ESTIMATION OF VEHICLE DEMAND FOR DOOR-TO-DOOR SEPARATE WASTE COLLECTION

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ABSTRACT

The paper analyses the current system of waste collection and waste quantity in a particular service area. It suggests an appropriate and applicable collection system that meets the legal requirements. The scenarios' waste flows are examined for various selective activities. The collection vehicle demand is designed for each scenario. As a result, a collection system for door-to-door collection is proposed that meets the needs of the residents and can be operated with the possible lowest cost.
Keywords: waste management, door-to-door collection, separate collection, vehicle demand

INTRODUCTION

Europe and other continents have recognized the potential of the wastes as material resources. Accordingly, there is a significant shift from the collection of mixed waste towards the separately collected materials. The appropriate choice of the collection system is important for the public service providers, since the increasing logistics is associated with more costs. The introduction of separate collection is an EU standard and it is also a Hungarian legal obligation (*Directive 2008/98/EC of the European Parliament and of the Council*, 2008; *2012/185 Act on waste*, 2013; *385/2014 Goverment regulation on the waste public service*, 2015). The Hungarian regulation requires the separate collection of the following fractions, at least:

- mixed municipal waste,
- separately collected paper and cardboard,
- separately collected plastics,
- separately collected glass,
- separately collected metal,
- hazardous waste,
- clothing and textiles waste.

The collection frequency of waste containing biodegradable ingredients is regulated by lawas well. Accordingly, it should take place in urban and small town environment at least twice a week and in rural areas at least once a week. (*16/2002. Regulation of Ministry of Health*, 2002).

Different forms of collection and disposal are used worldwide, because regional and municipal authorities have to adapt to their specific circumstances. The authorities must consider many factors for the different ways and features of

household waste collections that vary in the respective regions and countries. (*Williams and Cole*, 2013). A preferable waste treatment and recycling system should save a large amount of virgin resources and has to reduce environmental emissions, as well as the total costs, significantly. The utilization of the existing facilities can help to reduce the fixed cost (*Fujii et al.*, 2014). Separate collection has been applied successfully throughout Europe, however, the overall cost of systems, the various local implementation issues, and the generally disappointing results in contamination levels from urban areas have initiated a continuous discussion on the possible alternatives (*Cimpan et al.*, 2015). *Ionescu et al.* (2013) developed a scenario model according to the requests of EU regulation, involving also the selective collection rate and degree. They found that in the Central European region the curb-side (a.k.a. kerbside or door-to-door collection) collection system was efficient. They suggested the following separate waste streams: plastics, paper and cardboard, glass, metals, food waste, wood and inert waste (*Ionescu et al.*, 2013). In Hungary there is no regulation for separated collection of food waste, as well as wood and inert wastes can be contained in mixed municipal waste, so this paper works out solutions for the fractions of plastics, paper with cardboard, beverage carton glass and metal.

MATERIALS AND METHODS

The amount of the weekly collected waste was surveyed in the study area. As for a study area an average rural settlement was chosen, the town of Nagybajom. The waste amounts were registered for one year from July 1, 2014. The waste composition ratios for the rural region were processed and averaged. Next we determined the collection vehicle demand for the current system. The average amounts of the selective fractions that can be collected with a collecting vehicle, were determined from the practical data. With the knowledge of these data, we could determine the collecting vehicle demand, in accordance with legal requirements.

LITERATURE REVIEW

In Denizli, Turkey a new waste management system was introduced in 2003. They applied a curb-side system, using coloured bags for source separated and commingled recyclables (plastics, PET, metals and textiles). Paper with cardboard, metal and glass are collected in recyclable waste bins (*Agdag*, 2009). To collect the glass in the waste bin for commingled stream causes health and safety problems in the manual sorting, so we plan to collect it at drop-off points.

In China, recyclables are collected in two ways: one portion of the recyclables is collected by the residents themselves, while the other portion enters the municipal recycling system. In Beijing the percentage of household separation reaches 54%. The municipal waste is generally divided into organic matter, inorganic matter, paper, fibre, timber bamboo, plastic, rubber, glass and metal. Considering that kitchen waste appears in high proportion in municipal waste, some cities organize to collect food waste at source (*Tai et al.*, 2011).

Vaccari et al. (2013) elaborated six scenarios for the implementation of the system of selective collection in the municipality of Zavidovici, in order to provide

a useful tool for decision making. Costs, environmental and economic benefits of these scenarios were compared. At the time of the study, 90% of total waste was mixed, whereas in the "realistic" scenario this percentage decreased to 78% and the percentage of recycled materials was more than double (22%). In the "ideal" case, mixed waste was 74%, while recyclable fractions reached 26%.

