

# Developing a mesoscopic simulation model for examination of freight traffic of shopping malls in Budapest

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**Abstract** – Within the city freight transport the supply of shopping malls is a significant challenge. In Budapest there was no project to treat the logistics of the malls as a system. In the capital of Hungary there are 18 shopping malls, which are big city logistics junctions and now there is no possibility of a consolidated system to supply them. Budapest is the biggest city of Hungary; which area is 525,2 km<sup>2</sup> and the population is 1.750.000. In this city (in 2015) there were 32405 retailers, and more than 3000 of them were in shopping malls. This means, that more than the 10% of retailers of the city are concentrated in these 18 junctions. We started our project in 2015 to deal with the logistics characteristics of the malls on Budapest and we developed a methodology, which is suitable to examine the freight transports and the city logistics parameters of the malls. With our methodology we measured 3 shopping mall and more, than 300 shop of them. After this we prepared our mesoscopic simulation model, which helps us to examine the goods supply of the malls. This model is suitable to show us, which advantages it can have, when we organize the supplies of the malls in consolidated city logistics system.

**Index terms** – city logistics, consolidation scheme, shopping mall, mesoscopic model, simulation

## I. INTRODUCTION

We can say that smart devices became a part of our everyday life. The development of information and communications technology is unbroken and they have more and more important role in the city operation. Smart city is now not only concept, it is a part of the life. A smart city uses the available technology, information and communication possibilities in an innovative way and it helps to form a more sustainable urban environment and makes the rise of living standards and the considered treatment of the natural resources possible [1]. ICT itself can't answer a lot of important problems in organization of the cities, so does the city supply.

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If we can't organize the operation of city logistic in a rational way, which can keep the community interests in mind, then we can't achieve success and we can't keep the sustainability and green city logistics principles neither. That is why we find it important to examine the phenomenon from the organization-technology side too. By our view the real 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 H2020 cycle. The clear reason of this is that operation of supply in the most of big cities is wasteful and does not deal (or deals just a bit) with the essential principles of the green logistics mentality. The consequence of this is that in the operation of city logistics systems there are huge economic potentials too. But it is regrettable, that it is pretty 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. This gave us the motivation to form a simulation system model, which can make as to be able to estimate these potentials. Because the complex system of city logistics is too large, the first centre of our research were the shopping malls. To supply them in this concentrated form is a significant part of the whole city trade freight traffic in the case of most big cities. This led us to think that we have a great possibility to develop a simulation system model, based on the logistic system of shopping malls, which can help us later to examine the other segments of city supply too. In our paper, we are going to expound a mesoscopic simulation system model, which helps us to compare the current logistic system of shopping malls and the city logistics alternatives, and we can evaluate the differences between them with use of various indicators.

## II. EXAMINATION OF THE LOGISTICS PARAMETERS OF SHOPPING MALLS

### A. The methodology

We started in the summer of 2015 to examine the logistic characteristics of shopping malls in Budapest and we realized that there is no available data to prepare the appropriate analysis. So, we developed a methodology based on measurement and observation, by which the logistical characteristics of the shopping centers can be obtained. The methodology has two parts: an exploratory research segment

and questionnaire. We tested it on a middle-sized shopping mall in the center of Budapest [2] [3]. Later we made some changes on the methodology based on the results of the test, and then we added some specific questions (about deliveries between the shops, e-commerce and cargo bike deliveries) then to it, because of a research about using cargo bikes in Budapest. With this methodology, we examined two more shopping malls, so we have now data for 3 shopping malls and 327 shops of them, which means approximately the 10% of all the shops in malls. Now it is time for focusing on development a simulation model, which is suitable to examine the current logistics system and possible future systems too, which can integrate the green city logistic points of view.

### B. Results

After the examination of the three shopping malls it got proved, that the problems we expected in the case of logistics processes of the malls are real (for example there are unreasonably too many transports) [2] and they cause disruptions in organization of the supplies of the malls.

