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FORMATION OF ROUTES FOR THE TARGET REMOVAL OF THE HOUSEHOLD WASTE IN THE "SMART CLEAN CITY" PROJECT BASED ON HYBRID APPROACH USING EXPERT SYSTEMS

Abstract. An important component of the study of the target waste collection issues is the optimization problem for the complex dynamic systems. This article analyzes the problem of optimizing the process of controlling the collection of solid household waste as a part of the broad-spectrum of "Smart City" concepts. Mathematical model for solution of the optimization problems and transport planning for the directed waste collection is proposed. The model based on the network optimization algorithms is selected. Additional loading of the refuse collection vehicle during waste collection is the basis for optimizing of the parameters of the whole process. As an optimization criterion, the cost of the services rendered, the weight of the removed waste, and the reduction in idle run can be considered. The paper describes the continuation of the investigations published in the ICCCI-21 Conference Proceedings by the development of the new approach for building the route by using of the expert system with fuzzy rules based on the traffic expert knowledge that can be implemented as a part of the decision making in the route construction system is also considered.

Key words: smart city, optimal route, simulation modeling, waste collection, expert systems, fuzzy logic.

1 Introduction

"Smart Environment" can be considered as a part of the "Smart City" concept, the core of which is using the mobile communication technologies known as Internet of Things. It is obvious that the targeted solid industrial and domestic waste collection on time saves expenditures, fuel, reduces exhaust gas emissions, especially in megapolises. The problem of waste disposal is a part of the overall task of ensuring environmental safety in the urban space, the purpose of which is not to exceed the permissible level of negative impact of anthropogenic hazards on the environment [1].

There are various approaches for the waste collection. Many cities used collection targets for different solid waste: paper, plastic, end-of-life vehicles, end-of-life tires, waste of electrical and electronic equipment; batteries for further recycling. As a rule, the solution methods are based either on the typical transport task solution or on the approach of artificial intelligence using knowledge bases, they include also using of mobile technologies, information systems. This approach involves information, communication (based on mobile communication) and Web 3.0 technologies, which make it possible to accelerate decision-making processes, apply innovative methods of city management, and improve the urban space environmental safety [4]. Such tasks are of particular relevance, and at the moment the methodological foundations and applied methods of their practical solution are being developed [5, 6, 7].]. Using of the wireless sensor network for controlling of the filling of the waste bins by collecting data from the embedded sensors was proposed by many researchers [1-6]. But as a whole the task of the target waste collection is still actual. One of the priority areas for the analysis of such problems is the development of mathematical models that allow to determine the formal criteria for the effectiveness of the functioning of systems for the collection and disposal of household waste [8, 9] taking into consideration various aspects of the task [10,11].

2 Structure of the project "smart clean city" for development of applications

To optimize waste collection a special system called "Smart Clean City" (SCC) was developed to manage process.

The system allows to carry out following tasks:

– specialized truck performs waste collection only if the containers are filled by collecting data from the embedded sensors (target waste collection);

– each container has a sensor which generates the message on filling;

– rational distribution of containers according to the areas of the city.

– SCC allows to solve the following city problems:

– increasing the economic efficiency (fuel, funds for maintenance of equipment, optimization employment staff, resources and time for waste collection) of the company responsible for the waste collection;

– maintaining the proper urban sanitary and epidemiological situation.

The functioning of the SCC system is schematically shown in the Figure – 1. The system consists of two parts: software and special signaling equipment.

The technical part is represented by:

– equipment installed on each waste site with containers (WS);

– equipment installed on waste collection trucks (WCT).

Each WS is equipped with two types of equipment: transmitter unit of the sensor area and the filled containers with a transmitter. To detect the fullness of containers, it uses infrared (IR) and ultrasonic sensors. The range, measurement accuracy, and extreme nature of external conditions were considered while selecting sensor type for the WCT monitoring system and containers. Each waste site is equipped with two types of equipment: two-way receiver-transmitter unit for the waste site and fullness sensors of each container on this site with a transmitter. A built-in GSM module transmits data from the container transceiver unit to the control room.

