

Macroscopic simulation model of a multi-stage, dynamic cargo bike-based logistics system in the supply of shopping malls in Budapest

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Abstract — Nowadays, it is a big challenge to handle urban freight problems. To handle these problems is a significant task worldwide, because it is important to reduce environmental pollution and the overload of the city roads to make to cities more liveable. Within the urban freight transport problems, the so-called concentrated delivery points (shopping malls, shopping areas or markets) must be highlighted, because in these places there are several shops in a relatively small area. Deliveries of this kind of points mean a heavy load for the urban roads. In 2015 we started to examine the logistics system of the shopping malls in Budapest. In our research, we developed a mesoscopic simulation model, which was presented at the Smart Cities Symposium in 2017. In our paper, we would like to present a macroscopic simulation model, which was developed from our other, mesoscopic model. This new model makes it possible to examine a special logistics system, which can provide services for nearly 2000 shops of 18 shopping mall by use of cargo bikes and electric trucks in two-stage and three-stage systems. The model generates the required number of vehicles for the multi-stage logistics systems and shows us also the performances. Based on the results, we can say that such a system can reduce environmental pollution and the load of the roads on the one hand, but on the other hand naturally they have a significant investment demand too.

Index Terms — logistics, city logistics, modelling, shopping mall, simulation, simulation modelling, cargo bike, smart city

I. INTRODUCTION

In the last years, smart devices have become an important part of our everyday lives. The development of ICT is still unbroken, and they have more and more important roles in the city operation, so also in logistics. Smart city is now not only concept, it is more and more a part of our life. A smart city uses the available technology, information and communication possibilities in an innovative way and it helps to form a more sustainable and more liveable urban environment and makes the considered treatment of the natural resources possible [1].

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We can say, in spite of all this, that ICT itself can't answer a lot of important problems in the organization of cities, so does the city supply and all the other task in logistics. If we are not able to organize the operation of city logistic in a rational way, then we can't achieve success, and neither can we keep the sustainability and green city logistics principles. That is why we find it important to examine the phenomena from the organization-technology side too. In our view the real and the best solutions can be found in the intersection of organization and technology.

The aspirations to develop the freight traffic service of centres of big cities are particularly in focus in the Horizon 2020 [2] cycle. The main reason of this is that operation of supply in most big cities is wasteful and does not deal (or deals just a bit in some cases) with the essential principles of the green logistics mentality. The consequence of this all is that in the operations of city logistics systems there are possible huge economic potentials too. The only problem is that it is hard to show this savings, because many stakeholders (both the providers and the users) are interested in the operation of this system, so the global community interest stays unfortunately hidden, and the number of stakeholders makes it hard to measure and examine the processes [3].

This all motivated us, in 2015, to start to examine the logistics system of shopping malls (and other concentrated delivery points), primarily in Budapest, the city we are most familiar with, and we have examined in several previous projects. Our city logistics research group made several studies about the urban logistics system of Budapest [4], but we couldn't collect detailed data about the logistic characteristics of shopping malls earlier. Our first step was to develop a standard research methodology, which helped us to examine 327 shops of 3 shopping malls [5] and particularly a shopping area. As a result of this, we have data which described the logistic processes of the shops and this data made it possible to simulate these processes. Our mesoscopic simulation model was developed in MS Excel and its main functions were operated by random generators. In the simulation, we examined the processes of the current logistics system and a new, green city logistics system, where we placed a consolidation center between the suppliers and the shopping malls and logistic areas of the malls were replaced by cross docks. In this system, we served the shops of malls from consolidation center by green trucks, lorries and by trams. The results show us that it is worth to examine this kind of consolidated city logistics systems, because the performances were reduced in the new system - in the city even

by 90% and therefore the consumption and emission can be reduced too [3]. Our next examination showed us that on a mesoscopic level we can reduce also the costs by 25% in the new system. This is the reason as to why we started examining more complex systems. In this paper, we will examine multi-stage dynamic city logistics systems, where we use also the increasingly popular cargo bike in the logistics system of shopping malls in Budapest. Our main purpose in modelling was to get information about the necessary number of vehicles (electric trucks and cargo bikes) in the new system, while examining also the performance parameters in the current system and in the new system concepts.

