THE ADVANCED SYSTEM FOR DYNAMIC VEHICLE ROUTING IN THE PROCESS OF WASTE COLLECTION

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Abstract. This paper presents a developed system of monitoring and dynamic routing of vehicles for waste collection in the city area. By applying the modern technology, a better insight into the condition of the vehicle on the field as well as the changes in the quantity of waste on collection places are acquired. For this purpose, a special measuring system on the vehicle which uses mobile technology for sending process data about the current load route to the user is developed. The obtained data in post festum after statistical analysis are used to create new routes. In this way, system that allows dynamic routing with precise routes is established. The system can make corrections during or after the execution of existing routes.

Key words: Routing with Stochastic Demands, Logistics Software, Dynamic Routing

1. INTRODUCTION

Optimization in the area of vehicle routing for communal waste collection has a significant role in reducing transport costs since it represents a significant part of total costs. Problems that occur during optimization are primarily related to shortcomings in input data. Most routing algorithms assume that the amount of waste at collection places is known in advance (deterministic value) which in most cases it is not. The routes formed on these values are often not realized as planned.

A modern approach to the vehicle routing assumes that the amount of waste at the collection places is not a constant value, but that is changing in time. In order for the vehicle routing process to give more optimal results it is necessary to analyze the amount of waste at each collection place. The development of satellite technologies for defining the exact location on Earth as well as mobile technologies have enabled recording exact locations for waste collecting, duration of operations, mass and load area fulfillment on vehicles. A large number of collected data can be the basis for the determination of the ex-
pected value, standard deviation and distribution of random variables. If the data is recorded for a longer period of time, seasonal changes in the quantity of waste can be observed.

The vehicle routing problem with capacity constraint - CVRP by including stochastic values in the routing process use routing methods with stochastic demands CVRPSD \([2,3,6]\) or in case of routing with time window CVRPSDTW. The information for the routes forming can be changed after the creation of the primary route process of communal vehicle routing crossing from static to dynamic routing.

2. System Description

The recent communal waste collection problems are using known static routing techniques. The routes of vehicles formed in this way in the case of terrain deviations can be difficult to change. Any change of routes for specific vehicle affects the change of routes for other vehicles in the system. Due to the time window (the possibility of waste transport only in a period of day or week) this disorder is often carried over into other days for which the plan for waste collection is set.

With the project "Development of the model and logistic technologies for communal waste transport" \([1,11,12]\) the research of the dynamic routing model efficiency is carried out. A modern approach to the vehicle routing allows the process flexibility. It is reflected in the ability to change the established routes during the execution process. The necessary input data for route forming are not taken a priori as deterministic but as stochastic values. In order to form the dynamic routing model it is necessary to previously collect data about waste quantity at the collection places. The dynamic routing model is conditioned by the development of systems for collecting and processing data from the refuse collection vehicles (RCV). Schematic review and information flow through the system is shown in Fig. 1.

![Fig. 1. The basic scheme of information flow through the system](image)

This system can be divided into three sections. The first represents the equipment installed in the RCV. It consists of a GPS-GPRS device, which forwards data of vehicle
position and the data of pressure plate position. The second part is the software for data collection and database on the server. The third section presents individual host applications on workstations named Routing [12].

The Fig. shows two levels of data transfer. The first level represents the data transfer from the vehicle to the server. GPS position and other process data from the measuring channels are transferred through the public mobile phone network (GPRS) and thru the Internet to a database server. The server-side has the software installed with the task of processing any received data on a specific network port processing and their storage in the database. These data are stored in the database on the server, and since it is the database of the type MySQL (database on web server with php), they can be read through web browser from any location. For this purpose the software is developed on the server for collecting data coming from the vehicle. The main part of the tcplistener code in C# programming language is shown in Fig. 2.

```csharp
using System;
using System.Net.Sockets;
using MySql.Data.MySqlClient;

class Program
{
    static void Main(string[] args)
    {
        MySqlConnection MySqlConnection1 = new MySqlConnection("server=160.99.22.XXX;user id=pmilic;Password=###;database=oris");
        TcpListener newsock = null;
        byte[] data = new byte[16384];
        int port = 1702;
        try {newsock = new TcpListener(port); newsock.Start();}
        catch (SecurityException){Console.WriteLine("Osluškivanje nije moguće");return;}
        Console.WriteLine("Status: Aktivno osluskivanje porta 1702");
        TcpClient client = newsock.AcceptTcpClient(); NetworkStream ns = client.GetStream();
        while (true)
        {
            try
            {
                data = new byte[16384]; recv = ns.Read(data, 0, data.Length);
                if (recv == 0) break;
                Console.WriteLine(Encoding.ASCII.GetString(data, 0, recv)); //Primljeni podatak
                ns.Write(data, 0, recv);
                string celaporuka = "";
                string[] vrednostLinije = celaporuka.Split(";");
                string IDV = vrednostLinije[1];
                string podaci = vrednostLinije[3];
                string[] parcijalnipodaci = podaci.Split(',');
                string pod0 = "";
                ......
                pod11_nn = parcijalnipodaci[0];
                string upis = "$INSERT INTO oris1 (podatak0, ...) VALUES ('" + @pod0 + ", ...')"
                MyConnection1.Open();
                MySqlCommand MySqlCommand1 = new MySqlCommand(upis, MyConnection1);
                MySqlDataAdapter adapterUpisa = new MySqlDataAdapter(upis, MySqlConnection1);
                DataSet Mydataset = new DataSet();
                adapterUpisa.Fill(Mydataset);
                MySqlConnection1.Close();
                Console.WriteLine("Zapis uspjesno snimljen.");
            }
            catch (Exception){Console.WriteLine("Zapis nije snimljen!!!");}
            ns.Close();
            client.Close();
            newsock.Stop();
        }
    }
}
```

