GEOGRAPHICALLY IMPROVED CITY WASTE MANAGEMENT

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Abstract

The production of solid waste is strongly connected with the quality of nature as well as the society. The origin of waste and its disposal are up-to-date topics nowadays.
The aim of this paper is to design a spatial model for optimized location of bins for sorted solid waste to increase the motivation of residents for more efficient sorting of components of waste. The access to the bins for sorted solid waste motivates people to recycle solid waste into separates commodities. This fact is mentioned in many studies as one of the most important factors.
The main inputs into the model are: the current location of bins for each of components of sorted solid waste and the distribution of permanent population in urban areas. Input factors are: the present distance and the maximum acceptable distance between the places of the sorted waste bins location and places of permanent addresses of residents. Data about the present distance and the maximum acceptable distance were obtained from the questionnaire. Other factors are: location of public facilities (e.g. schools, offices, bus stops) as places of regular accumulation of people in an urban area. The limiting factor is the accessibility of bins for sorted solid waste in the street network for collection of sorted solid waste with routing vehicles.
The advantage of this model is the spatial accuracy of the address places of permanent residents as producers of solid waste. Population data as the number of people living on single addresses are a spatial weight for spatial modeling to highlight territories with higher concentration of the population. Calculation of distances between the places of the sorted waste bins locations and places of permanent addresses of residents are used for road distances using real street networks as well as pavement network.

Keywords: separated waste, waste management, collection, spatial bin optimization, GIS

Introduction

Solid waste production is one of the global problems. The amounts of waste are strongly correlated with the economical level of society. High standard of living, closely connected with high consuming of energy, food and other materials has the only possible results – the high production of waste. To the most common solid communal waste belong the packing of various goods and food, its´ leftovers, rapidly altered clothes, household appliance and furniture. Management of the waste, its´ separation, logistics, other manipulation or potential recycling has the own problems in the big cities with hundreds of thousands or even millions of inhabitants – the waste management differs from the one, realized in smaller towns or the country. Palacký University has been long focused on the problems connected with the waste management in the Olomouc city (approximately 100.000 inhabitants) and its surroundings

(small villages nearby with approximately 20.000 inhabitants). There are about ten city agglomerations with the similar urban structure and the communal waste management system in the Czech Republic, where created model can be used for the other cities.

Communal waste policy in the Czech Republic

The waste management is relatively young, but dynamically developing part of each modern national economy. While western economies have solved the waste problems in the 1980´s the first Act on waste in the Czech Republic was approved as late as in 1991. The waste management in the Czech Republic was neither legislatively ruled, nor controlled before. The current waste management (prevention of the waste production and the possible negative effects on the environment and the public health) ensures the Act No. 185/2001 Coll. on waste [1].

The municipal waste management (MWM) is one of the most important parts of the waste management. The inhabitants of the particular urban area produce the municipal waste. According to the law, municipalities are responsible for their own waste management. Municipal waste includes mixed municipal waste and also its separately collected fractions (esp. paper, plastics, glass, and composite packing), hazardous waste, bulky waste, garden waste etc.

One of the main goals of the Waste Management Plan (WMP) of the Czech Republic [2] is increase in municipal waste utilization up to 50% until the end of the year 2010 compared to the year 2000. The proportion of MW utilization in the year 2006 was only 20% [3], which represents 77.3 kg of MW per capita and year. It was much better than in the year 2000 (only 5.5%), but the goals for the end of the year 2010 are hard to achieve.

Nowadays, almost the whole amount of MW in the Czech Republic is deposited (93 % in 2006 [3]). According to WMP the weight proportion of MW deposited in the landfills in 2010 should be 20% lower in the comparison with 2000, but up to now this aim is not fulfilled [4].

Téměř veškerý směsný komunální odpad v ČR je v současné době sládkován (v roce 2006 to bylo konkrétně 93 %) [3]. Snížení hmotnostního podílu komunálních odpadů ukládaných na skládky o 20 % do roku 2010 ve srovnání s rokem 2000, tak jak je uvedeno v POH ČR z roku 2003, není plněn [4].

