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GEOINFORMATIONAL ANALYTIC CONTROL SYSTEM OF THE COLLECTION OF MUNICIPAL SOLID WASTE

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Abstract: One of the effective approaches to solve the problem of optimal control of the collection of municipal solid waste in cities and towns on the basis of geoinformational analytic system is studied in the present work. Its structure is shown in the form of three interconnected subsystems: geoinformational system, analytic system, subsystem of monitoring of the refuse collection vehicles. The main attention is focused on the analytic subsystem. The mathematical formulation of the problem of effective planning of the traffic routes of the refuse collection vehicles and efficient algorithm to solve it are set here. The control of implementation of the planned routes is carried out by the subsystem of monitoring of the refuse collection vehicles using GPS-navigation.

Key words: municipal solid waste, optimization of routes, subsystem of monitoring, energy saving, refuse collection vehicle.

INTRODUCTION

The problem of control of the collection and recycling of municipal solid waste (MSW) is the most priority one, ranking in the system of urban economy the second place for the costs and investments after the sector of water supply and sewerage.

MSW (municipal) are waste generated in the residential sector, in trade enterprises, office buildings, office blocks, institutions, offices, kindergartens and schools, cultural and sports facilities, railway and bus stations, airports, river ports.

Nowadays on the territory of Ukraine every city dweller annually emits between 100 and 400 kg of MSW, posing a serious sanitary and epidemiological threat. In recent years, the volume of MSW has dramatically increased. The collection of MSW is usually carried out with using of standard containers installed on the container platforms. The location of the container platforms in different parts of the city and the number of containers installed on them depends on the density of population in the attended area and the intensity of filling containers with MSW at the platform [1,2,5].

The removal of MSW from the filled containers is carried by means of specially equipped refuse collection vehicles (RCV), which implement the loading of MSW in the body (bin) of RCV and its pressing. After filling the body, RCV is used as a special truck to deliver collected MSW to the place of recycling.

On the verbal level, the main point of the problem of control of the collection of MSW is in the following:

- in time synchronization of processes of filling of the containers with MSW on each container platform and removal processes of MSW,
- in minimization of material and energy costs for the collection of MSW.

The process of filling of the containers with MSW is generally a non-stationary random process, depending on a number of chronological (weekdays, holidays, seasons), meteorological (temperature, precipitations) and organizational factors (area cleaning). The sense of synchronization is in the point that the time of delay between the end of the process of filling of the containers with MSW and the moment of their removal must not exceed a few (1-5) hours. Increasing of the time of delay is unacceptable, as it can contribute to serious pollution of the cities due to the overflow of containers, to increasing the risks of environmental disasters and to increasing of additional labor and time costs for the collection and loading of MSW spilled out of the containers. The removal of MSW from not fully filled containers is also undesirable because this leads to underloading of RCV and therefore to additional fuel expense by RCV.

The ensuring of minimization of material and energy costs for the collection and recycling of MSW is carried out by:

- effective planning of the optimal amount and minimum extent of daily traffic routes of each RCV with its maximum load,
- effective control by means of GPS-navigation over the strict implementation by each RCV of each planned route for it.

The structure and functionality of geoinformational analytic control system of the collection of MSW is examined in the present work (GIACS MSW).

THE STRUCTURE OF THE SYSTEM

GIACS MSW includes three interrelated subsystems – geoinformational, analytic and subsystem of monitoring of RCV.

Geoinformational subsystem. Spatial distribution of the city or town and the need in complete and accurate information about the spatial location of each container platform and each container, the structure and parameters of city building-up, approach roads, public transport routes led to the fact that the multi-level electronic cards have become the invariant core of all information databases. Each electronic card includes a topographic base and a plurality of associated layers. Each layer has a specific subset of spatially distributed objects of city districts or attended areas. Each object of the attended area, including container platforms, is a graphic image, which is associated with text databases containing all the necessary static information about this object: address, number of floors, the owner, etc. for block of flats, buildings and structures; number, type, and volume of each container and geodesic mark for each container platform. The dynamic information in the form of time series about actual intensity of filling of the containers located on this platform is additionally introduced for each container platform. Besides, the dynamic information is also entered for the state of the roads sections (open / closed for travel) and approach roads to each container platform. Each layer can be combined with the topographic or to any other layer, and also with their arbitrary combination.

Such structural organization of the databases is an essential information basis on which the decision of all analytical problems is based.

