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The Organization of Municipal Waste Collection: the Decision Model

Mariusz Izdebski, Marianna Jacyna
Warsaw University of Technology

1. Introduction

The organization of municipal waste collection is defined as designating the routes of vehicles which collect the waste. The vehicle routing problem referring to the municipal plants is an issue widely discussed in the literature (Jacyna-Gołda et al. 2017a, Izdebski 2014, Beliën et al. 2014). Solving the routing vehicle problem in the municipal plant one should take into account various aspects, including network structure (e.g. location of municipal plant, location of the points generated the waste) and form of relationships of objects in the network (e.g. constraints of waste collection). The vehicle routing problem is a key step in transport network design. The network is defined as a set of elements: inhabitants, plants linked to each other by the flow of the waste. Depending on the number of intermediaries in the way of movement of the waste, the network structure can be single-level (e.g. levels: a municipal plant – single loading points e.g. a hospital – a municipal plant) or multi-level (levels: a municipal plant – inhabitants – a municipal plant), so-called hierarchical. In the single-level network a vehicle collects the waste from one place and goes to the municipal plant, in the multi-level network a vehicle collects the waste from many places, e.g. inhabitants and goes to the municipal plant.

The municipal waste collection may be considered from two basic viewpoints, i.e. the single or multi-criteria decision making problem. The municipal waste collection in the single-decision making problem was solved by an ant algorithm (Bautista et al. 2014, Izdebski 2014), a genetic algorithm (Izdebski 2014, Jacyna-Gołda et al. 2017b). In this case the main criterion is a transportation cost.

In this paper the organization of municipal waste collection was presented in the context of the multi-criteria decision making problem (Jacyna 1999). In the literature the multi-criteria municipal waste collection problem was solved by Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) I and PROMETHEE II (Coban et al. 2018, Soltani et al. 2015, Mardania et al. 2015, Rousis et al. 2008), ELECTRE III (Perkoulidis et al. 2010, Banar et al. 2010, Soltani et al. 2015), a modified fuzzy TOPSIS methodology (Ekmekcioglu et al. 2010, Soltani et al. 2015), a TOPISIS method (Mir et al. 2016, Soltani et al. 2015). In this case the main criteria are transportation cost, operation cost, environmental risks, emissions to environment, infrastructure requirements. The decision model in these publication refers to the multi-criteria assessment. Among many variants the one variant is selected according to the adapted weight for each criterion.

In this paper the decision model of the organization of municipal waste collection bases on multi-criteria optimization. In this case the optimization algorithm was an ant algorithm. This algorithm was specially modified in order to solve multi-criteria decision making problem. The authors of this publication did not find the application of this approach and this algorithm in the literature to designate the organization of municipal waste collection.

The organization of municipal waste collection is a complex decision making problem and refers to the salesman problem (Izdebski 2014). The salesman problem belongs to NP-hard problems. In order to solve the salesman problem the heuristic algorithm must be used (Abdoun 2011, Nagata et al. 2013, Szczepański et al. 2014, Jacyna-Gołda 2015, Jacyna-Gołda et al. 2016). Fast time of generating the result by the ant algorithm is its main feature, what is desired in the process of designating the organization of municipal waste collection. This process depends on many factors, e.g. capacity of vehicles, the size of the tasks. The algorithm for designating this type of problem must be adapted to frequent changes of these factors and generate the solutions in a quick way. In municipal companies the time of generating the solution by the algorithm plays the most important role. The ant algorithm generates the results in a quick way and therefore this algorithm was selected in this problem. The presented decision model refers to the waste collection from individual inhabitants. The vehicle visits loading points (inhabitants) and collects the waste. The main aim is to designate this route. This fact additionally highlights the use of heuristic algorithm in this problem.

2. The decision model

The transportation network of municipal plants consists of the following elements: the municipal plant and the junctions. The places where the waste are generated are located between these junctions, on both sides of the road. The main task of the vehicle is to collect the waste from points located next to the road on a given route. When the vehicle is loaded and full, it goes to the municipal plant. On the Figure 1 the transportation network was presented, additionally the route of collection was presented (red arrows), waste (blue rectangles).

