ASSESSMENT AND MITIGATIONS OF HOUSEHOLD WASTE COLLECTION TRANSPORTATION RISKS

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Abstract

Collection and transportation of household waste in urban areas is a complex managerial, economic, ecologic and social challenge. Inhabitants of Latvia generate approximately 650 000 tons of waste annually, from which 590 000 tons are landfilled. Latvia has 10 sanitary waste landfills in operation, although, it has to be noted, that 9 of these landfills receive 50% of the overall waste amount for landfilling. One landfill in the Riga region - "Getlini", which is biggest sanitary waste landfill in the Baltic states, receives annually about 290 000 tons of waste. On the one hand it is positive that waste is landfilled and all illegal dumpsites have been closed and recultivated; on the other hand, waste transportation to the landfills requires large number of vehicles, negative impacts from which pollute the environment. Free market in waste management sector will lead to significant increase of number of vehicles and logistics density, which will require complex strategic and managerial decisions. Large number of management companies within one region leads to excessive transportation activities. Waste collection and transportation processes also can have negative impacts, which may result in polluting the territory, air emissions, noise and other pollutions.

The purpose of this study is to elicit and analyse factors that have an impact on human health and environmental pollution. The paper will assess types of risks that can appear during waste management and transportation and provide recommendations on risk minimization.

The methods used in the research will be risk classification and their assessment, causal-loop method for decision-making.

One of the main findings as well as practical implications of the paper is the management decision making, which will decrease number of routes and their length, their doubling, revealing most hazardous territories, due to waste generation and recommendations for usage of different types of vehicles and containers.

Social implications - this paper will line out first steps in improvement of human health and environmental protection.

The originality of the paper is emphasized with the lack of similar studies in Latvia. The research will be of a value for specialists in the municipalities, responsible for waste management and for waste management companies, allowing improvement of their business model as well as to foresee and decrease operational risks and optimize transportation costs.

The research is limited to the analysis of household waste transportation.

***Keywords**:* heavy-duty vehicle emissions, landfills, negative impact on environment, pollution, solid waste

1. INTRODUCTION

Municipal solid waste management is a multidisciplinary activity that includes generation, source separation, storage, collection, transfer and transport, processing and recovery, and, last but not least, disposal (Rada *et. al.* 2013). In European Union waste management has become a very significant topic recently. As 12 new Member states have joined the Union starting from 2004, in order to ensure more or less equal starting point and offered co-financing of the infrastructure and stimulated development of awareness of waste management issues in society. Waste management is a complex issue that includes a variety of risks. This paper is aimed on highlighting the most common risks and analysing them from economic prospective.

Because waste management is an intensive energy-consuming activity, aiming at preserving sustainability of life on earth and creating better habitats, efficiency improvement of waste management systems and related processes is a priority (Zsigraiova et al. 2012).

2. RISKS IN WASTE COLLECTION AND TRANSPORTATION

The waste collection problem is stochastic by nature as the amount of MSW is highly variable and the accumulation of waste depends on several factors such as the number of inhabitants per container, GDP per capita, lifestyle, and season (Nuortio et al., 2006). In addition, following factors have to be mentioned: existing waste collection system and infrastructure; forms of housing – as semi-detached houses generate much less waste then blocks of flats, etc.

According to Zsigraiova *et al.* (2012) for sustainability reasons modern societies have to mitigate the environmental impact of their daily activities, which are potential generators of ecological imbalances.

Waste transportation risks consist of several components, which are in detail assessed in the Table 1, below.

During waste transportation processes, increased risk of environmental pollution appears. Table 1 presents assessment of most common risks, faced by waste management companies during waste collection and transportation stages. It can be summarized, that free market and un-optimized rout risks have the highest predictability rates and have to be taken into consideration both by local government, in charge of waste management system development and by waste management companies.

Now let us take a more detailed look on the last two risks displayed in Figure 1.

Figure 1 provides a set of interrelations, linked to both of the risks and it can be clearly seen, that main effect is caused on the Stakeholders – State and Inhabitants. Some important economic causes and effects appear in the system as well.