Currently, the most problematic fraction of MW is the biodegradable waste. According to the law, the separation of the biodegradable waste has to start in 2011 in garden suburbs and in 2013 in the rest of the estate. Estimated production of biodegradable municipal waste is 60 kg per capita and year. The law and WMP, in accordance with the Council Directive 99/31/EC, place a duty on municipalities to cut the amount of biodegradable waste deposited in landfills in 2020 by 65% in comparison to 1995. The opposite trend was observed till 2006 as a result of much more expensive alternatives of waste treatment compared to depositing into the landfills [3].

Amount and structure of the communal waste in Olomouc, Czech Republic

The amount of the mixed municipal waste produced in 2009 by the inhabitants of Olomouc agglomeration is approximately 16217.4 tones per year whereas the production of separated waste amounts to 5602.2 tones per year. Actually, the following types of waste are primarily separated (by the citizens) in the whole city area of Olomouc, using the waste containers of different colours: plastics, paper, glass, and tetra packs. The separation of biodegradable waste appropriate for the composting is in hand. Other ways of separation logistics ensure the collection centres and the header places where the metals, electric machines, hazardous waste

materials (such as biological medical waste) and the bulk cargo waste are collected. The other types of waste belong to the „mixed municipal“ waste, which is currently transported and deposited on the city landfill situated approximately 15 kilometres from the city centre.
The regular monthly analyses of the mixed municipal waste have taken place since the September 2008 till the August 2010 in Olomouc with the aim to identify the proportions of particular types of the waste in the whole amount of the mixed municipal waste and their potential changes during the year. These analyses have been realized with the use of the municipal waste, produced in four different types of urban area in the city Olomouc – the historical core of the city, the large urban settlement with the slab blocks built from the 1960´s to the 1990´s, the modern garden-suburb built in the last two decades and the country-side type of the urban area of the small village nearby Olomouc.

Fig. 1 Nest of bins. Containers are for each component of separated waste – paper (blue), glass (green), plastics (yellow) and tetra packs (red). Source: www.norc.cz

According to the first year of the analyses results, the main part of the mixed municipal waste represents biodegradable substances (21.30 – 32.69% of weight). Furthermore, the largest proportion of the biodegradable part creates the plant materials like the kitchen scraps and plant cuttings, appropriate for the composting (56 – 71%). This fraction of the municipal waste was one of the hottest themes for the members of the research team, regarding the possibilities of the separation and following reuse of the biodegradable waste is one of the main goals of the city waste management. There are pilot projects focused on this part of municipal waste collection effectiveness testing, using either bulk cargo containers, or the small litterbins tested in particular areas, destined for individual households. So far, the waste collected in the experimental areas is transported to the composting unit in 25 km distance from the city, whereas the project for the fermentation station nearby the city is in hand.
The other tested way to reuse the biodegradable waste represents the project, during which are small composters offered to the particular households, where the type of the urban area enables the composter installation (houses with gardens). Surprisingly, according to our analyses comparing the four types of the settlement (see above), the largest proportions of the biodegradable substances in the mixed municipal waste were recorded just in the two types of urban areas, which were experimentally equipped with the composters, litterbins and so on two years ago (country-side and garden suburb). Considering the seasonal point of view, the largest amounts of this part of waste were recorded during the autumnal months, which can be explained with the autumnal loss of the leaves and the following garden works such a shoot pruning etc.