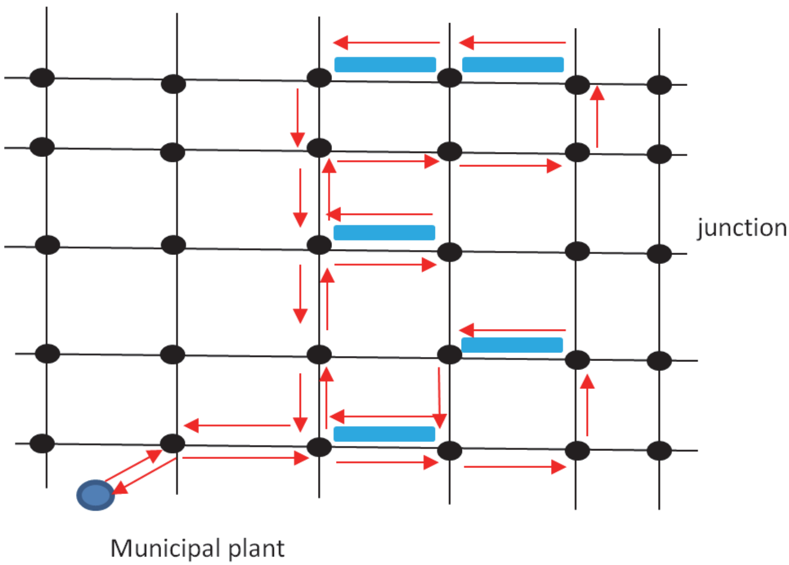

Fig. 1. The transportation network of municipal plant
Rys. 1. Sieć transportowa zakładu komunalnego

Source: own study

In order to describe the mathematical model the following variables were introduced:

- $\boldsymbol{V} = \{v : v = 1,2,...,v',...\mathrm{V}\}$ – the set of point elements of the transport network, i.e. municipal plants, junctions,
- $\boldsymbol{J} = \{v : \alpha(v) = 1$ for $v \in \boldsymbol{V}\}$ – the set of junctions,
- $\boldsymbol{MP} = \{v : \alpha(v) = 2$ for $v \in \boldsymbol{V}\}$ – the set of potential municipal plants,
- $\boldsymbol{VEH} = \{1,...,veh,...,\mathrm{VEH}\}$ – the set of numbers of vehicles,
- $\mathbf{Tr} = \{1,...,tr,...,\mathrm{TR}\}$ – the set of numbers of routes,
- $\mathbf{D}1 = [d1(v,v') : d1(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{MP}, v' \in \boldsymbol{J}]$ – distance matrices in relations: municipal plants - junctions,
- $\mathbf{D}2 = [d2(v,v') : d2(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{J}]$ – distance matrices in relations: junctions - junctions,
- $\mathbf{D}3 = [d3(v,v') : d3(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{MP}]$ – distance matrices in relations: junctions - municipal plants,
- $\mathbf{T} = [t(v) : t(v) \in \boldsymbol{R}^+, v \in \boldsymbol{J}]$ – transition time via the junction,
- $\mathbf{T}1 = [t1(v,v') : t1(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{MP}, v' \in \boldsymbol{J}]$ – time matrices in relations: municipal plants – junctions,
- $\mathbf{T}2 = [t2(v,v') : t2(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{J}]$ – time matrices in relations: junctions - junctions,
- $\mathbf{T}3 = [t3(v,v') : t3(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{MP}]$ – time matrices in relations: junctions - municipal plants,
- $\mathbf{T}4 = [t4(v) : t4(v) \in \boldsymbol{R}^+, v \in \boldsymbol{MP}]$ – unloading time in municipal plants,
- $\mathbf{T}5 = [t5(v,v') : t5(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{J}]$ – loading time in relations: junctions - junctions,
- $\mathbf{A} = [a(v,v') : a(v,v') \in \{0,1\}, v \in \boldsymbol{J}, v' \in \boldsymbol{J}]$ – 1 – there are the waste on a given connection, 0 – there are not the waste,
- $\mathbf{Q} = [q(v,v') : q(v,v') \in \boldsymbol{R}^+, v \in \boldsymbol{J}, v' \in \boldsymbol{J}]$ – the volume of waste between junctions,
- $\Delta\mathrm{T}$ – working time of the vehicle,
- $\mathbf{C} = [c(veh) : c(veh) \in \boldsymbol{R}^+, veh \in \boldsymbol{VEH}]$ – the cost of fuel consumption,
- $\mathbf{QV} = [qv(veh) : qv(veh) \in \boldsymbol{R}^+, veh \in \boldsymbol{VEH}]$ – capacity of the vehicle.

