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FUZZY FACTORS CONSIDERATION FOR THE OPTIMIZATION OF THE WASTE COLLECTION ROUTE IN THE TERRITORIAL COMMUNITY

The paper considers the process of the creation of the information technology module for the optimization of the waste collection process in the communities. The given module determines the expediency of inclusion of the waste container bin to the route of the dust cart, depending on the degree of loading of the container and impact of the external factors on its availability, determined by the intensity of the traffic on the road to the container and state of the road, connected with weather conditions.

Objective of the research *consists in automatic determination of those waste containers which do not need urgent waste removal, that is an important component of the optimization problem for the formation of the most reasonable routes for waste transportation.*

Scientific task of the research *includes: determination of the factors, influencing the relevance of the waste removal problem; substantiation of the expediency of using fuzzy logic for this purpose; formation of fuzzy linguistic variables and construction of fuzzy knowledge base; study the efficiency of the process of fuzzy logic conclusion, regarding the determination of the relevance of the containers removal on the base of the suggested influencing factors; conclusion concerning the rationality of the suggested approach.*

The process of the relevance calculation of the inclusion the waste containers into the route of the waste collection, taking into account the degree of their filling and availability by means of fuzzy logic tools is described. Analysis of the external factors, influencing the relevance of the waste collection from the specific container is performed. Fuzzy graph model is suggested, the model presents possible routes of the dust carts, linguistic variables are given, membership functions of their terms are formed, fragment of the knowledge base, supplied by the production rules, processes of the fuzzification and defuzzification are graphically illustrated using Mamdani fuzzy inference algorithm. Calculation of the actuality index of the waste collection is given on the specific example. Testing has been performed on the base of the data of trash enclosures in the city of Rivne. As a result of elimination ща non-actual containers from the route the length of the routes was cut by on average 10.43 %. Further improvement of the routes formation is possible, taking into account the degree of importance of the waste collection, for instance, such as from hospitals, schools, recreation spaces and other civil objects.

Key words: *litter, waste, container, fuzzy logic, linguistic variable, route, Mamdani fuzzy algorithm.*

Introduction

Years long accumulation of waste becomes global problem and dangerous threat for the environment and human health in many countries of the world. Annually according to the official data, Ukrainians produce 11 mil tons of waste, it is approximately 300 kg per capita, and only 3 % of this volume is recycled. According to the data of Ministry of Ecology and Ministry of Regional Development, environmental experts the total area of the landfills of Ukraine is more than 10 thousand ha, and the volume of waste – is approximately 1.2 km [1].

Problem of waste disposal has many components, one of these components is the optimization of dust carts routes for saving the fuel and reduction of the ecological pollution, formed by the dust carts [2]. As a rule dust carts routes optimization is reduced to classical travelling salesman problem, points of cruising are considered to be all the waste containers, irrespective of the level of their full ness and accessibility. In the given paper the authors suggest to take into account the factors of full ness and accessibility of the containers for the determination of the actuality of waste taking by the dust cart.

The term «accessibility» in this case means level of the roads congestion, their current state and possibility in different weather conditions. Account of the impact of these factors is complicated by the incomplete information regarding the fullness and accessibility of the containers and the state of the roads and its loading in real time, this stipulates the expediency of using fuzzy logic tools for their evaluation.

Object of the paper are the processes of determination the actuality of the waste collection from the container.

Subject of the paper are fuzzy models and methods of determining the actuality of waste collection from the container while formation of the dust cart current route.

Aim of the paper is the determination of the set of the containers, which will be included in the next route of the dust cart.