Analytic subsystem implements resource-saving and environmentally friendly technologies of the collection and recycling of MSW. The main element of the analytic subsystem is the subsystem of effective planning of routes of RCV.

THE EFFECTIVE PLANNING PROBLEM OF RCV TRAFFIC ROUTES

Mathematical model of human-vehicle park of RCV. Municipal utility company (MUC), occupied with the removal of solid waste has a park of RCV $V = \{1,2,...,p,...,m\}$, drivers of these vehicles and workers. The most suitable model of human-vehicle park of RCV is a statistic model which allows to take into account not only technical characteristics of each RCV, but also the features of its maintenance by drivers and workers. To construct such a model they daily include statistic data about the actual work performed by each RCV and its staff as well as all types of costs for this work in GIACS MSW database. While constructing the model of human-vehicle park of RCV it is assumed that all statistic data are implementations of the relevant random varieties $X(\omega)$ with normal distribution $X(\omega) \sim N(\bar{x},\sigma^2)$, which are completely characterized by two parameters: mathematical expectation $\bar{x}$ and dispersion σ^2. $\omega \in \Omega$: (Ω, B, P) - probable space, where Ω - the space of elementary events, B - σ - algebra of events from Ω, P - probability mass on B. As a result of statistic data processing we obtain the model of human-vehicle park of RCV in the form of a set of family of estimations of the mathematical expectation of the following technical characteristics for each p RCV:

$S^P(\omega)$ - lifting capacity of RCV, i.e. maximum quantity of the containers, the contents of which can be loaded in RCV,

$B^P(\omega)$ - fuel cost (winter - B_z^p, summer - B_l^p), consumed by RCV per 1 km of way,

$m^P(\omega)$ - engine oil cost (winter - $m_z^p(\omega)$, summer - $m_l^p(\omega)$), consumed by RCV per 1 km of way,

$b^P(\omega)$ - fuel cost (winter - $b_z^p(\omega)$, summer - $b_l^p(\omega)$), consumed by special equipment of RCV to perform the loading and unloading of MSW,

$t_p^p(\omega)$ - time spent on unloading (loading in the body) of RCV of one container,

$t_r^p(\omega)$ - time spent on unloading of RCV,

$V^P(\omega)$ - velocity of RCV on the route,

k^p - maximum quantity of the routes, which RCV can perform during a day.

Since the evaluations of the mathematical expectations obtained from the samples of finite length, they are themselves random varieties with normal distribution, the mathematical expectation of which coincides with the estimates obtained and the dispersion equal to σ^2/n, where n, the volume of the sample.

MATHEMATICAL MODEL OF THE TRANSPORT NETWORK

The basic model of the transport network in the problem of effective planning of the traffic routes of RCV for the removal of MSW in the city is undirected weighted graph $H=(V,U)$ with top set V from n elements, numbered by figures $1,2,...,n$ and ribs set U.

Each top $i \in V$, $|V|=n$ is associated with:

- address, allowing to position the container platform located in this top on the city map,
- random parameter $d_i(\omega)$, corresponding to the weight of MSW in all filled containers set out in this top;

To the top set V of the graph $H=(V,U)$ we add two additional tops: $\{n+1\}$, corresponding to the garage, in which there are all RCV and $\{n+2\}$ - corresponding to the place of recycling (unloading) of MSW. The place of recycling of MSW can be: polygon (refuse dump), garbage recycling plant, rubbish selecting or rubbish transloading station.

Let's introduce the set:

$$N = V \bigcup \{n+1\} \bigcup \{n+2\}, \text{ i.e. } |N| = n+2.$$

Tops i and j form in the graph $H=(N,U)$ ribs $\{\mathrm{i,j}\}$. The graph $H=(N,U)$ doesn't contain loops i.e. ribs $\{i,i\}$.

Each rib $\{i,j\}$, connecting top i and top j, assign the length $d_{ij} \in R_0^+$ of the way from i to j, i.e. the distance which RCV must overcome while moving from the top i to the top j.

In general case:

$$d_{ij} \neq d_{ji},\ i,j=\overline{1,n+2} \text{ and } d_{ij}=d_{ij}(\omega),$$

i.e. the distance which RCV must overcome while moving from the top i to the top j is considered as a random [8, 10, 16].