II. CARGO BIKES IN CITY LOGISTICS NETWORKS

Cargo bike deliveries are more and more popular worldwide. In several European cities (for example in Milan, Italy and Barcelona, Spain) they take part in the urban freight traffic and there are more and more cargo bike deliveries also in Budapest. The distinct types of cargo bikes can be used for small package shipping and with use of the bigger bikes we can deliver pallets too, so cargo bike system can handle very different delivery tasks. They can handle the inbound deliveries of shops, the inverse logistics tasks, the home deliveries or the deliveries between shops. We can say that in the most European cities, every second delivery task could be handled by cargo bikes instead of lorries or trucks [6].

The cargo bikes used in urban freight traffic can be two-wheeler, three-wheeler or sometimes four-wheeler vehicles. Within these categories, they can be fully human powered or assisted bicycles. The currently examined cargo bikes are assisted and they have also cargo area or cargo box for the delivered goods. In Budapest, nowadays there are approximately 10 companies using utility bikes for deliveries. In this city, some companies have two or three-wheelers cargo bikes (the BULLITT type cargo bike of Hajtás-Pajtás company can be seen on Fig. 1.). There is also a possibility to hire cargo bikes, like in a new system in Vienna, Austria [7]. There are some cargo bikes that are used for public space surveillance in the city, and earlier a company used cargo bikes in their waste management system. The cargo bikes in Budapest are usually used for small package shipping, and they are seeing a bigger and bigger role in the city logistics system of Budapest. At one of the biggest companies with cargo bikes in Budapest the share of cargo bike deliveries has increased more than tenfold since 2009, while in the same time the share of the motorized vehicles has decreased [6].



Fig. 1. BULLITT cargo bike of the Hajtás-Pajtás in Budapest [8]

Naturally, in other big cities in Europe cargo bike companies are operating with significant roles. DHL Netherlands must be highlighted, as they use special, four-wheeler cargo bikes (so-called quadracycles) in Almere, Netherlands, in the agglomeration of Amsterdam. In this special city logistics system, they deliver the goods by a lorry to the border of the district, which is served by the quadracycle. At the district-border they load the special intermodal unit to the cargo bike (see on Fig. 2.). This intermodal unit makes the loading operation much easier [9].



Fig. 2. Loading the DHL quadracycle in Almere, Netherlands [10]

Our previous research shows us that in the city logistics system of the shopping malls in Budapest, there are several tasks they can be served by cargo bikes. 79% of the examined shops uses boxes as delivery units, so small packages are the most popular, which can be usually delivered by cargo bikes too. Other results show us that there are often deliveries between shops, and home delivery tasks that must be handled [6]. Usually they are also small packages, so it is possible to adapt them into a cargo bike logistics system.

III. GEOMETRICAL MODEL OF THE SUPPLY SYSTEM OF SHOPPING MALLS IN BUDAPEST

At the formation of the structure to be modelled, it was a key step to develop the geometrical model of shopping malls. First, we defined an inner ring (in the city center), where we can find the so-called central shopping malls (in our case 6 malls). After this, we defined rays which were assigned to the central shopping malls. On these rays, there are further shopping malls (in our case 12 further malls, see on Fig. 3.).

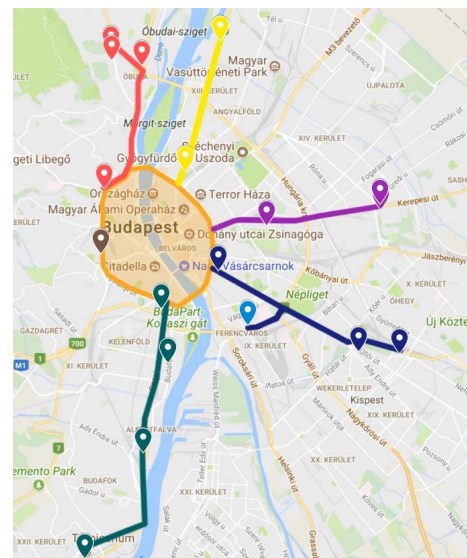


Fig. 3. The examined shopping malls in Budapest, on Google Maps

We can see on the figure above, where are the shopping malls (18 malls) in Budapest, with the inner ring and the rays. This map was the base of creating the geometrical model. On Fig. 4., the geometrical model of the logistics system of shopping malls in Budapest can be seen with the inner ring and the rays.