Analysis of the literature sources

Relevance of the problem, dealing with the organization of the waste transportation is proved by a wide range of the studies, carried out in this sphere. D. Rossit and S. Nesmachowe [3], investigating the problem of the containers location propose the criteria for optimization and application of the integrated approaches to the simultaneous determination of the container location addresses and tracing the route of their cruising. P. Litzinger [4] shows the dependence of the roads state on the weather conditions: temperature, wind speed, visibility, explaining the impact of these factors on the number of the road accidents. V. Balanov [5] analyzes the factors, influencing the motion of cargo trains according to the schedule and reasons of their delay by means of mathematical statistics of the trains routes. R. Kapustynskyi [6] uses Mamdani fuzzy algorithms for fuzzy control of the access system to the data base of the enterprise. N. Karadimas, V. Loumus and A. Orsoni [7] propose the model of waste collection assessment on the base of fuzzy logic that takes into account such parameters: population density, area and type of the shops, information about the roads, etc.

Results of the research

The map of the waste bins location on the territory of the community will be presented as a fuzzy graph $\tilde{G}$ = (X,$\tilde{F}$), set X=$\{x_i\}$; $and \in I = \{1,2,\ldots,n\}$ the vertices of which presents the set of the waste bins and fuzzy set $\tilde{F} = \{\mu_{\tilde{F}}(x_i,x_j)/(x_i,x_j)\}, (x_i,x_j) \in X^2$, edges of the graph – presents the fragments of the roads, connecting the bins.

On the set of the vertices X fuzzy subset of the filled bins $\tilde{V} = \{\mu_{\tilde{V}}(x)/x\}$, will be determined, the value of the membership function $\mu_{\tilde{V}}(x_i)$of which will determine the level of the bin x_i completeness. The value of the membership function $\mu_{\tilde{F}}(x_i,x_j)/(x_i,x_j)$ will determine the degree of «availability» of the road fragment between the bins x_i and x_j.

Input X_1- X_3, and output Y linguistic variables will be determined:

X_1= Fillness of the bin (empty, half empty, almost full, full);

X_2= Weather (bad, instable, fine);

X_3= Congestion of the road (night, early rush hour, day, evening rush hour, evening);

Y = Actuality of the removal (low, average, high).

For the presentation of the terms of linguistic variables quasibell-shaped membership function

$\mu_{\tilde{T}}(x)$ will be used, this function characterizes the degree of membership x to fuzzy term $\tilde{T}_B$ in the range [0,1] [8], as it is shown in Fig. 1.

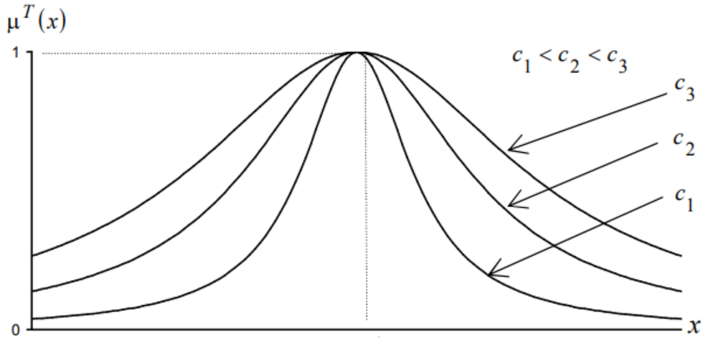

Fig. 1. Graphic representation of quasibell-shaped function

Such membership function is described by the formula:

$$\mu_{\tilde{T}}(x) = \frac{1}{1+(\frac{x-b}{c})^2}.$$

Terms of linguistic variables will be determined and their membership functions will be constructed.

Nowadays many settlements introduce trash enclosures with the sensors of waste filling [9]. However, in greater part of cases, ordinary bins are used, the information, concerning their filling is calculated on the base of statistical data or can be sent by means of the messenger or phone call (for instance, in public holidays or «special days» when certain public events occur).