Williams and Cole (2013) investigated the frequency of collection and the collected streams in England. Authors showed that the adoption of an AWC (alternate weekly collection, i.e. the frequency of curb-side collections changed from weekly to fortnightly) scheme had positive impact on recycling rates and the households' behaviour. The present paper does not deal with frequency questions, only with the changes of vehicle demand caused by increasing selectivity ratios.

If obtaining maximum yield of recycles is the primary concern, then dual stream option would be the optimal choice. This collection method consistently out-performed single stream, showing that residents were willing and capable of sorting materials into several different containers if they were supplied with large enough containers and had the room for storage. However, the trials showed that the single stream option (commingled materials in one container) was cheaper, easier to manage for the crew, and easier for residents to understand (*Williams and Cole*, 2013). In case of the introduction of a door-to-door separated system, it is important to facilitate the participation with an easy to understand collection system. Moreover, in Hungary it is very important to keep the cost of the collection system incurred by the public service provider as low as possible.

Gallardo et al. (2012) analysed the currently used separate collection systems in Spanish towns over 5000 inhabitants. Eight types of collection systems were characterised. The most widely implemented system is still the one that collects paper/cardboard, glass and lightweight packaging from drop-off points and mixed waste from kerbside bins. The efficiency indicators for quality in container and fractioning rate were used. They determined that the best system was, which collected mixed waste, organic waste and multiproduct door-to-door, while glass at drop-off points.

A LCA study in Italy developed twelve different municipal solid waste management scenarios. *De Feo and Malvano* (2009) obtained different percentages considering separated collection, as well as various types of treatment for the dry residue deriving from the municipal waste without the materials being separated, collected and recycled or composted. They found that all the considered municipal solid waste management scenarios produced negative impacts, and the highest percentage of separate collection corresponded to the highest avoided impact in total energy use.

In 2012 they performed a study about a high-toned kerbside collection model, applied to communities having inhabitants between 1,000-10,000. The following components were considered: organic, paper and cardboard, plastics, metals, glass, batteries and expired medicines, bulky and durable, green and wood, textiles, as well as dry residue. Timings and frequency of the separate collection were for organic three times a week, for paper and cardboard once a week, for dry residue twice a week, for commingled collection of plastics, alumina and tinplate once a week, for on-call service for bulky materials and durable goods at the end of life; and a separate collection for glass, batteries, expired medicines and textiles. The authors

stated that the 5000 inhabitant community is the lower level of the ideal size for an economically sustainable management of the kerbside separate collection service (*De Feo and Malvano*, 2012).

Calabrò (2009) stated that recycling systems were designed to obtain maximum benefits (high recycling rate, high quality of the recovered materials and simplification of the whole process from collection to waste treatment) at minimum cost. This effort often conflicts with the relevance of the emissions of greenhouse gases (actually the energy consumption of the processes). The commingled collection makes the collection simpler but increases the complexity and the energy demand of the recycling process.

Cimpan et al. (2015) underlined that mixed waste collection (i.e. the mixed waste fraction that can be sorted at mechanical or mechanical-biological treatment plants) resulted in a dependency on export markets with relatively low quality requirements, (e.g. in the Far East) because of poorer material quality. However, central sorting of residual municipal waste stays relevant for areas where source separation is difficult.

Gallardo et al. (2015) introduced a method to minimize the number of selective containers, which in turn will contribute to reduce the length of the collection routes and, as a result, also the final cost could be decreased. Two scenarios were proposed: scenario A considered that mixed waste (organic and reject fraction) would be collected door-to-door, paper/cardboard, light packaging and glass would be collected at drop-off sites, and medicines would be collected at the pharmacies. Scenario B considers that mixed waste will be collected in kerbside bins (street bins), paper/cardboard, light packaging and glass will be collected at drop-off sites located in the streets, while medicines will be collected at the pharmacies. The main difference between the two scenarios is that the mixed waste fraction in scenario A will be deposited in containers located at the front door of the buildings, while in scenario B it will be deposited in kerbside containers at a maximum distance of 30ms from the citizens.