**Fig. 2.** Port listener and data recording in a MySQL database – extract from the code

The second level of data transfer represents the data transfer from a database server to the workstations. The data in the database can be simultaneously accessed by multiple workstations which can only read data from the server and interpret them separately. Host application developed at the Mechanical Faculty in Nis[12] has the following purposes:

- Vehicle tracking and monitoring of process data,
- Static routing of traffic resources for waste collection (defining the routes that vehicles should use in the process of waste collecting),
- Dynamic vehicle routing based on data from the field.
Vehicle tracking is realized using GPS-GPRS device.
The purpose of the device is to transfer data about vehicle position and certain parameters of vehicle condition. The device does not give this information to the driver but sends them through Internet to the server. This part of the software is necessary for forming a real state of the waste collection process in the terrain at static and dynamic routing. Based on these data we can know exactly how the collection process is realized (whether all locations are visited, whether it is a well planned time or whether there are delays).

3. STATIC ROUTING AND PROCESSING OF MEASURED DATA

The basis of the routing is a network of roads with precisely defined GPS coordinates for the World Geodetic System (WGS84 ellipsoid), with defined direction, size and name of the road. In addition to these data for the road network, some other data can be collected such as delays at traffic lights, road capacity, etc. The developed software for distances calculation use the Vincent's iterative formula. Bigger problem in GPS devices usage in the city are so-called shadow places usually caused by high residential blocks or topology of the terrain. These are the places where the level of the signal from the satellites is low or the number of available satellites from this place is insufficient for precise positioning. To make the road network able to be used for routing of vehicles it is necessary to form a primary graph. The primary graph is a graph where the nodes on graph are crossroads of the road network while the arches of the graph are segments of the streets. The shortest distance between any two nodes (crossroads) can be calculated using the Floyd's algorithm. Once they are calculated, there is no need to recalculate the shortest distances for the whole map. The primary graph must include all the possibilities of movement and each branching of the road network regardless of however insignificant it may seem. The primary graph is only an intermediate stage which is necessary for forming the secondary graph with a significantly smaller number of nodes. Jams in the road network and slow switching on some crossroads (traffic lights) are included in the routing process at this stage in an indirect way by increasing the calculated distances. A distance increase is related to the given crossroad or road segment. For a medium size of town (200 ÷ 300 thousand inhabitants), the number of nodes of the primary graph is a couple of thousands and the number of collection places is significantly smaller. The process of generation of the primary and secondary graph is shown in Fig. 3.

![Fig. 3. Process of generation of the primary and secondary graph](image-url)
Defining the collection locations for waste transportation should be performed before the formation of the primary graph. Each collection place defines a new node of the primary graph. Its location is on an existing street segment with a defined additional distance to the collecting place.

In this way the problem is reduced to the problem of routing on the secondary graph.

The basic parameters of collecting places are:
- geographic node location, node location in the graph and the representing user,
- quantity and type of containers in which waste is disposed of,
- type of vehicles that can serve this location (depending on type of containers, location),
- period of the day when the waste can be collected,
- time required to waste collection at a specific location (loading operation) depends on the type of transport resources and types of used containers.

Parameters of the vehicle are:
- capacity of the vehicle, expressed as the maximum weight or volume for waste collection,
- road network sections where the vehicle can be used,
- types of containers which can serve the vehicle according to the built-in manipulator,
- costs related to vehicle use (per unit of covered distance and per unit of time),
- vehicle depot position,
- vehicle autonomy.

When solving vehicle routing problem a number of restrictions appear and the aim is acquired by setting one or more objective functions. The objective of the vehicle routing process can be:
- minimization of total transport costs, which are in the function of route length (or main traveling time) and fixed costs of vehicle and driver usage,
- minimization of number of vehicles or drivers with the goal of servicing all users,
- adjusting routes depending on the path time and vehicle load.