According to De Feo, Malvano (2012) focusing attention only on the economic aspects, the design of a proper MSW separate collection system should aim at minimizing costs, together with the aim of optimizing the service offered to the community. However, broadening the perspective of intervention, attention must simultaneously focus on the environmental consequences of the technical-economic choices made or to be made, according to an approach oriented to the safeguard of the environment and human health as well as a minimization of the consumption of resources.

The waste management sector has been identified as one of the sources of greenhouse gas (GHG) emissions, being responsible for about 5% of global emissions (Bogner et al., 2008). The waste management processes not only generate GHG (e.g. collection, transport and landfilling), but also have the potential to save such emissions by displacing use of virgin materials which have much higher emissions associated with their production (ISWA, 2009 and Scheutz et al., 2009).

Table 1

Risk assessment

Type of risk	**Influence on:**	**Effects/risk description**	**Predictability rate**
Illegal disposal	Air (Co_2, NO_x, CH_4, O_3); Greenhouse Gas (GHG); Water;	This risk may occur during waste transportation, when, in most cases due to high gate fee, the operator decreases the amount of waste brought to landfill.	***Low***

	Inhabitant health		
Incineration	Air (Co_2, NO_x, CH_4, O_3); GHG; Inhabitant health	Occurs due inflammation of waste inside the waste collection truck. In this case the truck has to be totally emptied and only then the fire has to be extinguished.	***Low***
Spilling	Air (Co_2, NO_x, CH_4, O_3); Water	High waste liquidity causes spilling of waste while transportation. It has an impact on air pollution (smell) and on water, in case the waste is absorbed and reaches the groundwater.	***Low***
Free market, small segmentation	Vehicle number increase; GHG; Operational expenditures	Increase of vehicle density has a direct impact on air pollution and increase of number of accidents.	***High***
Un-optimized routes	Air (Co_2, NO_x, CH_4, O_3); GHG Noise; Operational expenditures	Existence of various management companies within one region leads to ineffective usage of vehicles and increases volume of emissions.	***High***

From business prospective, all of the abovementioned risks are highly linked with expenditures, and according to Tavares et. al. (2008), the high costs of collection and transportation of municipal solid waste on the overall waste management budget (this figure varies across the countries from 50% up to even more then 75%) makes it an issue to be urgently addressed for improvement. One of the heavy costs, presented in municipal waste management systems is the fuel price, as well as the fact, that waste collection trucks account for heavy duty vehicles (HDV). HDV constitute a very important vehicle category of the road transport sector, operated in a wide series of activities, from passenger and freight transport to very unique applications (G. Fontaras et al. 2012). Both of these factors are inevitably associated with undesired pollutants emissions. This is why optimisation of routes and fuel consumption optimisation have significant positive impacts both for waste management company in terms of cost saving and for environment in terms of pollution decrease.

