OPTIMISATION OF REVERSE LOGISTICS WITH METHODS OF OPERATIONAL RESEARCH

Vladislav Zitrický
University of Zilina, Slovakia
E-mail: vladislav.zitricky@fpedas.uniza.sk

Lenka Černá
University of Zilina, Slovakia
E-mail: lenka.cerna@fpedas.uniza.sk

Jozef Gašparík
University of Zilina, Slovakia
E-mail: jozef.gasparik@fpedas.uniza.sk

Rudolf Kampf
Institute of Technology and Business in České Budějovice, Czech Republic
E-mail: kampf@mail.vstecb.cz

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Abstract

Optimisation of routes and searching for the shortest journey is currently an inevitable action during the management of logistic processes which significantly affect the production activity of businesses. There in a market environment it is necessary for businesses to plan transport routes effectively. This represents a key to achieve savings, and a fast and quality customers' satisfaction; last but not least the effectively set transport processes affect the environment protection, too. Thus the optimisation of transport routes represents one of very important aspects of all logistic systems. The protection of the environment is directly related to another important part of a logistic system - reverse logistics. This term includes handling of waste, its management, recycling and disposal. For waste producers, households and businesses, the concerns with waste end with its throwing into containers intended for it; for waste processors, however, this represents the beginning of the whole cycle of processing. The first important part of processing the waste is the waste collection and haulage to its further processing. Optimisation of this part is therefore significant for the economy of the entire waste processing. The article deals with the optimisation of collection and haulage of a selected type of sorted waste. For the sake of a general illustration the optimisation will be performed with heuristic algorithms in a real street network of a selected town. The aim of the article is to determine reserves of the current system of waste collection in a company, to evaluate the options to eliminate these reserves to an essential minimum, to choose appropriate optimisation tools and subsequently to use these tools, and to make the system of waste collection and haulage more effective.

Key words: Route optimisation, transportation networks, reverse logistics, waste sorting, waste disposal.

1. INTRODUCTION

Environmental burdens arise due to problems in the industrial production and waste economy (Abramovic, 2012). Such an arisen toxic source may be removed (eliminated) or it represents a threat for the future. One of important logistics activities is the reverse logistics which aims to remove and dispose a waste material, arising in the process of production, goods distribution and packaging (Lizbetin, 2018). Mostly it comprises activities such as ensuring a temporary storage of these materials, their subsequent haulage to a disposal site, processing, re-using or recycling. Optimisation of this part is therefore significant for the economy of the entire waste processing.

Currently there increases a general interest in recycling and re-using of materials very much, and thus a considerable attention is paid to this issue (Janíčková, 2012). It is especially true for Europe where with respect to a limited number of dumping sites there exist some relatively very strict restrictions regarding removing packaging material and outdated products (Skrucany, 2018; Dolinayova, 2015).

The aim of the article is to optimise collection and haulage of a selected type of sorted waste of the enterprise Městské služby Písek, s.r.o. The main goal is to determine reserves of the current system of waste collection in the company, to evaluate the options to eliminate these reserves to an essential minimum, to choose appropriate optimisation tools and subsequently to use these tools, and to make the system of waste collection and haulage more effective. Based on the analysis of the current state of sorted waste in the monitored area it was found out that a weak point in the waste haulage is the frequency and routing of vehicles in case of haulage of glass in two different containers. In the conclusion of the article there is a comparison of routes of the current state and the state after optimisation.

2. METHODOLOGY OF THE SOLVED PROBLEM

To address the observed problem there will be a scientific methodology used in the paper. The methodology is divided into several parts, and its primary goal is the optimisation of a multi-circuit, capacitive limited haulage/distribution issue. Specifically it is the haulage of sorted municipal waste by the enterprise Městské služby Písek, s.r.o. The first part of the methodology describes the observed problem; it provides information required for the optimisation of routes and explains some terms from the area of a reverse logistics, mainly of waste haulage. Collected information, complexity and depth of examined indicators were the basis for creating a research plan which exactly identified individual phases, methods and procedures. The following part of the methodology evaluates the effectiveness of the current haulage logistics in Písek, identifies weak points and reserves of sorted waste haulage, describes options to reduce the weak points, and in the final part of the methodology there is the determination of optimisation tools for streamlining the system of waste haulage in the monitored area. Optimisation tools used to eliminate weak points of the reverse logistics are represented with a Clarke-Wright Method intended to solve circular routes, and the Nearest Neighbour Method.

The Clarke-Wright Method is probably the most known heuristic method, solving a circular transport problem. The authors introduced their method as early as in 1964; thanks to its attributes and simplicity the method has been applied up to now (Stopka, 2015; Hansut, 2017). It is mainly used to solve multi-circuit transport problems where it is necessary to count on driven kilometres as well as other restricting conditions which divide the whole concept into more sub-circuits. The method improves existing solutions up to the moment when it is not possible to achieve any better solutions (it would lead to breaking of conditions of capacity, time, etc.) (Clarke G, 1964).

The Nearest Neighbour Method represents a very simple heuristic approach which applies principles of so called greedy algorithms and is sequentially progressive (Jablonský, 2007). It means that for a current peak the best option is chosen; in case of a route optimisation it is the nearest peak from the point of view of distance. For this peak there is the search for the nearest, so far not operated peak applied again. The process continues this way until all operation peaks are completely run out of. It is appropriate to apply this procedure so that all the peaks of the operation network are taken as the initial peak which creates a plenty of routes with their count equal to the count of individual peaks. Afterwards the distance (in kilometres) among individual peaks of all computed routes is computed; the choice falls on that route which has the least driven kilometres (Fiala, 2010).

