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OPTIMIZATION OF SEPARATED HOUSEHOLD WASTE COLLECTION SYSTEMS ON THE BASE OF GIS MODELLING

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Abstract: The Hungarian waste management sector is under transformation now. The new (2012/CLXXXV) Law on the Waste applies such requirements on the household waste collection enterprises that cause restructuring among the players on the waste market. Besides this, the deposit fee system (that are defined by 209/2005 government decree) proposed to be changed. The proposals are extending the scope of the products that are under this regulation towards the packaging materials, thus the paths of the flows of packaging waste between the consumers and the recycling factories will evade the traditional separated waste collection routes. The aim of the system transformation is enhancing the proportion of separately collected waste in accordance with the EU directives. Evaluation of the collection efficiency by collection methods and by application areas under practical boundary conditions seemed to be useful in the course of the transformation. Results of my research towards planning of efficient separated waste collection systems (by means of planning software tool development) are summarized in this article.
Keywords: geo-information systems, logistics, optimization.

1. Introduction

It is necessary to choose the appropriate collection method for establishing a logistically effective waste management system that supports the recovery of the secondary raw materials on a service area. Practically, the proper method for collecting and transporting the separately collected waste from the households to the treatment facilities means housing supply on the area of family houses and means the application of kerbside collection islands on the area of blocks of flats. Appropriateness reflects to the difference among the effectiveness of the collection routes with different collection methods applied for the collection of the household waste at the whole service area (generally in a settlement). The measurement of the route effectiveness is usually the quotient of the collected waste quantity and the collection distance that are covered by the fleet in order to the waste collection. The measurement unit is [tons/ kilometres]. There are settlements with mixed structure of building types in Hungary on which marking incisive borderlines between the zones of family houses and block of flats is impossible. Differentiation means separation of the area segments in which different collection method will be applied. This separation has to be carried out in such way that ensures the maximal aggregated efficiency of the collection routes (both housing supply and kerbside islands collection service).

I have developed a waste collection route planning software tool on the base of the data that are supplied by the market leader companies of the waste management in North-Eastern Hungary during my years of PhD research. This tool is a module which designed for the ESRI ArcGIS platform. Initial database of the route planning are the digital map of the service area and the database of the consumers of the waste collection public service.

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The software tool provides solution for the task of area differentiation and the task of route planning both. The solution includes

- the separated areas for application of different collection methods (in disjunctive area segments),
- the number, location and capacity of the kerbside collection islands in the area of block of flats,
- the number and location of the households which to be served by means of housing supply,
- measurements of the collection efficiency (the quantity of the collected waste and the distance of the collection routes).

2. Literature overview

The problem of capacitated vehicle routing (CVRP) is originated from the asymmetric travelling salesman problem which is classified to be in the class of NP hard problems. CVRP is the most applied method for searching a solution to the routing of waste collection vehicles. There are a big number of households to be served therefore there are many heuristics detailed in the literature for approximation the exact solution of the waste collection routing.

The actual load statuses of the waste containers are considered to be known at each on every heuristic algorithm. Technical background for this information can be ensured for example by application of telemetric measuring appliances. The investment costs of the telemetric system can be covered only if IT background of the whole waste management system (e.g. real-time monitoring, forecasting on the base of historic data series) is able to exploit the information from the data measured and able to use this information for enhancing the efficiency of the collection routes [1].

Dynamic (so called on-line) route planning on the base of actual load statuses is the key factor in the practice for application of usage based pricing system. In general, the efficiency of the dynamically planned collection routes is higher than the efficiency of the routes that are planned on the base of static data of waste [2]. Predicates the validity of this statement independently from the balancing effect which is given to the summary of (big amount) static data containing uncertainties with different signs. The most significant advantage of dynamic route planning is the ability of adaptation to the unexpected situations (e.g. turning up a huge amount of waste at a service point). According to the economic conditions of the operator enterprises of Hungarian waste collection systems there are only a few on-line monitoring systems in function. For the others, development such route planning tool which moderate the stochasticity of the loading rate of waste containers seemed to be useful.

There is a statistic examination with socio – demographic attitude which aim was to define the most important factors and their values that have influence on the relationship of the consumers to the separated household waste collection systems described in [3]. The distance between a household and the collection container (on the kerbside island) was defined as the most negative factor with the value of –0.31. The most important message of [3] is the expression that the use of distant household waste collection container by an environmentally sensitive consumer could be characterized only with less probability.

Evaluation of efficiency and environmental sustainability of the separated household waste collection are described in [4]. Service coverage of the settlement areas is marked to be the main indicator regarding usage of the household waste collection systems in this article. Carrying distance (between the households and the collection containers) is used for measuring the service coverage in parallel with the statements of [3].

Demographic and economic coefficients are frequently used (calculated on the base of the number of inhabitants and measured in e. g. [kg/capita/year]) to characterize the waste quantities that are generated during a certain time period [5]. These coefficients are simplified into constants in most cases thereupon the difficulties or the missing information that hinder their calculation. Accurate estimation of these coefficients is possible only if the necessary time series of generated waste quantities are available. The coefficients that are included in [5] demonstrate differences among such waste quantities which are originated from areas with different building types.