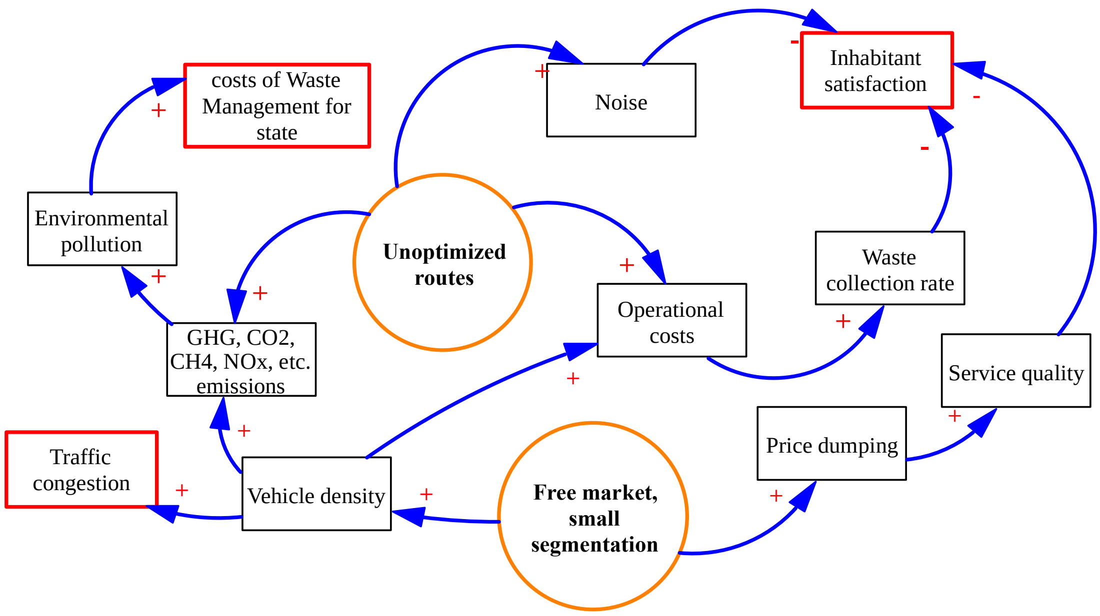

Figure 1. Causal loop diagram of un-optimized route and free market, small segmentation risk

Route optimisation and different methodologies have been studied by a vast number of researchers (Baetz 1990; Bhat, 1996; Clark and Gillean, 1974; Cordeau et al. 2002; Badran and El-Haggar 2006; Armstrong and Khan 2004; etc.). Sonesson (2000) presented a model to calculate the time and energy consumption during waste collection, which is a function of the travelled distance, extra time and fuel consumed during hauling, stopping and compacting of waste.

Latest worldwide tendency shows that diesel operated HDV, used for waste management are being replaced by natural gas vehicles. A clear benefit of such switch is observed in Table 2, below, adopted from Cannon (2006).

Table 2

Summary of Benefits: Natural Gas vs. Diesel Waste collection Vehicles

Impact	Pollutant	% Reduction with natural gas
Air pollution	Particulate matter	67% - 94%
	Nitrogen oxides (NO_x)	32% - 73%
	Non-methane hydrocarbons	69% - 83%
Noise	Decibels	50% (behind) 90% (inside) 98% (beside)
Water pollution	Organics	100%

Although, it when turning to the case of Riga 100% of HDV for waste collection, operating in the region use diesel as main combustible. Waste collection vehicle upgrade to natural gas combustible is a separate issue, researched by the authors and is not involved into current paper. Still, studies, carried by European Union working groups have revealed that heavy duty vehicles are the second-biggest source of emissions within the transport sector, i.e. larger than both international aviation and shipping. As a result, the need for a strategy addressing CO_2 emissions from this sector has been recognized by the Commission in its 2010 Strategy on Clean and Energy Efficient Vehicles (12).

It has to be mentioned, that European Union has developed strict emission regulation standards since 1992 (Euro 1, Euro 2, Euro 3, Euro 4, Euro 5). These regulations significantly decrease volume of emissions, exposed to the atmosphere. From the other hand these regulations might have an impact on waste collection fee increase for the inhabitants, as substitution of outdated waste collection vehicles is a costly operation.

Very clear route optimisation benefits have been presented in the papers of Tavares *et. al* (2008) and Zsigraiova *et al.* (2012).Moreover, in terms of air pollution and energy consumption, Figure 2 (a, b) provide a comprehensive representation of truck speed and emission interrelation. It is obvious, that the less the average speed the more pollutants enter into air.