The decision variable take the following form:

- $\mathbf{X}1 = [x1(v,v',veh,tr):x1(v,v',veh,tr) \in \{0,1\}, v \in \boldsymbol{MP}, v' \in \boldsymbol{J}, veh \in \mathbf{VEH}, tr \in \mathbf{TR}]$ – 1 – there is connection between the municipal plant and the junction realized by the vehicle in the route, 0 – there is no connection,
- $\mathbf{X}2 = [x2(v,v',veh,tr):x2(v,v',veh,tr) \in \{0,1\}, v \in \boldsymbol{J}, v' \in \boldsymbol{J}, veh \in \mathbf{VEH}, tr \in \mathbf{TR}]$ – 1 – there is connection between junctions realized by the vehicle in the route, 0 – there is no connection,
- $\mathbf{X}3 = [x3(v,v',veh,tr) : x3(v,v',veh,tr) \in \{0,1\}, v \in \boldsymbol{J}, v' \in \boldsymbol{MP}, veh \in \mathbf{VEH}, tr \in \mathbf{TR}]$ – 1 – there is connection between the junction and the municipal plant realized by the vehicle in the route, 0 – there is no connection.

The constraints of the mathematical model take the following form:

- working time of the vehicle must be less than allowable time of work:

$$\forall veh \in \boldsymbol{VEH}$$
$$\sum_{v \in \boldsymbol{MP}} \sum_{v' \in \boldsymbol{J}} \sum_{tr \in \boldsymbol{TR}} x1(v,v',veh,tr) \cdot \left[t1(v,v') + t(v')\right] + \sum_{v \in \boldsymbol{J}} \sum_{v' \in \boldsymbol{J}} \sum_{tr \in \boldsymbol{TR}} x2(v,v',veh,tr) \cdot \left[t2(v,v') + t(v') + a(v,v') \cdot t5(v,v')\right] + \sum_{v \in \boldsymbol{J}} \sum_{v' \in \boldsymbol{MP}} \sum_{tr \in \boldsymbol{TR}} x3(v,v',veh,tr) \cdot \left[t3(v,v') + t4(v')\right] \le \Delta \mathrm{T} \quad (1)$$

- capacity of vehicle must be met:

$$\forall veh \in \boldsymbol{VEH}, tr \in \boldsymbol{TR}$$
$$\sum_{v \in \boldsymbol{J}} \sum_{v' \in \boldsymbol{J}} x2(v,v',veh,tr) \cdot q(v,v') \le qv(veh) \quad (2)$$

The criteria functions minimalize the total time of realization of the routes and the cost of fuel consumption:

- the total time of realization of the routes:

$$\mathbf{F}1(\mathrm{X}1,\mathrm{X}2,\mathrm{X}3)=\sum_{v\in \boldsymbol{MP}}\sum_{v'\in \boldsymbol{J}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x1(v,v',veh,tr)\cdot\left[t1(v,v')+t(v')\right]+$$
$$\sum_{v\in \boldsymbol{J}}\sum_{v'\in \boldsymbol{J}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x2(v,v',veh,tr)\cdot\left[t2(v,v')+t(v')+a(v,v')\cdot t5(v,v')\right]+$$
$$\sum_{v\in \boldsymbol{J}}\sum_{v'\in \boldsymbol{MP}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x3(v,v',veh,tr)\cdot\left[t3(v,v')+t4(v')\right]\longrightarrow \min \qquad (3)$$