In case of more than 60% of the retailers (they have more shop than one) at least the half of the shops can be found in shopping malls, this shows us that it worth to deal with the integration of supplies of them into a consolidated logistic system. Most of the vehicles is lorry (total weight less than 3,5 ton) or car. This means that in there are only a few items in a transport and this means the lot of supply transaction. In all 3 cases, more than 80% of the shops deliver in boxes, and less than 30% of them use pallets, so the smaller non-standard sized delivery units are usual. There are lots of fragile and perishable goods, the handling of them means another important challenge. The moving of the goods is made by the employees of the shops or the delivery employees in every case. This means that the shop workers must spend lot of time on moving goods or the freight vehicles must wait while the driver is working. The number of daily supply transactions is very high, there is 0,738 daily transport per shop in average. This number is huge, but in a consolidated city logistics system it would be possible to reduce it. We can estimate the sum of delivery transactions of the shopping malls in Budapest starting from this value: there are more than 2300 transports to the approximately 3000 shops of 18 malls per day.

All in all, there are several problems and challenges in case of the shopping malls, with which it is worth to pay attention on. After examination of three shopping malls we can say that now enough data is available to start to create the grounds of possible alternative logistics systems. These could make possible the rationalization of supply of the shopping malls and they could serve green points of view too. It is important to highlight that a well-organized consolidated common logistics system could be advantageous for the city transport system too. There are several possibilities for this system, and if we integrate the data (we obtained from our methodology) into a simulation model, it is going to become possible to examine them and then we can compare the current system with the

results of simulation.

## III. COMPARING OF THE CURRENT SYSTEM AND THE POSSIBLE FUTURE SOLUTIONS

### A. Evaluation of the current system

Now the supplies of the shopping malls work as we can see on Fig. 1.

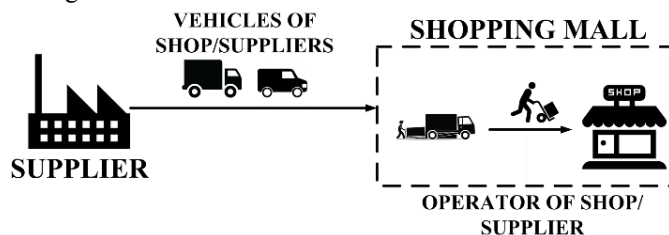


Fig. 1. Current (one-stage) supply system of shopping malls

From the supplier the shop, the supplier itself or a logistics provider transports the goods to the shopping mall. In the mall from the ramp (which means the logistics area of the mall) or in several cases from the parking the employees of the shops or the drivers must move the goods in the shops or in the storages. In the other, two-step case a logistic provider is added between the supplier and the shop. In this case the shops do not take part in the supplies and sometimes the provider makes some consolidation in the system.

The suppliers serve the shopping malls usually in FTL-system (there is LTL only in some cases). So it means except for access delivery transactions in most of cases. There are deliveries between the shops too and the e-commerce transactions are made mixed from the shops and from central stock of the retailers. The different kind of transactions are not coordinated in lot of cases. We can see the logistics network of the malls on Fig. 2. Green or red lines are the deliveries between the supplier and the shops, blue lines are the deliveries between shopping malls, light blue and orange lines are deliveries between malls and other shops, purple dashed lines are the e-commerce transactions.