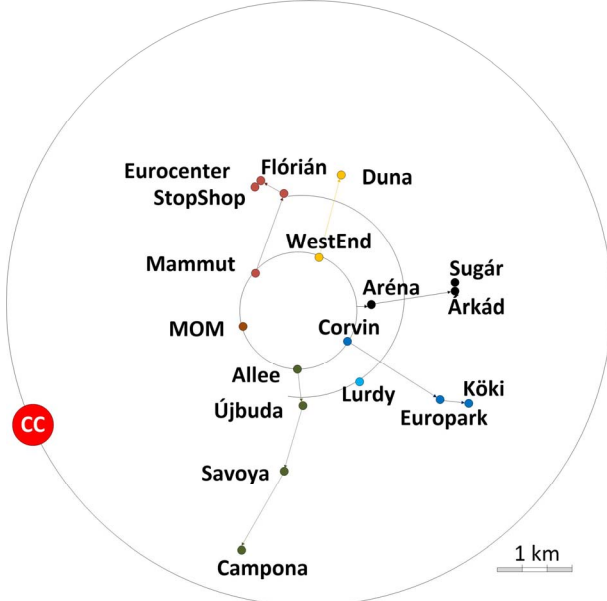


Fig. 4. Geometrical model of the supply system of shopping malls in Budapest

This geometrical structure makes it possible to assign the deliveries to the central shopping malls. In this system, there is an outer ring (in the case of Budapest, this is motorway M0), the consolidation center can be found near this because of the transport connections. We assigned an exact location for the center because of the simulation. In the modelled new system, the electric truck (which functions in this system as a “mobile storage”), which goes to the central shopping malls. We use the logistics area of the malls as a cross dock and serve the further malls on the rays by cargo bikes from the cross docks.

IV. THE MACROSCOPIC SIMULATION MODEL

We developed our macroscopic simulation model in MS Excel, based on the mesoscopic simulation model we developed and presented earlier [3]. It models the current system with use of aggregated data of 18 shopping malls and also models four other innovative, multi-stage city logistics system concepts. It models the system by shopping malls on a macroscopic level.

A. Presentation of the modelled cases

In the model, we examined four cases (four new city logistics systems), the first one is a two-stage system, the other three are three-stage system with cargo bikes.

In the first case (system concept “A”) we can integrate every delivery of the shopping malls into the system, and the goods will be delivered from the consolidation center at the city border by use of electric trucks. This one is a two-stage system, where the suppliers can deliver to the consolidation center at the city border, and a city logistics provider delivers from there to the shopping malls by use of electric trucks, with FTL and also LTL organized routes. In this case, the first stage is the center and the second stage are the cross docks in the shopping malls.

In the second case (system concept “B”) the shopping malls are divided into two groups, like in the geometrical model of the supply system of shopping malls in Budapest. The suppliers can delivery again to the consolidation center. From there, we deliver the goods to the central shopping malls by use of electric trucks, and we deliver the goods from the central malls to the other shopping malls on the rays by cargo bikes. So, in this system, the first stage is the consolidation center, the second stage the cross dock in the central shopping malls and the third stage the cross dock in the shopping malls on the rays. In this system, the tours have always a various number of shopping malls and they go always to other malls of the system depending on the given demands, so we can say this is a dynamic system.

