

Method of Dynamic Optimal Rout Calculation in the “Smart Clean City” Project

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Abstract: A solution of the optimization garbage removal problem in the large cities is suggested. In this paper there is described a system architecture to find time-optimal dynamic route for garbage trucks within “Smart Clean City” project which unites an approach to put special electronic devices on the garbage containers with the developed software responsible for the detecting the filled up containers and building the optimal way to collect the garbage. There is proposed a formal mathematical model of the task of dynamic optimal route and formal the optimization criterion for time-optimal garbage collection of all waste from landfills. The system includes the knowledge base which contains the rule describing the expert knowledge of the city traffic situation.

Key words: Dynamic network, clean city, optimization tasks, traffic flow, knowledge base.

1. Introduction

Waste management problem is actual both for each big city. In every city there are special organizations and companies engaged in the collection and removal of waste in special dump places. Most of the companies collect garbage according to the schedule or on demand of the customers. However, there are situations when the garbage truck arrives but garbage containers are half-filled; at the same time the truck does not arrive to the real full garbage container. This is due to the fact that manager does not take into account the real container fullness. This problem is a part of a general theme of creating the comfortable environment in modern cities and can be considered as the “Smart Environment” which is described by attractive natural conditions, pollution, resource management and also by efforts towards environmental protection [1]. “Smart Environment” can be considered as a part of the “Smart City” technology. There are many definitions of the “Smart City” term [2]. An important component of the smart city concept is the use of new information mobile technologies. This approach emphasizes the following

definition as a city “*combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability [3]*”.

There already exist special software and hardware systems that allow to solve the problem of calculating an optimal schedule for the waste disposal. There are various approaches that use different types of detectors, which allow on-line control of the level of filling of the garbage containers [4-8] but the problem of optimal garbage collection in case of dynamic changes in the level of fullness of the containers and current changes of the real traffic situation in the city has not been solved yet.

2. Description of the Proposed Method

Special system called “Smart Clean City” was developed to optimize garbage collection and manage this process. The system allows to carry out the following tasks:

- (1) to generate the special message by the garbage containers when they are filled up;
- (2) to manage the process of sending a specialized

Corresponding author: Olga Dolinina, Ph.D., DR., artificial intelligence, reliability of the knowledge.

truck for the garbage collection only if the containers are filled;

(3) to develop an optimal rout for the garbage collection in the city;

(4) to distribute rationally the containers in the areas of the city.

“Smart Clean city” allows to solve the following city social and economical tasks:

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

- maintaining the proper urban sanitary and epidemiological situation.

The system consists of two parts: software and special signaling equipment. The technical part is represented by:

- equipment installed on each garbage site;
- equipment installed on garbage trucks.

Each AGC (area for garbage containers) is equipped with two types of electronic devices: one unit of two-way receiver-transmitter and sensors to determine the fullness of each container with a transmitter.

Each container is equipped with a special vandal-resistant device, which is located on the side wall of the container. It includes sensors detecting the level of the garbage in the containers (infrared and ultrasound) for the inspection of the fullness. Sensor is connected to the radio transmitter that transmits a signal of a fullness level for container to host receiver-transmitter unit. All elements are powered by the internal power supply. To save energy, the sensors do not work all the time, and with some frequency, controlled by the microcontroller. This reduces the probability of false signal transmission.

Information from the container transceiver unit is transmitted to the control room using a built-in GSM module. This makes it possible to transmit the received data via cellular communication. Information

goes to the processing server and will be processed by server software. Software system consists of the client and server parts.

The tasks of the client part of the application:

- displaying routes graphically;
- client registration;
- warning about the need to empty the containers;
- notification of inability to continue work due to force majeure;
- automatic authorization to get information depending on the area of truck’s driver responsibility;
- automatic authorization to obtain client zone-responsibility;
- periodically send info to a server about truck’s position.

The server part of application:

- storage of information about the AGC: address, location, number and capacity of containers, date of the last maintenance;
- storage of information about garbage trucks: type, number of mobile devices, device ID, capacity;
- receive and process messages from the garbage sites;
- information about the fullness of the AGC in general and deciding on the need for removal of garbage from it;
- specification of the garbage truck for AGC needs to be cleaned, we take into account its current location;
- generating an optimal route in accordance with the road traffic data;
- transmission optimal route to a AGC for garbage truck;
- receiving information from the client application;
- dynamic updates on the status of AGCs for garbage in accordance with the actual situation;
- reporting and statistical analysis.

The software part provides interface between AGC, dispatch center and garbage trucks. Operation of the system takes place as follows:

- (1) Information about the status of the garbage

containers (fullness/emptiness) in the area is transmitted to the central Server where the software calculating the optimal routes is implemented. If the whole AGC is filled with more than 70%, the system decides to remove garbage from it.

(2) AGC is added to the list to be visited.