Fig. 4 shows the modular structure of the developed software "Routing". For software working it is necessary to establish the necessary data base for process monitoring and VRP.

![Fig. 4. Modular structure of the software "Routing"](image)
The monitoring module uses the elements of the GIS system of the city or the area for placing the basic map and server data for showing location. Based on data from the server about the location, times of data recording and data from measuring devices application can show the length of traveled distance, average and maximum speed, periods when vehicle is not active and the other data obtained by statistical analysis.

The Clark Wright algorithm is used for the beginning of route forming. The process of zoning has not been considered because the formation of route is performed for the pre-defined urban areas. Clark Wright's algorithm considers the case of uniform vehicle fleet when all the capacities of vehicles are equal. Thus, the formed route is a starting point for initiating the process of waste collecting. Each vehicle has a defined path and the collecting places that need to be served. Extending the system by device for measuring fulfillment of loadspace (Fig. 5) is enabled by the creation of a special database with data of waste quantity and the location at which it arises.

![Fig. 5. The principle of vehicle fulfillment measurement](image)

The system consists of the measuring sensor, the angular displacement converter and the modem. The modem is so set that the input voltage changes from the converter (analog the overall hydro-cylinder angle change) are appropriate to the changes of the measured size from 0 to 100%. This change corresponds to reposition of the pressure plate from the beginning to the end of the loading area. The percentage value of the hydro-cylinder position angle further forwards the server together with other data. Determination of fulfillment is determined by the software on the basis of obtained percentage values. For defined collecting places, the vehicle which it handles is defining the initial amount of waste. It is formed based on the experience from the process of waste collection in this region or on other indicators (population, waste structure ...). The initial routes are formed based on these data. By realization of the defined routes changes of measured parameters
are recorded. The flow of measuring process of loading area fulfillment for RCV vehicle is shown in Fig. 6. The vehicle passage of the given route and its collection of the waste from collection places $CP_i$ increases the amount of collected waste. The system does not register a change in the level of fulfillment by passing through each collection place. This change is registered in increments for volume of 1% of the total volume of loading area of RCV vehicle.

![Fig. 6. Graphic interpretation of registering the quantity of waste](image)

Fig. 6 illustrates the observed positions from which a signal is sent. The change of loading area fulfillment degree of RCV vehicle is sent to a database server together with GPS coordinates at which the change occurs. To determine the deviation of the collected amount of waste from the assumed it is necessary to allocate collecting places where change occurs from 1% of vehicle fulfillment.

The algorithm for determining the deviation of waste amount at collection places from assumed is shown in Fig. 7. From the database of collected measured data from the vehicle, software extracts positions in which changes of degree of fulfillment occur. These positions forming a fulfillment changes points vector $FCPV = [PFC_1, ..., PFC_n]$. From the database of formed routes it is necessary to allocate all collecting places between successive points of $FCPV$ vector. In the algorithm this operation previously implies extraction of route segment $RSPV = [P_i, ..., P_k]$ in which the change occurs. For the extracted route segment, from the database of collecting places, are extracted collecting places $CPV = [CP_{m}, ..., CP_{n}]$.

![Fig. 7. The algorithm of waste leveling](image)
In this way the segment of route is located, that is, the place where 1% of vehicle fulfillment of waste is collected as well as an appropriate volume of waste depending on the type of vehicle. The ratio of sum of assumed volumes of waste on separated collection places with 1% volume of vehicle makes leveling factor (originally introduced in this study [12]). This factor indicates that the amount of waste at a given location is higher or lower than assumed. Waste quantity on collection places from the original base of collecting places or from the leveled can be used for the formation of new routes. Using this method for a longer period of time makes it possible to monitor waste levels in some urban areas, seasonal variations, increasing or decreasing tendencies of waste amount.

$$k_{n} = \frac{\sum Q_{\text{out}}}{Q_{\text{in}}}$$ \hspace{1cm} (1)

4. Dynamic Routing with Stochastic Demands

In the waste collection process it may happen that, for one reason or another, the planned route cannot be fulfilled. The causes may be different. Some of them are exceeding the amount of waste in relation to the planned or there are unannounced changes in the road network, the failure of transport equipment (exclusion of certain vehicles and load redistribution of other vehicles), exceeding the scheduled time, etc. If it is found out by comparing the planned and the actual situation that the process deviates, it is necessary to change the route of the vehicles. This can be done by the dispatcher’s decision or by the software based on implemented software logic. The dispatcher can make route changes based on indicators of changes in the state during the execution of given route or on the basis of estimates due to unforeseen circumstances, which makes the system more flexible.

