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DEVELOPMENT OF A CONCEPTUAL MODEL OF AN EXPERT SYSTEM FOR DYNAMIC VEHICLES ROUTING FOR MUNICIPAL WASTE COLLECTION

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Abstract. *The paper discusses the problem of waste collection in urban areas. This problem is solved as a vehicle routing problem - VRP. VRP belongs to the class of NP-hard combinatorial optimization problems. Waste collection is one of the sub-functions of waste management and has the highest costs in the entire management system. The main goal of developing a conceptual model for waste collection in urban areas is the optimization of costs incurred during waste collection and transportation. The model is based on the application of information and communication technologies.*

Key words: *vehicle routing problem, collecting waste, optimization.*

1. INTRODUCTION

Solutions related to improving the vehicle routing problem of municipal waste collection – VRPWC create a difference between the operational planning of a vehicle's route before the start of the drive and the dynamic conditions that occur during the collection of municipal waste. Very often, due to traffic congestion, pre-planned routes are impossible to implement. For this reason, if the real situation in route planning is considered, the distance traveled by the vehicle can be reduced, as well as the time for municipal waste collection. The output results are positive for a company's costs and environmental protection. In recent decades, a great advance has been achieved in the implementation of information and communication technologies to municipal waste collection vehicles. The application of information and communication technologies in vehicle routing problems, deployment and vehicle tracking contributes to companies increasing their business efficiency [1]. In addition to improving the operational planning of vehicle routes, the efficiency of the entire system and transport networks can also be improved. Solutions related to the improvement of transport networks are increasingly

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being applied in practice. Solutions that deal with VRPs compare planned vehicle movement routes with and without considering possible events during the actual implementation (e.g., traffic stoppage on a section of the transport network). Certainly, when possible, events are taken into account when designing routes, and better performance of the final solution is obtained, which results in an increase in efficiency and a reduction in negative environmental impacts. Solutions that consider real-time data [2] do not aim only to improve the VRP based on the probability of the event, but to provide the most efficient solution in real time, under the conditions of the occurrence of the event. In practice, it often happens that when vehicles start to execute given orders (routes), they encounter a problem, as a result of which they cannot follow the planned routes. The most common problems encountered by operators of municipal waste collection vehicles are traffic accidents, due to which streets are blocked for a certain period of time; improperly parked vehicles, so access to containers is impossible; inadequately disposed waste, due to which the planned time is exceeded; works on certain sections of streets, etc. All these problems require intervention in real time to collect municipal waste in the time interval provided, i.e. to comply with operational constraints.

In the paper by Marković et al. [3], a model of waste management with stochastic search at the locations of containers was considered. In this paper, solving the defined problem led to significant savings compared to the traditional way of collecting municipal waste. However, even with this model, there may be an unnecessary waste of resources, because individual containers for communal waste may be partially filled. The application of information and communication technologies should solve the shortcomings of classic models of municipal waste collection systems, which will be explained in this paper.

2. MATHEMATICAL FORMULATION OF THE PROBLEM

To optimize a municipal waste collection system, the waste management method is divided into three very clear levels of management, i.e. optimization: strategic, tactical, and operational [4]. In this paper, the emphasis is on the operational level, which represents the optimization of waste management systems by choosing the optimal routes for waste collection and transportation. A municipal waste collection system has high operational costs, and for this reason many researchers are trying to reduce these costs by improving vehicle routes, finding the most favorable locations for municipal waste containers, and reducing the number of vehicles used for municipal waste collection.