– the cost of fuel consumption:

$$\mathbf{F}2(\mathrm{X}1,\mathrm{X}2,\mathrm{X}3)=\sum_{v\in \boldsymbol{MP}}\sum_{v'\in \boldsymbol{J}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x1(v,v',veh,tr)\cdot d1(v,v')\cdot c(veh)+$$
$$\sum_{v\in \boldsymbol{J}}\sum_{v'\in \boldsymbol{J}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x2(v,v',veh,tr)\cdot d2(v,v')\cdot c(veh)+$$
$$\sum_{v\in \boldsymbol{J}}\sum_{v'\in \boldsymbol{MP}}\sum_{tr\in \boldsymbol{TR}}\sum_{veh\in \boldsymbol{VEH}} x3(v,v',veh,tr)\cdot d3(v,v')\cdot c(veh)\longrightarrow \min \qquad (4)$$

3. The modified ant algorithm

In order to solve the multi-criteria routing vehicle problem of municipal plants, the method based on the ant algorithm was developed. Theory of this algorithms introduces the concept of artificial ants (Dorigo et al. 2004). The main task of ants is to determine the loading route consisting of all loading points. The value of the ant must be interpreted as the length of routes which are realized by the vehicles or one vehicle in the collection process. Each ant builds its own route till the moment when all loading points are visited. The ant goes to the municipal plant in the case when the realization time of the collection (1) is not met or all loading points were visited or capacity of vehicle is not met (2). Each ant has own capacity which equals the capacity of a given vehicle. At first the data input needs to be determined: the set of ants was defined as ***MR***, the number of iterations of the algorithm ***I***. The starting and ending point of each route is in the municipal plant. In the ant algorithm the following steps were distinguished:

- Step 1. The choice of the municipal plant in a random way in the case when there are many plants. The first ant and the first iteration of the algorithm is set in this step.
- Step 2. The ant goes to the junctions with a certain probability:

$$PR^{mr}{}_{zz'}(t) = \left\{ \frac{[\tau_{zz'}(t)]^{\alpha} \cdot [\eta_{zz'}(t)]^{\beta}}{\sum_{z' \in Z} [\tau_{zz'}(t)]^{\alpha} \cdot [\eta_{zz'}(t)]^{\beta}} \right. \qquad (5)$$

where:

$\tau_{zz'}(t)$ – the intensity of pheromone trail between the z – the a z' – the point in t – the iteration,

α, β – parameters determining the effect of pheromones and the heuristic information on the behavior of ants,

Z – the set of junctions which are connected with analyzed junction (z), this set is different for each junction (z),

$\eta_{zz'}(t)$ – the heuristic information, in this case in order to take into account the multi – criteria aspect of the problem, the heuristic information takes the following form:

$$n_{zz'}(t) = \frac{1}{\frac{t(z') + tmr(z,z')}{Const1} + \frac{d(z,z') \cdot c(mr)}{Const2}} \qquad (6)$$

where:

$t(z')$ – in the mathematical model the variable $t(v)$,

$tmr(z,z')$ – in the mathematical model the variable $t1(v,v')$, $t2(v,v')$, $t3(v,v')$, $t5(v,v')$

$d(z,z')$ – in the mathematical model the variable $d1(v,v')$, $d2(v,v')$, $d3(v,v')$

$c(mr)$ – in the mathematical model the variable $c(veh)$

$Const\,1$ – the value greater than the numerator of the first quotient, the value is established at the beginning of working the algorithm,

$Const\,2$ – the value greater than the numerator of the second quotient, the value is established at the beginning of working the algorithm

The probability of selection of a given connection between points increases when the heuristic information increases. This situation takes place when the denominator of the equation (6) approaches the minimum value. The smaller value of the criteria function, the larger the value of the probability of selection of a given connection (5).