These literature resources gave me inspiration for choosing the directions of my research towards developing new planning tool for waste collection routing. My research results are rely on the conclusions of the literature and are having novelty by taking into account the different areas (from the viewpoint their building types) and the different collection services on them.

3. Specialties of route planning in waste collection systems

The transport demands marked by (q_i) are pre-defined before the planning of the routes in general collective or distributive transport systems. This q_i is quantified by the actual load status of the waste containers therefore have uncertainties in case of the waste collection. It is necessary to carry out estimations to define q_i in this case. For accurate estimations the following interrelations have to be taken into account.

Collected waste quantities (q_{gy}) and collection distance (s_{gy}) is necessary to be measured for defining the collection efficiency:

$$\eta_{gy} = \frac{q_{gy}}{s_{gy}} \tag{1}$$

q_{gy} – can be divided into two parts regarding the areas of different building types:

$$q_{gy} = \sum_{i=1}^{n} q_{gyh\,(i)} + \sum_{j=1}^{m} q_{gysz\,(j)} \tag{2}$$

where:

i	–	represents the households
n	–	number of households with family houses
q_{gyh}, q_{gysz}	–	waste quantities which are generated in the family house- and in the blocks of flats areas
j	–	represents the kerbside waste collection islands
m	–	number of kerbside waste collection islands

By applying (2) in (1):

$$\eta_{gy} = \frac{q_{gyh} + q_{gysz}}{s_{gy}} \tag{3}$$

In (3) q_{gyh} and q_{gysz} waste quantities are collected together while the collection vehicles perform s_{gy} long collection routes. If areas with different buildings are served by different routes s_{gy} can be broke into 2 components:

$$s_{gy} = \sum_{k=1}^{p} s_{gyh\,(k)} + \sum_{l=1}^{r} s_{gysz\;(l)} \tag{4.1}$$

where:

p	–	number of collection routes in the areas with family houses
k	–	represents the collection routes in the areas with family houses
r	–	number of collection routes in the areas of blocks of flats
l	–	represents the collection routes in the areas of blocks of flats
s_{gyh}, s_{gysz}	–	lengths of the collection routes in the family house- and in the blocks of flats areas

It is important to note that the collection route lengths can be characterized with the following formula if areal differentiation is avoided (or by applying not this sense of differentiation):

$$s'_{gy} \geq s_{gyh} + s_{gysz}\,, \tag{4.2}$$

(4.2) represents the case when the collection routes have not got disjunctive service areas therefore they are heading through areas with both types of buildings.

On the base of (4.1) collection efficiency could be characterized with the following interrelation:

$$\eta_{hgy} = \frac{\sum_{i=1}^{n} q_{gyh\,(i)}}{\sum_{k=1}^{p} s_{gyh\,(k)}} \;;\quad \eta_{gysz} \frac{\sum_{j=1}^{m} q_{gysz\,(j)}}{\sum_{l=1}^{r} s_{gysz\,(l)}} \tag{5}$$

where:

η_{gyh}, η_{gysz} – efficiencies of the collection routes in the family house- and in the blocks of flats areas

The efficiency of the whole waste collection system on the service area can be calculated by means of (4.1) as a sum of the collection efficiencies of the areas with different building types.

These efficiencies are applied as Key performance indicators (KPIs) for developing the GIS based route planning tool. KPI_1 means the collection efficiency on the areas of family houses and KPI_2 represents the collection efficiency on the blocks of flats areas. (5) demonstrates that the efficiency of the whole waste collection system in a service area could be emerged by improving the collection routes of the different areas in parallel.

It is necessary to emphasized that because of (4.2) the interrelations (3) and (5) resulted in different summarized efficiency with regards to the whole collection system.

$$\eta'_{gy} \leq \eta_{gyh} + \eta_{gysz} \tag{6}$$

There is close to direct proportion between the average separately collected waste quantity that are generated by a household (and carried into the waste container) and the carrying distance [3] therefore the following consequence could be drawn: the average loading rate of waste containers in the kerbside collection islands are faster on the areas of blocks of flats than on areas of family houses because of the minor lengths of the carrying distances have to be covered there. In consequence establishing of housing supply in the family hose areas seemed to be proven. In parallel the collection efficiency in the blocks of flats areas could be improved by determining the proper location and capacity of the collection islands in order to minimize the carrying distance there.

Each aims could be taken into account by combining the functions of the geo-information systems (GIS) with the methods of route planning. My work towards development of this new planning tool will be outlined in the next chapter.