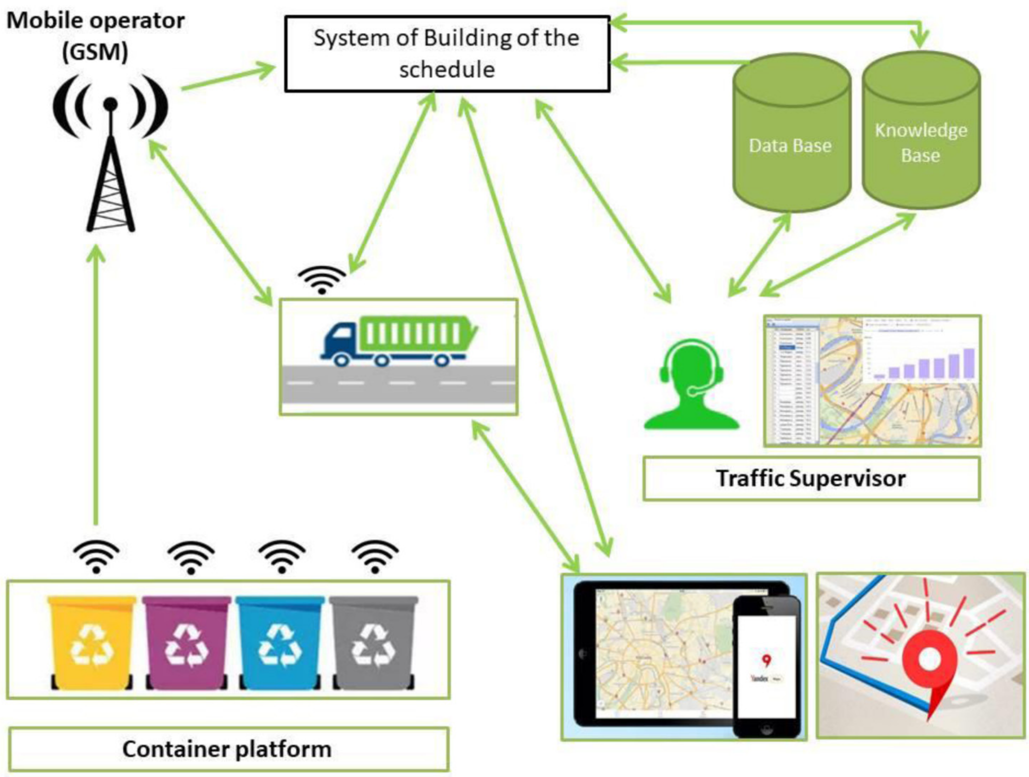


Figure 1 – System Overview

The general structure of the system “Smart Clean City” and optimization schedules algorithms for waste collection trucks are described in [12, 13] where the system model is presented in the form of a dynamic graph, which weight functions depend on time and are determined by the current state of the area for waste containers (GC) and current road traffic. The structure of the platform for application development within the project “Smart clean city” is presented in Figure 2.

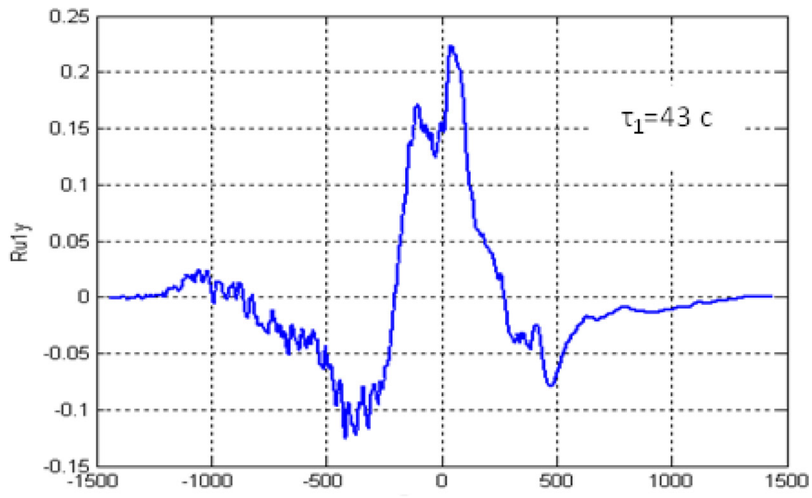


Figure 2 – SCC operation diagram [13]

Several subsystems integrated into the single platform allow solving of various tasks of analysis and management of the solid waste collection and disposal system. These subsystems are combined by means of special adapters that allow to synchronize data, manage various parts of the entire system. At an early stage of development such interaction was carried out directly between subsystems with the help of inherited interactions between them. Developed applications have a unified interface and allow to manage the data integrity model in various subsystems.