MATHEMATICAL MODEL OF THE PROCESS OF FILLING THE CONTAINER WITH MSW

As it was previously mentioned the intensity of emission of MSW by inhabitants is non-stationary random process depending on a great number of chronological, meteorological and organizational factors. As the quantity of the containers installed on each container platform and their volume are known a priori instead of the intensity of emission of MSW the index connected linearly with it, but more effective is used in GIACS MSW – the time of full filling of all of the containers with MSW on the container platform. To predict the time of filling of all of the containers with MSW on each container platform in GIACS MSW an integrated multifactor model ARIMA introduced in [3] for forecasting the processes of consumption of targets products in the engineering networks is used. Time prediction of full filling of all of the containers with MSW is calculated in the form of conditional mathematical expectation for each container platform and is approximated for the nearest integer value: day, two days, …, L days. As a result of solving the problem of prediction to each top V of the graph $H=(V,U)$ the index $l_i=\{1,2,3,4...,L\}$, corresponding to the predicted time (in days) of full filling of all of the containers installed on this top is put. The interval of effective planning of traffic routes of RCV accept equal to the length of the maximum interval $l_i=L$, i.e. the interval of planning $T=[1,L]$.

MATHEMATICAL FORMULATION OF THE PROBLEM OF THE EFFECTIVE PLANNING OF TRAFFIC ROUTES OF RCV

Determine the value of the mathematical expectation $\bar{d}$ of the quantity of containers which must be removed daily on the interval of planning:

$$T=[1,L]:\ \bar{\mathrm{d}} \le \underset{\omega}{M}\sum_{i=1}^{n} d_i(\omega)\big/ l_i\,, \tag{1}$$

In real conditions the value $\bar{d}$ is considerably bigger than one of the lift capacity $\bar{S}^P$ of any p- RCV, i.e. $\bar{d} >> \bar{S}^P$. In practice, it means that for the daily removal of all filled containers some number of RCV, each of which can carry no more than k^p runs per a day, is necessary.

Divide the set N into a series of random subsets $N_p^k(l,\omega)$ so, that:

$$N=\bigcup N_p^k(l,\tilde{\omega}):\quad \bigcap N_p^k(l,\tilde{\omega})=n+2,$$
$$k=1,2,...,k^p,\quad p=\{1,2,...,m\}, \tag{2}$$
$$l=\{1,2,...,L\}.$$

For each fixed $\tilde{\omega}$ each of the subsets $N_p^k(l,\tilde{\omega})$ is a set of nodes of the network graph $H=(N,U)$, included in k- route, carried by p- RCV in the first day of the planned period $T=[1,L]$.

Under the above labeling, the mathematical formulation of the problem of effective planning of the traffic routes of RCV can be presented as:

$$\underset{\omega}{M}\sum_{l=1}^{L}\sum_{k=1}^{k^p}\sum_{p=1}^{m}\sum_{i\in N_p^k(l)} \tau_i(N_p^k(l,\omega))d_{ij}(\omega)\to \quad , \tag{3}$$
$$\to \min_{<k^p,m,\tau(\bullet)>\in\Omega}$$

$$\Omega: P\Big(\sum_{i\in N_p^k(l)} d_i(\omega)\le S^p(\omega)\Big)\ge\alpha,\ k=1,2,...,k^p, \tag{4}$$
$$p=\{1,2,...,m\},\ l=\{1,2,...,L\},\ j=\tau_i(i).$$

where: $\tau_i(N_p^k(l,\omega))$ - cyclic rearrangement, defining the order of passing $N_p^k(l,\omega)$ of the tops k - route, carried by p - RCV on the l - day of the planned period $T=[1,L]$, α - a constant, which determines the probability of implementation of the condition of overload of p - RCV.

The problem (3), (4) belongs to the class of problems of discrete stochastic programming M type with interline probabilistic constrains. To solve the problem (3), (4) the deterministic equivalent is constructed by means of replacement of all random varieties included into the objective function by their mathematical expectations and recalculation of the probability inequalities (4) into deterministic inequalities on the basis of known statistical properties of random varieties $d_i(\omega)$ and $S^P(\omega)$.

The deterministic equivalent of the problem (3), (4) refers to the class NP-complete problems, exact algorithms solutions of which do not exist at the present time [17]. Therefore, to solve the deterministic equivalent of the problem (3), (4) the close algorithm is used.