In this three-stage system concept, all goods of the central shopping malls will be delivered, but we integrate only those deliveries of the shopping malls on the rays, for them maximum one cargo bike tour is enough (the quantity of goods to be delivered is less than the capacity of one cargo bike), so if “Q” is the weight of the goods to be delivered, “V” is the volume of the goods, “C” is the capacity of the cargo bike (in weight or in volume) and n is the safety factor (in the simulation n=90%):

$$Q_{supply} \leq n \cdot C_{bike}^m \quad (1)$$

$$V_{supply} \leq n \cdot C_{bike}^V \quad (2)$$

The third case (system concept “C”) is similar to the second one. The only difference is that we integrate only those deliveries on the rays, for them a maximum two cargo bike tours are enough (the quantity of goods to be delivered is less than the sum capacity of two cargo bike, and the delivery can be divided into two part), so:

$$Q_{supply} \leq n \cdot 2 \cdot C_{bike}^m \quad (3)$$

$$V_{supply} \leq n \cdot 2 \cdot C_{bike}^V \quad (4)$$

The last (fourth) case (system concept “D”) is similar too. The only difference here is that we integrate only those deliveries on the rays, for them a maximum three cargo bike tours is enough (the quantity of goods to be delivered is less than the sum capacity of three cargo bike, and the delivery can be divided into three part), so:

$$Q_{supply} \leq n \cdot 3 \cdot C_{bike}^m \quad (5)$$

$$V_{supply} \leq n \cdot 3 \cdot C_{bike}^V \quad (6)$$

This means that in the different cases we limit differently the quantity delivered by cargo bike.

B. Operation of the macroscopic simulation model

The macroscopic simulation model has three main components. The first simulates the operation of the current supply system of the shopping malls in Budapest between the suppliers and the shopping malls.

First, the model generates the daily number of deliveries based on the input data and calculated probability parameters, this is the base unit of the simulation model (see on Fig. 5.). We developed such a random generator, which simulates the current system with 100% accuracy by month, so the monthly number of deliveries is the same as expected, based on the earlier collected data.

Fig. 5. The daily supply-generator worksheet of the simulation model of the current logistics system

The simulation model randomly generates, for the deliveries, the sum weight of goods (based on the daily minimum and maximum weight) and calculates the sum volume proportionally. Next, it calculates the sum delivery driving performance in the city, based on the location of the examined shopping mall. Further, the model calculates from this the delivery performance, the petrol and fuel oil consumption ([11], [12]) and from this the emission [13], [14].

The part of the model which models the new system concepts has two components. The first one simulates the volume to delivered into the malls, so it models the processes between the suppliers and the consolidation center. The output of the first component is the input of the second one, which simulates the processes between the consolidation center and the malls.

The base unit of the first component is the supply generator again, which works similar to the current system, so it says how many deliveries do we have from the suppliers to the consolidation center. Next it generates, for the deliveries, the daily weight of goods and the volume proportionally. In the

next step, it generates the number of deliveries and the weight to delivered from the consolidation center to the shopping malls. At this stage, the model examines the stock of the consolidation center and calculates the weight of goods which can be delivered to the shopping malls from the center. Based on this, it calculates the actual weight and proportionally the volume of goods which we deliver to the malls. Finally, it calculates the possible number of truck and cargo bike tours in the four ("A", "B", "C", "D") new concepts. As output data of this component, we will know with 95% confidence the interval of the parameters.

The other component of the model of the new system concepts generates the quantity of good to delivered in the four cases ("A", "B", "C", "D") based on the previous confidence intervals. Next, it assigns the deliveries to the central shopping malls based on the geometrical structure and calculates the required number of difference FTL and LTL-organized tours for every concept, calculates the performances, the sum time need and the energy consumption (see on Fig. 6.).

Fig. 6. The worksheet which calculates the necessary number of vehicles in the simulation model of the future logistics system

Finally, the model calculates the required number of vehicles (electric trucks and cargo bikes) for the four new system concepts, based on the geometrical model, the charging time, loading time and the driving performance.

V. RESULTS OF THE SIMULATION RUNS

Before the simulation runs, we generated the input data table and we did the design of experiment.

A. Input data of the simulation

In this project, we examine 18 shopping malls and we have exact data about three of them. Based on this data, the main profiles and the number of the shops in the examined shopping malls, we estimated the parameters of the other shopping malls.