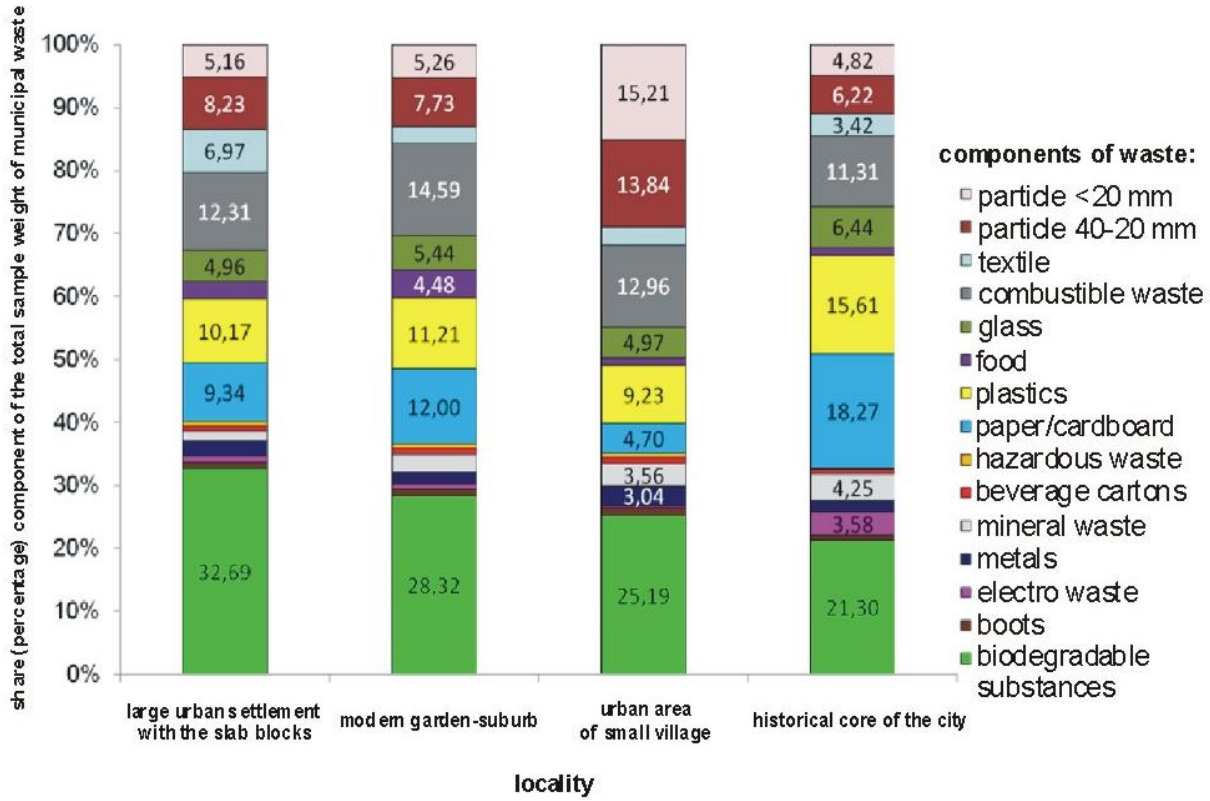

Fig. 2 Mass percentage of communal waste in four types of localities in urban area of Olomouc. Source: Authors, measurement period September 2008 – August 2009

The other significant part of the municipal waste was the siftings – all the small particles, which were sieved through the sifter with the size of mesh 40 mm. While the samples from the old city settlement, garden-suburb and the block of flats contained in the annual average from 11.04 % to 13.39% of the siftings, the samples from the country-side, with the many local furnaces, producing ash, contained 29.05 % of siftings in the annual average. Whereas the siftings percentage by weight rose during the winter months to 30 – 40 % in this area, in the rest of the year were considerably lower and comparable with the other three experimental areas.

We focused on the plastics as well during the analyses. All the types of plastic materials together represented 9.23 – 15.61% of the mixed waste weight. The values seem relatively low. but plastics played the significant role especially due to its´ volumes. Such a low numbers in percentage by weight mean far higher proportion according to the volume of the fraction in the whole volume of the waste With the 45.67 – 48.23% for the all 4 types of urban areas. the plastics were the most voluminous part of the analyzed waste.

The main types of plastics in analyzed samples of the waste were the various types of packing, plastic foils or the time-expired plastic products. The one-way bottles (made from PET) represented the minority (7-15% of weight) of plastics fraction of the waste with approximately 1% of the whole waste weight. This could be caused by the relatively long tradition of separation of this type of plastics in our country.