The subsystems are server software applications that allow to develop a model of the system of collection and removal of waste (SUB_1), apply optimization algorithms for the schedule of trucks on several parameters (SUB_2), use in the decision-making system the knowledge base built on the experience of the enterprise organization of waste disposal (SUB_3), special expert knowledge of the traffic situations in the city. Developed applications are located both on the server part of the system, and in client applications using mobile platforms.

The structural hardware-software implementation of the solution is shown in Figure – 3. When managing the removal of household waste, information on the degree of filling of containers with an indication of the type of waste in (1) is recorded online in the database of the system. This makes it possible to determine automatically the possibility of its joint transportation with other wastes. Taking into account the economic component of the operation, the time spent on processing and the existing optimal routes for visiting places with dumpsters, requests for the possibility of additional loading of transport units (GT) on the route are being investigated.

It is assumed that before running the algorithm, a predetermined primary route for collection and removal of household waste is known.

The software and hardware complex allows to store and process information about transport units, the current state of containers for household waste, and waste disposal processes in general. The algorithm for constructing the GT route automatically monitors the received requests from GS and selects the options for passing additional loading. The system of automatic transmission of geolocation information and GT status consists of mobile equipment installed on GT.

It consists of a mobile device (7) with a mobile application installed, a GPS/GLONAS module (8) connected to the vehicle's electric engine control system (9). The module (8) is a hardware complex that includes everything necessary for the operation of the mobile part of the system as part of the entire system.

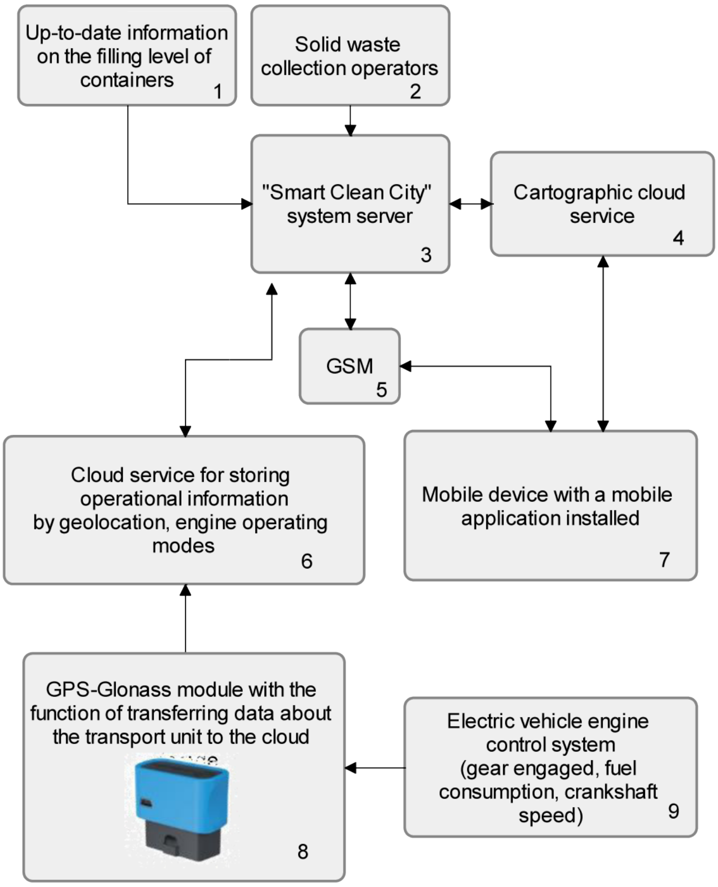


Figure 3 – The structural hardware-software implementation

In the next section, there is described the algorithm for optimizing the routes of the waste trucks, which is used for developing of the target waste collection system model and for analyzing of its effectiveness.

3 Formal statement of the route optimization problem

The task of the optimal routing modelling for the logistic systems of transport [14] using of global networks has been formulated. Operation methods and procedures of multicriterial decision making in risky conditions have been developed. Procedures of evaluation for formalized goals models are developed: for transportation schedules. The practical evaluation of the efficiency of the SCC system and constructing optimal routes for the collection of household waste is to calculate dynamic optimal routes for waste trucks. In the field of household waste collection, there are many irregular requests for waste collection that are not included in the general schedule of waste collection trucks.