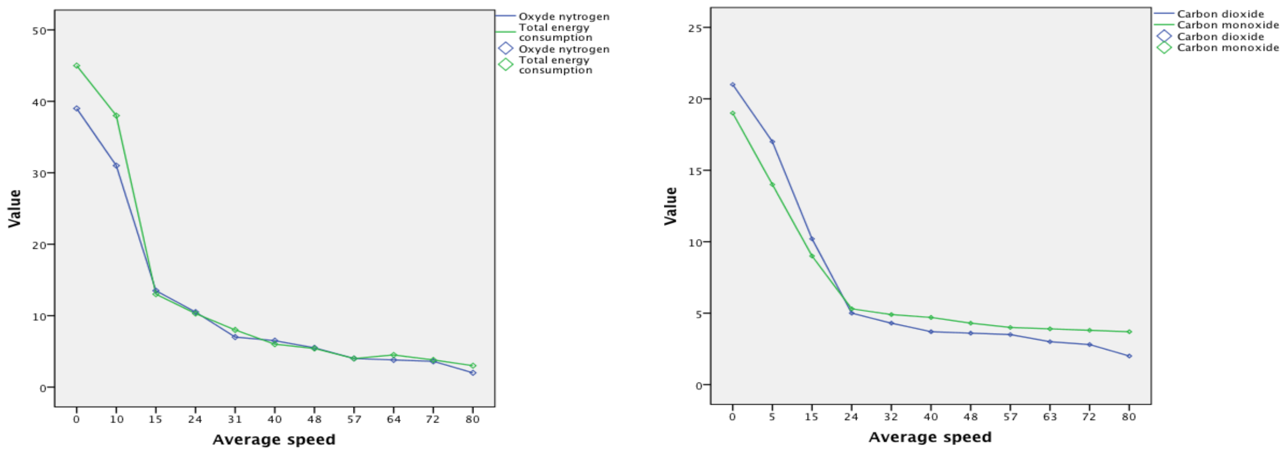

Figure 2 (a, b) Air pollution depending on average vehicle speed

Figure 2 (a, b) shows that the emissions of CO_2, NO_x increase dramatically with the decrease of speed. It has to be noted, that in urban areas average speed of a waste truck reaches only approximately 15-20 km/h. This leads to a conclusion that the bigger inhabitant density in the region is, the lower the speed of vehicles is and the higher are emissions into the environment. From the other prospective, the bigger inhabitant density, the more attractive the region is to waste management companies and they try to enter the market. In case they do, on the instant environmental pollution increases in geometric progression.

Latvian annual transport CO_2 emissions account for 3.495 kt, which is 40.6% of total CO_2 emissions (14). Most part of these 40.6% is due to heavy duty vehicles (constituting 40.2% of overall vehicle type in the country), which makes this research of increased importance.

The following table (3) provides data on heavy duty truck emission rates as well as on idle emission rates, where:

VOC - Volatile Organic Compounds equivalent to THC (Total hydrocarbons including methane) plus aldehydes minus both methane and ethane.

HDV, VII cat. – i.e. tow trucks, waste collection vehicles, according to Heavy-duty vehicle classification.

Table 3

Heavy-duty truck emissions

Pollutant	fuel	HDV, VII cat. (in grams per km)	Pollutant	Idle emissions	
VOC	gasoline	1,775	VOC	g/h	3.503
	diesel	0,281		g/min	0.058
TOC	gasoline	1,814	TOC	g/h	3.553
	diesel	0,285		g/min	0.059
CO	gasoline	14,372	CO	g/h	19.055
	diesel	1,068		g/min	0.318
Nox	gasoline	2,609	Nox	g/h	30.343
	diesel	4,642		g/min	0.506
PM2.5	gasoline	0,029	PM2.5	g/h	1.093
	diesel	0,110		g/min	0.018
PM10	gasoline	0,035	PM10	g/h	1.188
	diesel	0,119		g/min	0.02

Source: EPA, 2008

According to Huai *et. al.* (2006) despite their relatively small population, heavy-duty diesel vehicles (HDDVs) are (in 2005) disproportionate contributors to the emissions inventory for oxides of nitrogen (NO_x) and particulate matter (PM) due to their high individual vehicle emissions rates, lack of engine after-treatment, and high vehicle miles travelled.

3. MATERIALS AND METHODS

This study is aimed on assessment of main risks that occur during waste collection and transportation. After their classification and assessment of impacts, an example case study of the data, gathered by the authors is presented. The research is based on statistical data analysis. Alongside a causal-loop diagram is used to facilitate comprehension and assessment of such risks as un-optimized routes, free market and small segmentation as well as for the aim of revealing the unobvious connections and consequences of particular decisions. The choice of particular works within the article stands as a proof for the fact that this particular topic is of an issue during quite a long time period and the solution requires a complex and multidisciplinary approach. The research is based on a case study of the city of Riga and on the analysis of waste collection routes. The authors have performed the route evaluation field research in 2011.