Algorithm of solving the problem of effective planning of the traffic routes of RCV includes the following steps:

1. Calculate the value m of the necessary quantity of RCV for daily removal $\bar{\mathrm{d}}$ of the containers under the condition:

$$\sum_{k=1}^{k^p}\sum_{p=1}^{m}\bar{S}_k^p \ge \bar{d}\,. \tag{5}$$

2. Divide the set N into a number of subsets so, that:

$$N=\bigcup N_p^k(l):\ \ \bigcap N_p^k(l)=n+2,\ k=1,2,...,k^p,$$
$$p=\{1,2,...,m\},\ l=\{1,2,...,L\}.$$

$$\sum_{i\in N_p^k(l)}\bar{d}_i\le\bar{S}^p. \qquad (6)$$

Each of the subsets $N_p^k(l)$ is a set of nodes, belonging to k-route, carried by p- transport facility (TF) on l-day of the planned period $T=[1,L]$.

The separation of the set N into subsets $N_p^k(l,\tilde{\omega})$ is performed by the hierarchical method of 3D-clustering [6].

3. The length $d_{ij}\in R_0^+$ of the shortest way between all the tops $i,j\in N_p^k(l,\tilde{\omega})$ taking into account all traffic rules while implementing of the conditions of possibility of passing this way by a particular TF is determined according to the map of the city.

4. The construction of each detailed route of minimum length passing through the set of tops $N_p^k(l,\tilde{\omega})$, is performed by the Little's method [10]. Each received route is presented in the form of circular permutation $\tau_i(N_p^k(l,\tilde{\omega}))$, at that the minimum length of each route is:

$$L_p^k(l)=\sum_{i\in N_p^k}\tau_i^*(N_p^k(l,\tilde{\omega})\,\bar{d}_{ij},\qquad j=\tau^*(i). \qquad (7)$$

Thus the solution of the problem (3), (4) is:

- minimum required value of the number of runs carried by each RCV on each l-day of the planned period,
- minimum value p_l^* - the number of RCV necessary for removal of MSW on each l-day of the planned period,
- $\tau_i^*(N_p^k(l,\tilde{\omega}))$ - k-optimal route of minimum length carried by p-RCV on l-day of the planned period.

5. The calculation of the additional parameters for each detailed route:

- average fuel cost for the implementation of all k_l^{p*} routes by p- RCV on l-day of the planned period:

$$\bar{B}^p(l)=\sum_{k=1}^{k^{p*}}\bar{B}^p\sum_{i\in N_p^k(l,\tilde{\omega})}\tau_i^*(N_p^k(l,\tilde{\omega}))\,\bar{d}_{ij}+\bar{b}^p, \qquad (8)$$

- average time spent by p-RCV for the implementation of k_l^{p*} route on l-day of the planned period:

$$\bar{T}_p^k(l)=L_p^k(l)/\bar{V}^p+\bar{t}_r^p+\bar{t}_p^p\sum_{i\in N_p^k(l,\tilde{\omega})}\bar{d}_i. \qquad (9)$$

SUBSYSTEM OF MONITORING OF RCV

The subsystem of monitoring of RCV is an integrated in GIACS MSW system of collecting, recording and supplying of the information about the location of RCV on the territory of the city.

The main aim of the subsystem of monitoring of RCV is providing of the supervisory service and the direction of MUC with actual and effective information about the location of RCV under their control, the realization of efficient methods of collecting, processing and distributing of the information, procedures and technical means of data exchange. The main functional tasks of the subsystem of monitoring of RCV are:

- control over the location and condition of RCV,
- coordination of the activity of the departments which support RCV of the company,
- preventing of no-purpose use of RCV of the company,
- ensuring of the maintenance of the technical conditions of the exploitation of RCV.

Subsystem basis is the geoinformational system that allows to solve the problems of collection, storage and data processing of various types and origin.

Coordinates and location of RCV on a city map are determined by means of GPS technology using satellite system NAVSTAR. Nowadays it is the only completely deployed and operable satellite navigation system. Data about the location of RCV are fed to the board radio terminal which collects and processes simultaneously the information about the status of various systems and units of the vehicle. Data transfer from RCV to the server is provided through the network of mobile communication GSM 900 standard using the GPRS protocol of data transmission.

The subsystem of monitoring of RCV is an integrated set of functional modules, information resources and standardized technological procedures of information processing, telecommunication and computing environment.

The subsystem is designed to allow its further modernization with minimization of time and financial costs without changing of system platform and data communications protocols.

The subsystem has a wide range of possibilities of graphic display of vector models of the place and wide set of report forms.

The subsystem of monitoring of RCV gives an opportunity to follow any changes of RCV status and its characteristics. The database structure allows to carry out the expansion of information structure about RCV.

The subsystem basis is a centralized data depository with distributed processing.

The subsystem is constructed according to the modular approach that allows, in case of necessity, to replace certain subsystem modules keeping its operability in general (Fig. 1).