Gallardo et al. (2010) gathered information by means of a survey in 2010 about the selective collection system in Spanish cities with over 50,000 inhabitants. They concluded the best solution with the following elements: organic waste and mixed waste in kerbside bins; paper/cardboard, glass and lightweight packaging from drop-off points. This way keeps waste materials as clean as possible from the moment when they are separated in the households until they reach the recycling plants. However, citizens must make a greater effort in this respect.

The study of *Alvarez et al.* (2009)presented a reconsidered collecting system that used drop-off points for light packaging materials. They concluded that with the redistribution of drop-off points, it was possible to reduce the number of collection points significantly, in addition, the quality and coverage of the collection service could also be maximized.

Facility planning decisions became a critical issue in designing a proper reverse logistics network to deal with waste management and material recovery. This is mainly due to the fact that the number of facilities and their locations have a great impact on global transportation efficiency (*Toso and Alem*, 2014).

Iriarte et al. (2009) compared three selective collection systems operating in densely populated areas. These systems are: the mobile pneumatic, the multi-container and

the door-to-door ones. The door-to-door system has the highest energy demand, which is 57% higher than the multi-container system and 38% higher than the pneumatic mobile system. However, the door-to-door system delivers higher recovery rates of waste, compared with other collection options, which improves the environmental profile. Therefore, in order to minimize the environmental impacts of selective collection of municipal waste in densely populated urban areas, the following actions should be evaluated: to increase the efficiency of inter-city transport, locate recycling/disposal facilities at shorter inter-city distances and integrate recycling/treatment facilities within urban industrial estates.

A comparison of municipal solid waste management scenarios was made by *Rada et al.* (2014). Separate collection of recyclable materials, organic fraction and other waste flows (textile, electronic equipment, bulky waste etc.) was available for citizens. The residual waste goes through mechanical-biological treatment in the first scenario and through a direct thermal treatment in the second one. They found that second case was preferable, given the option of not having pre-treatments on the incoming waste, since efficient waste separation removed the previously non-combustible and putrescible fraction (*Rada et al.*, 2014). This system does not fit to the tenor of EU at all, as efforts are made to keep the materials in the economy as raw material instead of incineration.

Besides the transport system, another important factor is the willingness of the participation of waste producers. To establish a well performing separate collection system is only possible if the consumers' habits and the regulatory enforcement power are taken into consideration (*Mosonyiné*, 2008). Until 2015 in Hungary the usage of drop-off points was typical. Many service providers introduced the door-to-door collection as well, but in these cases the focus was put on the amount of collected materials, not on the costs of the collection. After 2013 the waste service fees were frozen at a decreased level, so this expensive kind of service element was terminated as well. Modification of waste regulation by 2015 had terminated the drop-off points and preferred the door-to-door separate collection only. Many practices were introduced in 2015: commingles collection in yellow sack, commingled collection in bin, separate collection of paper and plastics in two bins etc. Unfortunately, these systems were not supported by calculations; the chosen form was influenced principally by the existence or the nonexistence of tender money for bins and collecting cars.

RESULTS AND DISCUSSION

Having studied the available literature and the current Hungarian waste legislation, I developed several scenarios to examine the vehicle demand of separate collection. For the analysis I chose the town of Nagybajom as a typical municipality both in waste production and in territorial speciality. It lies in the Western part of Somogy County, Hungary. The number of the properties contracted with the waste service provider is nearly 1000. *Table 1* shows the composition of the size of the contracted waste bins. Most of them are 120 litre dustbins; while the weekly contracted volume is 130 m³. Service provider: South-Transdanubian Waste Management Nonprofit Ltd. (Dél-Dunántúli Hulladékkezelő Nonprofit Kft. – DDH Nonprofit Ltd.)

**Table 1**

Contracted dustbins in the city of Nagybajom

Size of the bin (l)	Bin (pieces)	Total volume (l)
35	1	35
50	9	450
60	132	7 920
120	851	102 120
240	21	5 040
1100	15	16 500
Sum:	1029	132 065

Source: *Based on data of DDH Nonprofit Ltd.*

The amount of waste collected last year is shown in *Figure 1*. The amount of selective collected material is not significant in Nagybajom currently. Based on the data, collected for one year, the average amount of collected waste is 9 951 kg weekly, with a standard deviation of 2 778 kg. It is visible that the waste amount is not constant along the year, but there is a significant increase in summer and the minimal values are in February. From week to week there can be unpredictable fluctuations. This fact makes the route planning more difficult. The smaller amount does not fill the collecting car, so part of the capacity is left unused. During the summer the vehicle may be overloaded.