(3) The garbage sites are represented as the nodes of the city network (see details below). The system changes the weights of the edges on the basis of data traffic and road conditions. Traffic data are taken from the online road map service.

(4) Server application calculates optimal routes on the base of time necessary for each garbage trucks. Thus, the driver sees only the route to area for garbage containers, which really needs to be cleaned.

System structure overview is shown in Fig. 1.

The suggested formalization and method for solving optimization problem are original for the following reasons. Firstly, the network model of the transport system has dynamic nature [9]. Secondly, information about filling containers handled automatically by the system during the development of an optimal plan.

Formal network problem statement for dynamically optimal route:

To solve the problem let’s to define the weighted mixed network (there are directed and undirected edges)

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

V —set of network vertices,

E —set of directed arcs corresponded to city road network, arcs connects location of garbage containers, places of their discharge, home bases of garbage truck (garages) and linking them road network;

$f: V \times T \rightarrow R$ —vertex weight function at time t , which determines the amount of time to pass truck through the vertex;

$g: E \times T \rightarrow R$ —arc weight function at time t , which determines the amount of time to pass truck through the arc;

$w: V \times T \rightarrow R$ —vertex weight function at time t ,

which determines the amount of filled containers at the place of their location.

Vertices superimposed on the map of city road network. Arcs and edges correspond to roads (with one-way and two-way traffic, respectively). There is the following partition of the set V

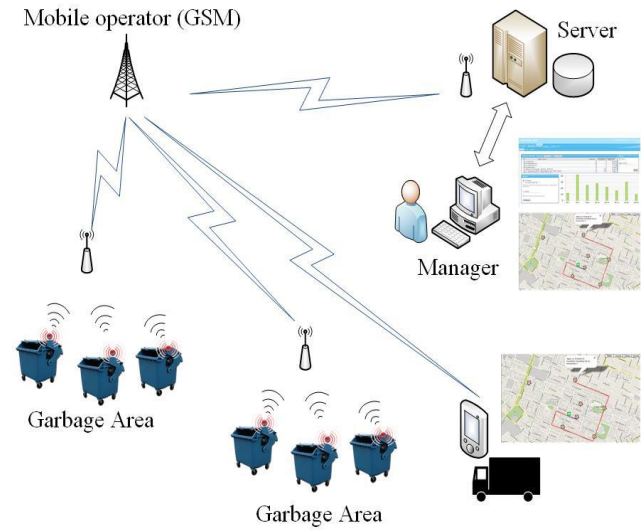


Fig. 1 System overview.

$$V=V_1 \cup V_2 \cup V_3 \cup V_4, \quad (2)$$

where

V_1 —network vertices correspond to garbage site with containers;

V_2 —network vertices correspond to solid domestic garbage dumps;

V_3 —network vertices correspond to garages location;

V_4 —vertices correspond to the connection points of road segments (crossroads).

Let’s define mapping f (temporal characteristics of road network vertices).

Vertices’ weight defines temporal characteristics of the garbage truck to pass through this vertex, weight is defined by membership of corresponding partition block and current time as follows:

$f(v, t)$ —time required for loading contents of containers on a specific garbage site for $v \in V_1$;

$f(v, t)$ —time to unload a truck for $v \in V_2$;

$f(v, t) = 0$ for $v \in V_3$;

$f(v, t)$ —value that characterizes the delay of garbage

truck at a crossroads (traffic light, unregulated crossroad), this value is determined on the basis of experimental data for $v \in V_4$.

Let's define mapping g (time characteristics of a road network arcs).

For all network arcs (edges) $e \in E$ $g(e, t)$ —value represents time to pass on route segment (depends on speed limit, quality of the roadway, segment road distance, traffic on this segment) defined for time moment t . This value is determined according to the actual traffic situation.

Let's define mapping w (number of filled containers).

For all vertices from blocks of partition V_2, V_3, V_4 and for any time moment t value $w(v, t) = 0$.

For vertices that corresponds garbage containers location the value of function returns the number of filled containers on site at time t .

$$w(v, t) = \begin{cases} 0, & \text{if } v \notin V_1 \\ \text{number of filled containers} & \\ \text{at the site } v \text{ at time moment } t, & \text{if } v \in V_1 \end{cases}$$

Values for vertices and arcs of network at any time t call *markup*. At starting point of the network ($t = 0$) we call initial *markup*. Dynamics of network changes is depended on actual traffic road situation, fullness of containers on garbage sites (varies in time), which results in a change of function values, change of *markup*.