Terminal ND GPS terminal 031 produced by Ltd «Navidev» (http://navitron.mobi) is used in the subsystem.

In the basic configuration this subsystem allows to evaluate the following parameters of each RCV under control: current location, passed route, route deviation from the agreed one, speed, time of movement, time and places of parking, exit and entrance into the area (Fig. 2).

With appropriate sensors it is possible to control the following additional parameters: fuel quantity in the tanks, travel fuel consumption, fuel filling and fuel draining, engine speed, engine running time, the state of “panic button”, loading level, positions of mechanisms (for special equipment), opening of the door etc.

The fuel sensor ДУ-01М produced by «Orgtechavtomatica» Ltd is used in the system.

The subsystem also allows to control various devices: lock the door, turn off the engine etc. on condition of appropriate hardware component.

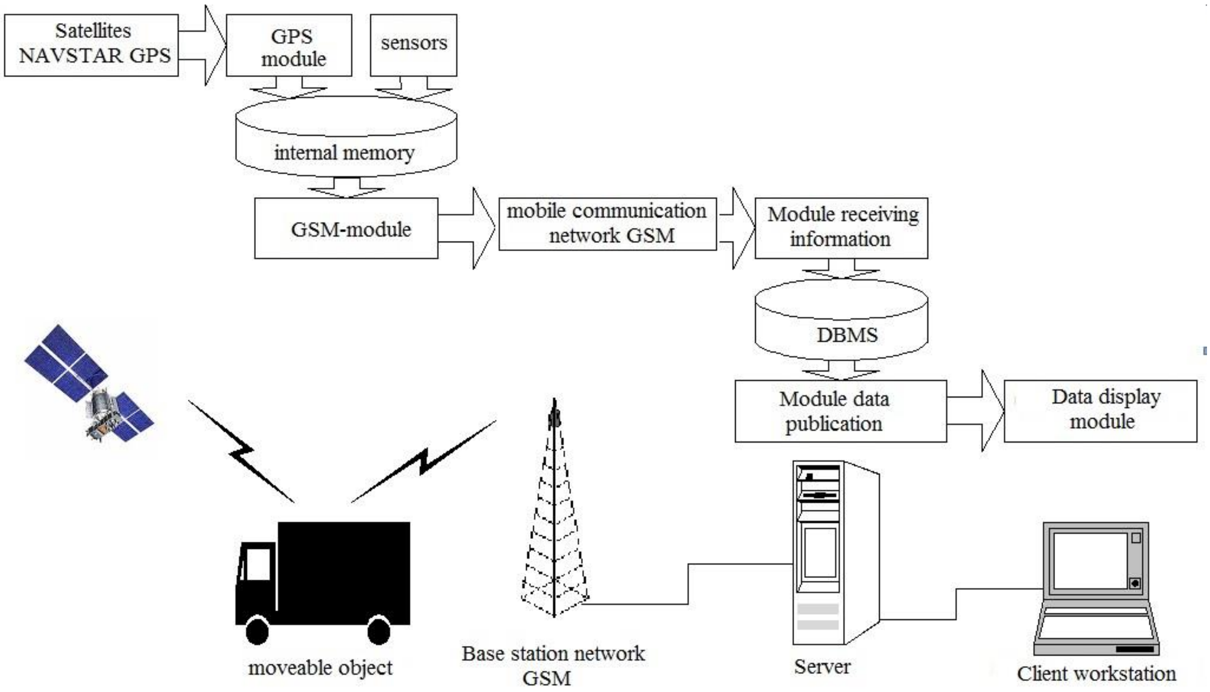


Fig. 1. Subsystem of monitoring of RCV

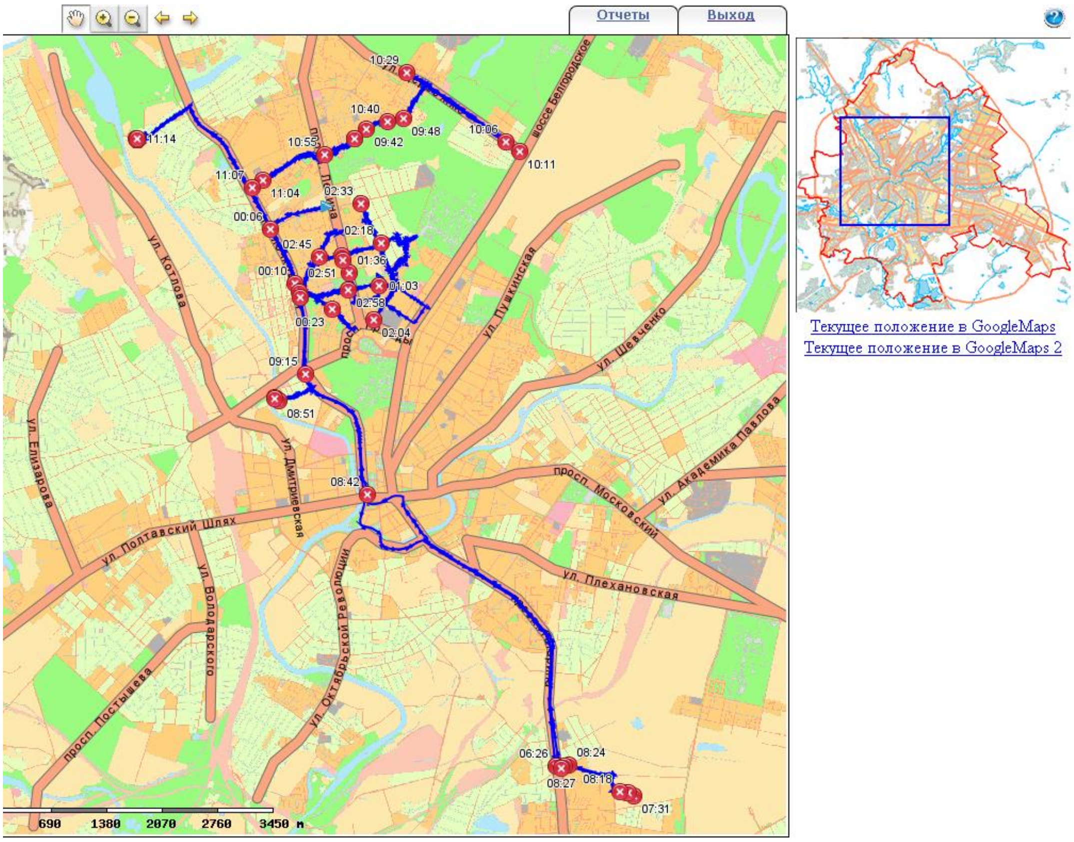


Fig. 2. System of RCV monitoring

The effects of the implementation of the system: POL saving and other resources saving connected with the exploitation of RCV, optimization of the operating functions of the controller, reducing of unproductive and dummy run, monitoring and