Figure 1

Amount of the weekly collected waste
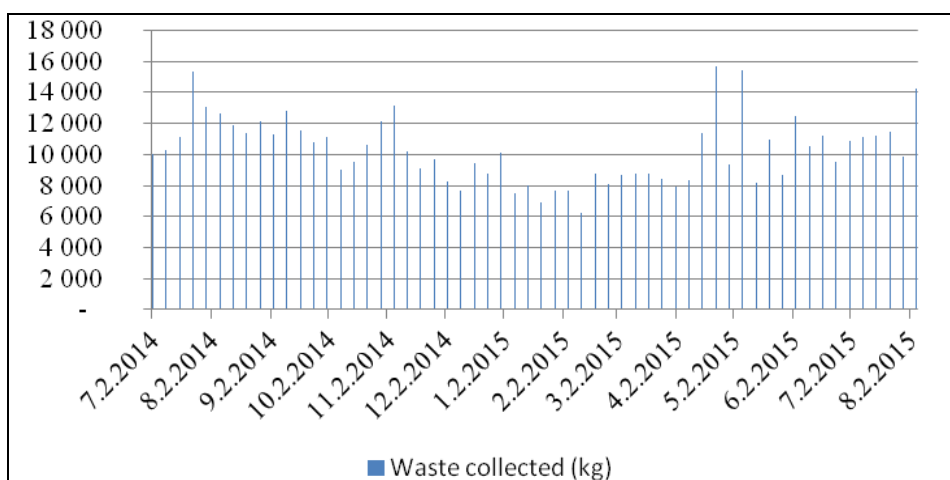
Source: Based on data of *DDH Nonprofit Ltd.*

Legislation contains the description of the compulsory elements of the system. Subject to compliance with legal requirements, the following collection system fully meets all expectations.

The favoured separation system in Hungary is door-to-door collection. Drop-off points can be used only in the areas where the local specifications justify it. According to the recent regulations, the following collection systems are appropriate:

1. Door-to-door collection for following streams:
   - mixed waste
   - plastics
   - paper and cardboard
   - metal
   - bulky waste
2. Drop-off points:
   - glass
   - textile
   - hazardous waste once a year at temporary collection points
3. Optional possibilities:
   - composting at home or door-to-door collection for biodegradables
   - door-to-door collection of food waste once a week
   - electrical and electronic waste and used tire collection before bulky waste collection at temporary collection points

This paper calculates with the simplification of collecting only two waste streams: door-to-door collected recyclables and mixed waste. The amount of glass and textile is added to the amount of mixed waste. Collecting the waste is contained in this paper, the two main activities of waste logistics are as follows: the trip to the workplace and the emptying process of waste into the collecting vehicle. The time and the cost calculations took this fact into account.

In door-to-door separate collection both dustbins and coloured sacks can be used. Mixed waste can only be collected in dustbins. The glass collection is still at the drop-off points. The optimum solution for green waste is home composting. Biodegradable waste can be collected separately, if not, then it can be placed in the bin for mixed waste.

It is important that not only the volume of waste is changing, but also the composition of it. The average composition (m/m%) for the period 2011-2015 is summarised in *Table 2*.

The weight portion of the separated fractions, collected door-to-door is 40.34%, which comprises the following streams:
- Paper
- Cardboard
- Beverage carton
- Plastics
- Metal

The calculation is made for 10 tons of waste a week. 59.66% of the sum is collected as mixed municipal waste, 40.34% of it as source separated material, while the whole amount is collected by door-to-door collection. Four scenarios were

developed. The versions differ from each other in proportion to the separate collection. The total weight of the involved material is 4034 kg/week. The first version considers the separate collection of 12.5%, while the second 25%, the third 50% and the fourth 75%. *Table 3* shows the weight of the collected recyclables.

Table 2

Composition of municipal waste

Type of waste	m/m%
Biodegradable waste	24.83
Paper	8.43
Cardboard	2.89
Beverage carton	3.33
Textile	4.39
Sanitary waste	4.11
Plastics	21.83
Non-classified combustible waste	4.93
Glass	3.41
Metal	3.87
Non-classified non-combustible waste	5.73
Hazardous waste	0.64
Small grain waste (<20 mm)	11.60

Source: Based on data of *DDH Nonprofit Ltd. and its predecessors*

Table 3

Amount of the recyclables at different source-separation rates

Type of waste	%	v1	v2	v3	v4
		Rate of the separation			
		12.5%	25%	50%	75%
		Collected amount (kg)			
Mixed waste	59.66	9 496	8 991	7 983	6 974
Paper+cardboard+ beverage carton	14.64	183	366	732	1 098
Plastics + metals	25.70	321	643	1 285	1 928

The collection vehicle demand of the above scenarios is shown in *Table 4*. In this calculation the recyclable material is collected in two separate streams (paper, cardboard and beverage carton, as well as plastics and metal), so the number of flights in the settlement are three. The calculations are made with an average useful mass of 10 tons per collecting car.