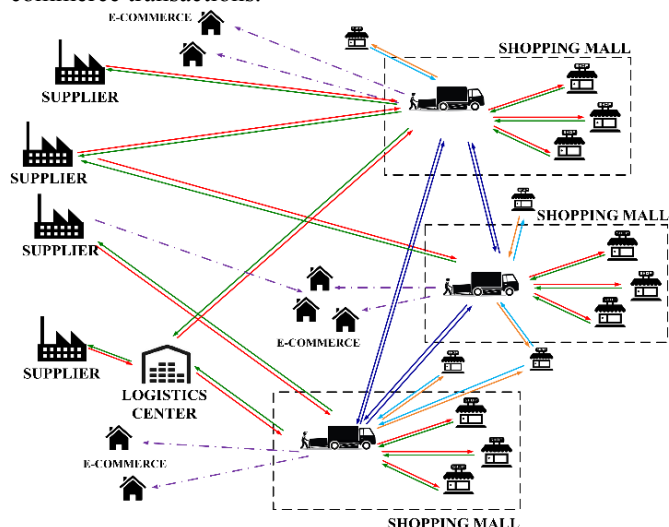


Fig. 2. Current logistics system of shopping malls in Budapest

### B. Evaluation of the possible future solutions

In the simulation modelling our purpose was examination of the vision on Fig. 3. Into the system we added a consolidation center, from where a city logistics provider transports the goods through a cross-dock warehouse (which replaces the freight ramp of the mall and integrated to the loading system of shopping malls) to the shops. Then the consolidation center can take inventory function over. Using by the consolidated city logistics units, the number of supply transactions can be reduced, which means the reduction of load of the city roads. In the mall the handling of the goods is going to be a function of an internal provider, so the employees of the shops must work less.



Fig. 3. Possible future (multi-stage) supply system of shopping malls

One possible consolidation-based future formation of the logistic system of shopping malls is modelled by the logistics network which can be seen on Fig. 4. The colours of the lines are the same than earlier on Fig 2.

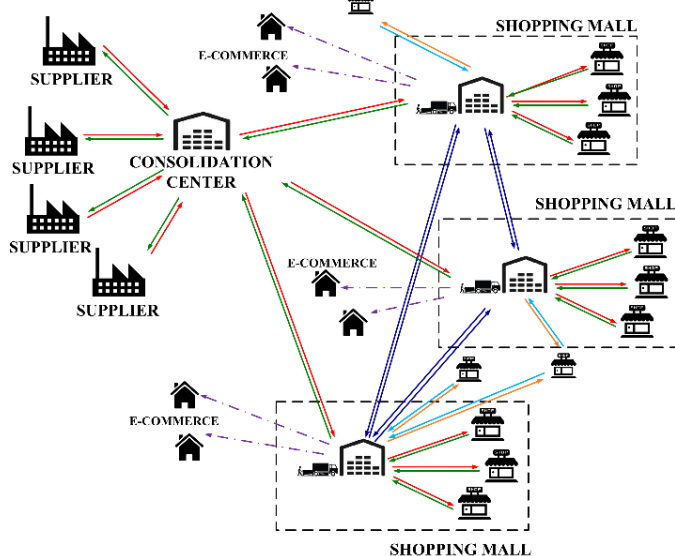


Fig. 4. Possible future logistics system of shopping malls in Budapest

In this case the goods is transported from the suppliers to a consolidation center, from where it can be transported by the city logistics provider to the cross-dock of the shopping mall. Then we can adapt the deliveries between shops and the e-commerce transactions to this system at the cross-dock and we can synchronize the different kind of transports.

One of the most important parts of the imagined system is the consolidation center (later: CC). It is important that is must be approachable by road and rail vehicles too. The CC must take logistics services from the suppliers over. The most important role of the CC is to perform the delivery transactions, so it must deliver the incoming goods to the appropriate shopping malls.

The cross dock in the shopping mall must fit (in the viewpoint of logistics network) to the CC. The logistics subnetwork, which consist of the CC and the cross dock, adumbrates the vision of a closed system, which is operated by a city logistics provider. Than the responsibility of holding the service levels is devolved to the logistics provider. The CC can provide additionally inventory functions too. If they do, the delivery volumes to the CC from the suppliers are going to be bigger, considering the inventory cycle time.

In our present research, we are not going to examine the deliveries between the shops and the e-commerce, but later it is possible to add them to the simulation model. It is important to highlight that in theory we can model FTL and LTL too, but in the case of shopping malls there are such big volumes that in the most cases the result is an FTL-system. We have now right detailed data for 178 shops of 3 shopping malls. In these shops an average of 123 deliveries per day is done, and there are average 14,6 boxes and 0,5 pallets per delivery.