First, we performed data cleaning for the data from the 327 shops in three malls - so we deleted or corrected the incomplete data series. Next, we calculated the expected values of the examined parameters (number of deliveries, delivery units, weight, volume and suitability of the examined BULLITT cargo bikes) for each profile. For these parameters we got four expected values: three for the three shopping malls we examined in our previous project and one general expected value based on every data. Next, with use of formula (7), we calculated the parameters of the shops of the three shopping malls that had not given us data in our previous project. So, the value of parameter “x” of the shop “i” (in shopping mall “l”) with profile “j” is the same as the expected value of the “x” parameters of the shops with profile “j” in the shopping mall l:

$$x_{i(j)} = M(x)_j^l \quad (7)$$

So, we know the overall parameters of the three shopping malls we examined in our previous project. Based on these expected values, with formula (8) we calculated the parameters for the 15 other examined shopping malls. So, the estimated value of parameter “X” of the shopping mall (which was not examined earlier) “l” is the same as the sumproduct of the number of shops with profile “l” (we have 20 different profiles) in the examined shopping mall and the overall expected value (calculated from every data) of the examined parameter:

$$X_l = \sum_{j=1}^{20} N_j^l \cdot M(x) \quad (8)$$

B. Results

Before the simulation runs, we performed the design of experiment with 95% reliability and 10% error. Next, we performed the required number of simulation runs for the current system and for the new system concepts too and finally we evaluated the results.

The monthly number of deliveries and parameters of the quantity of goods (expected value: $M(x)$, standard deviation: $D(x)$ and the lower and higher limit of the confidence interval with 95% reliability can be seen in Table I.

	Number of shops	Monthly number of deliveries	Sum weight [t/month]	Avg daily weight [t/day]	Sum volume [m ³ /month]
M(x)	1903	37900	21217	702,2	169 998,6
D(x)	constant because of the model structure	constant because of the model structure	412,9	13,8	3 342,1
LL			20921,6	697,4	167 607,8
HL			21512,3	717,1	172 389,4

The deliveries of the 18 examined shopping malls generate, monthly, 680.043 km mileage only in the city based on the estimated parameters. Because the number of deliveries is constant, the monthly driving performance in the city is constant. The monthly sum delivery performance is approximately 12,720 tons-km in the current system, the monthly petrol consumption is 5278.7 l, and the fuel oil

consumption is monthly 40,642.5 l only in the city. The emission from this consumption can be seen in Table II. We can see that in the current system the deliveries of the malls mean on the one hand a significant load for the roads in the city and on the other significant environment pollution.

	Monthly sum emission [kg]	Monthly sum emission per average shopping mall [kg]	Monthly sum emission per average shop [g]
CO	42	2,33	22
CO₂	8012,4	445,13	4210
HC	3	0,17	2
NO_x	15,8	0,88	8
PM	1,9	0,11	1

In the modelled new system concept “A”, we must handle the same quantity of goods, in system concepts “B”, “C” and “D” the quantity is less. In case “A” we deliver 708,14 tons (the standard deviation is 12,54 t; this means approximately 21200 tons per month) daily. In the other three cases the weight is smaller, and we deliver several tons of goods by cargo bikes. At the modelling, we calculated by use of electric truck EMOSS CM12, and by cargo bike BULLITT.

In case “A” we need 167 deliveries (truck tours) per day to serve the 18 shopping malls, and the expected value of delivery performance is approximately 12200 tons-km. The energy consumption in this case is daily 3506,8 kWh. The change of the parameters in the current system and in case “A” can be seen on Fig. 7.

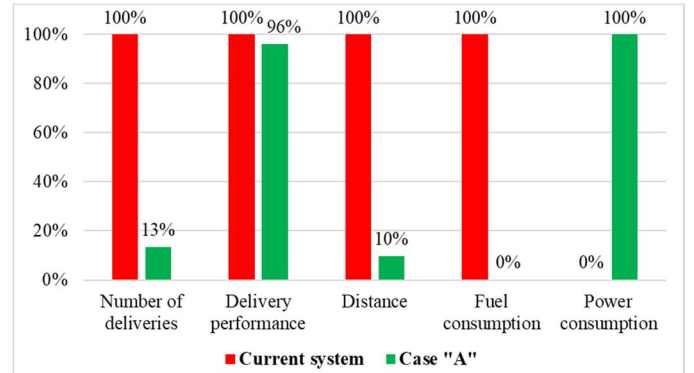


Fig. 7. Delivery parameters in the current system and in the examined case „A”

