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THE IMPACT OF THE TRANSFER STATION ON THE ORGANIZATION OF MUNICIPAL WASTE COLLECTION

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ABSTRACT - Transfer stations are construction facilities for the reception and temporary disposal of unsorted municipal waste. Waste from collection vehicles is loaded for further processing or final disposal to large-capacity vehicles. Municipal waste collection in the city of Zenica is organized with vehicles of different sizes and carrying capacities that are adapted to traffic conditions and the size of containers located in the area of the city from which the waste is collected. The change in the organization of waste collection and transport by using a transfer station is reflected in the shortening of transport distances for individual waste collection vehicles, because the waste is transported to the transfer station, which is located on the border of the urban zone, and not to the Regional Landfill "Mošćanica", which is 17 km away from the city. This paper presents several performance indicators (consumption), as well as environmental impact, which define the efficiency of municipal waste collection organization in direct transportation to a landfill and with a transfer station. The analysis of the transfer station operation will examine organizational, environmental and economic indicators.

Keywords: Transfer Station, Waste Management, Municipal Waste, Environmental Protection, CO_2 Footprint.

INTRODUCTION

The costs of municipal companies whose main activity is waste collection and transport make up the majority of expenditures in municipal waste management systems and range from 50-70% of total costs. In addition, waste collection and transport cause greenhouse gas emissions. Optimization of waste collection and disposal involves analyzing of a large number of influential factors that can be grouped as: locational, technical, legislative and organizational [1].

Technical and organizational aspects can refer to: waste collection vehicle and containers (technical characteristics), organization of collection (working hours, number of employees, collection path).

The direct impact on CO_2 reduction is reflected in fuel consumption per ton of waste transported, which has both economic and social impact. The carbon footprint is calculated by multiplying the emissions of each of the six greenhouse gases: carbon dioxide CO2 (factor 1), methane CH4 (factor 28), nitrous oxide N2O (factor 265),

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hydrofluorocarbons CHF3 (factor 12400), difluoromethane CH2F2 (factor 677) and sulfur hexafluoride SF6 (factor 16300), by its 100-year global warming potential (GWP) [2].

The paper analyzes the vehicle fleet used for the collection and transportation of municipal waste in the city of Zenica and presents environmental, economic and organizational indicators. Based on the parameters: vehicle fuel consumption, transported tons of waste, number of waste collection service users, number of employees in waste collection, number and type of waste collection containers, an assessment of the characteristics of the municipal waste collection service system is made for the period 2014, when reloading is performed from small waste vehicles (up to 4 tons) and 2024, when reloading is performed from all waste vehicles that collect less than 9 tons of municipal waste (transfer station).

EXPERIMENTAL

The city of Zenica is located in the central part of Bosnia and Herzegovina on an area of 550 km^2, of which 44 km^2 is inhabited. The number of inhabitants, according to the 2013 census, is 110 663 [3].

ALBA Zenica d.o.o. is a utility company that provides the service of collection and disposal of municipal waste from the area of the city of Zenica. Collected waste is taken to the Regional Landfill "Mošćanica", 17 kilometers from the city center, where it is disposed.

The municipal waste collection and disposal system can be divided into:

- individual collection, where each user is assigned a container and the frequency of its emptying is in accordance with the signed contract (once a week),
- collective (joint) collection, where several users are assigned to one container and it is emptied depending on its fullness (several times a week).

In Zenica, waste collection containers are used that differ in volume, shape and method of emptying. For the collection of municipal waste, special purpose vehicles are used for emptying containers and transporting waste, which can be classified into the following groups:

a) small waste vehicles (6-11 m^3) for bins (120-240 liter) and containers (1.100 liter),
b) medium waste vehicles (12-18 m^3) for containers and bins,
c) large waste vehicles (19-21 m^3) for containers and bins,
d) grapples (32 m^3) for metal bells (2.500 liter) and underground containers (3.000 liter).

The system recognizes types of containers, grouped by area, which as a rule correspond to the area of local communities. Zenica is divided into 74 local communities.

The waste collection area is divided according to the types of containers into:

a) bins (0.12 – 0.24 m^3) – 68 local communities (rural and suburban areas),
b) containers (1.1 m^3) – 16 local communities (city area),
c) underground containers (3 m^3)- 19 locations and metal bells (2.5 m^3) - 29 locations in 11 local communities (city area).

Inhabited areas are connected by roadways, which, together with the places where waste collection containers are located and the frequency of emptying, determine the type of vehicles used for waste collection system.

The area of municipal waste collection related to individual housing is predominantly located on the outskirts of urban areas or in rural, mostly hilly areas. It is characterized by narrow roads that require the use of smaller waste vehicles.