The freight vehicles are now in every case road vehicles, usually cars or lorries (total weight 1,5-7,5 ton). In case of Budapest in a system with CC there is two realistic alternatives: use of (possibly green) road vehicles or use of the tram-network. Use of cargo-ships is less possible, because some shopping malls are far from the water ways, and we can use cargo bikes only in deliveries between the shops or in e-commerce because of the volumes. In case of trams (freight trains on the tramway-network, see on Fig. 5.) in one supply transaction we can talk about bigger units of the goods. The carriages of the freight trams should have universal container superstructure, which can be used at the road transports too. In this case the goods can be delivered in the containers and in the cross dock we only have to change the full container to an empty one.



Fig. 5. Freight train with „Muki” [4] freight-tram in Budapest

## IV. EVALUATION OF THE MESOSCOPIC SIMULATION MODEL

The purpose of our simulation model is to show that the possible future system how can be better than the present one, examining by various points of view. In the model, we examined six main parameters: the number of transports, the distance of the city (covered by the deliveries), the delivery performance, the fuel/energy consumption, the emission and the parameters of the stock of CC. At the development of the model we concentrated on these parameters. We used for the modelling Microsoft Excel and VBA platform.

### A. Input data of the simulation model

After evaluation of three shopping malls we have data about 327 shops of them. In the first round we can work in the simulation model whit these data. From these we can use only

those, where we know for the appropriate detailed modelling the supply frequency, the typical transport units, the quantity of them per delivery, the time of the deliveries within a day and the starting point of the goods (the deliveries can start in the city or outside the city, it is important at modelling the distances). After filtration of the data (by these points of view) we can examine the logistics processes of 178 shops. We can see one part of the input data table on Fig. 6.

| Shopping mall ID | Supplier ID | Shop ID | SKU ID | Daily transports | Weekly transports | Monthly transports |
|------------------|-------------|---------|--------|------------------|-------------------|--------------------|
| SM001            | SUP0064     | SH0064  | SKU001 | 1                | 5                 | 0                  |
| SM001            | SUP0065     | SH0065  | SKU001 | 0                | 2                 | 0                  |
| SM001            | SUP0066     | SH0066  | SKU001 | 4                | 0                 | 0                  |
| SM001            | SUP0067     | SH0067  | SKU001 | 0                | 0                 | 1                  |
| SM001            | SUP0068     | SH0068  | SKU001 | 0                | 5                 | 0                  |
| SM001            | SUP0069     | SH0069  | SKU001 | 0                | 1                 | 0                  |
| SM001            | SUP0070     | SH0070  | SKU001 | 0                | 2                 | 0                  |
| SM006            | SUP0071     | SH0071  | SKU001 | 2                | 0                 | 0                  |
| SM006            | SUP0072     | SH0072  | SKU001 | 0                | 4                 | 0                  |
| SM006            | SUP0073     | SH0073  | SKU001 | 2                | 0                 | 10                 |
| SM006            | SUP0074     | SH0074  | SKU001 | 1                | 0                 | 0                  |
| SM006            | SUP0075     | SH0075  | SKU001 | 1                | 0                 | 0                  |
| SM006            | SUP0076     | SH0076  | SKU001 | 0                | 2                 | 0                  |
| SM006            | SUP0077     | SH0077  | SKU001 | 0                | 2                 | 0                  |
| SM006            | SUP0078     | SH0078  | SKU001 | 0                | 2                 | 0                  |
| SM006            | SUP0079     | SH0079  | SKU001 | 1                | 2                 | 0                  |
| SM006            | SUP0080     | SH0080  | SKU001 | 0                | 2                 | 0                  |

Fig. 6. One part of the input data table in Excel

In case of the shops which can be examined in the simulation model weekly transports are the typical. Considering all deliveries there are maximum daily 123 and maximum monthly 3601 transport for the 178 shops. 50% of the goods is delivered in a lorry (total weight 3,5-7,5 ton), cars and bigger trucks occur in the case of 25% of the shops. There are boxes in case of 148 of the 178 shops, they use pallets in 25, and other units in 18 cases. At one delivery, there is average 14,6 piece of boxes (standard deviation 25,9 pcs), the typical size is between 1-5 kg and there is average 0,5 piece of pallets (standard deviation 1,68 pcs), the typical size is between 100-500 kg.

