

Research Article

Advanced Design of Separated Household Waste Collection Systems on the Base of GIS Modelling

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The Hungarian waste management sector is under transformation now. The new (2012/CLXXXV) Law on the Waste applies requirements on the players of the waste market that will result in the reorganization of the whole waste management industrial sector. The aim of the system transformation is enhancing the proportion of separately treated waste in accordance with the EU directives. Emerging waste quantities to be separately treated means challenge for the existing logistic capacities (e.g., collector vehicles); thus evaluation of their actual efficiency and utilization seems to be useful in the course of the transformation. With this object in view, a new separated waste collection system planning approach and a software module were developed on the base of a geographic information system (GIS) platform. The software module was designed to help choose and localize the appropriate collection methods and define the logistically effective collector vehicle routes according to the settlement structures of urban environments.

1. Introduction

Most of the Hungarian towns established their own separated collection systems for valuable secondary raw materials (mainly in the form of kerbside collection islands for PET bottles, packaging paper, and aluminium beverage cans) more than a decade ago. These collection systems were implemented and operated independently from each other by the local public service providers. There are fair differences among these systems regarding the collected quantities as well as regarding the operation costs. Moreover, inequalities regarding the collection performances (measured, e.g., in m^3 /month) of the kerbside islands are observed and proved by statistics that are made upon the data of accounting reports. These inequalities manifest themselves in many forms. Both the negative impacts of overfilled collection containers on the environmental consciousness of the inhabitants and economic disadvantage of unloading low filled collection containers raise local waste collection service providers' demands to abolish these inequalities. A local waste collection service provider expresses its development needs to

the Environmental Management and Logistics Department of Bay Zoltan Nonprofit Ltd. for Applied Research for R&D expertise contribution. This cooperation results in the new planning approach and the GIS software module.

Figure 1 shows the results of the time series of waste quantity data processing which confirms the assumptions regarding the mentioned negative effects. Impacts of several factors which marked to have direct or indirect influence on the loading rates of the separated waste containers by the literature resources [1, 2] (e.g., seasons, temperature, etc.) are examined in the outlined time series, however, in most cases these factors cannot be demonstrated.

The necessity of a new planning approach could be outlined by drawing the conclusions of the following bibliographic resource reviews.

Reduction of the state space of routing algorithm has to be carried out before route planning. State space that have to be discovered by the routing solver algorithm as the problem of capacitated vehicle routing (CVRP) is originated from the asymmetric travelling salesman problem which is classified to be NP hard problem where there are not known

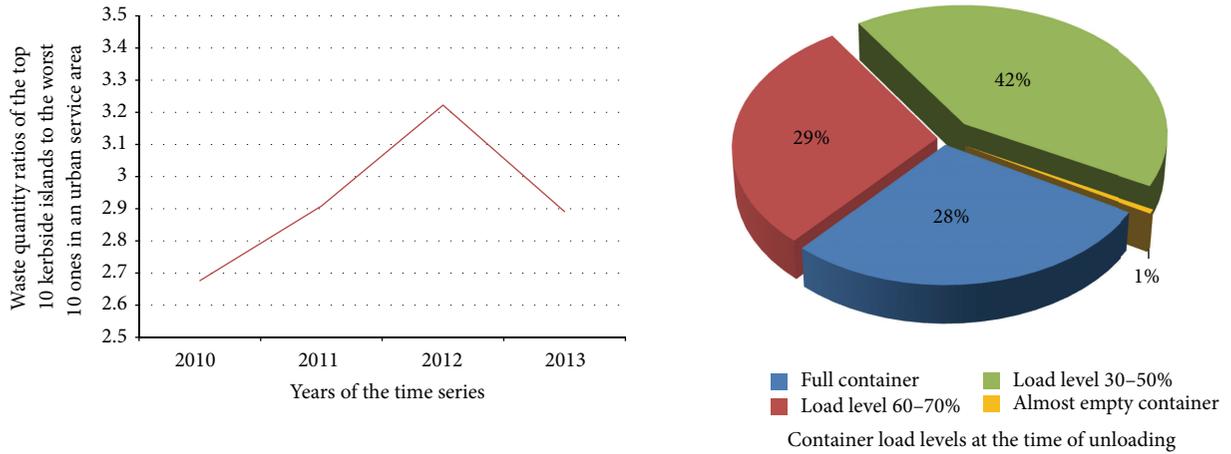


FIGURE 1: Differences among the performances of the kerbside collection islands.

polynomial-time solver algorithms. Nevertheless, CVRP is the most frequently applied method of searching solutions to the routing of waste collection vehicles [3].

