This pulls the reduction of emission, for example CO_2-emission is reduced to 3.5 t (by 51.5%). If trams are used in the new system, the sum distance is reduced to 312,890.1 km based on the simulation results (by 50.8%), and these transactions by trams give us 17,169.2 kWh electricity consumption, and it reduces a little bit more the sum emission in the new system. In case of lorries, the sum delivery performance is 174,983.4 tkm (14.5% growth), in case of trams it is 181,136.9 tkm (18.5% growth). In case of the delivery performance, there is growth because of the new node in the system (the consolidation centre). Therefore, all the goods need to travel more, but because of the reduction of the number of transactions, all the other parameters are reduced in the new system. The change of some important parameters (in percentage, where the current system is 100%) can be seen on Figure 13.

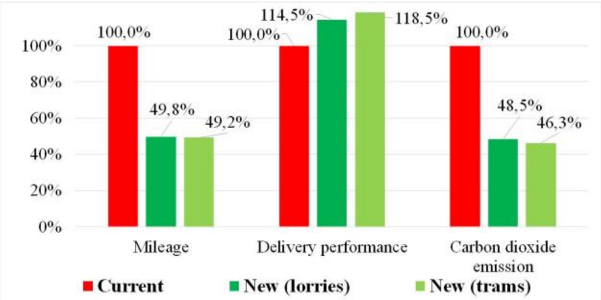

Figure 13: Comparison of the current and new systems

4.3. Cost parameters

After analysing the performance parameters, the costs had to be examined too, based on the simulation. Earlier, we assumed that the operation of the new system is going to be more expensive because of the new node (CC). Based on the simulation runs, the sum logistics operation cost (for 178 stores; these costs must be payed by the storeowners) in the current system is 287,993 EUR/month (st. dev. 6,859 EUR, min. 273,489 EUR, max. 311,067 EUR). Most of it comes from the delivery cost, which is 229,411 EUR/month.

Contrary to our assumptions, based on the experiments we can reduce the sum logistics costs in the new system. By use of lorries, it is 216,153 EUR/month (st. dev. 4,654 EUR, min. 206,579 EUR, max. 227,125 EUR, 24.9% reduction), and by use of trams, it is 195,599 EUR/month (st. dev. 4,815 EUR, min. 183,423 EUR, max. 206,836 EUR, 32.1% reduction). This is a significant reduction, mostly due to the reduction of the delivery cost (by lorries 43.8% and by trams 53.9% reduction). This means that in the new system, not only the performances and emissions, but the operation costs could be reduced as well, this is one of the most important results of the simulation runs. In the future, the analysis of the investment costs and the sizing of the nodes of the new concepts are going to be very important tasks.

By use of the simulation model, we performed sensitivity analysis too, looking for the correlation between the sum savings and change of some parameters. Based on the results of the simulation, the growth of the number of deliveries (and with them the growth of the goods amount) has the most significant effect, because of the high impact of the delivery costs. By use of the real (current) input data, the saving is 71,840 EUR/month, which is going to be 211,216 EUR/month with the number of deliveries doubled. The change of specific delivery costs has also a significant effect (this scenario can be significant e.g. in case fuel prices growth), but the growth of the home delivery share does not change the savings significantly, as it can be seen on Figure 14.

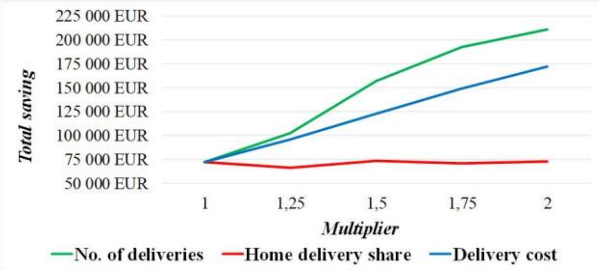

Figure 14: Change of the total savings

5. NEXT STEPS OF THE RESEARCH PROJECT

Naturally, there are several additional tasks in our research project, especially with improving the simulation model of the logistics systems of CSDP. The MS Excel based discrete event simulator became slow because of the big amount of data to be handled, so we started to develop the simulation model in an agent-based simulation software, which also has a supply chain simulator module. The pilot simulation model in this software gave us similar results for the new system with lorries for one shopping mall. In addition, we reckon that it is still a possible direction to examine discrete event simulator, but instead of MS Excel we would like to test a specific simulator built for this system. It is going to be significant to develop the simulation model in one of the above modes, and we would like to examine the shopping areas by use of our simulation models as well. We created a pilot model for them and the results were similar to the earlier presented ones.

Sizing of the system is going to be also very important. We started this phase of our research with sizing cross docks for open and closed infrastructure CSDPs, and we are going to continue this phase with examination of consolidation centres and loading areas. In their cases, not only the sizing going to be significant, the calculation of their number and optimal location by use of the simulation model can be also a vital task of our research.

6. SUMMARY

We started our research without any real data about the logistics systems of concentrated sets of urban delivery points, so earlier the effects of new logistics solutions could be only estimated without specific, general models. In the first phase of our project, we collected data of 490 stores of four CSDPs, to construct the current structure and provide input for the models. In the next steps, we developed some new city logistics solutions, the mathematical model and the mesoscopic simulation model of the current and new city logistics systems of CSDPs, and the topological model of shopping areas. *These models can make it possible in the future to examine the given concentrated sets by simulation*, if the input data is available. The provided simulation results are going to help us to compare the current system with new system concepts in terms of performances and costs. Earlier, without a general simulation model this was not possible, and in former city logistics projects only some subsystems (e.g. only shopping malls or only shopping areas) were examined.

Based on the results of some former European projects and our simulation results, we can conclude that there is a significant saving potential in the operation of new, gateway-concept based systems compared to the current one, in case of the concentrated sets of urban delivery points. Performance and emission parameters could be reduced by up to half, with 25-30% reduction of the logistics operation costs. The investment costs of new systems can't be neglected but based on the results it is clear that the presented models can provide us the necessary information in the design phase of new city logistics systems for CSDPs. These models are going to make it possible to develop the optimal system architecture, to choose the best city logistics solutions, so they are going to help green logistics efforts, make cities more liveable, and to help future city logistics projects.

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