### B. Boundary criteria in the model

In the model, naturally we must pay attention on several limiting factors, we must define well that which conditions must be completed, if we would like to use the model, and we must circumscribe why did we neglect some parts of the logistics system of the shopping malls.

We suppose, that the trucks or trams of the consolidated system can use the city roads and the tram network. The trams can be fitted in the timetable and at the shopping malls there is industry track for them. The different kind of delivery units can be transported together, every good can be stocked, now we do not examine the perishable goods. In the new, consolidated city logistics system the vehicles are standard-sized, all of them has the same capacity (this capacity is in the model a variable parameter) and the sum capacity of the suppliers is enough in every case.

The data of the shops, they deliver together, we examined together in our former research [3] and in the modelling too. There are shops, they work in LTL delivery-system, but per our exploratory research, the number of them is law, so in this case we neglected them in the modelling.

The CC has only a provider role, not a leader one, so CC

hasn't a control role in the city logistics network. The time of the supplies depends only on the supplier, and the deliveries from the CC depend only on the requests of the shops, based on the stock of the CC. The shops can order from stock of the CC, and if it can't complete the request, the request is lost. Furthermore, the CC has only an inventory function, and the cross dock has enough capacity to handle the goods. The goods, they arrived from a city-depot to the shopping mall (and big part of them is produced outside the city), are handled in the model like the goods, they arrive outside the city, so every good is delivered to the CC from the country. This means that the city roads are loaded only at deliveries from the CC. In this case the goods, they are produced in the city, can be neglected.

In the current supply system, the cars are handled as petrol-powered, the lorries and trucks as diesel fuel-powered, because according to the data of the Hungarian Central Statistical Office (at the end of 2014) 72,9% of the cars in Hungary used petrol and 93,8% of the trucks used diesel oil as fuel [5].

In our present research, we handle the deliveries of the shops aggregated, because we have no itemized data about the suppliers. In the simulation model, we can enter more supplier per shop too. We ranked all the goods in one modelled good-cluster, because we have no itemized data about them, but in the input table we can enter more cluster per shop and it is going to model them separately.

### C. Developing of the model

The ground of the simulation model is stochastic supply-generator (see one part of it on Fig. 7.), it can model sufficiently precisely the real supplies with use of the input data. In case of the current system and the possible future systems too, we needed to develop a supply-generator. The model works in 30 day long periods, with hour accuracy. It generates that on which day in which hour is a delivery to a shop. We calculated the probability parameters after several tests. Naturally, we paid attention on the quantity and the dispersion of the deliveries.

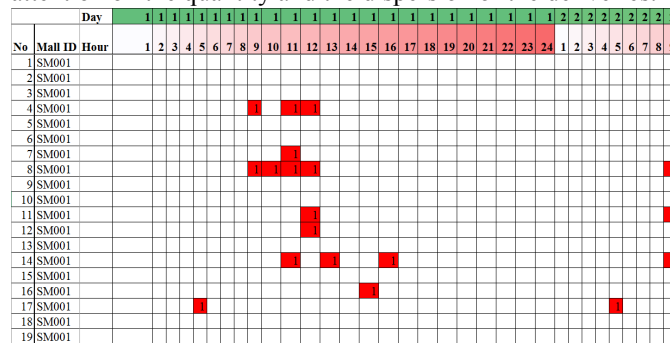


Fig. 7. One part of the stochastic supply-generator in MS Excel

The model has two main units: one models the current system and another models the possible future system, which examines the alternatives with the use of a CC.