Let the garbage truck has a capacity of L containers. At the initial moment ($t=0$) on AGC v_j we have K_j filled containers that we need to take to the solid domestic garbage dump. It is clear that $K_j = w(v_j, 0)$. Consequently, the garbage truck must visit each point of discharge (dump) at least S_j time, where

$$S_j = \left\lceil \frac{K_j}{L} \right\rceil \quad (3)$$

The total number of downloads—discharge cycles in this case is equal to

$$S = \sum_{1 \leq j \leq |V_1|} S_j$$

The total number of filled containers is equal to

$$K = \sum_{1 \leq j \leq |V_1|} K_j$$

Suppose we have a single truck that collects garbage from all AGC and transfers it to the dump. In this case there are several possible optimization criteria. In this paper we consider only time optimization, but the task is really multiobjective. We can consider other areas of analysis, such as maximizing the volume of handled garbage by trucks and some other

Designation: Let P —some route in network G , $U \subseteq V$. Designate $|P|$ as length of route P , and $|P|_U$ —the number of occurrences of vertices from set U in P . It is clear that for any route in the network $|P| = |P|_V$.

Problem statement for one garbage truck:

For given dynamic network a route P is developed

$$P = v_0, v_1, v_2, \dots, v_m$$

and the following conditions are satisfied

(1) $v_0 = v_m$; $v_0 \in V_3$ (garbage truck departs from garage at the beginning of the work and returns to the same garage after work completion);

(2) $\forall_{v_i \in V_1} |P|_{\{v_i\}} = S_i$ (every AGC visited as many

times as necessary to empty filled containers);

(3) $|P|_{V_2} = S$ (dumps are visited S

times—required amount of times for unloading filled containers);

(4) $\sum_{i=1, m} (f(v_i, t_i) + g(v_i, v_{i+1}, t_i)) \rightarrow \min$, where the

minimum is taken over all routes that satisfy conditions 1, 2, 3.

t_i corresponds to time of events related to network vertices. It's clear that

$$t_1 < t_2 < \dots < t_m$$

The problem generalization for n trucks:

Let the number of used garbage trucks is equal to n . For the given dynamic network there must be found n routes

$$P_i = v_0^i, v_1^i, v_2^i, \dots, v_{m_i}^i \quad (i=1, n)$$

and following conditions are satisfied

$$(1) \quad \forall_{i=1,n} \quad v_0^i = v_{m_i}^i, \quad v_0^i \in V_3 \quad (\text{garbage trucks depart}$$

from garage at the beginning of the work and return to the same garage after work completion);

$$(2) \quad \sum_{i=1,n} |P_i|_{V_1} = S \quad (\text{every AGC is visited as many}$$

times as necessary to empty filled containers);

$$(3) \quad \sum_{i=1,n} |P_i|_{V_2} = S \quad (\text{dumps are visited } S$$

times—required amount of times for empty all filled containers);

$$(4) \quad \sum_{i=1,n} \sum_{j=0,m_i} (f(v_j^i, t_j^i) + g(v_j^i, v_{j+1}^i, t_j^i)) \rightarrow \min$$

where the minimum is taken over all routes that satisfy conditions 1, 2, 3.

t_j^i corresponds to time of events related to network vertices for i -th truck. It's clear that for any $i=1,n$

$$t_1^i < t_2^i < \dots < t_{m_i}^i$$

If we want to provide uniform load distribution for garbage trucks then one more condition should be added

$$(5) \quad \text{Let} \quad W_i = \sum_{j=0,m_i} (f(v_j^i, t_j^i) + g(v_j^i, v_{j+1}^i, t_j^i))$$

$$\text{then} \quad \forall_{i \neq k, i, k=1,n} |W_i - W_k| \rightarrow \min$$

“Smart Clean City” approach combines the described algorithm of building the optimal path with the knowledge base consisting of the rules:

$$pr_i: r_i: \text{If } a_j \text{ then } b_k \text{ with the confidence } c_k, \quad (4)$$

where, $r_i \in \{R\}$ —the set of the rules,

$pr_i \in \{PR\}$ —the set of the priorities,

$a_j \in \{A\}$ —the set of the facts which represent ,

$c_k \in \{C\}$ —the set of the linguistic variables, where $C = \{\text{'possible', 'probable', 'most likely'}\}$, c_k represents with the fuzzy variable described with the trapezoid function. Rules are formed by the experts who are 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 change the other route or to wait. If the described algorithm of the building of the optimal path tries to select the next node v_i but gets the message from the mobile maps service (for example, Google Maps) about the high load of the transport services and 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).

3. Conclusion

System “Smart Clean City” allows to optimize garbage collection in the big cities and provides effective management of this process. In the paper there is presented one optimization criterion by the time to empty all filled garbage containers. Developed algorithm takes into consideration the expert rules for making the final solutions. Obviously dynamic nature of chosen mathematical model suggests other criteria. One of the most important of which is the “uniformity” of the garbage trucks loading that imposes additional restrictions on the algorithm for calculate routes. The advantage of the proposed system is the integration of information on the status of containers for garbage on special area with traffic situation in real time.

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