The results of optimisation will be compared to the current state of specific waste (glass) haulage, and in the final part of the methodology they will be evaluated from the economics point of view. The methodology represents a sequence of steps to ensure the effectiveness of the concept of sorted waste haulage in Písek.

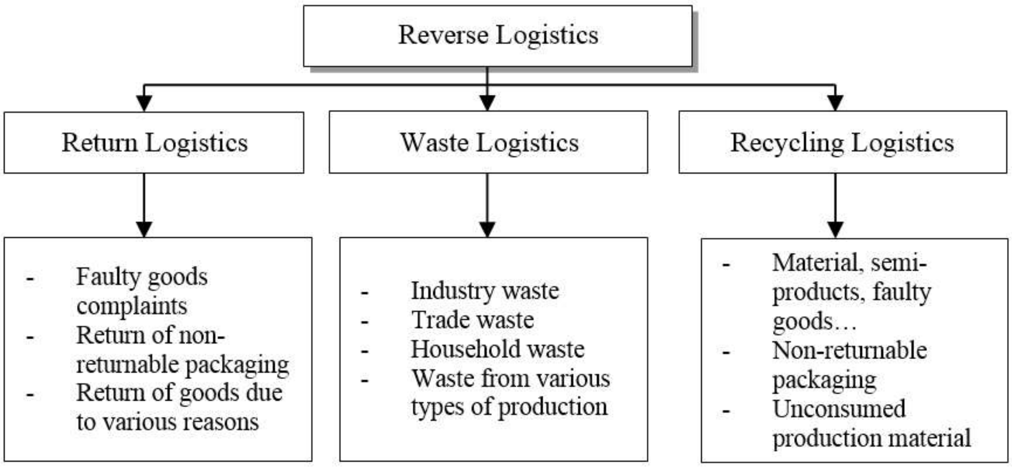
3. REVERSE (BACKWARDS) LOGISTICS

The term "backwards logistics" is synonymous to the term "reverse logistics" (Cudzilo, 2018). It can be used to denominate a backward physical motion in backward oriented distributional contract flows which are provided with the following logistics (Tomková, 2015):

- return logistics,
- waste logistics,
- backward logistics,
- recycling logistics.

All terms above are correct because they indicate specific logistic subsystems which are usually part of a certain integrated logistic system. For the sake of solving the aim of waste haulage optimisation the term "reverse logistics" will be used in the article. The following Figure 1 shows a scheme of division of the reverse logistics.

Figure 1. Division of Reverse Logistics



Source: Tomková, 2015

Currently there exist two perspectives on the reverse logistics, which differ in the subject of interest of the reverse logistics (Jeřábek, 2012):

- the American notion of the reverse logistics - the subject of interest is returned goods (goods under complaint, unsold stocks, etc.); from this point of view the reverse logistics deals with complaints, unneeded and redundant goods,
- the European notion of the reverse logistics - the subject of interest is the option to recycle municipal and industrial waste with regard to increasing ecology requirements which are evoked mainly with the pressure of ecology groups, and legislation.

The reverse logistics is a flow of used products, packaging and other materials which come from a consumer. Mostly these are flows of already consumed products, i.e. waste, and empty packaging as well as goods under complaint. The main content of the reverse logistics is the collection, sorting, dismantlement and processing of used products, components, side products, redundant stocks and packaging material where the main aim is to find their new use or material valorisation in a way that is environment-friendly and economically interesting. The importance of the reverse logistics differs by industry. Generally speaking, the reverse logistics plays a significant role in industries with a high value of goods or with a high share of returned products. Enterprises in these industries devote big efforts to improve the process of backward material flows.

3.1. Importance of the Reverse Logistics

Logistics plays a big role in the waste processing. At the beginning of the 90s the waste logistics was considered only as a way how to reduce costs or handle complaints. In the following years the complexity of the reverse logistics was developed; this happened not only with regard to enterprise's costs but also with regard to the environment. The reverse logistics even defines a duty to sort waste in certain enterprises. Its main content is the collection, sorting, and processing of used products, side products, and redundant stocks where the main aim is to find their new use.

The reverse logistics works with two communication strategies (Pazourková, 2015). Specifically, these are the Push strategy and the Pull strategy. The Push strategy is grounded mainly on the Environment Protection Act, ecology directives, but also on protests of civil initiatives, or ecological behaviour of competitors. The Pull strategy is governed with wishes of customers and ecologically aware consumers.

3.2. Logistics of Municipal Waste

The logistics of municipal waste deals with the issue of placing the waste on the site of its origin, with the following transport into the site of processing and then with the waste processing itself. From the point of view of the municipal waste haulage it is mainly the mapping of the haulage route and its optimisation; the output is the most economic route. At the same time this route should be economic from the point of view of time as well as from the point of view of costs on transport. For the sake of optimisation it is required to know the location of collection sites. To achieve optimisation, it is also necessary to know the quality of land communications, availability of collection sites, and rush hours, too, (Zefreh, 2018).