Waste collection from populated areas where containers are located on open areas, which are also accessible to larger vehicles, is carried out by trucks with higher carrying capacity, thus achieving better operating parameters, i.e. greater efficiency.

When analyzing municipal waste collection activities, the work process is usually divided into:

a) emptying waste containers, which involves emptying them into a vehicle and moving the vehicle up to 100 meters between containers,

b) vehicle transporting from the starting station to the area with containers for emptying and transporting the vehicle from the area where the containers are emptied to the landfill, or municipal waste treatment plant.

The ALBA Zenice d.o.o. work process controlling department keeps data on consumption and realization parameters. For the purposes of this work, monthly data for April 2014 and 2024 were observed.

RESULTS AND DISCUSSION

In 2014, the reloading was carried out from small waste vehicles with a carrying capacity of 4 tons into a large vehicle with carrying capacity of 10 tons (grappler without trailer). In 2024, small, medium and large vehicles were reloaded, except when the mass of loaded waste exceeds 9 tons, which refers to fully loaded large waste vehicles.

Fuel consumption per unit of time, or distance, is noticeably higher for vehicles for waste collection and transportation compared to long-distance vehicles. The difference in consumption indicators is conditioned by the driving style (start-stop), the area of movement (populated areas with slow traffic) as well as the fact that the waste collection and compaction equipment is driven with hydraulic elements that are powered by a hydraulic pump connected to the truck engine.

Fuel consumption and time consumption indicators in relation to the work performed, efficiency, are presented in Table 1 for 2014 and Table 2 for 2024.

Table 1 Municipal waste collection indicator – work and consumption April 2014 [4]

waste vehicle	km	l	t	shift	landfill	transfer station	t/unload	240 l	1100 l	crew
waste vehicle 6-11m^3	7879	3529	792	96	83	167	3,2	27405	1754	11
waste vehicle 12-18 m^3	2363	1733	285	34	44	1	6,3		6474	5
waste vehicle 19-21 m^3	4651	3737	716	61	78	1	9,1		13218	6
grapple	2594	2410	428	27	57	0	7,5			1
	17.487	**11.409**	**1.793**	**218**	**262**	**169**	**4,2**	**27.405**	**21.446**	**23**

Table 2 Municipal waste collection indicator – work and consumption April 2024 [5]

vehicle and machines	km	l	t	shift	landfill	transfer station	240 l	1,1 m^3	2,5 m^3	3 m^3	32 m^3	crew
waste vehicle 6-11 m^3	5525	3243	950	107	0	316	43992	1791				15
waste vehicle 12-18 m^3	1173	738	217	21	19	21	1045	7236				3
waste vehicle 19-21m^3	4464	3328	682	62	57	33	7892	8738				7
grapple	1428	1073	317	27	47	19			1108	636		1
roll-off tipper with trailer	2870	2645	1322	30	80						156	1
wheel loader		465	1322	26							156	1
	15.460	**11.491**	**2.167**	**217**	**203**	**389**	**52.929**	**17.765**	**1.108**	**636**	**312**	**28**

Efficiency is observed through indicators of working hours and fuel consumption per ton transported, kilometer traveled and waste container. The efficiency of smaller vehicles, with a carrying capacity of up to 4 tons, is lower due to their lower carrying capacity, so their use for the removal of municipal waste over longer distances should be avoided. In order to improve the indicators of increasing efficiency, better utilization of labor resources and reducing fuel consumption, as well as increasing the use of smaller vehicles due to the characteristics of roads in remote parts of the city of Zenica, in rural areas, a municipal waste transfer station was put into operation in 2016, 17 km from the Regional Landfill. Since then, municipal waste collected in smaller and medium-sized vehicles, or partially filled large vehicles, has been sent to the transfer station, and after being reloaded into 32 m^3 roll containers, it is transported to the landfill by truck with a trailer.

The introduction of the transfer station has changed the ratio of fuel consumption by relevant performance indicators (t, km, shift, containers). The justification is shown through the performance indicators of the waste collection system when only small vehicles (up to 8 m^3) perform the transfer and the collection system and when only large vehicles (21 m^3) transport waste to the landfill, and the other trucks are directed to the transfer station, from where the waste is then sent to the landfill by a larger capacity transport vehicle. Table 3 and Table 4 show the consumption of time, fuel and kilometers transported, per shift, container and per ton of municipal waste sent to the Mošćanica Regional Landfill, without and with the transfer station. By analyzing the presented data, the values of the indicators for both cases can be compared.