The solution of such a problem based on changing the route of movement and the collection of additional volumes of associated waste is proposed. To solve the problem, a mathematical model of the transportation system in the form of a weighted network is determined as follows:

$$G = (V,\ E,\ f,\ g,\ w) \qquad (1)$$

V – the set of nodes (vertices) of the model network.

There is the following partition of the set $V = V_1 \cup V_2$, where

V_1 – nodes corresponding to locations and addresses that are sources and points of delivery of waste;

V_2 – nodes corresponding to the places of discharge of waste having geographic coordinates as additional attributes.

E – set of edges (arcs) corresponding to the road network (taking into account one-way and two-way traffic), which connects the above sets of nodes of different types.

The structure and functionality of the developed SCC system are described in more detail in [16, 17].

Transportation is defined as a list of *S* tuples of the form $< v, u, w, volume, cost, type$, where

$w, volume$ – accordingly, the weight of available waste and its volume;

$cost$ – declared cost of the operation for the removal of household waste from node *v*;

$type$ – type of household waste, determining the possibility of their joint utilization.

For an arbitrary route $p = v_1, v_2, ..., v_n$ in the network model, we determine the function $f\colon p \times T \to R$,

which returns the cost (the sum of the transportations cost) for all transportations included in route *p* at time *t*:

$$f(p,T) = \sum_{i=1}^{n-1} cost(v_i, v_{i+1})|$$

$$f(p,T) = \sum_{i=1}^{n-1} cost(v_i, v_{i+1})| \quad (2)$$

$g\colon p \times T \to R$ – function for determining the distance passing along the route p at time t. The function g is defined as the sum of the shortest distances between pairs of vertices in .

$w\colon p \times T \to R$– function for determining the travel time of the route p, determined taking into account the distances and average speed provided by the map services.

The dynamics of the network change is associated with a change in the travel time of the sections of the route, in accordance with the current traffic situation, vehicle load.

Formally, the problem can be formulated as follows: for a given list of requests for the household waste collect *S*, allowable distance for increasing route length *L* and permissible increase in the value D of the travel time along the route, the primary transportation route with the initial vertex v_1 and final vertex v_n, find such a route $p = v_1, v_2, ..., v_n$ in the network *G*, that for a given time *t*

$$f(p,t) \to max \quad (3)$$

under the condition

$$| g(p,t) - g(v_1,v_n) | \le L \quad (4)$$

$$| w(p,t) - w(v_1,v_n) | \le D \quad (5)$$

Formula 5 represents the optimality condition for the objective function *f*, Formulas 4, 5 represent the constraints under which the extremum of the objective function is sought. With this formalization, we have a single objective function and functional limitations on the proposed solution.

In the proposed formulation, the formulation of the multicriteria optimization problem is also possible, when the requirements for finding extrema for functions will be superimposed simultaneously on one or more functions from the list f, g, w.

4 Dynamic algorithm for finding ways with additional loading of passing cargo

It is assumed that when developing the algorithm, there is a certain departure route (primary route) for waste disposal, starting from which its economic benefits are calculated.

The initial route is built by the logistics organization of the carrier based on the data of the regular requests from the customers for waste collection.

The associated waste search algorithm is based on the several principles:

– the logistics of the carrier organization determines the restrictions on deviations from the primary route (by distance, by time, by the timing of the delivery checkpoints), additional incidental requests for the removal of waste are determined based on these restrictions;

– each waste collection operation is supplied with attributes that determine the admissibility (inadmissibility) of additional loading, if additional loading is prohibited, optimization is carried out only by constructing the shortest route in the framework of optimization algorithms of the SCC system;

– associated additional loads should be compatible with the type of household waste of the primary route from the point of view of their joint utilization, as the associated cargo is added, it is necessary to control the general parameters of the tonnage and volumetric characteristics of waste.

Main algorithm calls the PGR and COMP procedures. PRG procedure builds a ranked list of all the requests for removal of waste that can be considered as “passing” for the primary route. The result of the algorithm is a list of all requests that are concurrent in the sense described above. It is important to note that concurrent requests can be mutually exclusive in terms of their possible addition to the primary route

Different types of household waste can be combined in one trip only if it is possible to jointly dispose of all waste along the route. If there is a possibility of additional loading of the vehicle, then in addition to "passing ", time limits, distance, it should be considered according to the parameters of the waste involved in joint transportation.