Parameter x1 – «Completeness of the bin».T(x1) = <empty, half full, almost full, full>. This factor is determined at the universal set U(y1) = [0; 100], which presents the measure of the percent of the bin completeness. Terms are presented by fuzzy sets:

Empty = {<1/0>; <1/10>; <0.7/20>; <0.35/25>; <0.1/30>};

Half empty = {<0/0>; <0.15/10>; <0.7/20>; <0.93/25>; <1/30>};

Half full = {<0/15>; <0.1/25>; <0.19/30>; <08.4/4>; <1/50>};

Full = {<0/60>; <0.19/65>; <0.91/70>; <0.98/75>; <1/95>}

Graphic representation of the terms of the set $T(x_1)$ is shown in Fig. 2.

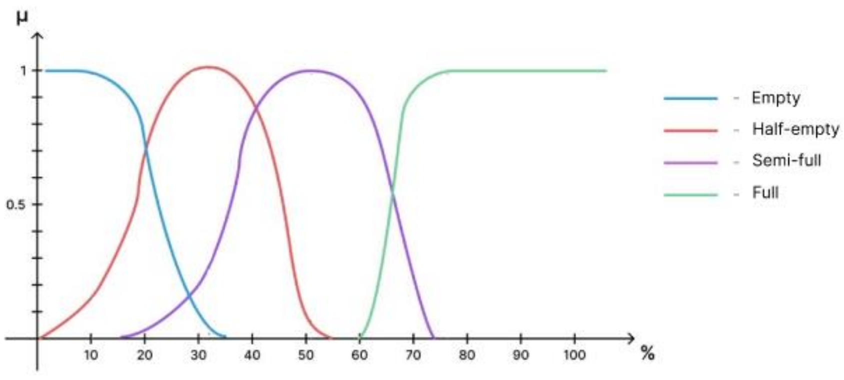

Fig. 2. Graphic representation of the parameter «Bin completeness»

One of the important factors of the bin accessibility is the weather, that changes the visibility, state and possibility of the road (glaze ice, drifting show) that leads to the change of the drivers behavior. Bad weather results in the reduction of the traffic speed, increase of the distance between the motor vehicles and number of the traffic accidents [4]. Impact of the weather conditions to the traffic is shown in Table 1. Drivers get into the traffic jams, the transport operators observe the reduction of the road capacity.

Table 1

Impact of the weather conditions on the drivers [4]

Weather conditions	Value	Unit of measure	Engine power loss (%)	Decrease in speed (%)
Temperature	1 – 10	ºC	1	1 – 1.5
	0 – (-20)	ºC	1.5	1 – 2
	<-20	ºC	6 – 10	0.3 – 6
Wind speed	16 – 32	km/h	1 – 1.5	1
	>32	km/h	1 – 2	1 – 1.5
Road visibility	1,6 – 0,82	Km	9	6
	0,8 – 0,4	Km	11	7
	<0,4	Km	10.5	11

Parameter x2 – «Weather». T(x2) = <bad weather, worse weather, fine weather>. This factor was determined at the universal set U(y3) = [0; 100], which measures the conventional percent drop of the road quality as a result of the weather change. Terms are presented by the fuzzy sets:

Fine = {<1/10>; <0.96/20>; <0.92/25>; <0.3/30>; <0.18/33>};

Instable = {<0/10>; <0.12/20>; <0.47/25>; <0.9/30>; <1/40>}

Bad = {<0/40>; <0.05/50>; <0.39/55>; <0.92/60>; <1/80>}

Graphic representation of the set terms T(x2) is shown in Fig. 3.