prevention of misuse of RCV, adoption of the management decisions on the basis of reliable statistic reporting data, increasing of the discipline level of drivers and controllers, reducing of accidents.

RESULTS AND DISCUSSION

Let’s present the results of solving the problem of effective planning of traffic routes of RCV for one of the cities of Ukraine with population about 40 thousand people and the quantity of the containers 431. As the input data are given the addresses of the container platforms (103), the quantity of the containers on them (1-13), the intensity of their filling (1, 2, 3, 7, 15, 30 days), as well as the set of constrains on the traffic routes of RCV.

As a result of solving the problem of effective planning of the routes of removal of all of the containers it is turned out that it was enough two vehicles: RCV KAMAZ with parameters S^1=40 containers, B_z^1=0,318 l/km, B_l^1=0,334 l/km, b_z^1=14,0 l, b_l^p=13,3l and RCV GAZ with parameters S^2=16 containers, B_z^2=0,309 l/km, B_l^1=0,294 l/km , b_z^2=6,1 l, b_l^2=5,8 l. Both RCV must perform 4 runs a day.

In the tables 1 - 3 the parameters of developed detailed routes are shown under V^P=37 km/h, t_p^p=3 min, t_r^p=10 min. The fragment of optimal routes are shown in the fig. 3

Table 1. Optimal routes of RCV1 (KAMAZ) for the first day (*l*=1)