When creating a model, to solve the problem of directing municipal waste collection vehicles, it is necessary to set up a model in a mathematical form that can most faithfully represent the problem being solved. The model must be such that it responds to all changes in parameters, to respond to the real problem under the influence of changes in the corresponding factors. The solutions of the model represent properly designed routes of movement of vehicles for the collection of communal waste, i.e. optimal routes. Defining the model, i.e. the procedure for planning the routes of vehicles for the collection and transport of municipal waste, can be divided into two stages. The first stage of the route design procedure involves defining the elements of the transport network, as well as defining the amount of municipal waste in the transport network. The amount of municipal waste in the nodes is defined using the demand matrices in the nodes. The second stage of the route design procedure includes: a) Defining the distance matrix or vehicle travel time matrix between pairs of nodes in the transport network and b) Defining the corrected distance matrix or vehicle travel time matrix between pairs of nodes in the transport network. The distance matrix is a cost matrix with the assumption that the total cost of the path is proportional to the distance of the nodes. However, this approach requires a transport network whose sections of roads are flat (without slopes), which is not the case when solving real problems. The conditions of the transport network refer to the quality of the road surface, the density and flow of traffic, and the ideal situation is when these conditions are uniform. For the solution to the problem to be satisfactory, ideal conditions of the transport network are required, and such conditions are especially important when it comes to a transport network in which there are large distances between pairs of nodes. To bring the distance/cost matrix closer to the real problem, it is necessary to correct it by introducing correction factors for each section of the transport network. Correction factors may include total transport costs, configuration, and state of the infrastructure as well as traffic conditions on the transport network. Total transport costs include energy consumption costs and transport vehicle depreciation costs. The configuration and condition of the infrastructure of the transport network are determined by the configurations of the network branches (straight, inclined, uphill, intersection, roundabout, number, and type of traffic signals).Traffic conditions on the transport network depend on traffic density and traffic signals. The configuration of the sections (uphill) has the biggest share in the increase in energy costs, because fuel consumption increases significantly on such sections. The correction factors k_u for the configuration are given as a percentage increase in fuel consumption compared to the consumption on a straight road, depending on the degree of ascent/decline of the section and the speed of the vehicle. Using the correction factor for the configuration ku, the corrected distances between pairs of transport network nodes are determined using the form[3]:

$$d_{(i,j)k} = \sum d_{(i,j)r} + \sum k_u d_{(i,j)u} \tag{1}$$

where: $d_{(i,j)r}$–the straight length of the part of the section (branch) of the transport network (section without rise or fall); $d_{(i,j)u}$ - the length of the part of the section (branch) of the transport network on the way up or down; $d_{(i,j)k}$–the total length of the corrected section (branch) of the transport network; k_u–the correction factor of the terrain configuration. After defining the model, the choice of method for solving the model itself is approached. Waste collection models are most often solved as capacity-constrained vehicle routing problems – CVRP. The CVRP model assumes that all vehicles are identical and have a common starting point (depot), and the only limitation that exists is the vehicle's capacity. The objective function expresses the requirement to minimize the total transport costs when collecting municipal waste from the transport network [4].The following notation was used to define the CVRP mathematical formulation:

K – the maximum number of used vehicles,

n – the number of nodes from which waste is collected,
N– the number of waste containers per node,
Q_k – the maximum capacity of vehicle k,
V– the set of nodes, V={$1,2,..,n$},
V_0 – the depot, the place from which the vehicle departs,
d_{ij} – the shortest possible distance between node i and node j; $i, j \in V$,
c_{ijk} - the transport costs of vehicle k between node i and node j; $i, j \in V$,it is assumed that $c_{ij}=d_{ij}$
q_i - the demand in node i, $i \in V$; the demand in the depot is equal to zero.

The decision-making variables x_{ijk}are1if the vehicle visits node i after node j and otherwise 0.

After the introduction of the above nomenclature, the mathematical formulation of the CVRP can be presented in the following manner:

$$min \sum_{k=1}^{K} \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ijk} x_{ijk} \tag{2}$$

subject to:

$$\sum_{i=0}^{n} x_{i0k} = 1 \quad k = 1,2,\dots,K \tag{3}$$

$$\sum_{i=0}^{n} x_{0jk} = 1 \quad k = 1,2,\dots,K \tag{4}$$

$$\sum_{k=1}^{K} \sum_{i=0}^{n} x_{ijk} = 1, \quad j = 1,2,\dots,n \tag{5}$$

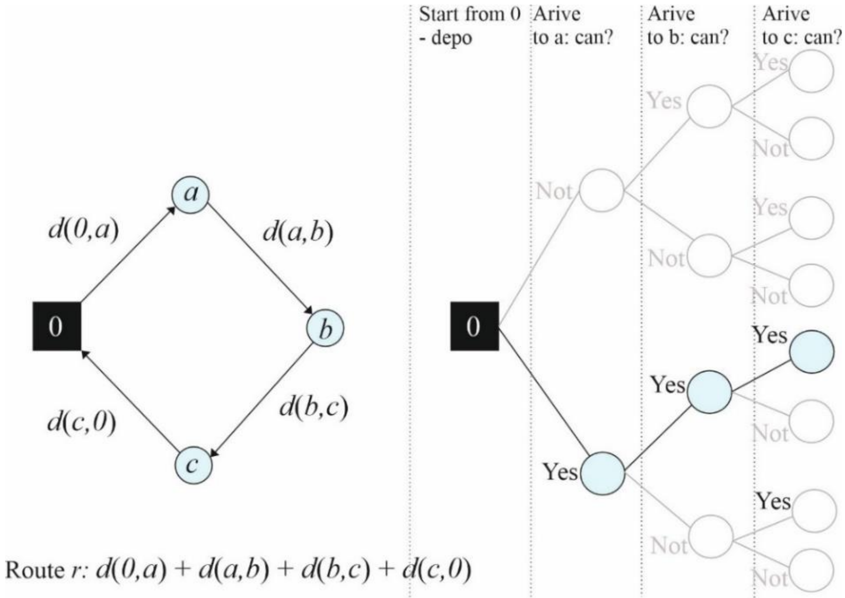
$$\sum_{i=1}^{n} q_i x_{ijk} \leq Q_k \quad k = 1,2,\dots,K \tag{6}$$

$$\sum_{i=1}^{n} x_{ijk} = \sum_{i=1}^{n} x_{jik} \begin{matrix} j = 1,2,\dots,n \\ k = 1,2,\dots,K \end{matrix} \tag{7}$$

$$\sum_{i,j \in S} x_{ijk} \leq |S| - 1 \quad \forall S \subseteq \{2,\dots,n\}\, k = 1,2,\dots,K \tag{8}$$

$$x_{ijk} = \{0,1\} \quad i,j = 1,2,\dots,n k = 1,2,\dots,K \tag{9}$$

Constraints (3) and (4) imply that every vehicle that leaves a depot returns to that same depot. The constraint shown by equation (5) stipulates that each user must be visited only once by exactly one vehicle. Constraint (6) implies that the total capacity of user requests, served by one vehicle, must not exceed the capacity of that vehicle. Constraint (7) enables the preservation of vehicle flow, i.e. the fulfilment of the condition that vehicle k must leave user j after serving user j. Constraint (8) prevents the occurrence of cycles that do not represent a complete route. Constraint (9) defines the passage through the branch between users i and j by vehicle k and can have a value of 0 or 1. The route determination procedure is illustrated in Fig.1.



Route	Constraints
$r_1 : d(0,a)$	$r_1 : q(a) \le Q_k$
$r_2 : d(0,a)+d(a,b)$	$r_2 : q(a+b) \le Q_k$
$r_3 : d(0,a)+d(a,b)+d(b,c)$	$r_3 : q(a+b+c) \le Q_k$
$r : d(0,a)+d(a,b)+d(b,c)+d(c,0)$	$r : q(a+b+c) \le Q_k$

Fig. 1 An example of a transport network with a designed route with limited vehicle capacity.

3. CONCEPTUAL MODEL OF AN EXPERT SYSTEM FOR DYNAMIC VEHICLES ROUTINGFOR MUNICIPAL WASTE COLLECTION

The first step in the development of a conceptual model for dynamic routing of municipal waste collection vehicles – *CMESDVRMWS*, is the definition of input parameters. The transport network, as a basic input parameter, contains data on node coordinates (latitude and longitude), data on traffic infrastructure as well as data on the geographical area. Given the progress of information and communication technologies in the field of municipal waste collection, the transport network can be modelled using a geographic information system – GIS. The application of GIS in defining the transport network enables optimization in the deployment of nodes as well as insight into the traffic infrastructure in real time [5, 6]. To define the transport network during the development of *CMESDVRMWS*, a correction factor was introduced for streets that are on a slope. This definition of streets is of great importance when forming a time matrix for vehicle movement.

The number of traffic lights on the observed traffic infrastructure is another parameter that was considered when defining the transport network. The number of traffic lights also affects the timing matrix.