Case study of Riga city

Capital of Latvia occupies 304 km^2 – 259 km^2 of which is land and 44 km^2 is water. It has 699 203 inhabitants. Population density in the city is about 2 331.4 inhab. /km^2 (2 700 inhab. /km^2 on the land area). As Riga is the capital, it is most populated area of the country and has highest population density. Until 2004 Riga was mainly serviced mainly by 2 waste management companies, and was more or less dividend among them. Later 4 more companies were given permission to operate in the market. Currently the market has 6 biggest waste management companies, which in total collect about 80% of waste generated in the region, as well as there are approximately 120 companies, which in total bring to landfill 20% of waste generated, which is mainly generated by themselves. It has to be stressed, that waste management is also a field with clear economies of scale and means that often small companies are not able to catch up with latest European emission standards and thus possess environmental threat in air pollution. Market opening lead to service price decrease to the inhabitant, as the price dumping started. From one side this had its benefits, although only the inhabitant now had free choice of operating companies, which were interested in increase of their market shares. From the other side – the same inhabitant currently experiences increase of air pollution, as well as more often noise from waste collection truck passing by. This is explained by the fact that there are cases when neighbour buildings are serviced by different waste management companies, which makes an increase of waste collection vehicle per street or neighbourhood as well as an increase in environmental pollution. Currently no regulations on waste management in the city of Riga are in force and the market liberalization has raised a fundamental issue – as increase of HDV density in residential districts, lack of route optimization, air pollution and increase of operational costs for waste management companies.

Practical part of this research is based on analysis of waste collection routes in the city of Riga. Over 50 routes have been observed within one month period and most significant results are described below. The authors have chosen 6 routes to be analysed, as they represent different results.

Table 4

Route characteristics

Route	No. Of clients	Collection de facto, m^3	Collection according to contracts, m^3	Hours
A	177	7091	5041	218
B	478	3468	5377	208
C	469	7747	6083	319.5
D	733	6166	6812	252
E	962	4542	4545	342
F	1618	6210	5560	252

Table 4 provides a comparison of general information regarding the routes. It already can be noted, that each route differs significantly in terms of length. For example – route A and B require approximately the same time to be completed, which also is seen from table No. 4, but at the same time, number of clients on the routes differs for over 2.5 times.

It has to be taken into account, that no weighting at the collection point is used currently in Riga. It is clearly seen that on the route B there is a convincing overestimation of waste generation, which has a direct impact on the cost, paid by the clients for waste collection. The de facto collection at the particular month reached only 63% of overall planned volume. Other routes show the increase from 0.5% up to 41% in de facto waste collection. Unfortunately waste statistics in urban areas is very approximate and has to be analysed over a longer time period, taking into account the seasons, migration of population and other factors. Many authors agree that there is a generalized lack of reliable information on the mass and volume of waste in individual containers (Zsigraiova et al. 2012). This means that until waste weighting system at its collection point will not be introduces, the data will vary significantly.

Table 5

Gathered data on sample routes

Route	Emptied containers	Overall route length	Number of journeys	Tons	Fuel, l	Idling time, h
A	7261	2817	35	450	1 594	39.24
B	3192	2864	34.5	270.78	1 471	27.04
C	8728	3062	74	826.69	2 162	63.9
D	5418	2271	48	418.68	1 418	37.8
E	6729	2549	67	576.10	1 570	51.3
F	9061	4988	85	844.73	2 328	50.4

The routes, chosen for a sample are located in medium to high density neighbourhoods; this is why idling time is assumed to be 13-20% of overall time spent on the route. According to Lim (2000), fuel consumption rate for idling is 3.1 l/hr. Still, practical experience reveals that vehicle during idling time in some cases can consume up to 10 l/h. This leads to the results displayed in Table 6.