Flight 1				Flight 2			
№	Address	Number of containers	Intensity of filling (days)	№	Address	Number of containers	Intensity of filling (days)
1	Garage			1	Polygon		
2	Lomonosov str. 26	3	1	2	Кavкaz str.	1	2
3	Lomonosov str. 3	10	2	3	Michurin str. beach	2	2
4	Oktiabrskaya str. 21	1	1	4	Michurin str. 46(1)	3	2
5	Jubileyniy distr. 27Б, 9, 16	17	1	5	Michurin str. 1	1	2
6	School lane	4	1	6	v. Golubovka PS	2	45
7	Komsomolskaya str. 42	2	1	7	Michurin str. 123, 144, 159	3	2
8	Ovrazniy lane	1	1	8	Mechnikov str.15, Michurin str. 181	2	2
9	River lane	2	1	9	Selskiy lane 44	1	2
10	Polygon			10	Ucraine str. 55	1	1
	amount of containers	40		11	Lenin str. 49,52,47,60	12	1
Flight 3				12	Communist str. 6	7	1
1	Polygon			13	Lenin str. 42	4	1
2	Lenin str. 19	8	30	14	"Obriy", world furniture	2	15
3	1 May str. 19	1	15	15	Usikovskaya str.	1	2
4	1 May str. 37	1	30	16	Polygon		
5	Communist str. 30	1	2		amount of containers	38	
6	Pushkin str.	2	40		Flight 4		
7	Sports lane	1	1	1	Polygon		
8	Lenin str. 114	1	30	2	North str.2	1	1
9	Lenin str. cemetery	4	15	3	Hospital str. 10(1) 28(2); Bugorny lane	5	1
10	Lenin str. 103 Ukrautogaz	2	30	4	Sidorenko str. 56	1	1
11	Jubileynaya str.	3	1	5	Jubileynaya str. 87	2	1
12	1 May str. 57,55	7	1	6	Demkina str. 5	2	2
13	1 May str. 59 vetclinic	2	40	7	Davydov Luchitskiy str. 1a, 1д	6	1
14	1 May str. 59. School 34	4	15	8	60 years of USSR str.119(1), 50(1)	2	3
15	Technical lane. 3	3	1	9	60 years of USSR str. 55(1), 75(1)	2	3
16	Ukrainian str. 48, .2a	2	1	10	60 years of USSR str. 19(2)	2	3
17	October sq. 12, 20	10	1	11	Gardening str. 100	2	1
18	1 May str. 34, Department of Culture	2	15	12	Gardening str. 7	2	2
19	Lenin sq. 1, music school	1	30	13	Gardening str. 7	2	1
20	Komsomolskaya str. 50	1	1	14	Kharkiv str. 9	4	1
21	Khmelnitsky str. 6	1	2	15	Chapaev str .2	1	2
22	Polygon			16	Chapaev str. 30	2	2
	amount of containers	29		17	Komsomolskaya str. 34	4	3
				18	Polygon		
				19	Garage		
					amount of containers	40	

Table 2. Optimal routes of RCV12 (GAZ) for the first day (l=1)

Flight **1**

№	Address	Number of containers	Intensity of filling (days)
1	Garage		
2	Lenin sq. 39 АТВ-мarket	3	2
3	Komsomolskaya str. 5	13	1
4	Polygon		
	amount of containers	**16**	

Flight 2

№	Address	Number of containers	Intensity of filling (days)
1	Polygon		
2	Kolhoznaya str. 44	1	2
3	Vorovskiy str д.9	2	2
4	Lermontov str. 41	3	2
5	Rovenskaya str. 110	2	2
6	Shevchenko str. 19	1	2
7	Karl Marx str.12	1	2
8	Flower str.	1	2
9	Forest Glade str.	1	2
10	Dobrolyubov str.	1	2
11	Artem lane. 1	1	2
12	entry Komsomolskiy 10	1	2
13	Akhtyrsky lane 6	1	2
14	Polygon		
	amount of containers	16	