The model of the current system realizes the below function: generation of the delivery days, generation of the deliveries (with hour accuracy), generation the weight and volume of goods, generation of the starting points of goods, generation of

the covered distance inside the city (based on the average city border-shopping mall distances, which was calculated by use of Google Maps and VBA, see on Fig. 8.), calculation of delivery performance, calculation of fuel consumption, calculation of emission (based on data of the United States Environmental Protection Agency [6].

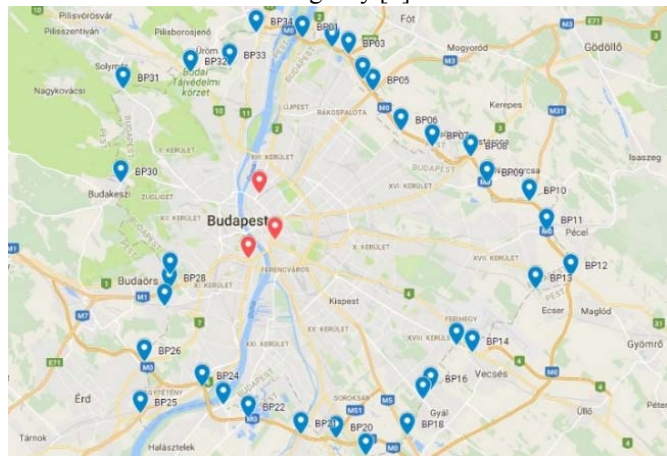


Fig. 8. The three shopping malls and main roads of Budapest at the entry points of city borders on Google Maps

The other component of the simulation model can examine the alternative logistics systems. This city logistics system uses in one case green road vehicles (for example electric vehicles [7], in the other case the tram-network and there is a CC added between the suppliers and the shopping malls. In this case the CC grants such an infrastructure, to where the suppliers can transport its stock and with which the CC can deliver the daily orders into the malls based on requests of the shops.

This component of the model realizes the functions below: generation of the deliveries (with hour accuracy), generation the mass and volume of goods, calculation of the daily weight and volume, generation of output weight of goods (from the CC to the malls), calculation of the stock of CC in weight, calculation of real output weights (based on the stock of CC), generation of output volume of goods, calculation of the stock of CC in volume, calculation of real output volumes (based on the stock of CC), calculation of daily number of consolidated deliveries (in case of road vehicle and tram too), calculation of distance covered in the city, calculation of delivery performance, calculation of fuel and electric power consumption, calculation of emission.

We performed the simulation test after design of experiment, with 95% reliability ( $R=0,95$ ) and with 10% permissible relative error ( $\varepsilon=0,1$ ).

## V. RESULTS OF THE SIMULATION RUNNING

After the simulation, the current system became comparable with a city logistics system, which use a consolidation center and a cross dock.

We validated the simulation model based on the sum weight of the goods. In the current system, the average monthly sum weight is 1353,4 t (standard deviation 25,4 t) and in the alternative city logistics system is 1382,8 t (standard deviation

43,6 t), so the difference between the two generators is only 2,13%. In cases of the three shopping malls the difference is under 5% too, so the two system is comparable based on the average sum weights and volumes.

The number of monthly supply transactions in the three cases can be seen on Fig. 9. In the current system, the average monthly number of supplies is 3393 (standard deviation 17,95), in the new system, if we use road vehicle, it is monthly 269 (standard deviation 7,12), and in case of using tram it is monthly 122 (standard deviation 3,52). This means that with road vehicle the number of monthly transactions can be reduced with 92,07%, and with using tram with 96,4%. If we convert it to daily transactions, it is in average daily 114 supply in the current system, and in the new one 9 with road vehicle and 4 with tram to the 178 shops of 3 shopping malls.