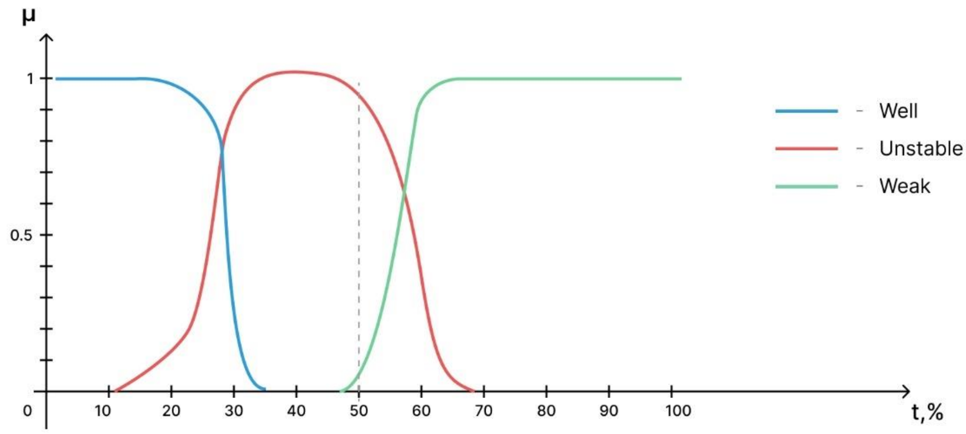

Fig. 3. Graphic presentation of the parameter «Weather conditions»

Traffic loading influences greatly the dump cart travel duration. Degree of loading depends on the time of the day. We will calculate it on the base of the available statistical data or obtain from the video monitoring cameras, installed along the road [10]. Separately two peak periods should be allocated: morning, transport moves in the direction of work/school and evening, when all come back home.

Parameter x3– «Road condition». T(x3) = <night, morning peak, day, evening peak, evening>. This factor is determined on the universal set U(x3) = [0; 24], which indicates hours of the day.

Terms are presented by fuzzy sets:

Night = {<0/1>; <1/3>; <0.6/4>; <0.96/4>;<0.27/6> };

Morning peak = {<0/1>; <0.1/3>; <0.73/6>; <1/8>; <0.19/12>};

Day = {<0/5>; <0.18/9>; <0.31/10>; <1/12>;<0.5/15> };

Evening peak = {<0/10>; <0.22/13>; <0.58/15>; <1/17>; <0.19/20>}

Evening = {<0/16>; <0.35/19>; <0/8/20>; <0.93/21>; <1/23>}

Graphic presentation of the term of the set T(x3) is shown in Fig. 4.

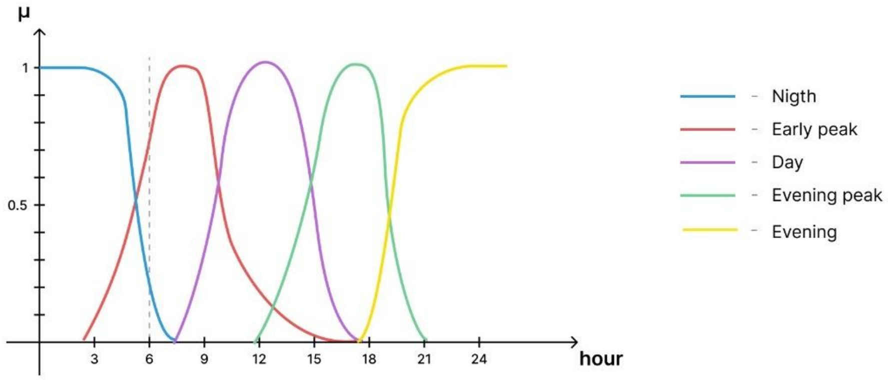

Fig. 4. Graphic presentation of the road loading parameter

Output linguistic variable Y – «Actuality of the collection», determines the expediency of the bin inclusion into the route of the dust-cart: T(y) = < low, average, high>. This factor is determined on the universal set U(x3) = [0; 100], which indicates the percent measure of the actuality of the waste collection actuality. Low actuality is within the limits of 0 – 40 %, average – 40 – 70 %, high – 70 – 100 %.