Optimisation is solved with two typical problems - the Chinese Postman Problem, and the Travelling Salesman Problem. Each of these problems can be solved using several methods, and each problem fits another type of waste.

The Chinese Postman Problem can be applied to the haulage of mixed municipal waste. The main reason is because there in case of the mixed municipal waste haulage entire streets - edges must be operated. On the other hand, the Travelling Salesman Problem can be applied to the haulage of sorted waste, where individual locations of collecting containers are represented with individual peaks of the chart - here the peaks of the chart must be operated.

4. PROCESSING OF MUNICIPAL WASTE

Mixed municipal waste is stored in containers, so called rubbish bins/litter baskets. This is all the waste which households get rid of without any sorting or placing into a facility for further processing. Mixed municipal waste cannot be recycled. It can, however, be energetically utilised through its direct burning without any previous treatment (provided a minimum energetic efficiency of facilities is met), or it can be processed using a mechanic-biological adjustment.

Biodegradable municipal waste is a biodegradable waste which arises exclusively in a municipal sphere - it belongs to municipal waste.

In order to determine the volume of biodegradable municipal waste production it is necessary to come out from the volumes of arisen municipal waste as well as from the composition of municipal waste. However, the composition of municipal waste must be understood as a ratio of individual components/fractions in municipal waste, i.e. potential volumes which can be separated out of the municipal waste.

Plastic is placed into yellow containers. On average it takes the most space out of all wastes and therefore its sorting as well as pressing or compressing is of a greater importance than throwing away. The majority of plastic waste which arises in households comprises packaging of food and consumables. After plastic is hauled into centres intended for a further processing this plastic is further processed. This is a very important step because some undesirable foreign substances are removed through final sorting, and it leads to dividing plastic to basic groups by material. Each of these materials is further processed separately (Jaktridit.cz, 2016).

Glass is thrown into a green or white container. If both are available, it is important to sort glass by colour, too: coloured glass belongs to a green container, transparent glass belongs to a white container. If there is only one container for glass, it is placed in regardless of its colour. Since there follows a further final-sorting, it is not necessary to break glass. The purpose of the final sort is to perfectly remove everything which is not made of glass. The final sort must be thorough; otherwise it could result in deterioration of the entire batch of glass products. In the first stage of sorting there are large impurities, such as porcelain, pottery, metals and another mess removed. Afterwards glass is crushed and modified on a vibration network. Finally it is cleaned using optoelectronic sensors (Jaktridit.cz, 2016). Thanks to its properties glass waste can be recycled over and over again.

Paper is placed into blue containers. Its production by households is the biggest out of all types of sorted waste. Its placement into a container for paper represents the easiest way how to get rid of this waste. An alternative is to place it into collection centres of sorted waste where they pay for it, so sorting also brings a small economic benefit for households.

Paper can be placed in any way, however, it should not be dirty or wet. Cartons, cardboards, paper packaging, newspaper as well as books can be placed there. Paper clips or envelopes with plastic boxes are not an obstacle either. Before any further processing paper is manually final-sorted according to needs of individual purchasers of raw materials. Undesirable foreign substances are also removed with manual sorting. Sorted paper is then pressed and taken to a further processing.

Besides waste which can be sorted into colour containers there in households arises waste which is also required to be sorted. This category includes metals, large-volume waste, hazardous waste, biowaste, outdated electrical appliances and batteries. Generally there are no containers to sort these types of waste (in some towns there are containers for electrical waste and biowaste); scrapyards and collection sites serve for passing it on a further processing.

5. ANALYSIS OF THE CURRENT STATE OF WASTE COLLECTION IN PÍSEK

Increasing legislative requirements of the government for handling with packaging, waste and dangerous products represent one of main factors which cause a bigger interest of enterprises in the reverse logistics. Enterprises are required to take responsibility for the environment not only by the government, but they are also expected to do so by their customers.

5.1. Characteristics of the Enterprise Městské služby Písek, s.r.o.

Městské služby Písek, s.r.o., is a company with a wide coverage of services provided to town citizens. Besides others these services include all maintenance of communications (altogether 74 km), road signs on communications, maintenance of urban green areas, maintenance of a playground, market hall, animal cemetery, public fountains, paid parking areas, public toilets, and last but not least concerns about waste.

The enterprise Městské služby Písek is a haulage company of all household refuse. The haulage frequency in the town is set to a weekly haulage. The enterprise Městské služby Písek provides containers with the volume of 110 l and 1,100 l for town citizens who are engaged in the waste system of the town; 110 l containers are mostly intended for family houses and some flats, 1,100 l containers then serve for inhabitants of residential areas as common containers for an entire block of flats. Distribution, number and type of containers are determined by the Environment department and Municipal office. Inhabitants of Písek may also utilise 7 scrapyards which serve for placing bulky and sorted waste.

Moreover, there are 130 facilities for placing sorted waste in the town. The number of containers within these facilities is different for individual locations; it always depends on the need of the given site. 80 of these facilities contain a container for glass, other ones contain only containers for paper and plastic. Some of them are classic - above the ground, and in the historical centre of the town there are underground containers. This waste is processed and meant for a further application. Only persons, namely inhabitants of Písek, may place the waste into scrapyards. Specifically, the following waste can be placed there: old furniture, wood, carpets, PVC, old clothes, rags, appliances, and all secondary raw materials. Then also hazardous waste, such as accumulators, oil filters, oils, fabrics stained with harmful substances, brake fluid, waste containing mercury (fluorescent lamps, gas tubes), paints, varnishes, old medications, galvanic cells, etc. In the region of the town there are 2,000 containers for biowaste distributed, too. Citizens put waste suitable for composting into these containers. The containers are specifically designed for such a kind of waste.