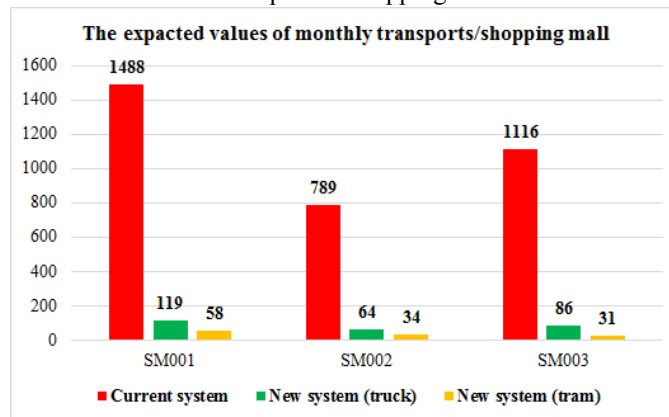


Fig. 9. The expected values of monthly transports/shopping mall in case of current system and in cases of the two possible future systems

The expected value of the delivery performance in the current system is monthly 23655,88 freight-tkm (standard deviation 1115,19 freight-tkm), in the new system with road vehicle 14250,48 freight-tkm (standard deviation 457,21 freight-tkm), and with using tram 21235,8 freight-tkm (standard deviation 832,7 freight-tkm). This means a reduction by 39,76% and 10,23% in the two cases.

The average monthly sum in the city covered distance (examining only the supplies, without inverse logistics processes) is in the current system 53810,2 km (standard deviation 1550,92 km), in case of the new system with road vehicle it is 2928,7 km (standard deviation 85,74 km), with tram it is 1936,2 km (standard deviation 51,4 km). This means, the with use of a green, high-capacity road vehicle in the new system we can reduce the sum of distance in the city by 94,56%, so we reduce the sum of load of the city roads (which get a huge load because of the freight traffic) too. In case of using tram, we can replace the whole load to the tramway-network.

On Fig. 10. we can see the comparison of above written parameters of the current and the possible future systems. On the figure, the current system is 100%.

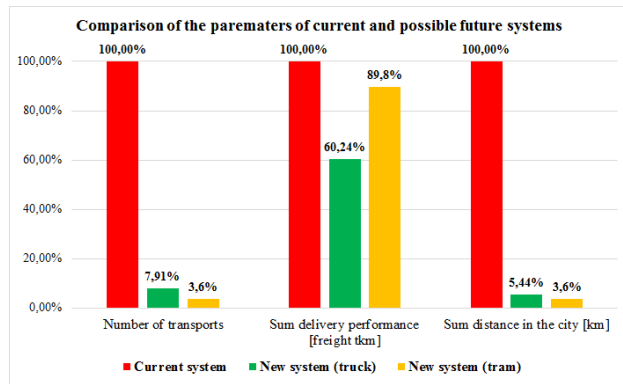


Fig. 10. Comparison of the parameters of current and possible future systems

In the current system, we examined the consumption of the two different fuels. The petrol-consumption is in the whole system monthly 628,41 l (in case of cars; standard deviation 42,84 l), the sum diesel oil-consumption is monthly 2863,98 l (in case of lorries and trucks; standard deviation 86,27 l). We calculated the consumption based on the consumption-norms given by the Hungarian National Tax and Custom Administration [8]. In the new system (examining only the road vehicles) the standard-sized truck uses diesel-oil, the sum of monthly consumption is 222,6 l (standard deviation 6,5 l). In HUF, in the current system this consumption means 1.211.581. HUF (based on the fuel prices in time of the simulation [9]), in the new system it is 77.459. HUF, so there is a 93,61% reduction of fuel-costs.

In case of using tram the sum energy-consumption is monthly 8426,7 kWh (standard deviation 316,9 kWh), calculated with 0,4 kWh/freight-tkm [10]. In HUF, calculated with the average price of one of the Hungarian energy-providers, it is monthly 291,564. HUF, this means a reduction by 75,76%.