In the examined case “B” (where we do not integrate every delivery to the new system and we use cargo bike to serve the shopping malls on the rays), we need 96 truck tours each day, and 21 cargo bike tours. This generates approximately 6550 tons-km delivery performance daily and 1823 kWh energy consumption. In case “C”, we need 96 truck tours per day again, and 119 cargo bike tours. This means daily 6600 tons-km delivery performance and 1829 kWh energy consumption. In the last case “D”, we need 96 truck tours daily, again and 184 cargo bike tours, which means daily 6635 tons-km delivery performance and 1833 kWh energy consumption. We can see that the number of truck deliveries is constant, so we only need to add new cargo bike tours to serve the malls.

Now, we can calculate the required number of vehicles in the four examined cases, with use of parameters in Table III.

	Loading time [min]	Avg speed [km/h]	Battery [kWh]	Distance/one charge [km]	Charging time [h]
BULLITT	10	15	0,5	90	2
EMOSS CM 12	45	25	120	150	2,8

The expected values of the number of vehicles can be seen on Fig. 8. for the four examined cases. The standard deviation of these parameters was in every case under 1.

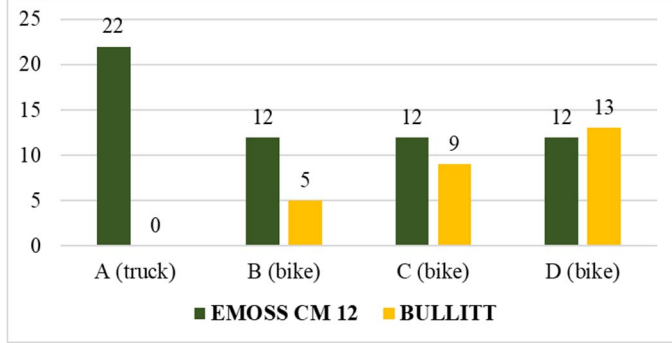


Fig. 8. Number of vehicles needed in the new system, in the examined cases

So, 12 trucks are enough in the examined three-stage systems and we must add 5, 9 or 13 BULLITT cargo bike to them. We can see, the expected value of the number of vehicles is not too high, we can serve 18 shopping malls (with 2,000 shops) with use of these vehicles. This shows us that it is worth to examine this kind of new city logistics systems and we should start to deal with developing the theoretical components of this system.

VI. CONCLUSION

In this paper, we presented a city logistics system with cargo bikes for the supply system of shopping malls in Budapest and the macroscopic simulation model of it. Our results show us how valuable it is to examine these special systems.

Naturally, there are several further important tasks. First, we need to examine how to integrate those goods into this system that cannot be delivered by use of cargo bikes; and we need to develop some other system concepts using other vehicles, for example freight trams or cargo boats.

The most important step is to examine the costs, which is now in progress. First, we developed the mathematical model of the cost structure for our mesoscopic simulation model which was the base of this macroscopic model. Based on the simulation runs, we could reduce the logistical costs of the supply system of shopping malls by 25% with use of the examined two-stage system [15]. We need to add this cost model to the macroscopic simulation model too. In this system, we need to examine the investment costs, because in this three-stage system the infrastructure, the IT system and the electric freight vehicles are going to mean extra costs.

There is an other interesting question which should be highlighted: what happens if the weather does not allow it to deliver by use of opened construction cargo bikes (e.g. it is too cold and the ways are slippery etc.)? On the one hand, in this special case we can use electric lorries in the system (for example Nissan eNV-200) and on the other hand there are also

bikes with covered construction (like in case of Barcelona, where the bike drivers are protected from the daylight [16]). This means, we can operate in this system in case of severe weather conditions too, and naturally in the construction phase we must take into account this.

It is very important to highlight that we developed such a simulation device, which helps us with the appropriate input data to examine a special, dynamic and green city logistics system, which uses electric truck and cargo bikes. This system could mean a significant emission and amortisation reduction. In the future, we can naturally integrate other concentrated delivery points into this system, such as markets, shopping areas or shopping streets. This system could be a great device in a well-organized smart city to overcome the problems of city freight transport.

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