Regularly there happens the collection and haulage of litter bins which are located mostly in parks and busy sites. During the bins installation peripheries of the town were not forgotten either. Altogether there are 240 litter bins positioned. (Městské služby Písek, s.r.o., 2014)

5.2. Frequency of Waste Collection in Písek

Currently the separated waste is hauled once or twice a week depending on the type of the waste. In case of paper it is twice a week, every Monday and Thursday; plastic is also hauled twice a week, every Tuesday and Friday. Glass is hauled once a week, every Wednesday, due to its smaller volume.

There are 3 hauling vehicles used for the haulage. That one which is intended for collection of paper and plastic, enables to compact the waste with a linear compacting machine which allows for serving a bigger number of sites in one haulage cycle (from the volume weight of approx. 20 kg/1,000 l the following volume weight of approx. 250 kg/1,000 l may be achieved through compacting). The second vehicle equipped with a hydraulic arm is intended for haulage of waste from underground containers. This vehicle is used to haul all kinds of sorted waste; moreover in case of hauling glass from underground containers it is also used for the haulage from containers of a "bell" type. The third vehicle serves for haulage of glass waste from plastic dumping containers for glass, when there happens no waste compacting.

For all kinds of sorted waste the routes of hauling vehicles are basically the same. In case of glass due to a smaller number of sites intended for glass placing these routes are different. Since majority of sites which are intended for collection of paper and plastic only, are located on a route intended for glass, too, a bigger number of such sites does not have a big impact on driven kilometres. There exists only a difference from the time point of view, when a bigger number of containers for paper and plastic requires a longer operation time.

The optimisation of sorted waste haulage in Písek will be focused on changing the frequency of haulage, and changing routes of glass haulage (plastic containers and containers of a "bell" type) with a subsequent proposal of new routes, taking into account the capacity of hauling vehicles. In case of glass haulage it was found out that the filling level of all containers is small; in all observed cases it even did not reach half of the container's capacity. The frequency of glass haulage is not set optimally.

5.3. Current Concept of Glass Haulage

Current glass haulages are performed once a week, on Wednesdays, with two transport vehicles. One is intended for haulage from plastic containers, and another one from other containers. Routes of individual vehicles were part of the analysis (Table 2).

Total costs on haulage consist of several items. They include costs on vehicles (driven kilometres, amortisation), costs on staff (wages), and other costs. For the sake of frequency and routes optimisation, only the costs on hauling vehicles will be taken into account (Table 1).

Table 1. Costs by Container Type

Type of container	Annual costs (€)
Plastic containers	2, 294.87
Bells	4, 689.04
Total	6, 983.9

Source: Koraba, 2016

Table 2. Vehicles Intended for Waste Haulage

Type of vehicle	Useful volume (l)	Load capacity (kg)	Operation costs (CZK/km)
Vehicles with an arm for containers of a bell type	16,000	7,000	1.21
Vehicle for dumping of plastic containers	16,000	6,000	1.21

Source: Koraba, 2016

The optimisation calculates with 10 % capacity reserve in case of fluctuations in waste volume (Table 3).

Table 3. Existing Routes of Glass Haulage

Route for containers of a bell type	Route length (m)	Waste volume (l)	Costs on route (€)
DEPOT – 39 – 14 – 5 – 71 – 6 – 3 – 1 – 2 – 66 – 67 – 76 – 8 – 21 – 19 – 13 – 30 – 31 – 41 – 42 – 53 – 54 – 55 – 56 – 60 – 62 – 4 – 51 – DUMPING SITE – DEPOT	34,200	7,210	40.98
Route for plastic containers			
DEPOT – 22 – 37 – 35 – 36 – 38 – 24 – 23 – 25 – 26 – 27 – 28 – 79 – 78 – 77 – 73 – 74 – 75 – 15 – 16 – 9 – 10 – 12 – 11 – 17 – 18 – 20 – 7 – 72 – 69 – 68 – 70 – 64 – 63 – 40 – 59 – 61 – 57 – 58 – 52 – DUMPING SITE	33,500	13,750	40.14
DUMPING SITE – 33 – 29 – 32 – 34 – 43 – 80 – 44 – 46 – 47 – 45 – 48 – 49 – 50 – DUMPING SITE – DEPOT	36,380	3,960	43.59
Total	104,080	24,920	124.74

Source: Koraba, 2016

6. OPTIMISATION OF GLASS HAULAGE IN PÍSEK

In case of sorted waste haulage by the enterprise Městské služby Písek the weakest point seems to be the glass haulage. The frequency of haulage does not correspond to facts - containers for glass are filled only to a small extent in case of a weekly haulage, and thus it is necessary to adjust the haulage frequency. The adjustment of glass haulage frequency will also bring a change in existing routes of glass haulage (due to capacity possibilities of vehicles).

The optimisation of haulage of glass placed in plastic containers and containers of a "bell" type will be implemented using the Clarke-Wright Method and the Nearest Neighbour Method. The goals of optimisation of haulage of glass in plastic containers and containers of a "bell" type will be as follows:

- change in haulage frequency,
- reduction of driven kilometres.