Table 6

Influence of idling time on overall time and fuel consumption

Route	Idling time, h	Idling fuel consumption	Hydraulics working time	Hydraulics, fuel consumption
A	39.24	121.644	60.51	484.07
B	27.04	83.824	26.60	212.80
C	63.9	198.09	72.73	581.87
D	37.8	117.18	45.15	361.20
E	51.3	159.03	56.08	448.60
F	50.4	156.24	75.51	604.07

According to practical data, vehicle fuel consumption during the work of hydraulic system increases to 8-18 l/h. From the table 6 it is clearly seen that in order to empty all the containers on the route one vehicle consumes in average 25.6% of total fuel consumption (if 8 l/h is taken as a calculation basis).

Following figures will present an analysis of route efficiency in the studied area. Figure 3 shows the comparison of fuel consumption and amount of waste collected in each route.

It has to be emphasised that these routes are managed by one company and one vehicle. Although, due to free market that currently exists in Riga and Riga region it is quite common, that the routes cross and one neighbourhood can be operated by two or three waste management companies simultaneously. This results in creation of excessively polluted areas within region and from environmental prospective is increasable harmful both for nature and human health.

Table 7 provides the data on emissions during one month period, by each particular car on the route. In case these figures are transferred on the neighbourhoods and free market is being taken into consideration, all these emissions increase in geometric progression, as well as the figures from Table 8. Thus, in comparison with Table 8, emissions from Table 7 are spread while vehicle is driving.

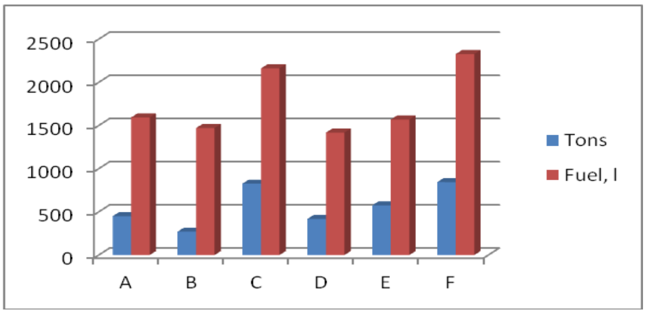

Figure 3. Fuel consumption and waste collection chart

Table 7

Pollution per month during operation of HDV

Pollution, kg	Routes					
	A	B	C	D	E	F
VOC	0.793	0.806	0.862	0.639	0.717	1.404
CO2	3.009	3.059	3.271	2.426	2.723	5.328
Nox	13.077	13.295	14.215	10.543	11.833	23.156
PM2.5	0.310	0.315	0.337	0.250	0.280	0.549
PM10	0.336	0.342	0.365	0.271	0.304	0.595

This table provides emissions that appear from idle standing vehicle, thus not taking into consideration the work of hydraulic equipment. These results possess even more threatening figures then ones from Table 7. According to the table, the higher population density, the higher volume of waste generated at one area. This leads to the fact that the vehicle has to stay longer on the waste collection point and this increases the pollution volume in the particular place. Waste collection points with waste containers themselves possess considerable risk of environmental pollution and results of the analysis state, that in addition they receive pollution from waste collection vehicles.

Table 8

Pollution per idling time, kg/month

Pollution	Routes					
	A	B	C	D	E	F
VOC	5.394	2.561	14.303	5.005	9.219	8.898
THC	5.471	2.598	14.508	5.077	9.350	9.025
CO2	29.340	13.932	77.806	27.227	50.147	48.403
Nox	46.721	22.186	123.897	43.355	79.853	77.076
PM2.5	1.683	0.799	4.463	1.562	2.876	2.776
PM10	1.829	0.869	4.851	1.697	3.126	3.018

Table 9

Route comparative ratios

Route	Cont./h	km/t	l/t
A	33.31	6.26	3.54
B	15.35	10.58	5.43
C	27.32	3.70	2.62
D	21.50	5.42	3.39
E	19.68	4.42	2.73
F	35.96	5.90	2.76

When analysing Table 9, it has to be taken into account that the routes are not totally similar and have their own nuances. Anyway, from these comparative ratios we can summarize that main risk in waste collection and transportation from business prospective – is to ensure time effective and cost efficient routes, which at the same time will be aimed on maximal decrease of environmental pollution.