For the development of *CMESDVRMWS*, it was assumed that the vehicle stays at each traffic light for one minute. The number of traffic lights also affects the definition of the matrix of the shortest distances between nodes of the transport network. This means that if there are traffic lights between node *i* and node *j* and it is the shortest distance in terms of length, due to the correction factor (number of traffic lights) another distance between node *i* and node *j* can be taken which is longer. Another parameter that was considered when defining the transport network, and affects the distance and time matrices, is the number of intersections. The transport network modelled in this way, taking the previous parameters, represents the optimal network in GIS. The next step towards the development of *CMESDVRMWS* is the definition of the matrix of the shortest distances, the matrix of the shortest times, and the matrix of the amount of municipal waste by nodes for the selected transport network. As we have already mentioned, by applying GIS, it is possible to define all these matrices in real time. Defining matrices as offered by *CMESDVRMWS* is possible for deterministic requirements and for stochastic requirements. When it comes to the deterministic requirements of the matrix of the shortest distances and times, it is possible to form it by applying certain algorithms, such as the *Floyd–Warshall* algorithm [7]. However, in practice, the time between all pairs of transport network nodes, as well as the amount of waste per node, is a stochastic quantity. After defining the input parameters, the next step in the development of *CMESDVRMWS* is to calculate savings using the Clark Wright - CW savings algorithm, form a list of savings, define operational constraints and form an initial solution. To obtain the initial solution, when it comes to deterministic requirements, the CW saving algorithm is used, and when it comes to stochastic requirements, then the algorithm presented in the paper [3] is initiated. After the formation of the initial solution, the improvement of the initial solution is carried out.

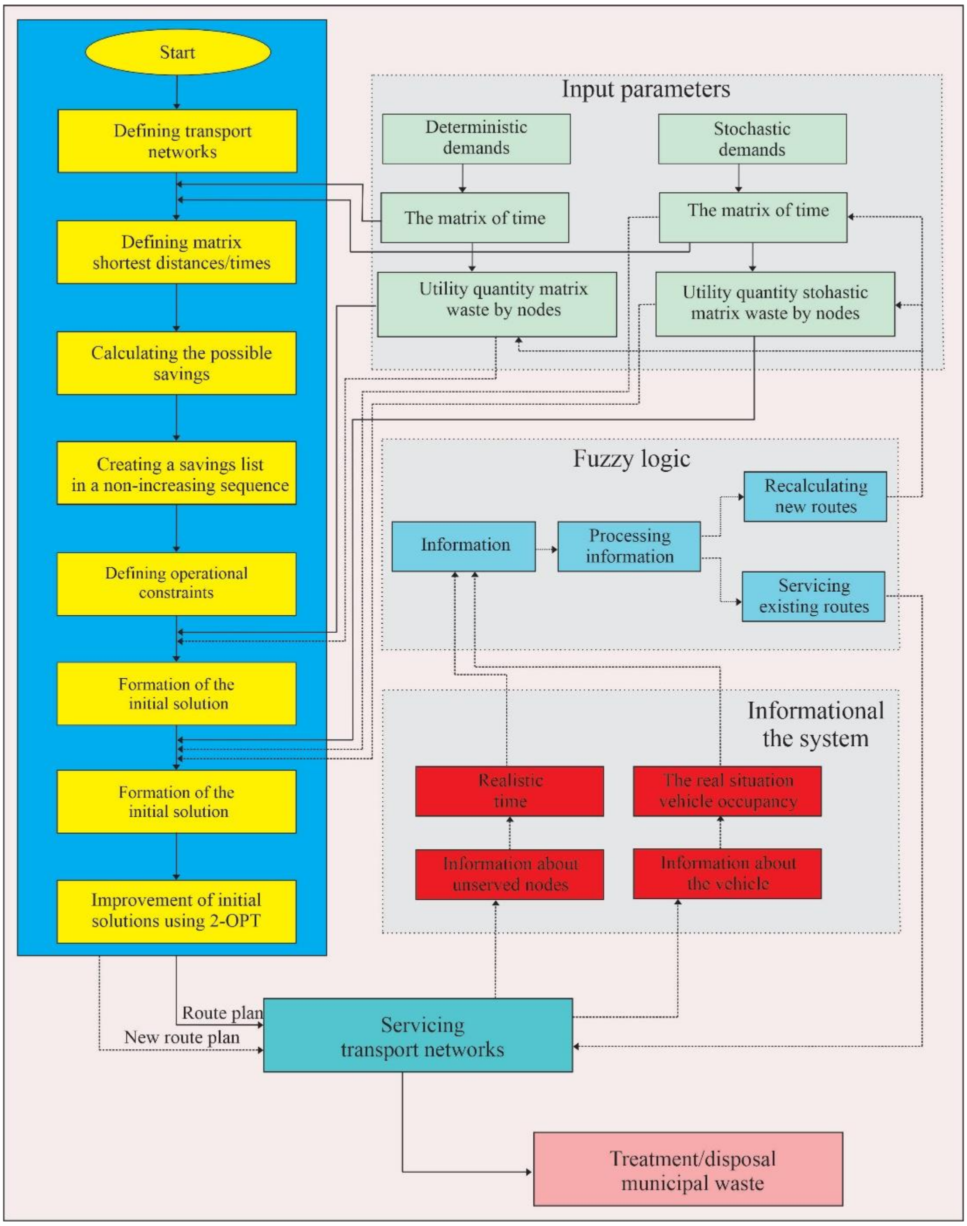


Fig. 2 Conceptual model for dynamic vehicle routing of municipal waste collection and transport.