For using the Mamdani fuzzy inference algorithm [11] fuzzy data base is formed, this base contains 60 rules, built on the base of fuzzy production model of the statements «If – Then», which connect input variables $x_1 - x_w$ with one of the possible output solutions (Fig. 5):

$$If\ (X_1 = a_1^{11})I\ (X_2 = a_2^{11})I\ \dots\ I\ (X_w = a_w^{11}),$$

$$Or\ (X_1 = a_1^{12})I\ (X_2 = a_2^{12})I\ \dots\ I\ (X_w = a_w^{12}),$$

$$Or\ \dots\left(X_1 = a_1^{1\delta_1}\right)I\left(X_2 = a_2^{1\delta_1}\right)I\ \dots I\left(X_w = a_w^{1\delta_1}\right),$$

$$Then\ Y = d_1 and\ \ etc.$$

where x – is the input variable and with the coefficients – is the term of the corresponding input linguistic variable, δ_q – is the number of rules, that determine the value of the output variable y.

Examples of fuzzy productive rules of the data base are shown in Fig. 5.

Rule 1: IF «Container fullness» = «Half-full» & «Weather» = «Weak» & «Road condition» = «Early peak», THEN «relevance of the collection» = «low».
Rule 2: IF «Container fullness» = «Semi-full» & «Weather» = «Well» & «Road condition» = «Early peak», THEN «relevance of the collection» = «middle».
Rule 3: IF «Container fullness» = «Semi-full» & «Weather» = «Unstable» & «Road condition» = «Evening peak», THEN «relevance of the collection» = «middle».
Rule 4: IF «Container fullness» = «Full» & «Weather» = «Well» & «Road condition» = «Day», THEN «relevance of the collection» = «high».

Fig. 5. Examples of fuzzy productive rules of the database

Table 2 shows the rules presentation by the matrix knowledge base.

Table 2

Example of the fragment of the matrix fuzzy knowledge base

Rule №	Filling of the bin	Weather	Road condition	Actuality of the collection
1	Half full	Bad	Early peak	Low
2	Half empty	Fine	Morning	Average
3	Full	Unstable	Evening peak	Average
4	Full	Fine	Day	High

By means of Mamdani fuzzy inference algorithm the degree of actuality of the bin inclusion into the route will be calculated, taking into account the values of the input variables, indicated in the Table 3.

Table 3

Set of testing input data

Filling of the bins	Weather	Road condition
70	50	6

Fuzzification process is illustrated by vertical dashed lines in Figs. 2 – 4. Table 4 contains the representation of its results in the matrix fuzzy knowledge base.

Table 4

Example of knowledge base verification

№ of rule	Filling of the bin (μCF)	Weather (μW)	Road Condition (μRC)
1	0.25	0	0
2	0	0.95	0.15
3	0.9	0.8	0.6
4	0.9	0.95	0.85

Results of the application of the rules of the fuzzification results processing are:

Rule: 1: $\mu_{\text{CF}}^{\text{half complete}} \& \mu_{\text{W}}^{\text{bad}} \& \mu_{\text{RL}}^{\text{early peak}} = 0{,}2 \& \ 0 \ \& \ 0 = \mu_{\text{T3}}^{\text{low}} = 0$

Rule: 2: $\mu_{\text{CF}}^{\text{half empty}} \& \mu_{\text{W}}^{\text{fine}} \& \mu_{\text{RC}}^{\text{morning}} = 0 \& \ 0{,}95 \ \& \ 0{,}15 = \mu_{\text{T3}}^{\text{low}} = 0$

Rule: 3:$\mu_{CF}^{full}\&\mu_{W}^{non\ stable}\&\mu_{RC}^{evening\ peak} = 0{,}9\&\ 0{,}8\&\ 0{,}6 = \mu_{T3}^{average} = 0{,}6$

Rule: 4: $\mu_{CF}^{empty}\&\mu_{W}^{fine}\&\mu_{RC}^{day} = 0{,}9\ \&\ 0{,}8\ \&\ 0{,}6 = \mu_{T3}^{high} = 0{,}85$

Graphic presentation of the defuzzification by the center of gravity method is shown in Fig. 6.