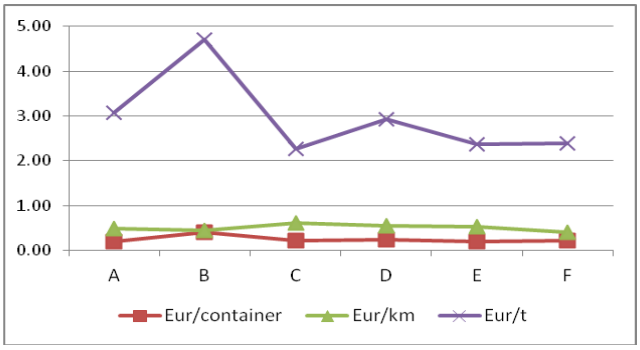

Figure 4. Waste collection expenditures

Figure 4 provides an insight of rough expenditure calculations (transport maintenance is not taken into account in this study). From the chart it can be noted that the routs have different density and economics. For example, it is obvious, that expenditures per ton of waste starting from approx. 600 t become more or less stable (routes C, E, F); waste container density in routes C and F, taken into account the overall route length show very good economics. Route B drops out slightly from the overall picture – this is explained by long route and low inhabitant density, which results in low total amount of waste collected. From abovementioned it may be concluded that when planning the waste collection routes, Management Company has to take into account a vast variety of different factors, in order to ensure that each particular route is designed as optimal as possible.

4. RESULTS AND DISCUSSION

The aim of this paper was to assess and analyse environmental risks that arise during waste collection and transportation. It has been evaluated, that risks with highest predictability ratio are – free market and un-optimised routes. These are also the risks that waste management companies would likely omit, as they have a direct impact on waste collection costs for inhabitants – which might decrease company's competitiveness in the market, as well as on operational costs, which instantly reflects on the revenues.

Future research will be focused on the issue of environmental pollution, in the cases when waste collection vehicles are transformed from diesel-operated to natural gas vehicles. Alongside, more economic aspects of the issue will be covered in the upcoming research.

5. CONCLUSIONS

During waste collection and transportation a range of risks that are dependent on managerial decisions, like number of waste management companies in the region, waste collection routes, etc. arise. On the other side there are more technical parameters – how are waste collection points managed by inhabitants, what type of waste is discarded and so on. This paper has a focus mainly on managerial parameters. Managerial decisions connected with region division into areas could provide more effect then various technical decisions. One waste management company operating in the region can ensure route optimization, which for the company itself results in significant cost-savings. In case, the region is not strictly divided into areas and more then one waste management company is offering it's services there, the risk of "cherry picking" arises (when operating companies start competing for most profitable clients, often leaving less profitable part of clients with limited service offered).

The research has led the authors to a conclusion that significant improvements have to be performed during tender procedure. These improvements would involve evaluation of not only technical equipment of the competitors and their offered waste collection rates, but it should also include their forecasted route optimisation scheme. This scheme should have emphasis on route minimisation and optimisation of waste collection, decreasing operational risks – the total distance covered by one vehicle.

In order to ensure decent environmental protection, it is of vital importance for waste management companies to have waste collection trucks, complying with at least Euro 4 standards in their possession.

The companies, with collect and deliver their own produced waste, which are numerous in Riga city region, harm environment in a greater volume then professional service providers. This is explained with: transportation of lower volume of waste; often incompliance of the vehicles with latest Euro emission regulations; lack of compression system in the vehicle, etc. Still, it is notable, that these 120 operating companies in total deliver only 20% of the total generated waste amount to the landfill.

The research has established interrelation between environmental pollution and motion of waste collection vehicle: while no-load driving; while running in the working neighbourhood and manoeuvring; directly while unloading containers.

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