During the development of *CMESDVRMWS*, problems that often arise in practice were considered and a solution based on information and communication technologies was proposed. *CMESDVRMWS* offers the possibility to reorganize the given plan of vehicle movement routes in real time to comply with operational constraints, i.e. route duration and vehicle capacity. The *CMESDVRMWS* information and communication system functions as follows. If the vehicle, which has received a route plan for a given transport network, at some point due to some obstacle (closed street) is not able to carry out the given route plan, the vehicle operator sends that information to the depot (the dispatcher working in the depot). The information that the dispatcher receives is the geographic position of the vehicle and the information about the exact time. Figure 3 shows that the vehicle should serve the transport network according to the given plan with two routes, namely the first route: depot-1-2-3-4-depot and the second route: depot-10-9-8-7-6-5-depot. However, in the first route, the vehicle after serving node 3 encounters a problem (the road between node 3 and node 4 is blocked), which means that a new route plan should be made in real time so that the vehicle continues the optimal route to serve the transport network. The flow of information is realized according to the system developed by a group of collaborators including [8].The modem, which is located in the vehicle itself, has GPS and GSM modules (GPS - global positioning system and GSM - global mobile telephony system). GPS satellites located in the earth's orbit (fig. 3) send radio signals that are received by the GPS module in the vehicle and send further data to the dispatcher about the current position via GSM. The data received by the dispatcher may be different and depend on what GPS/GSM device is connected to the installation of the vehicle itself (fuel level, oil level, tire pressure, etc.).

The dispatcher uses the information he receives in real time to create a new plan of optimal routes. When deciding whether it is necessary to make a new plan of vehicle movement routes or to continue with the existing plan, the dispatcher is assisted by the *CMESDVRMWS* segment, which is called the phase system for evaluating the fulfilment of the conditions for changing the route.

Fuzzy systems provide a formal methodology for manipulating and implementing human heuristic prior knowledge and reasoning about whether a new vehicle routing plan needs to be designed. Instead of using the language of mathematics to solve the problem of routing optimization management of vehicles for municipal waste collection and transport, the goal of the fuzzy approach is to enable the implementation of engineering experience on decision making regarding the conditions under which the optimization algorithm should be dynamically applied. In this phase model, the system offers the possibility to suggest, based on previous knowledge and engineering experience, whether there are conditions to approach the design of a new vehicle movement route or whether it is suggested to continue proceeding along the existing vehicle movement routes. In this way, the proposed fuzzy system helps the dispatcher in making this important decision. If the fuzzy system suggests that it is necessary to design new vehicle movement routes, this means that a new matrix of the shortest distances and a time matrix must be created