6.1. Procedure of Optimisation of Haulage of Plastic Containers with Glass (Clarke-Wright Method)

Since the adjustment from a weekly haulage to a biweekly one would lead to exceeding of capacity options of a hauling vehicle, it is necessary to choose such a method which will divide a drive of one vehicle into several drives. Individual drives must respect the capacity of the vehicle and at the same time the number of driven kilometres must be as smallest as possible. It seems that the most effective method is the Clarke-Wright Method; it is a heuristic, solving a multi-circuit, capacitive limited circular problem.

Clark and Wright (1964) condensed the method into the following steps:

1) For a given transport network S = (V, H) a matrix of distance D = {d(i, j)} is created, where i, j = 0, 1, …, n; n = |V|. Furthermore, the following values are given:
   i. capacity of a vehicle,
   ii. amount of transported elements,
   iii. maximum time of the vehicle motion away from the starting peak V0,
   iv. other parameters.
2) There is created an initial solution, i.e. a set of so called elementary routes (V0 – Vi – V0) for all peaks of the network i = 1, ..., n. The routes are logged into a table and information about individual routes (route length, amount of load, time, etc.) is added.
3) The matrix D is used to calculate a profitability matrix with the most profitable coefficients Z = {z_{ij}}, where i, j = 1, …, n. The calculation is performed using the formula zij = d0i + d0j – dij.
4) There in the matrix Z is the most positive element z_{ij} found and, if possible, routes (V0 – Vi – V0) and (V0 – VJ – V0) are joined into a route (V0 – Vi – VJ – V0). If there is no element z_{ij} available anymore or if the capacity of all vehicles is fulfilled (all processed peaks), the algorithm has reached its end and the actual set of circular routes is the result of the optimisation. Otherwise the step 5 follows.
5) In case there arises an acceptable route after joining the routes: the value of the given element z_{ij} is set to 0, and the step 6 follows. If for any reason it is not possible to join the routes (development of a cycle, exceeding the capacity of a vehicle), the value of z_{ij} is set to 0 and the step 4 follows).
6) If after joining the routes there arise some peaks, which are not marginal ones, the most profitable route is updated. Furthermore, the table of routes must be updated with a newly created route. Elementary routes as well as routes created with a previous joining process may be joined. Then the step 4 follows.

Since the depot site of vehicles and the dumping site are in different locations, it is required to adjust the matrix of distances. This drive is acceptable only in case of an empty car, i.e. in the direction from a dumping site do a depot. The modification is performed as follows: for all connections from network peaks to the depot there is set a value which is greater than the length of the connection from the dumping site do the depot. This ensures that this edge will be included in one of resultant drives. This drive will then be divided into a technological part of the containers operation and the return to the depot.

After adjusting the matrix of distances there is the profitability matrix Z = {zij} formed, where i, j = 1, ..., n according to the formula zij = d0i + d0j – DIJ. At the same time the table of elementary routes must be created. This table contains all initially solved problems and thus the connection from V0 to individual peaks V_i and back to V0. It is also necessary to state individual observed quantities into the table so it is clear whether any of the conditions was broken or not.

6.2. Procedure of Optimisation of Haulage of a Container of a "Bell" Type with Glass (the Nearest Neighbour Method)

With respect to the number of waste containers of a "bell" type and underground containers the vehicle capacity was not exceeded even in case of the proposal of a biweekly waste haulage. It even did not happen in case of including a reserve which is needed for a potential coverage of an above-average volume of hauled waste. For this reason the Nearest Neighbour Method was chosen; it is a heuristic method looking for the shortest one-circuit circular drive.

This method is simple and does not require any complex calculations. Data source is represented with the matrix of distances among individual peaks which is progressively searched for.

In the beginning of the whole procedure an initial peak is chosen. In the distance matrix for the given peak there is the nearest, not operated peak found, and this connection is logged into the concurrent solution of the route. This procedure is applied to all peaks step by step; after finding the last peak there happens its linking to the initial peak. This way the entire route can be found. We do also recommend performing a reduction of the distance matrix after each finding a route peak. This step mainly serves to make the matrix well arranged for a subsequent procedure. This reduction lies in a removal of a column which determines the distance to the given peak from the other ones because there leads no route to this peak.

Since the connection between the dumping site and the depot is mandatory, it is necessary to modify the distance matrix through setting the distance between these peaks to zero (or shorter than the shortest distance between the depot and the nearest point, and the dumping site and the nearest point). This ensures that this edge will always be part of the resultant route. Zeroes in the diagonal indicating the route from a peak to the same peak are ignored during the calculation. In the first place it is necessary to create a distance matrix.

The following Figure 2 represents the process of searching for the shortest route for the initial peak V10. There in the first row of the table is the sequence of operations - order of columns being removed. There in the first column is the sequence of peaks for which the nearest neighbour is searched for. Cells indicating the nearest neighbour and the distance from this neighbour are highlighted in yellow. The procedure for other points is not mentioned here since it is the same repeated procedure. In the figure there are only the resultant routes represented.