There are several GIS software tools specialized for routing in waste collection systems but a combined planning approach which integrates spatial partitioning and routing has not been developed. Importance of such an approach will presumably be proved by its application for routing in Hungarian urban settlements. These towns have mixed structure of building types; marking incisive borderlines on the maps of these settlements between the zones of family houses and block of flats is impossible [4].

Due to limited financial resources of the system operation offline route planning method can only be applied as the high investment costs of the telemetric monitoring system (that is precondition for online routing) will return only if computational (IT) background of the whole waste management system is able to exploit the information from the data measured and is also able to use this information to enhance the efficiency of the collection routes [5, 6].

Application of GIS platform is obvious as there is strict correlation between collected waste quantities and spatial arrangement of the collection system. This statement is proved by

- (i) statistic examinations with sociodemographic attitude which were carried out to define the most important factors on the relationship of the consumers to the separated household waste collection systems. The distance between a household and the collection container (on the kerbside island) was defined to be the most important negative factor [7];
- (ii) evaluation of efficiency and environmental sustainability of the separated household waste collection systems [8] which defines the term and importance of carry distance (similarly to [7]);
- (iii) examinations regarding demographic and economic coefficients which are frequently used to characterize the household waste generation during a certain time

period [1]. Some of them demonstrate the differences among waste quantities which were originated from areas with different building types.

2. Basics of the New Planning Approach

The transport demands (marked by q_i) are predefined in case of route planning for general collection or distribution transport systems. In case of planning waste collection routes q_i is quantified by the actual loads of the household waste containers (bins) which may vary in wide range. The following interrelations have to be taken into account for accurate offline estimation of the waste quantity to be collected and transported (q_{gy}) in a service area.

Collected waste quantities (q_{gy}) and collection distance (s_{gy}) are necessary for defining the collection efficiency

$$\eta_{gy} = \frac{q_{gy}}{s_{gy}}. \quad (1)$$

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

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

In the formula, i represents the households; n is number of households of family houses; q_{gyh} and q_{gysz} are waste quantities which are generated in the family houses and in the blocks of flats areas; j represents the kerbside waste collection islands; m is the number of kerbside waste collection islands.

By applying (2) in (1), we get

$$\eta_{gy} = \frac{q_{gyh} + q_{gysz}}{s_{gy}}. \quad (3)$$

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

$$s_{gy} = \sum_{k=1}^p s_{gyh(k)} + \sum_{l=1}^r s_{gysz(l)}. \quad (4)$$

In the formula, p is the number of collection routes in the areas of family houses; k represents the collection routes in the areas of family houses; r is the 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} and s_{gysz} are the 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 there are no disjunctive service areas*:

$$s'_{gy} \geq s_{gyh} + s_{gysz}. \quad (5)$$

In such waste collection systems the collector vehicles pass through areas with both types of buildings. On the base of (4) collection efficiency could be characterized with the following interrelation:

$$\eta_{hgy} = \frac{\sum_{i=1}^n q_{gyh(i)}}{\sum_{k=1}^p s_{gyh(k)}}, \quad \eta_{gysz} = \frac{\sum_{j=1}^m q_{gysz(j)}}{\sum_{l=1}^r s_{gysz(l)}. \quad (6)$$

In the formula η_{gyh} and η_{gysz} represent the effectiveness 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) as a sum of the collection efficiencies of the areas with different building types. Because of (5) the interrelations (3) and (6) resulted in different summarized efficiency with regard to the whole collection system:

$$\eta'_{gy} \leq \eta_{gyh} + \eta_{gysz}. \quad (7)$$

On the base of (7), a spatial partitioning which defines appropriate disjunctive service areas seems to be necessary before offline planning efficient waste collection routes. In this way, application of the proper collection method means housing supply on the area of family houses and means the application of kerbside collection islands on the area of blocks of flats. The measurement of the collection effectiveness is usually the rate of the collected waste quantity to the collection distance that has to be covered by the waste collector fleet (tons/kilometres or m³/kilometres).

3. GIS Modeling towards Development of Planning Software Tool

The established new approach was implemented into a planning software module which relies on the GIS platform. Geospatial information system software (GIS) provides creation, visualisation, analysis, and interpretation of

data with spatial binding. By supporting model building and examination with mapping tools GIS software helps in discovering hidden spatial interrelations among information which is originated from different data sources. Therefore the spatially dependent efficiencies that are outlined in (7) could be applied as key performance indicators (KPIs) for the planned routes. Equation (6) demonstrates that the efficiency of the whole waste collection system in a service area could be emerged only by parallel improvements of the collection routes in the different service area partitions.