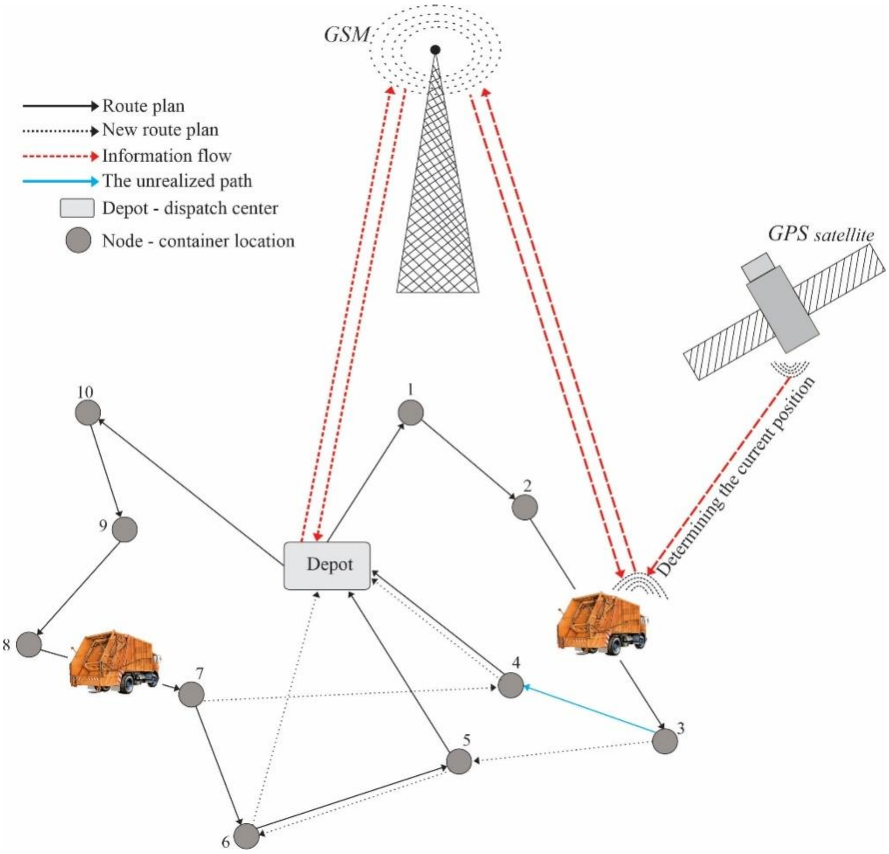


Fig. 3 An example of a dynamic VRP using an information system.

in the GIS environment based on the current position where the vehicle stopped. Given that the dispatcher can have an insight into the real volumetric filling of the vehicle, it is of great importance for planning the new matrix of the amount of waste by nodes, that is, for the new plan of vehicle movement routes.When the dispatcher looks at this information, that is, forms new matrices, then the procedure in *CMESDVRMWS* is repeated, meaning that savings, a list of savings, initial solution and optimization of the initial solution are formed (Fig. 3).When a new route plan is received, the dispatcher sends a new plan (reorganized route plan) to the operator via GSM signal and the vehicle operator acts according to the new plan. For the operator to receive this data, it is understood that they have one of the PDA devices in the vehicle, on which they will receive route plans. The new route plan, according to the example from the picture (fig. 4), has the following appearance: the first route is depot-1-2-3-5-6-depot, and the second route is depot-10-9-8-7-4-depot.

Another possibility offered by CMESDVRMWS is the option of serving a certain "*region*" with a vehicle that is not intended for that "*region*" but for a neighbouring "region" due to the sudden cancellation of a certain route. Such a problem is shown in Figure 4.The flow of information is similar to the problem in Figure 3, with the fact that here the dispatcher looks at all the vehicles on the field. The system of including more vehicles in the transport network service system is much more complex. In this case, the transport network is divided into zones or "regions", since that term has already been used. Each "region" has planned vehicle movement routes, and service within the "region" can be performed with one vehicle or with several vehicles. If it is planned that each "region" is served by one vehicle, *CMESDVRMWS* will function as follows. If we have a transport network with two "regions" (Fig. 4) where "region" 1 has two designed routes (first route: depot -1-2-3-4-depot and second route: depot-6-5-7- 8-9-10-depot) and "region" 2 has one route (depot-11-12-13-14-depot), the vehicle operator in "region" 1 reports congestion (road works) on the road between node 3 and node 4, and then the same information transfer as in the previous problem from Figure 3 is performed. However, in this case, when designing new routes, the dispatcher looks at the neighbouring "region" 2. This means that CMESDVRMWS offers the possibility of optimizing the transport network when more vehicles are used. This kind of real-time optimization is quite similar to practical problems and offers optimal loading of all vehicles, and for this reason a new organization of routes was carried out in "region" 2.After designing the new routes from the picture (fig. 4), node 10 from "region" 1 is connected to the route in "region" 2, which should lead to all engaged vehicles on the transport network being evenly loaded.

Such a logistic model offers great opportunities to companies dealing with the collection and transport of waste in urban areas. Reducing costs, through reducing the vehicle-kilometres, is of great importance for companies, especially for companies that have older vehicles. Such vehicles have high fuel consumption considering their operation (so-called start-stop-go), which in addition to economic consequences also has environmental consequences, and for this reason the application of *CMESDVRMWS* is justified.

4. CONCLUSIONS

Empty corridors in many municipal companies that deal with waste management cause increased costs of providing services. Unlike other systems, when transporting municipal waste, in almost 90% of cases, the owner of the process opts for a transport model that includes an empty wheel. This directly causes the value of technology to decrease. The process of collecting and transporting municipal waste from households is one of them. In urban areas, this process occupies one of the leading places on the scale of the most important transport processes of general interest.