Figure 2. Procedure of Searching for the Shortest Route

		26	16	15	14	8	6	13	24	2	1	3	4	28		5
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15
26	V1	x	2760	2570	2490	2330	1630	2370	2030	1400	1100	1560	1680	2100	2700	1200
16	V2	2760	x	190	510	950	1130	390	1790	1960	1660	2120	2240	3800	4100	2000
15	V3	2570	190	x	320	760	940	200	1600	1770	1470	1930	2050	3610	3910	1810
14	V4	2490	510	320	x	680	860	120	1520	1690	1390	1850	1970	3530	3830	1730
8	V5	2330	950	760	680	x	700	560	1360	1530	1230	1690	1810	3370	3670	1570
6	V6	1630	1130	940	860	700	x	740	1300	830	530	990	1110	2670	2970	870
13	V7	2370	390	200	120	560	740	x	1400	1570	1270	1730	1850	3410	3710	1610
24	V8	2030	1790	1600	1520	1360	1300	1400	x	1230	930	1240	1100	3070	3370	1270
2	V9	1400	1960	1770	1690	1530	830	1570	1230	x	300	160	300	2440	2740	640
1	V10	1100	1660	1470	1390	1230	530	1270	930	300	x	460	580	2140	2440	340
3	V11	1560	2120	1930	1850	1690	990	1730	1240	160	460	x	140	2600	2900	800
4	V12	1680	2240	2050	1970	1810	1110	1850	1100	300	580	140	x	2720	3020	920
28	V13	2100	3800	3610	3530	3370	2670	3410	3070	2440	2140	2600	2720	x	600	1800
	V14	2700	4100	3910	3830	3670	2970	3710	3370	2740	2440	2900	3020	600	x	2100
5	V15	1200	2000	1810	1730	1570	870	1610	1270	640	340	800	920	1800	2100	x
17	V16	3150	1770	1580	1500	820	1520	1380	2180	2350	2050	2510	2630	4190	4490	2390
18	V17	3470	2090	1900	1820	1140	1840	1700	2500	2670	2370	2830	2950	4510	4810	2710
23	V18	5270	3890	3700	3620	2940	3640	3500	4300	4470	4170	4630	4750	6310	6610	4510
19	V19	3710	2330	2140	2060	1570	2080	1940	2740	2910	2610	3070	3190	4750	5050	2950
20	V20	3550	2170	1980	1900	1410	1920	1780	2580	2750	2450	2910	3030	4590	4890	2790
21	V21	3370	1990	1800	1720	1230	1740	1600	2400	2570	2270	2730	2850	4410	4710	2610
22	V22	3230	1850	1660	1580	1090	1600	1460	2260	2430	2130	2590	2710	4270	4570	2470
10	V23	2690	1310	1120	1040	550	1060	920	1720	1890	1590	2050	2170	3730	4030	1930
9	V24	2490	1110	920	840	350	860	720	1520	1690	1390	1850	1970	3530	3830	1730
11	V25	2540	1160	970	890	710	910	770	1570	1740	1440	1900	2020	3580	3880	1780
12	V26	2720	1340	1150	1070	890	1090	950	1750	1920	1620	2080	2200	3760	4060	1960
7	V27	2070	690	500	420	260	440	300	1100	1270	970	1430	1550	3110	3410	1310
25	V28	2850	2360	2170	2090	1910	2110	1970	820	2050	1750	2060	1920	3890	4190	2090
27	V29	0	6730	6540	6460	5970	6480	6340	7140	7310	7010	7470	7590	9150	9450	7350

		17	18	23	19	20	21	22	10	9	11	12	7	25	27
		V16	V17	V18	V19	V20	V21	V22	V23	V24	V25	V26	V27	V28	V29
26	V1	3150	3470	5270	3710	3550	3370	3230	2690	2490	2540	2720	2070	2850	0
16	V2	1770	2090	3890	2330	2170	1990	1850	1310	1110	1160	1340	690	2360	6730
15	V3	1580	1900	3700	2140	1980	1800	1660	1120	920	970	1150	500	2170	6540
14	V4	1500	1820	3620	2060	1900	1720	1580	1040	840	890	1070	420	2090	6460
8	V5	820	1140	2940	1570	1410	1230	1090	550	350	710	890	260	1910	5970
6	V6	1520	1840	3640	2080	1920	1740	1600	1060	860	910	1090	440	2110	6480
13	V7	1380	1700	3500	1940	1780	1600	1460	920	720	770	950	300	1970	6340
24	V8	2180	2500	4300	2740	2580	2400	2260	1720	1520	1570	1750	1100	820	7140
2	V9	2350	2670	4470	2910	2750	2570	2430	1890	1690	1740	1920	1270	2050	7310
1	V10	2050	2370	4170	2610	2450	2270	2130	1590	1390	1440	1620	970	1750	7010
3	V11	2510	2830	4630	3070	2910	2730	2590	2050	1850	1900	2080	1430	2060	7470
4	V12	2630	2950	4750	3190	3030	2850	2710	2170	1970	2020	2200	1550	1920	7590
28	V13	4190	4510	6310	4750	4590	4410	4270	3730	3530	3580	3760	3110	3890	9150
	V14	4490	4810	6610	5050	4890	4710	4570	4030	3830	3880	4060	3410	4190	9450
5	V15	2390	2710	4510	2950	2790	2610	2470	1930	1730	1780	1960	1310	2090	7350
17	V16	x	320	2120	880	840	660	520	1090	890	1250	1430	1080	2450	5280
18	V17	320	x	1800	560	820	980	840	1410	1210	1570	1750	1400	2770	4960
23	V18	2120	1800	x	1600	1860	2040	2080	3020	2820	3180	3360	3200	4380	4300
19	V19	880	560	1600	x	260	440	480	1420	1220	1580	1760	1640	2780	4400
20	V20	840	820	1860	260	x	180	320	1260	1060	1420	1600	1480	2620	4660
21	V21	660	980	2040	440	180	x	140	1080	880	1240	1420	1300	2440	4840
22	V22	520	840	2080	480	320	140	x	940	740	1100	1280	1160	2300	4880
10	V23	1090	1410	3020	1420	1260	1080	940	x	200	550	730	620	1750	5820
9	V24	890	1210	2820	1220	1060	880	740	200	x	360	540	420	1560	5620
11	V25	1250	1570	3180	1580	1420	1240	1100	550	360	x	180	470	1200	5980
12	V26	1430	1750	3360	1760	1600	1420	1280	730	540	180	x	650	1380	6160
7	V27	1080	1400	3200	1640	1480	1300	1160	620	420	470	650	x	1670	6040
25	V28	2450	2770	4380	2780	2620	2440	2300	1750	1560	1200	1380	1670	x	7180
27	V29	5280	4960	4300	4400	4660	4840	4880	5820	5620	5980	6160	6040	7180	x