The monthly average emission (in case of the road vehicles) can be seen in Table I. This means that the sum the CO<sub>2</sub>-emission can be reduced by 93,1%, the NO<sub>x</sub>-emission by 85,57% and PM<sub>2.5</sub>-emission by more than 85%.

|                   | Emission in the current system [g/month] | Emission in the possible future system [g/month] |
|-------------------|------------------------------------------|--------------------------------------------------|
| VOC               | 1414,81 g                                | 123,3 g                                          |
| THC               | 1444,62 g                                | 124,96 g                                         |
| CO                | 9239,82 g                                | 637,49 g                                         |
| NO <sub>x</sub>   | 16465,95 g                               | 2375,89 g                                        |
| PM <sub>2.5</sub> | 376,67 g                                 | 55,72 g                                          |
| PM <sub>10</sub>  | 409,66 g                                 | 60,41 g                                          |

The last examined parameters were the specificity of the stock of the CC, it can be seen in Table II. Based on this data we can estimate the quantity of the stock, which must be placed in the CC.

| Parameters in weight                                   |                                                                  |
|--------------------------------------------------------|------------------------------------------------------------------|
| Average stock                                          | 600,2 t (standard deviation 70,9 t)                              |
| Confidence interval lower limit (with 95% reliability) | 576 t                                                            |
| Confidence interval higher limit                       | 633,35 t                                                         |
| Inventory turnover                                     | 2,3 (standard deviation 0,3)                                     |
| Average days of inventory on hand                      | 13 day (standard deviation 1,6 day)                              |
| Parameters in volume                                   |                                                                  |
| Average stock                                          | 3747,9 m <sup>3</sup> (standard deviation 198,7 m <sup>3</sup> ) |
| Confidence interval lower limit (with 95% reliability) | 3654,9 m <sup>3</sup>                                            |
| Confidence interval higher limit                       | 3840,9 m <sup>3</sup>                                            |
| Inventory turnover                                     | 2 (standard deviation 0,1)                                       |
| Average days of inventory on hand                      | 14,7 day (standard deviation 0,9 day)                            |

Knowing the results, we can say that based on the same input data with use of the model we can compare the current system and the possible future logistics systems, which use a CC and cross docks. In the new systems, the reduction of every parameters is significant, the reduction is over 80% in the most cases. This means, that a system with a CC could have a very important role in supply system of shopping malls in Budapest, we could have cost-reduction in many area, the load of the city roads could be lower and the emission too. Comparing the two new alternative system, the number of supply transactions is better in case of using trams, but the delivery performance and the consumption is better in case of using the road vehicles.

The reductions seem to be very high at first sight, but it works similar in the case of passenger transport too. According to the latest the of Centre for Budapest Transport (BKK), the 55,9 m long CAF Urbos 3 trams [11], which can deliver 345 passengers, can replace 144 cars on the tram line 1, if we calculate with 1,6 passenger/car and 67% utilization of the trams.

After all it is important to examine the cost of the systems (like in case of other city logistics systems [12], but this cost model must be a special one for the shopping malls) We must examine the costs of the infrastructure, the vehicles and the operators in the case of the current system and in the case of the alternatives too. Now there is no available data for this, we do not know the specific costs for the current system, we have no data to calculate it. The next important steps of this research is to recognize these costs, but we can say that there is a huge potential in consolidation of deliveries of the shopping malls in Budapest.

## VI. CONCLUSIONS

Earlier we got data about 178 shops of 3 shopping malls, which made that possible to examine the current logistics system of the shopping malls and the alternative, possible future systems too.

With use of our mesoscopic simulation model we know, that in the examined new city logistics system the number of delivery transactions could be reduced by 90% and could have a significant reduction of fuel and energy consumption too,

which means the reduction of emission. Based on the result we can say, that a city logistics system with a CC could have a very important role in case of the shopping malls.

Naturally, the supply system of the shopping malls is very complex, so we can add many units to the simulation model. Now we have a research about using cargo bikes in supply system of the shopping malls, with use of an expanded version of the simulation model. The most important of the next steps is to build a cost-model for this system to make it possible to compare the costs too.

Based on our results we can say, that it is worth to deal with the role of the shopping malls in the city logistics system of Budapest, and a system like this could an important part of a smart, green and sustainable city in the future.

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