Table 3 Municipal waste collection indicators – performance April 2014

vehicle	l/t	l/km	l/container	l/shift	t/shift	t/worker/ shift
small w. vehicle	4,46	0,45	0,12	36,76	8,25	1,02
medium w. vehicle	6,08	0,73	0,27	50,97	8,39	1,58
large w. vehicle	5,22	0,80	0,28	61,27	11,73	2,76
grapple	5,63	0,93		89,26	15,87	15,87

Table 4 Municipal waste collection indicators – performance April 2024

vehicle and machines	l/t	l/km	l/container	l/shift	t/shift	t/worker/shift
small w. vehicle	3,41	0,59	0,071	30,31	8,88	0,59
medium w. vehicle	3,39	0,63	0,089	35,13	10,35	4,14
large w. vehicle	4,88	0,75	0,200	53,68	11,00	1,62
grapple	3,39	0,75	0,615	39,75	11,74	5,87
transport	2,00	0,92	16,95	87,65	44,08	33,80
wheel loader	0,35		2,98	15,00	50,86	43,04

Based on the calculated values, there is a visible difference in the carbon footprint generated by municipal waste collection activities in the city of Zenica when reloading from small waste vehicles (up to 4 tons) and when reloading all waste vehicles when transporting less than 9 tons of municipal waste (transfer station).

$$t_{CO2_{14}} = \frac{l \cdot 2{,}65}{1000} = \frac{11409 \cdot 2{,}65}{1000} = 30{,}23 \quad (1)$$

$$t_{CO2_{24}} = \frac{l \cdot 2{,}65}{1000} = \frac{11491 \cdot 2{,}65}{1000} = 30{,}45 \quad (2)$$

Using the CO_2 emission calculator for diesel fuel consumption, the impact on CO_2 emissions is also visible. Comparing the resulting CO_2 footprint to the transported tons of waste in 2024 is a reduction of 14% per ton visible.

With every journey, motor vehicles emit carbon dioxide (CO_2) from the exhaust gases. Surprisingly, CO_2 weighs more than the fuel that was originally filled. Jörg Sauer from the Institute for Catalysis Research and Technology at the Karlsruhe Institute of Technology (KIT) explains why is this so [6].

When a vehicle consumes one liter of petrol, it emits about 2.37 kilograms of CO_2. If diesel is used, it emits 2.65 kilograms of CO_2. It may seem confusing, but in the end it all comes down to chemistry. Fuel is a mixture and consists of many hydrocarbon chains. While driving, the fuel burns in the engine, and the carbon (C) reacts with oxygen (O_2) in the air. One by one, the atom combines with two oxygen atoms in the carbon dioxide (CO_2) molecule. In simple terms, the light hydrogen atoms (atomic mass 1) from the hydrocarbons are exchanged for heavier oxygen atoms (atomic mass 16). The hydrogen atoms in turn combine with oxygen to form water (H_2O).

In order to present the results obtained in full, it is necessary to show the total amount of waste disposed of, i.e. the number of waste collection service users in the observed case. (Table 5)

Table 5 Overview of total quantities of municipal waste transported from Zenica 2014/2024

year	waste collected	housing	companies	total	per user
2014	26.665 t	24.371	939	25.286	1,055 t/year
2024	27.449 t	29.944	1.710	31.654	0,867 t/year

The improvement of the municipal waste collection and disposal system in Zenica can be analyzed through data with indicators of the provided waste collection service and work engagement for its realisation (Table 6.).

Table 6 Work indicators by fuel consumption and time April 2014-April 2024

	ton	liter	km	user	shift	workers	containers	l/t	l/user	h/t	h/user
april 2014	1.79	11.40	17.48	25.246	218	23	48,851	6,36	0,45	2,27	0,16
april 2024	2.16	11.49	15.46	31.328	217	28	72,438	5,30	0,37	2,29	0,15

In 2024, a larger amount of waste was collected from a larger number of users, in a larger territory (distance) with lower fuel consumption and a lower number of kilometers traveled.

CONCLUSION

Looking at the above data, it can be concluded that the use of a transfer station in the municipal waste collecton system is justified. Larger amount of waste from a larger territory is collected with lower costs.

The above data, in addition to reduced consumption, also indicate a more environmentally friendly way of working (CO_2 footprint).

Due to the increased volume of work, the number of employees providing the service has increased, but the time (h) indicators of service execution have improved, with the exception of the time spent per ton, which can be expected considering that the amount of waste per user of the service has decreased (table 5), which is conditioned by the increase in the number of households included in the system.

It can be concluded that changing the transport of waste to the landfill, by including transportation to vehicles with higher capacity, is a correct business decision that contributes to better business and environmental results.

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