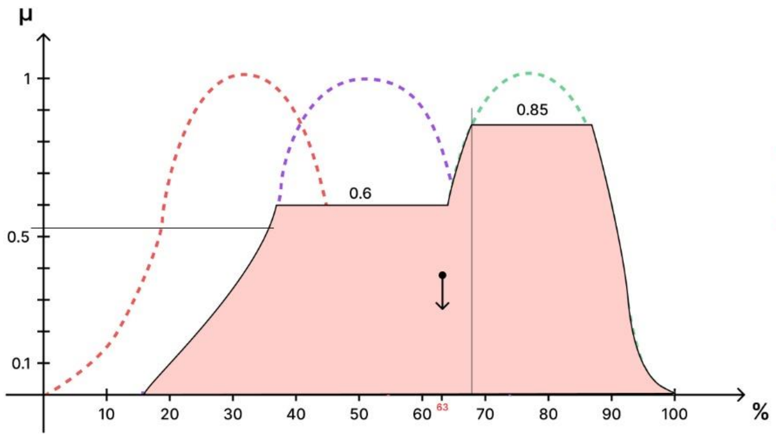

Fig. 6. Defuzzification by the center of gravity method

Relevancy of the waste collection from the bin is calculated by the formula:

$$EA = \frac{\sum_{i=1}^{n} \quad \mu(EA_i) \times EA_i}{\sum_{i=1}^{n} \quad \mu(EA_i)}$$

As a result of the calculations we obtain:

$$\frac{20 * 0.1 + 25 * 0.2 + 30 * 0.33 + 35 * 0.52 + 40 * 0.6 + 45 * 0.6 + 50 * 0.6 +}{0{,}1 + 0{,}2 + 0{,}33 + 0.52 +}$$

$$\frac{55 * 0.6 + 60 * + 65 * 0.6 + 70 * 0.85 + 75 * 0.85 + 80 * 0.85 + 85 * 0.85 +}{+0{,}6 * 7 + 0{,}85 * 4 +}$$

$$\frac{+90 * 0.6 + 95 * 0.15 + 100 * 0}{+0{,}15} = 63.208$$

The obtained result x =63.208 proves the relevancy of this bin inclusion into the route 9 of the dust cart.

Testing of the suggested approach is performed using the data regarding the location of the waste bins in the town of Rivne [12] and the algorithm of the dust cart route formation on the base of the genetic algorithm [9]. The information about the weather conditions in the period [4] and road condition, taken from the interactive map of the town of Rivne was also used [13].

Exclusion from the dust cart route of partially filled bins, taking into account their accessibility, provided the possibility to decrease the length of the route up to 10.43 %. Results of testing are shown in Table 5.

Table 5

Testing of the studies on the base of the data about the bins in the town of Rivne

Route	Number of bins from the source	Length of the route	Number of bins excluded from the route	Length of the route	Percent of improvement
Route 1	53	40.84	6	37.21	8.88%
Route 4	42	32.57	8	29.17	10.43%
Route 7	68	54.43	7	49.53	9.01%
Route 9	61	48.801	8	45.49	6.78%
Route 11	34	28.657	8	25.91	9.56%

Conclusions

1. Problem of waste management becomes more serious due to the constant growth of the waste volume and increase of the expenditures for its transportation.

2. Efficiency of the waste collection can be improved by means of dust carts routes optimization, taking into account the degree of the bins filling, that will decrease the traffic loading and fuel consumption of the vehicles.

3. Absence of the accurate information regarding the degree of the bins filling stipulates the fuzziness of the problem of the dust carts routes determination and the expediency of usage fuzzy logic for this problem solution.

4. The suggested solution of the dust carts routes optimization on the base of fuzzy logic enables to take into consideration the filling ratio of the bins, as well as weather conditions and traffic intensity.

5. The studies carried out of the suggested approach proved its efficiency, providing the exclusion of the empty bins from the route and reducing it by 10.43 %.

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