The waste, which cannot be used other way than through the termic use (one-way nappies, polluted paper, timber) was about the same contains in all experimental areas (11.31 – 14.59% of weight). We experimentally tested the energetic value of this waste in 2008, with the results of 13.6 – 18.3 MJ/ kg of the specific combustion heat. It means, the energetic value of this type of waste was higher than the indicated value for the dry timber or the brown coal, which advert to perspective of the future usage of the commodity.

The other sorts of waste such as metals, glass, time-expired electric appliances or the hazardous waste were found in the mixed municipal waste less commonly, what can be explained through the high responsibility of the citizens, accustomed to sort these types of waste. All these commodities have been collected separately in particular places; furthermore, the metals are bought back for relatively high prices.
According our study, the education and the tradition have the major part in the separation effectiveness of the particular sorts of the mixed municipal waste. Whereas the traditionally separated commodities represent the low proportion of the mixed waste, the recently introduced separation of the biodegradable waste is still often neglected. The important role can play the fact that the biodegradable waste can not be stored in the household for the longer time, like the plastics, paper etc., due to its´ fast decomposition.
The above mentioned results of the mixed municipal waste analyses will be used to time and spatial model of waste logistics, enabling its´ effectiveness increase, regarding the concrete type of city estate, calculating the potential future extension of the separated waste scale.

GIS in waste management

Geographical Information System can be used as a decision support tool for planning waste management. Manual methods adopted for analysis of many factors would be a length and tedious work. Also there are possibilities of errors while merging the spatial and non spatial data. In GIS, as the work is carried in layers, there are least chances of confusion or error and the system is capable enough to coordinate between spatial and non spatial data. There are several areas where the municipal bodies are striving hard to provide best of their services for the betterment of the city. This can be achieved using GIS to process different data forms like spatial as well attribute data simultaneously [5].

Spatial data model design

The model is based on the spatial distribution of containers for separated waste for the purpose of spatial optimization. Containers for separated waste are typically located in ”nests” – localities for the concentration of separated waste containers. In Olomouc there are mostly containers for at least there, mostly for four different types of separated waste (plastics, paper, glass, and tetra packs). These nests are accessible from places of residence of the population (represented by the points of address) through the pavement network.

Tab. 1 Input data set for collection of separated waste

Type of data	Description	Format	Source
street network	spatial vector line data-set for network analysis	shapefile	CEDA, a. s. (private company)
pavement network	spatial vector line/polygon data-set for network analysis	shapefile	Municipal authority of Olomouc
“nests” of bins for separated solid waste	spatial point data-set of group of bins for separated waste (paper, glass, plastic)	shapefile	Municipal authority of Olomouc
waste collection vehicles	non-spatial data-set about technical parameters (loading capacity for solid waste)	list of vehicles	Technical Services of Olomouc City
spatial representation of addresses	spatial vector point data-set of addresses including count of residents in every address	shapefile	Municipal authority of Olomouc

According González-Torre and Díaz-Adenso (2005) (Tab. 2) an environmentally concerned person normally does not expect to spend more than five minutes going with his or her bags to the selective collection bins. Because of the proximity of bins in the majority of cases, the time spent carrying items to selective collection bins is not appreciated by citizens as an important point for deciding between separating household waste or not. However, the distance to the selective recycling bins does affect the number of fractions that citizen separate at home.
Ball and Lawson (1990) claim that people use the trip for other purposes and dropping off the refuse on the way, the citizen is willing to go further, and in fact does so, than if the displacement were solely to deposit refuse in the bin.

Acceptable distance between the places of residence to nests of containers for three and more separated waste components is one of the factors which motivate people to sort waste. The research results of authors González-Torre and Díaz-Adenso (2005) according to the results in (Tab. 2) indicates that the importance of facilitating access to the container for separated waste motivates people to recycle waste. Their results also support the general assumption that if citizens who are environmentally friendly and if they are near his house in the separated waste containers, are more willing to recycle even more factions than it has for separating waste walk long distances, especially as If the discomfort within the meaning of large volumes of waste. This synergistic effect increases the incentive of separovatelných components of the waste.