Initial data of the planning module are the digital map of the service area and the database of the consumers of the waste collection service. The software module provides solution both to the task of spatial partitioning and to the task of route planning. The solution includes

- (i) estimation regarding the separately collected waste quantity as a part of the communal waste quantity that is generated during the time period between the services;
- (ii) separated areas of different collection methods (in the form of disjunctive partitions of the service area);
- (iii) the number, location, and capacity of the kerbside collection islands in the area of blocks of flats;
- (iv) the number and location of the households which have to be served by the housing supply service;
- (v) measurements of the collection efficiencies (the rate of quantity of the collected waste to the distance of the collection routes).

The waste collection system is defined by an iteration procedure built upon the following planning phases:

- (1) building a geodatabase using the initial data of the service area (road network, location of the households, capacity of communal waste bins);
- (2) partitioning of the service areas according to the different building types (based on the size of the waste bins);
- (3) defining 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).

Figure 2 shows the connections of the planning phases within an iteration cycle. The iteration procedure is driven by the KPI values. Every phase relies on the previous one. During this process, several partitions, localization, and collection routes are developed for searching the optimal partition of the areas in which collection can be operated with maximal efficiency.

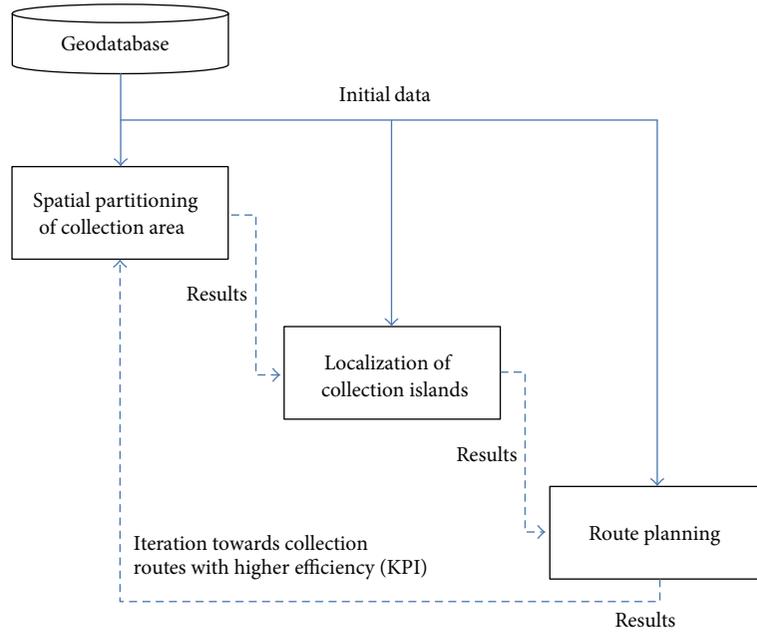


FIGURE 2: Scheme of iteration for emerging the collection efficiency.

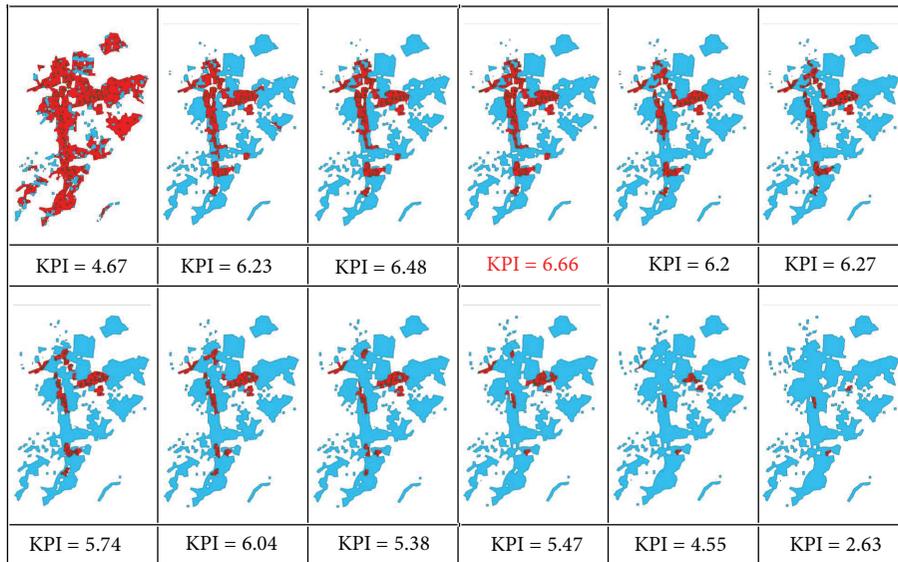


FIGURE 3: Versions of service area partitioning formulated by the planning software module during the development of the efficient waste collection system.