It is assumed that each type of the waste is associated with types permitted for joint disposal. This is required not only by the rules of possible sharing, but also by restricting the use of certain vehicles having special equipment for carrying out transportation. It is also necessary to take into account the general weight parameters of jointly transported goods and restrictions on the dimensions of transportation. It is clear that the sequence of rebooting the car can lead to exceeding the permissible weight of the cargo, incompatible with general restrictions. COMP procedure checks the compatibility of associated requests for waste collection. This check is carried out only if the primary route implies the permissibility of additional loading. A detailed description of the PGR and COMP procedures is presented in [14].

The Block diagram of the algorithm for constructing a ranked list of routes (RList) with possible additional loadings shown in Figure – 4. The algorithm is recursive and at each step completes the current route by adding requests for waste collection compatible with the current route parameters that are allowed by restrictions.

The algorithm performs an exhaustive search and implements the branch and bound method. At each step, the algorithm tries to "embed" a waste removal request into the current primary path.

At the initial stage of the algorithm, a list of all associated routes for a given initial is constructed, at the second, all routes that are incompatible in type, weight characteristics and dimensions with the load of the reference route are deleted from it.

Next, the algorithm tries to add a passing request to the primary route. In reality, there is a complete enumeration of all options for constructing a new route. The complexity of the algorithm and the time of its operation are also affected by restrictions on the size of the permissible deviation from the reference route.

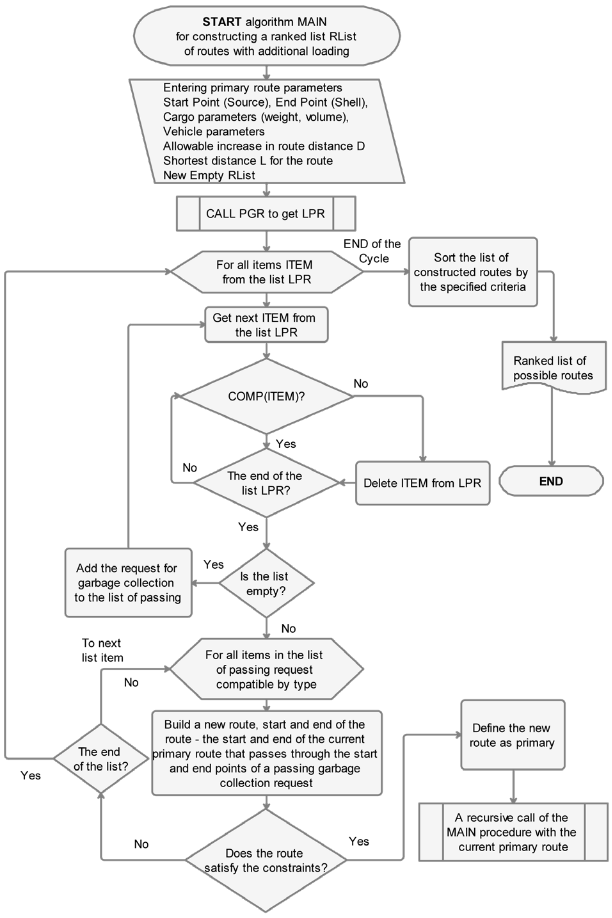
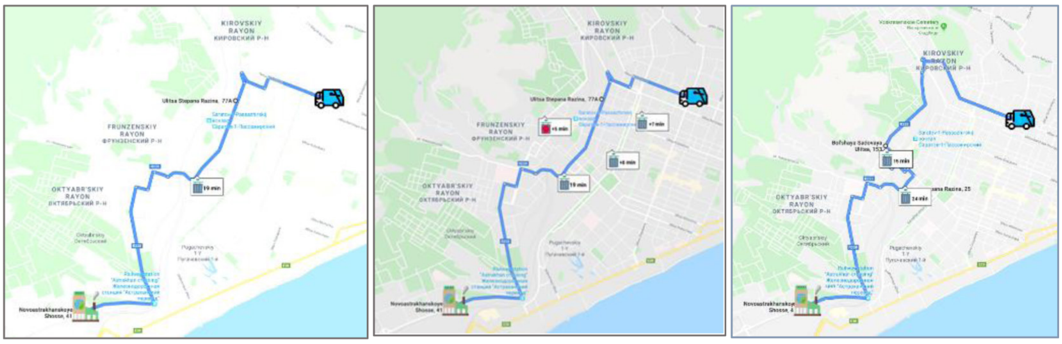


Figure 4 – Block diagram of the MAIN algorithm for constructing a ranked list of routes with on-the-way loadings



(a) (b) (c)

Figure 5 – Primary route on the cartographic service (a), primary route with an additional waste disposal request included (b), new route includes an additional waste disposal site

Figure – 5 shows the software interface with the marked primary waste collection route (a), additional waste disposal requests available in the system that can be used to build the final route (b), a route that is built on a primary basis and includes an additional waste disposal site. The route is built taking into account data on the current state of traffic.