Tab. 2 Time spent dropping-off refuse in the bins and the number of items recycled (significance level in brackets)

Contingency table (total percentages) of the time spent dropping off refuse in the bins and the number of items recycled (significance level in brackets)					
Number of items recycled	Time needed to carry waste to bins				χ^2
	<1´	1´- 5´	5´- 10´	>10´	
0	7.8	9.0	0.6	0.2	24.819 (0.016)
1	5.9	3.2	0.7	0.1	
2	7.4	5.5	0.9	0.1	
3	9.0	9.4	1.3	0.3	
4	21.9	15.6	1.0	0.2	

Note: One minute walk at an average speed of 4 kmh^{-1} corresponds to a distance of 67 m.

To determine the extent of this factor in the Czech Republic, the period from October 2009 to December 2009 the survey was carried out at selected locations in Olomouc. People were asked about the current proximity and the maximum acceptable proximity between a container nest for separated waste and place of their residence to motivate them for more efficient waste sorting. The survey results show that respondents estimated an average distance about 76.4 m, in areas of block of flats is the proximity about 35.8 m. According to Kalani, Lal Samarakoon (2010) is normally acceptable walking distance about 100 m.
Separated waste from containers is collected with trucks using street network for their move within the city. Localization of nests of containers is the spatial link between vehicle routing problem of trucks collecting the content of containers and accessibility of container for citizens through pavement network. Thus the model of optimization has to include both - distance to houses, as well as accessibility to roads (street network), through which passes through the take-away vehicle.