Source: Koraba, 2016

The following route was found using a progressive search with the origin in the peak V10:

V10 – V9 – V11 – V12 – V15 – V6 – V27 – V5 – V24 – V23 – V25 – V26 – V7 – V4 – V3 – V2 – V16 – V17 – V19 – V20 – V21 – V22 – V18 – V8 – V28 – V1 – V29 – V13 – V14 – V10 (Figure 2).

The length of V29 – V1, which was replaced with 0 during the adjustment of distance matrix, must be added to the total route length, which arose from the algorithm. The total length of this route is 39,520 m.

6.3. Result of Waste Haulage Optimisation

The evaluation of effectiveness is realised per a period of one distribution cycle of a newly proposed route which represents 1 haulage/14 days. Costs on 1 km are 1.21 €.

A: Result of Optimisation of Haulage of Plastic Containers with Glass

Table 4. Resultant Routes

Route	Volume of waste (l)	Route length (m)	Driving time (min.)	Operation time t (min.)	Total time t (min.)
DEPOT – 7 – 11 – 10 – 12 – 48 – 49 – 50 – 46 – 47 – 45 – 44 – 43 – 80 – 52 – DUMPING SITE	9,020	24,590	98.36	14	112.36
DUMPING SITE – 15 – 16 – 9 – 17 – 18 – 20 – 24 –	14,300	27,280	109.12	21	130.12

23 – 25 – 26 – 27 – 28 – 22 – 37 – 36 – 38 – 35 – 33 – 29 – 32 – 34 – DUMPING SITE					
DUMPING SITE – 58 – 57 – 40 – 63 – 59 – 61 – 65 – 64 – 70 – 69 – 68 – 72 – 73 – 74 – 75 – 77 – 78 – 79 – DUMPING SITE	12,100	21,020	84.08	18	102.08
DUMPING SITE – DEPOT		8,100			

Source: Koraba, 2016

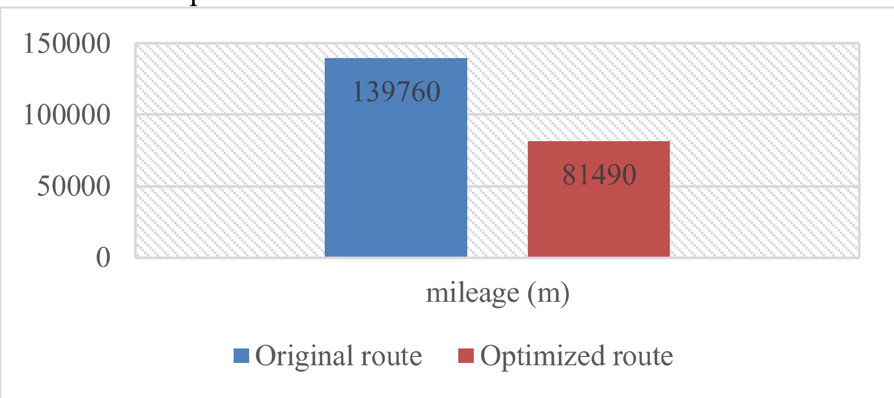
Table 5. Routes Comparison

Routes	Total route length (m)	Costs on haulage (€)	Saving in distances (m)	Percentage saving in costs (%)
Original	139,760	168.85	-	-
Optimised	81,490	98.44	58,270	41.7

Source: Koraba, 2016

The table makes it clear that thanks to the frequency change there has happened a 41.7 % saving in costs, which represents 70.4 € for 14 days. The optimisation has also brought a saving in kilometres: 58.27 km.