5 Alternative approach based on fuzzy logic

Smart Clean City approach combines the described algorithm of building the optimal route with the intellectual approach represented by the knowledge base consisting of the fuzzy rules:

$pr_i : r_i : v_i$: if a_j then b_k with the confidence c_k,
where:
$r_i \in \{R\}$ – the set of the rules,
$pr_i \in \{PR\}$ – the set of the priorities,
$v_i \in \{V\}$ – the set V, see (1);
$a_j \in \{A\}$ – the set of the facts which represent the current situation,
$c_k \in \{C\}$ – the set of the linguistic variables,
where C = {'possible', 'probable', 'most likely'}, c_k represents the fuzzy variable described with the trapezoid function. Such an approach finds application in solving problems of finding optimal routes depending on hard-to-formalize factors [15, 16].

Rules are formed by the experts (from the traffic police or professional drivers) who are well acquainted with the traffic situation in the city. For example, in case of the traffic accident and corresponding traffic jam the experts could make the solution what step should be made – to select the other route or to wait. If the described algorithm of the building of the route tries to select the next node vi but gets the message from the mobile maps service about the high load of the transport on the way to v_i and the knowledge base contains the rule r_i with the priority $pr_i \geq 80$,then the solution is made on the base of the selection of the r_i (to follow the algorithm or to select the other node or change the route to the new one).

The algorithm assumes the following WCT statuses and related information requests:

- (Status) Registration
- (Status) Ready
- (Status) Faulty truck
- (Status) On the route
- (Status) WCT is not full
- (Request) Get all day schedule
- …
- (Request) Get optimal route to AGC (area for GC)
- (Request) Recalculate route for additional loading.

The last request involves building a ranked list of routes for additional loading using the MAIN algorithm and selecting the best one. The algorithm takes into consideration the cases which are known to the city experts where the weather can influence the decision, for example, a heavy rainstorm can lead to impassable passage of certain places in the city where there may be problems with storm sewers, and the need to change the route(Figure – 6).

Knowledge base consists of the rules (912 rules) the examples of which are presented below:

80: $r_{32} : v_i \in V_1$: if status (GCT) = "On the route" AND
status (GCT) = "GCT is not full"
then Recalculate route for additional loading;

100: r_5 : $v_i \in V_1$: if status (GCT) = “On the route” AND

status (GCT) = NOT “GCT is not full”

then continue with primary route with confidence “most likely”;

100: r_{14} : $v_i \in V_1$: if status (GCT) = “On the route” AND

status (GCT) = “GCT is not full” AND

RList=∅

then use the primary route;

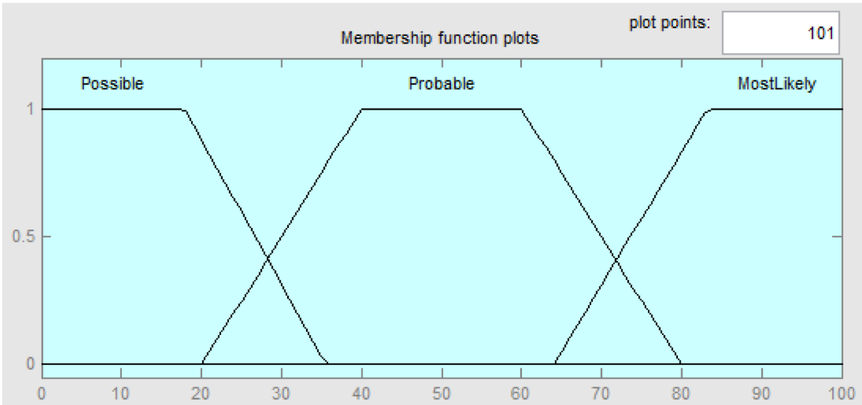


Figure 6 – The membership function for the linguistic variable “Degree of confidence”

95: r_{318}*:* $v_i \in V_1$*: :* if status (GCT) = “On the route” AND

Status (node) = “traffic overloaded”

then Continue on the route;

100: r_{514}*:* $v_i \in V_1$*: :* if status (GCT) = “On the route” AND

Status (node) = “flood”

then Recalculate route for additional loading.