4. Designing efficient waste collection systems using ArcGIS

I have developed an ArcGIS ModelBuilder application that supplies the planning of selective household waste collection systems. The waste collection system is defined after an iteration procedure which contains the following steps:

1. building a geo-database from the basic data of the service area (road network, the location of the households, the capacity of communal waste bins of the households)
2. differentiation of the areas with different building types (on the base of the waste bin size)
3. definition the location and capacity of the kerbside collection islands
4. planning the collection routes (housing supply for family houses and kerbside islands for blocks of flats)

The iteration procedure is driven by the KPI values. Every step relies on the previous one. During this process, several differentiation, localization and routes are developed for searching the optimal partition of the areas in which collection can be operated with maximal efficiency.

Termination is bounded to a condition for which the differences between the KPI summaries of the iteration cycles are calculated.

$$\begin{array}{l} \text{if } \left|\Delta KPI\right| > 0{,}2 \text{ iteration continues} \\ \text{if } \left|\Delta KPI\right| < 0{,}2 \text{ iteration is terminated} \end{array} \tag{7}$$

KPIs that are calculated in the iteration cycles are shown in Table I. and in Figure 2. The pre-defined condition (7) for termination is fulfilled when the sum of KPIs reach the value of 6.66. The partition of the service area is shown in Figure 3 for this iteration cycle. Housing supply is applied in dark grey areas and kerbside collection islands are located into the darker dots in the lighter grey areas (which are represents the areas of blocks of flats). The collection efficiency of the island service can be characterized with 5.73 m^3/km while the housing supply performs only about 1m^3/km.

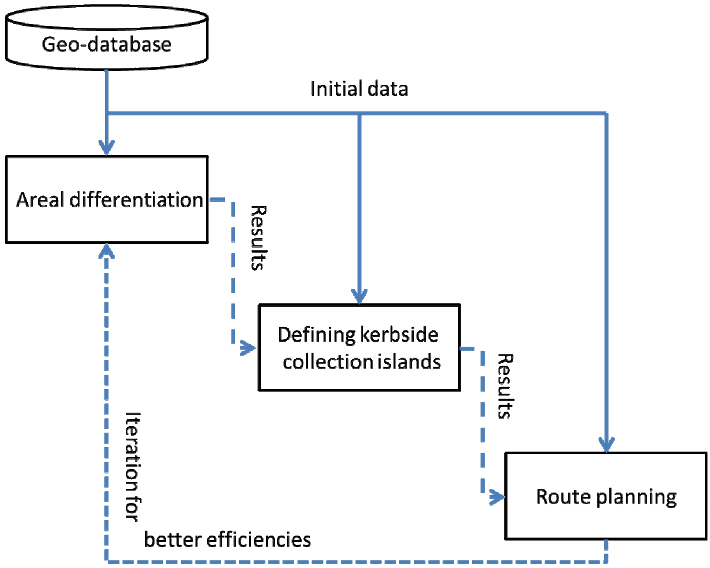

Figure 1. Scheme of iteration for emerging the collection efficiency

Table 1

Collection efficiencies

Threshold of average volume of waste containers (k)	KPI_1	KPI_2	$KPI_1 + KPI_2$
900	1,67	0,95	2,63
800	3,60	0,94	4,55
700	4,52	0,95	5,47
600	4,41	0,96	5,38
500	5,07	0,97	6,04
400	4,80	0,94	5,74
300	5,34	0,93	6,27
275	5,27	0,93	6,20
250	5,73	0,93	6,66
200	5,57	0,91	6,48
175	5,33	0,90	6,23
100	4,29	0,38	4,67

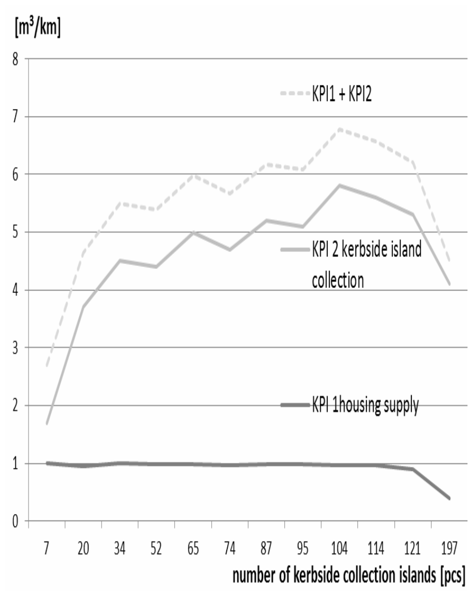

Figure 2. Areal differentiation versus collection efficiency

Figure 3. Optimal partition of the service area of a separated household waste collection system

Further development possibilities are the following:

- development of algorithms in the planning steps by searching for quicker heuristics
- discovering possibilities for speeding up the whole iteration procedure
- integration with data that are supplied by telematics measuring appliances

5. Summary

Enhancing the efficiency of the collection routes seemed to be a real possibility by applying this new planning tool for the separated household waste collection operator enterprises. All the necessary initial- and working conditions can be represented in the software therefore it is ready for application in the practice. The planning tool was applied for revision of the collection system of a north-eastern town where significant collection efficiency growth was resulted. The practical test towards modifying the collection system on the base of the results is in progress.

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