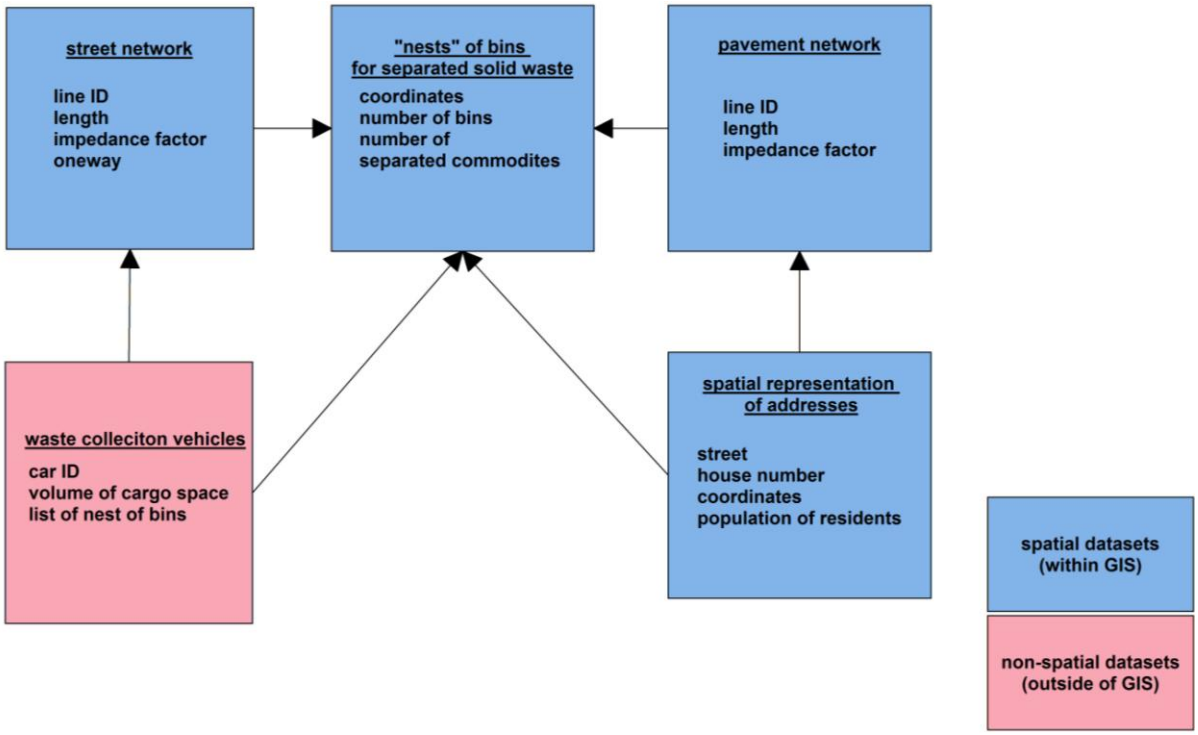

Fig. 2 Data model with links between different data sets to address the spatial distribution of containers for separated waste in Olomouc

Advantages and disadvantages of the model

The advantage of designing model for spatial optimization of containers for separated waste is the spatial accuracy of addresses and citizens as producers of waste and population data of residents. Using population data can be created spatial weights for each address derived from the number of residents living here. For calculation of the network distances, there are used values of length of street network and pedestrian network.

The disadvantage of designing model is the inaccuracy in the methodology of population data collecting. Data on population includes only citizens who are residents. There are not involved citizen who are not residents or who are not registered at city council as residents. The data address points (population register) are the only existing relevant data, which can be used for larger areas without a local inquiry.

Another fact, which can influence results, is inaccurate estimate of the population. People's determination of the current and acceptable distance from their homes to the nests of containers is highly variable.