95: r_{516}*:* $v_i \in V_1$*: :* if status (GCT) = “On the route” AND

Status (node) = “heavy rain” and Duration > 3 hours

then Recalculate route for additional loading;

95: r_{517}*:* $v_i \in V_1$*: :* if status (GCT) = “On the route” AND

Status (node) = “shower” and Duration > 1 hour

then Recalculate route for additional loading.

In many cities there are problems with storm water drains and traffic situation could get much worse with heavy showers. The membership function of the linguistic variable “Rain force” is presented on the Figure – 7.

It is planned to develop the fuzzy rules for each megapolis street and crossroad which help to make an optimal solution of the route selection. Using of the fuzzy rules increases the efficiency of decision making in real traffic situations.

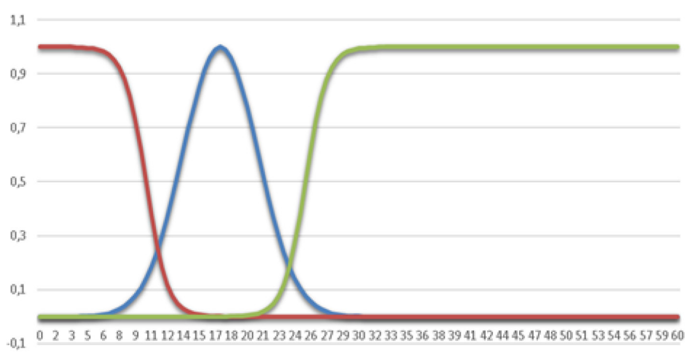


Figure 7 – Graphic of the membership function of the linguistic variable “Rain Force”

Membership functions for the variable "Rain Force" are defined by

$$\mu_{Rain}(x) = \frac{1}{1+\exp(a(x-b))}, \text{ (sigmoid left)},$$

a= 1, b=10

$$\mu_{Shower}(x) = \exp\left[\frac{-(x-b)^2}{2a^2}\right],$$

a=2,55, b=17

$$\mu_{Flood}(x) = \frac{1}{1+\exp(a(x-b))},$$

(sigmoid right), a=--1, b=25.

6 Conclusion

The solution obtained by the algorithm can be used to change the waste collection procedure within a predetermined schedule. It can also be used to build a route in case of an unscheduled request for waste collection. The results of the algorithm application are the reduction of the empty run of the waste truck, the reduction of time for waste collection, and the increase in the efficiency of the whole process.

The separate solutions, which are currently implemented in conglomerations, should be prepared for integration into the intellectual urban infrastructure. Tasks that arise in real life require a quick response to requests that arise outside the regular schedule.

The advantage of the proposed approach is the use of not only optimization algorithms when constructing routes, but also the inclusion in the process of finding solutions to evaluate them based on the experience of experts.

The described system "Smart Clean City" can be considered as a targeted waste management system; it has been tested in Saratov (Russia), city with a population of approximately 1 million people. Implementation of the system in the period from September 2015 to May, 2022 shows 23% decrease in the processing time of containers compared to traditional manual planning, without taking into account the dynamic parameters of the system described above. The trucks company, which uses the system as a tool for preparing timetables for the GCTs, has 24 trucks in its composition.

The described algorithm is used to reduce the costs when responding to the waste collection requests that are not in the regular schedule of waste trucks. They cannot be predicted with a reasonable degree of certainty. The proposed approach allows to reduce the empty run of waste trucks, to increase the weight and volume of waste taken out.

Comparative analysis has been carried out using real data and simulation results. The area of the Saratov city for which the model has been implemented has 322 containers at 60 sites. Each site contains 3-10 waste cans. Two landfills for the removal of solid household waste are used. Each container has a capacity of 100 kg. The carrying capacity of the truck is estimated at 5000 kg (the actual capacity depends on the degree of compressibility of the waste).

Using of the fuzzy rule-based expert knowledge increases the efficiency of decision making in real traffic situations. Experiments evidently showed that using of expert rules makes it possible to increase the efficiency of decisions made by the driver in difficult traffic situations compared to the use of road navigators for smartphones, such as Yandex Navigator, Google Maps, Waze. Expert rules should also be useful for constructing optimal routes for urban emergency transport services.

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