4. Results of a Case Study

A validation procedure took place in the form of a case study examination. Initial database was compiled upon real time operation of the local waste management service provider company in an urban service area of North-Eastern Hungary.

Figure 3 shows how the planning software forms the most efficient collection system using the data of the case study. Application of housing supply service in areas marked blue and the application of service of kerbside collection islands in red areas of blocks of flats were proposed by the results

of the case study examination. The most efficient system version is characterized by appropriate localization of 104 pcs collection islands and by 6.66 m³/km collection efficiency. Figure 4 represents the change of the collection efficiencies during the iteration and it also proves the kerbside service to be the dominant part of the separated waste collection system as the alteration of kerbside service efficiencies rules the summary KPI value.

There are 109 pcs of kerbside collection islands existing on the whole service area in the practice. Figure 5 shows their actual location on the map of such partitioning that is marked

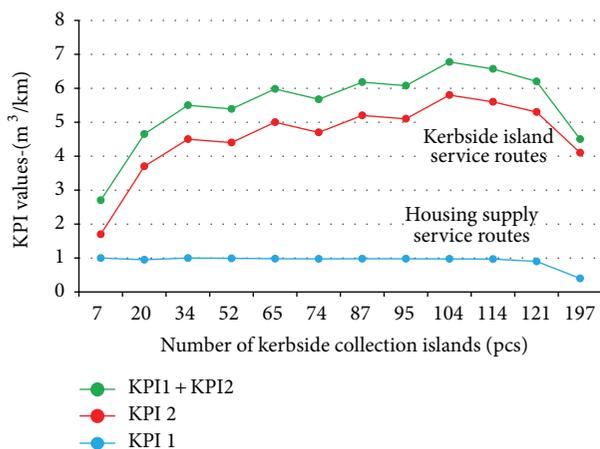


FIGURE 4: Change of KPIs of the waste collection system versions during the iteration of the case study.

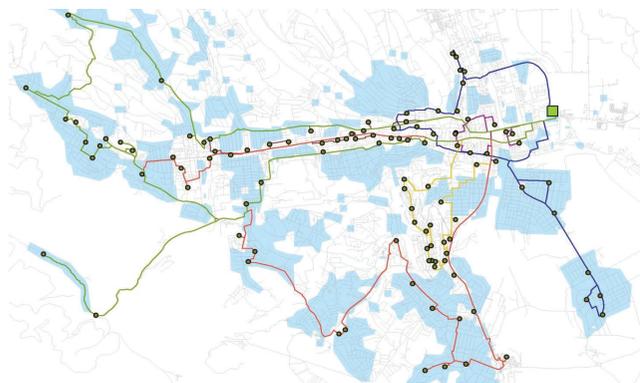


FIGURE 5: Change of KPIs of the waste collection system versions during the iteration of the case study.

by the planning results to be the most efficient. This layout makes comparison of the existing and planned collection systems possible. The dark dots on the areas marked blue represent such existing kerbside islands which are situated in areas that are declared by the planning module to be detached house areas.

A data processing on the initial database was carried out to compile collection performance statistics of the existing kerbside islands. Results of this survey prove the previously mentioned islands to be such collection points of the existing collection system which could be characterized by the least amounts of selective waste.

5. Summary

Shortening the length of the collection routes was the objective function applied for the routing procedure as the defined collection efficiency was built upon this measurement unit. Development steps are in progress for discovering application possibilities of other characteristic parameters of the collector routes (e.g., fuel consumption, service time, etc.). Nevertheless, enhancing the defined efficiency of the

collection routes by applying the new planning approach and the GIS software module is proved to be a real possibility for separated household waste collection systems that are operated in urban service areas. All the necessary spatial conditions can be represented in the software therefore it is ready for application in the practice. The further development possibilities are the following:

- (i) searching for other factors (and including them into the planning approach) which have quantifiable influence on waste generation and on the collection procedure;
- (ii) developing algorithms of the planning phases towards getting quicker heuristics and discovering possibilities of speeding up the whole iteration procedure;
- (iii) ensuring possibility of integration telematics measuring appliance supplied data.

Conflict of Interests

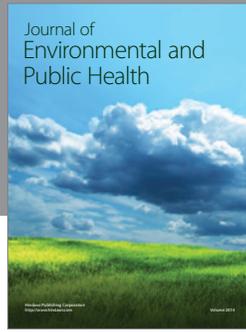
The author declares that there is no conflict of interests regarding the publication of this paper.

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