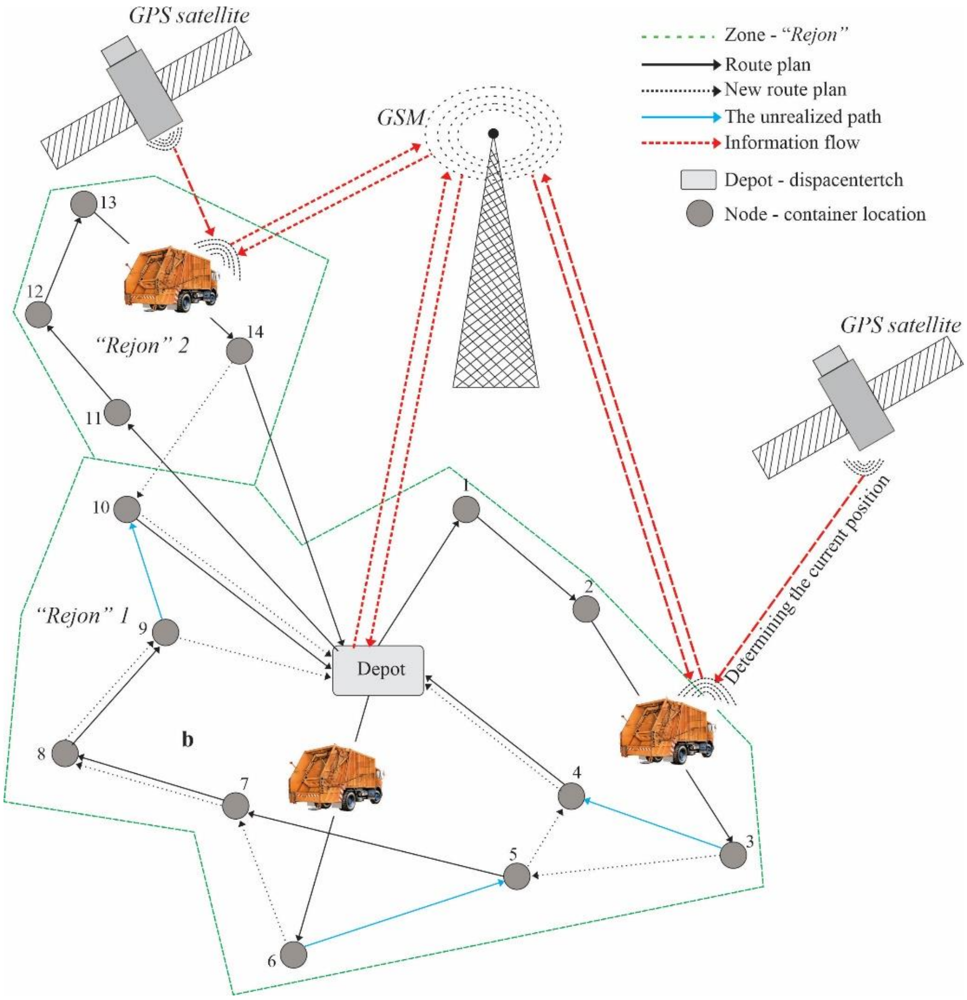


Fig. 4 An example of a dynamic VRP using an information system with two "regions".

The set of transport vehicles that support the process of collection and transport of municipal waste usually make up most of the vehicle fleet of communal companies, which is usually 50-70% of transport units, naturally, in those companies whose sphere of interest is public hygiene. This process is also dominant in those business systems that integrate several utility activities. They contain 15-40% of transport units that support the municipal waste collection process. According to collected research and statistical data, in large cities in Serbia, the average transport vehicle used, on an annual basis, has fuel costs between 400,000 ÷ 650,000 dinars. If one system (a large city) contains 30 transport units intended for the implementation of the objective function, the cost of fuel, under existing conditions, will amount to 12,000,000 ÷ 19,500,000 dinars per year.By optimizing and CMESDVRMWS only on one such system, it is possible to reduce energy costs for mechanization by 10 ÷ 25%.In the end, it should be noted that the proposed conceptual model for choosing the optimal vehicle routes for the collection and transport of municipal waste has great flexibility in terms of application to any urban environment. Also, it should be emphasized that the results of this study represent an original work with wide application.

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