Because of the low density of plastics fraction, it is worth exploring the commingled collection with the paper fraction. This requires additional resources in waste processing, but the logistic demand decreases as shown in the *Table 5*. As it is

clearly visible, the higher specific gravity of the mixed paper/plastics stream means significant savings in transport.

Table 4

Number of collecting vehicles in the case of three material streams

Type of waste	Vehicle demand (pcs)				
	v0	*v1*	*v2*	*v3*	*v4*
Mixed waste	1.00	0.95	0.90	0.80	0.70
Paper+cardboard+ beverage carton	-	0.03	0.07	0.13	0.20
Plastics + metals	-	0.21	0.43	0.86	1.29
Sum:	1.00	1.20	1.39	1.79	2.18

Table 5

Number of collecting vehicles in the case of two material streams (commingled collection of recyclables)

Type of waste	Vehicle demand (pcs)				
	v0	*v1*	*v2*	*v3*	*v4*
Mixed waste	1.00	0.95	0.90	0.80	0.70
Commingled recyclables	-	0.13	0.25	0.50	0.76
Sum:	1.00	1.08	1.15	1.30	1.45

Another possibility to reduce the demand for logistics is the introduction of home composting; it is also a desirable waste management activity. *Table 6* presents the effect of reducing green waste amount on the reduction of collection routes to different degrees. For example, if half of the produced biowaste were composted at the 1000 homes, that would decrease the necessary number of collecting vehicles by 0.09.

Table 6

Effect of home composting on the vehicle demand

	Ratio of the composted biowaste at home	Decrease of vehicle need (pcs)
b1	12.50%	-0.02
b2	25%	-0.04
b3	50%	-0.09
b4	75%	-0.13

Setting together the selection activity of recyclables and green waste reduction opportunities. *Table 7* shows the cumulative vehicle demand. It can be seen that

75% separate collection of recyclables besides 75% biowaste reduction (both values need a relatively high participation and awareness of the population) require more logistic resources and performance as *v0* version (in table 6-7). However, keeping the collected recyclables in the economy as raw material, it can be a significant achievement.

Table 7

Vehicle demand of various separate ratios and various home composting systems

Type of waste	Vehicle demand (pcs)				
	v0	*v1*	*v2*	*v3*	*v4*
		b1	*b2*	*b3*	*b4*
Mixed waste	1.00	0.93	0.86	0.71	0.57
Commingled recyclables	-	0.13	0.25	0.50	0.76
Sum:	1.00	1.05	1.11	1.22	1.32

In *Table 8* it is shown, how the costs and benefits of the various methods and ratios are changing. The costs of vehicle operations, the costs of waste processing and landfilling, as well as the average selling prices of the balled recyclables were taken into account. The table shows that under favourable conditions of costs, revenues and separation intensity, the two stream system has an increasing advantage against no separate collection and even three stream collection.

Table 8

Final cost of waste management

Waste management	Final cost of waste management (thousand Ft/week)				
	v0	*v1*	*v2*	*v3*	*v4*
Three waste streams	310.0	314.4	318.8	327.5	336.3
Two waste streams	310.0	305.9	301.8	293.5	285.3

CONCLUSIONS

The introduction of separate waste collection from households will lead to selective waste sorting. The density of mixed waste is so high that the three-axis collection vehicles are full to the maximum of their compacting structure and we cannot increase their maximum laden mass significantly. If the light density plastic and paper fractions are sorted and collected separately, then the vehicle's useful mass cannot be fully exploited. Looking at the current Hungarian regulations, it seems appropriate and legitimate to use collection systems that apply commingled collection for recyclables. Commingled collection is more efficient than the separate collection of paper and plastic fractions. This collection system requires additional

work during the subsequent waste sorting, but the logistic costs can be significantly reduced. Another way of minimizing generated waste is the promotion of home composting. It is to be noted that this paper assesses the demand for the collection vehicles for the whole logistics phase, where the time and resource requirements of the waste emptying phase is quite standard for all area, while the resource demand for transporting phase can vary in a wide range.

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