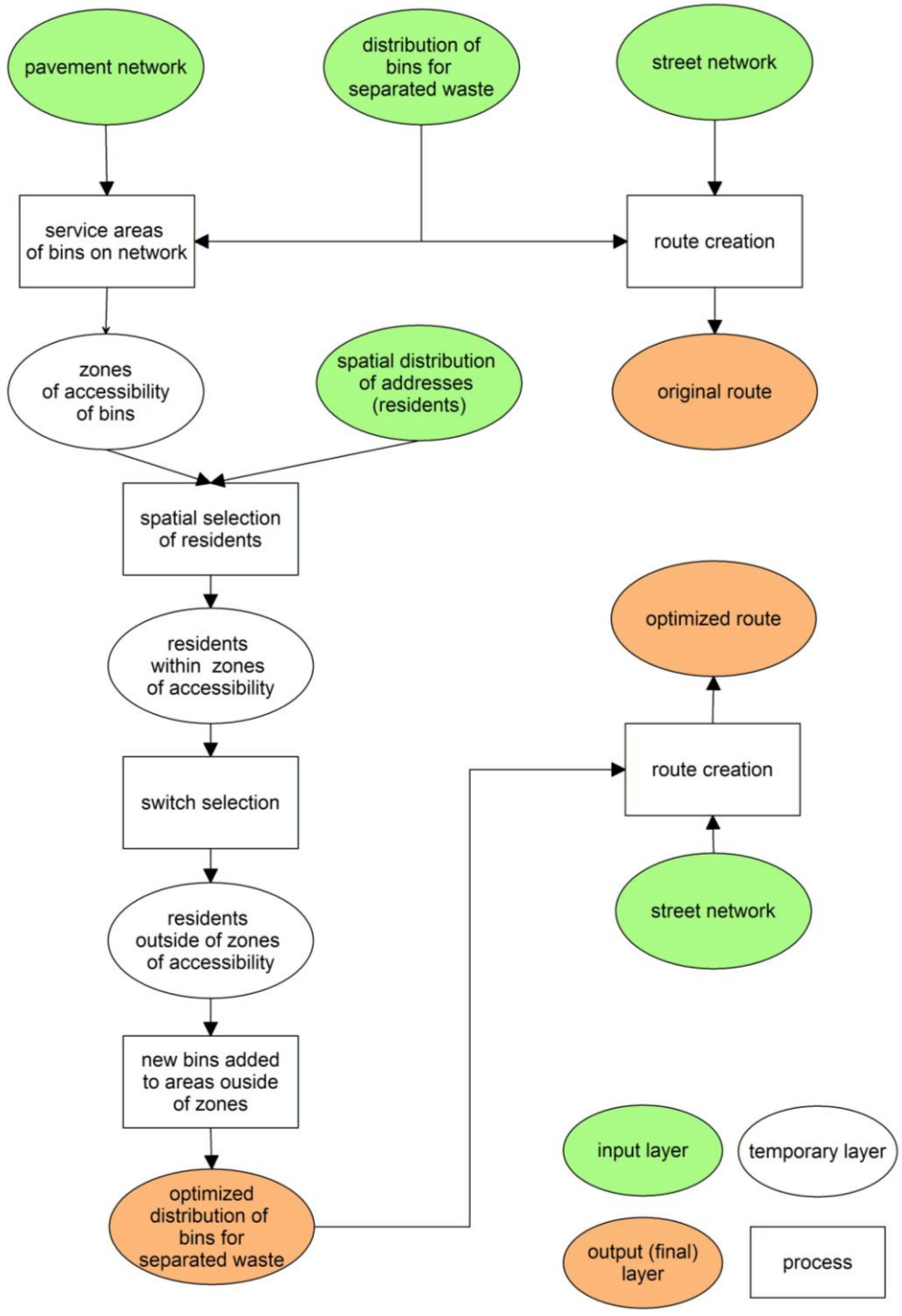

Fig. 3 Workflow diagram of model for spatial optimization of containers for separated waste

Optimal bin distribution (Olomouc case study)

The case study is focused on the area of Olomouc – Povel, densely populated settlement of block of flats. This settlement is well spatially defined from the surrounding of other parts thanks main roads – Brněnská, Velkomoravská and Schweitzerova Street. This district of Olomouc city was mostly built during communist era (late 1970´s and 1980´s). About 95 % of 6665 inhabitants live in block of flats. The area is situated in the southern part of the city of Olomouc.

The are located public services: health centre with two pharmacies, post office, supermarket Billa, supermarket Albert, two ATMs (GE Money Bank, Ceska Sporitelna), several restaurants and pubs, free-time activity children club, two elementary schools, two kindergarten, one hotel and public transport stops on these main roads - Pionýrská, Fakultní nemocnice, Hotelový dům, Zenit and Povel, škola.
Using various values for accessibility zones (see chapter spatial data model design) for motivation of residents were calculated in GIS. To each value of each zone of accessibility it is assigned a distance of residents who are within the proximity to the nests for separated waste containers.

Tab. 3 Proximity and zones of accessibility of nests of containers for residents

zones of accessibility (up to in meters)	number of residents within zone	share (%)
35.8	1629	24.4
67.0	4948	74.2
76.4	5362	80.5
100.0	5907	88.2
150.0	6563	98.5
200.0	6633	99.5

A rapid increase in number of residents living within accessibility zones is in first two zones. The population has increased from 24.4 % more than three-times up to 74.2 %. The increase of spatial accessibility of containers to residents is minimal and goes up to a value of 99.5 % of residents for the area within 200 meter buffer. The worst access to nests of containers is in the northeast area (298 residents), in northwest (240 inhabitants) and the central area of the eastern part with the urban area of detached houses (37 inhabitants).
According the disperse spatial distribution of points of interest, it was carried out for manual placement of containers for separated waste into the locations with the largest projected deficit "nests" of containers for separated waste (Fig. 4). Together there were located three new places (Fig. 5).

Tab. 4 Proximity and zones of accessibility of nests of containers after optimized distribution (three new nests added)

zones of accessibility (up to in meters)	number of citizens	share (%)	change in	
			number of new citizens	share (%)
35.8	1636	24.4	7	<0.1
67.0	5138	77.1	190	2.9
76.4	5636	84.6	274	4.1
100.0	6141	92.1	234	3.9
150.0	6633	99.5	70	1.0
200.0	6633	99.5	0	0.0

Fig. 4 Accessibility of containers (bins) nests; number of commodities of separated waste are highlighted

The addition of three new nests has improved waste management services for 274 residents (using buffer zone 76.4 m), although the length of routes of collecting vehicles has not significantly increased (Fig. 5). The original value of route of routing waste collecting vehicle was 5722 m, after optimization it has increased up to 5747 m.