Flight **3**

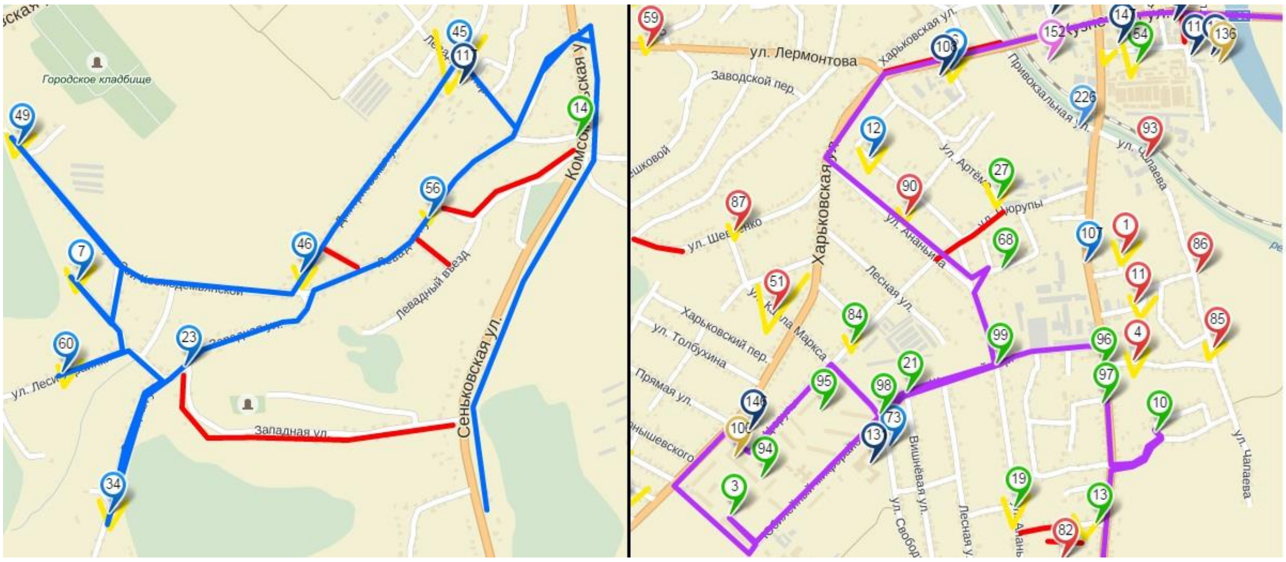
№	Address	Number of containers	Intensity of filling (days)
1	Polygon		
2	Podgorniy lane 1	2	1
3	1 May str. 39	4	1
4	1 May str. 4	4	1
5	Artem str. 38	2	1
6	Curupi str.. 20a	3	1
7	Sholkoviy lane	1	1
8	Polygon		
	amount of containers	**16**	

Flight 4

№	Address	Number of containers	Intensity of filling (days)
1	Polygon		
2	Krivoy lane 1	1	3
3	Dmitrievskaya str. 1	2	3
4	Dmitrievskaya str. 68	1	3
5	Kosmodemyanskoy str. 71, 57, 31	3	3
6	Lesya Ukrainka lane 10	1	3
7	Lesya Ukrainka str. 30	1	3
8	West str. 65	1	3
9	West str. 2, 16	3	3
10	Levadny str. 66	3	3
11	Polygon		
12	Garage		
	amount of containers	16	

Table 3. Characteristics of routes

Car	Flight number	Route length (km)	Fuel consumption (l) summer	Fuel consumption (l) in winter	The number of containers	Time, h
KAMAZ	flight 1	14,4	17,88	18,81	40	2h 28м
	flight 2	25	21,25	22,35	40	2h 42м
	flight 3	26	21,57	22,68	36	2h 31м
	flight 4	28	22,20	23,35	40	2h 46м
Sum	-	93,40	82,90	87,20	156	10h 27м
GAZ	flight 1	11,2	9,09	9,56	16	1h 12м
	flight 2	26,5	13,59	14,29	16	1h 32м
	flight 3	19,75	11,61	12,20	16	1h 23м
	flight 4	30	14,62	15,37	16	1h 36м
Sum	-	87,45	48,91	51,42	64	5h 43м
In total	-	180,85	131,81	138,62	220	-



a) b)

Fig. 3. Fragments of optimal routes of GAZ flight 4 - a), KAMAZ flight 1 - b)

CONCLUSIONS

The examination of the effectiveness of work of GIACS MSW was held for MUC, attended one of the cities of Ukraine with the population of about 40 thousand people. Using GIACS MSW for a given number of containers and predicted intensity of their filling allowed: to justify the duration of the interval of planning and minimum quantity of RCV; to develop effectively detailed traffic routes of RCV providing collection and removal of all of the filled containers with MSW for each day of the planned period, which are: implemented, i.e. they can be carried by suitable RCV; minimum according to the length among all possible routes passed through the specified addresses of the container platforms; optimal in the number of loaded containers in each RCV on each route, i.e. the lifting capacity of each RCV is used to the maximum; optimal to the fuel costs for RCV.

Developed detailed traffic routes of RCV exceeded in all indexes traffic routes of RCV providing collection and removal of all of the containers with MSW actually used by MUC. Practical implementation of the developed plan of realization of the detailed routes for the removal of MSW allowed to reduce considerably the necessary park of RCV (from three to two), to reduce significantly the total length of the routes carried by each RCV and to reduce the actual fuel costs for the planned period of one month by 35%.

General conclusion. Implementation of GIACS MSW is an effective means to improve the environmental safety, energy and resource saving of MUC.

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