Dynamic vehicle routing problem - DVRP implies that not all information relevant to the vehicle routing process known to the person who planned the route before beginning the routing process and information related to the routes formation can be changed after the initial formation of the first route [2,7,8]. Modern meta-heuristic methods for solving vehicle routing problems VRPSD use basic meta-heuristic methods such as Iterative local search, Tabu Search (TS), Simultaneous Annealing, Ant Colony Optimization, Evolutionary algorithms (Genetic Algorithm)[9]. Due to the improvements many algorithms are combined with traditional algorithms, and thus we get the hybrid algorithms with better performance [10]. To achieve dynamic routing with stochastic demands in the nodes of graph (waste amount) it is necessary to determine the distribution of the changes in the amount of waste on the basis of recorded data in the database server.

For the purpose of dynamic routing some appropriate assumptions are introduced:

- Demands in the nodes are independent random variables with known discrete or continuous distribution function,
- Demands at node (ξ) never exceed the vehicle capacity (Q) and it is non-negative random variable such that the probability is \( P(\xi \leq Q) = 1 \) for each node of the graph except for the first (\( v_i \in V \setminus \{v_0\} \)).
At least one return trip can be made on each route to the depot. This implies that the solution must be such that the probability of occurrence of more than one cancellation on any route $r_k$ be zero: $P\{\sum_{i \in r_k} \xi_i \leq 2Q\} \equiv 1$

Users whose time window is disrupted are serviced by a separate individual trip which creates a cost proportional to the length of the return path and the path to the depot.

Calculation of total transport costs:

If we observe a set of formed routes $r_k = (k=1,\ldots,m)$ with a set of nodes $r_k = (v_{0}^{k}, v_{1}^{k}, v_{2}^{k}, \ldots, v_{n}^{k})$ for a given first instance solution $R = (r_{1},\ldots,r_{m})$, the total cost function $F(R)$ is the sum of values: $\phi(R)$ and $E(\psi(R))$. Value $\phi R$ is a deterministic cost of the planned route, and $E(\psi(R))$ are the expected costs of rerouting, which can be present as the expected costs of rerouting $\theta(R)$ generated by returning to depot and expected cost $\zeta(R)$ due to the failure in servicing of requests in time window. The function of the total cost can be represented by the following formula:

$$F(R) = \phi(R) + E(\psi(R)) = \phi(R) + E(\theta(R) + \zeta(R))$$ (2)

Probability of route failure $P_{i}^{k}$ in the node $v_{i}^{k}$ on the route $r_{k}$ can be represented by the following equation [4]:

$$P_{i}^{k} = \sum_{x=0}^{\lambda_{i}^{k}} \lambda_{x}^{i} P_{x}^{k}(t) - \sum_{x=0}^{\lambda_{i}^{k}} \lambda_{x}^{i} P_{x}^{k}(t)$$ (3)

Cumulative probability demands $X_{i}^{k}$ from node $v_{i}^{k}$ on route $r_{k}$ can be calculated:

$$P_{x}^{k}(t) = \sum_{t=0}^{\infty} \lambda_{x}^{i} P_{x}^{k}(t-l) P_{i}^{k}(l)$$ (4)

Minimization formed function of total costs and knowing probability of route failure in the corresponding node of the route and application of these meta-heuristic methods can be carried out in the process of dynamic routing with stochastic demands [2,5,7,8].

5. CONCLUSION

The application of modern techniques in the process of routing vehicles has a great significance. They can achieve a better efficiency of the process, control level of tasks realization and provide an insight into the possible behavior of the system. With the application of these techniques, the process of vehicle routing for waste collection is basically changed. The results obtained (established routes of vehicles) are realized with a higher probability than the results obtained by applying the method of static routing. By applying the method of dynamic routing, the vehicle route changes are performed during the process of collection. This way ensure optimal solutions, thus reducing total costs. To obtain the optimal solution in real time it is necessary to use modern optimization methods.
REFERENCES


NAPREDNI SISTEM ZA DINAMIČKO RUTIRANJE VOZILA U PROCESU SAKUPLJANJA OTPADA

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Radom je predstavljen razvijeni sistem monitoringa i dinamičkog rutiranja vozila za sakupljanje otpada u gradskoj sredini. Primjenom savremenih tehnologija stiče se bolji uvid o stanju vozila na terenu kao i o promeni u količini otpada na sabirnim mestima. Za te potrebe razvijen je poseban merni system na vozilu koji posredstvom mobilne tehnologije šalje korisniku procesne podatke o trenutnom opterećenju rute. Dobijeni podaci u "post festum" nakon statističke obrade se koriste za formiranje novih rata. Na ovaj način je formiran sistem koji omogućuje dinamičko rutiranje sa preciznijim rutama. Sistem može vršiti korekciju u toku ili nakon izvršenja postojećih rata.

Ključne reči: rutiranje sa stohastičkim zahtevima, logistički softver, dinamičko rutiranje