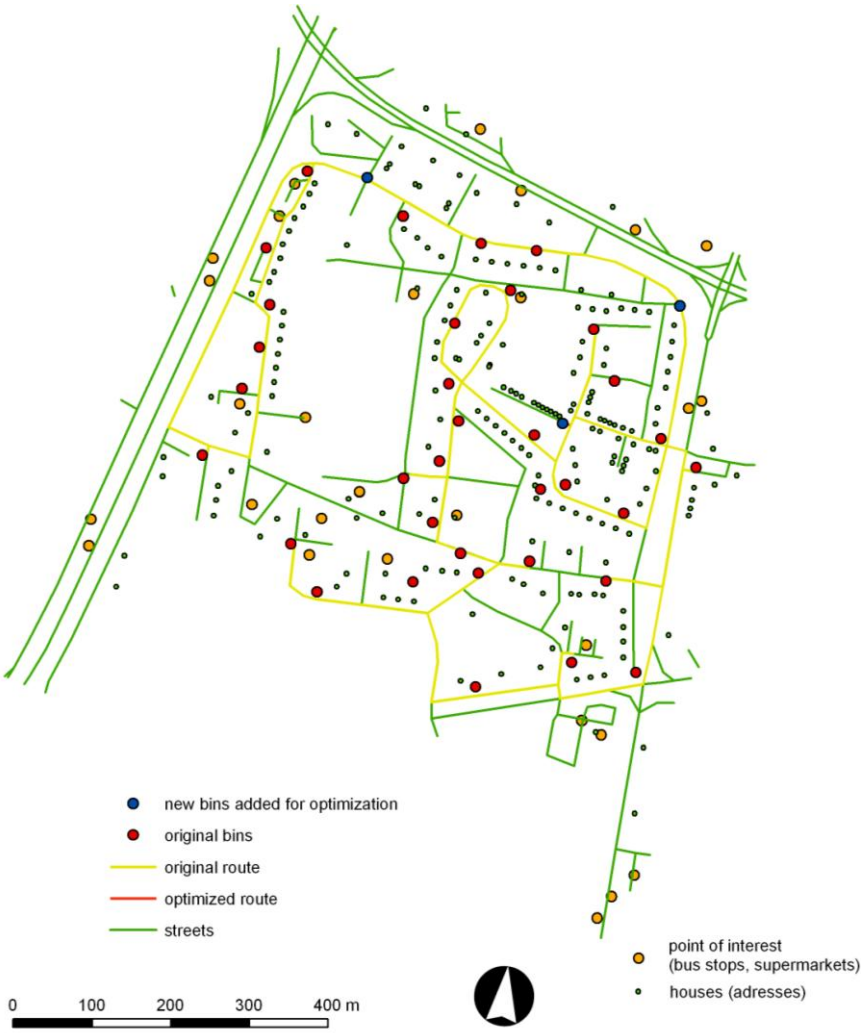

Fig. 5 Original (yellow) and optimized (red) route vehicles for collection of separated waste. The blue points show new added (containers) bins for spatial optimization.

Results and Conclusions

The methods, results and proposed next steps of their use are key parts of the project guaranteed by the Ministry of Environment of the Czech Republic and treated as a pilot project to improve the collection, separation and reuse of mixed municipal waste in the order of one hundred thousand inhabitants.

Implementation of spatial relationships modelling into the problematic of waste management, especially the spatial optimization of nests of bins separated waste is innovative not only in the Czech Republic, but also at international level. The process modelling involves the modelling of data (compilation of data for model calculations) and the modelling process (description of factors influencing the phenomenon under review). The team of authors is composed of experts on waste management and spatial information technology to carry out a pilot study and determine the applicability of the assembled model data and analytical possibilities of GIS.

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production from the point of view of possible use of its components (Struktura komunálního odpadu v závislosti na době a místu vzniku z pohledu další využitelnosti obsažených komponent).

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