Chart 1. Comparison of a Run Distance



Source: Koraba, 2016

B: Result of Optimisation of Haulage of Containers of a "Bell" Type with Glass

Table 6. Resultant Route

Route	Route length (m)
DEPOT – 31 – 30 – 76 – 8 – 39 – 21 – 19 – 13 – 14 – 5 – 67 – 66 – 60 – 62 – 1 – 2 – 3 – 6 – 71 – 4 – 42 – 41 – 56 – 55 – 54 – 53 – 51 – DUMPING SITE – DEPOT	28,700

Source: Koraba, 2016

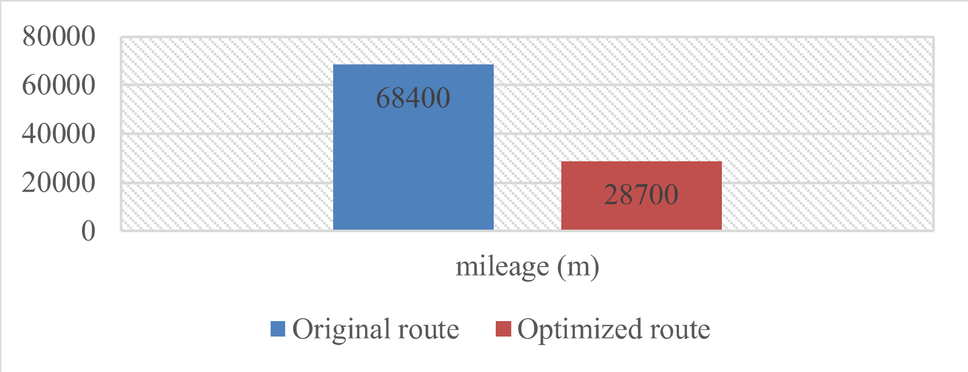
Table 7. Routes Comparison

Route	Total route length (m)	Costs on haulage (€)	Saving in distances (m)	Percentage saving in costs (%)
Original	68,400	82.64	-	-
Optimised	28,700	34.69	39,700	58

Source: Koraba, 2016

During the haulage of containers of a "bell" type the change did not happen only due to the haulage frequency change but mostly due to the improvement of existing haulage routes. For this reason the saving in original route is almost 60 %.

Chart 2. Comparison of Run Distance



Source: Koraba, 2016

6.4. Total Benefit of Glass Haulage Optimisation

Table 8. Routes Comparison

Routes	Total route length (m)	Costs on haulage (€)	Costs on haulage (m)	Percentage saving in costs (%)
Original	208,160	251.49	-	-
Optimised	110,190	133.13	97,970	47

Source: Koraba, 2016

Table 9. Annual Comparison of Routes

Routes	Total route length (km)	Costs on haulage (€)	Costs on haulage (km)	Percentage saving in costs (%)
Original	5,828.48	7,041.7	-	-
Optimised	3,085.32	3,727.5	2,743.16	47

Source: Koraba, 2016

Total saving achieved through the optimisation of haulage of plastic containers and containers of a "bell" type is 47 %. Total saving in costs is 3,314.16 €.

7. CONCLUSION

No mature society or household can exist without producing waste which arises in production, usage or consumption. The main source of waste is the industry (machine, building industry, etc.). The waste production, however, must be reduced and the arisen waste must be treated with properly. A way how to properly handle the waste is to recycle and separate it and also to use secondary raw materials for newly emerging products, (Junga, 2015).

Despite the reverse logistics has started to appear as a separate part of a logistic chain only in recent years, the role of its application in businesses is undeniable, (Caban, 2018) and (Segetlija, 2014). The reverse logistics is applied mostly in the European notion of this term (environmental point of view) which sees the reverse logistics as a means for a further utilisation of wastes arisen in previous components of a logistics chain. So there exists a way to utilise services in the waste economy when an enterprise will take care of arisen wastes, their transport and subsequent disposal or re-usage. For the recycling it is also interesting that the reverse logistics may serve as an instrument to obtain input raw materials, and this way to contribute to saving sources which enter the production process.

Important tasks of the current society include the reduction of waste which happens also thanks to returnable packaging, separation and sorting of waste, (Pazourková, 2015). Many of us, whether citizens, or businesses, realise it is time to start protecting the environment in order to preserve the nature (Torok, 2017).

The change of frequency has introduced a need for change in current circuits of vehicles. The glass haulage on current routes would not be possible due to an increase in the volume of hauled waste. For plastic containers whose occurrence is the highest within the town, the Clarke-Wright Method for solving a circular transport problem was chosen. Based on the information from available literature resources its application represents one of the most effective ways how to optimise capacitive limited circular drives. Using the method 3 routes were found; the entire volume of the hauled waste including a 10 % reserve for potential fluctuations in waste volume was divided among them.

Thanks to the optimisation there arose a 41.7 % saving in costs on the haulage, expressed in money: 1,806.50 CZK for 14 days.

For the second type of containers the optimisation through the Nearest Neighbour Method was chosen. This method was chosen due to the fact that even in case of a double waste volume and including the reserve the capacity of the vehicle was not fulfilled. The method improved the existing haulage route, thus the optimisation brought an even bigger percentage saving. In case of haulage of containers of a "bell" type there arose a 58 % saving, i.e. 1,230.50 CZK for 14 days.

Totally there were achieved annual savings of 85,038,- CZK, which is approximately 47 % of costs when compared to the original concept of the waste haulage. However, the money saving which only includes costs on the haulage itself (costs on vehicles) is not the only benefit brought with the optimisation. The haulage frequency change has led to a saving in labour forces. Haulage workers who currently perform the haulage once a week, may be utilised for other working needs, since a 50 % saving in working capacity of these workers has occurred there.

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