Random choice of the route between the point z and points z' begins from calculating the probability of the transition to the junctions. The first point in the route (z) is determined as the municipal plant, the another points are defined as junctions.

The next step is to calculate the distribution for each transition path (z,z') and draw the number r from the range [0,1]. The route *tro* about the value of the distribution q_{tr} which fulfills the condition $q_{tro\text{-}1} < r \leq q_{tro}$ is selected, where *tro* is the number of the route between z – the point and z' – the points.

- Step 3. The constraints of the model must be checked: working time of the vehicle must be less than allowable time of work and capacity of vehicle must be met. If the ant is full, it goes to the municipal plant. There are junctions in the network that are connected with the municipal plant. The ant seeks the junctions that are connected with the municipal plant. Additionally the ant goes to the municipal plant, when working time is finished or all the loading points are realized. This step is repeated until all the loading points will be collected.
- Step 4. Steps 1-3 are repeated for the next ant from the population.
- Step 5. In this step the pheromone update is actualized. Three types of the pheromone update can be distinguished: ant – density, ant – quantity, ant – cycle. In order to update the pheromone the ant – cycle was used as the most efficient version of the ant algorithm (Dorigo et al. 2004). At the beginning, it is assumed that the trail on the links between the points is equally strong. In subsequent iterations, the pheromone trail is calculated according to the formula:

$$\tau_{\mathbf{zz'}}(t+1) = (1-\rho)\tau_{\mathbf{zz'}}(t) + \sum_{mr=1}^{\mathbf{MR}} \Delta\tau_{\mathbf{zz'}}{}^{mr}(t) \tag{7}$$

where:

mr – another ant $mr \in \boldsymbol{MR}$ $mr \in \boldsymbol{MR}$, ρ – a factor pheromone ($0 < \rho \leq 1$), $\tau_{zz'}(t+1)$ – the strengthening of the pheromone, for the first iteration this strengthening takes the value τ_0 for each connections.

$$\Delta \tau_{zz'}^{mr}(t) = \begin{cases} \dfrac{1}{L^{mr}(t)} & \text{when the route } (z,z') \text{ was used by } mr \text{ – this ant otherwise} \\ 0 & \end{cases} \tag{8}$$

where:
$L^{mr}(t)$ – the heuristic information of the route in t iteration realized by mr – this ant, if the segment of routes (z,z') was realized by mr – this ant then $\Delta\ \tau_{yz}^{mr}(t)$ equals $1/\ L^{mr}(t)$, otherwise 0.

- Step 6. The steps 1-5 are repeated determined the number of iterations.
- Step 7. The stop of algorithm. Of all routes which were generated by ants, the route with maximum value of the heuristic information is selected.

4. Results

The algorithm was implemented by the use of the real input data in the C++ programming language. Distance between junctions [km], the driving time between junctions [h], the assignment of the waste to the links[1 or 0] take the following values [km, h, 0 or 1]: link (1,2): [3;0,06;0], link (2,3):[5;01;1], link (2,5):[7;0,14;1], link (2,6): [5;0,2,1], link (3,4): [10;0,2;0], link (4,5): [4;008,0]; link (4,8):[10;0,2;1], link (4,9): [11;0,22;0], link (5,6): [3;0,12;1], link (5,7): [4;0,08;0], link (5,8): [5;0,1;1], link (6,7): [5;0,2;1], link (7,8): [3;012;0], link (8,10): [10;0,2;1], link (9,10): [7;0,14;0], link (9,11): [4;0,2;0], link (10,12): [4;0,13;1], link (11,12): [3;0,12;0].

Additional input data: the capacity of vehicle: 2500 m^3, the cost of fuel consumption – 4,5 zł (32l/100 km), working time of the vehicle – 4h, the volume of waste between junctions for each links – 250 m^3, unloading time in municipal plants – 0,05 h, transition time via the junctions [h] (junction: 1 – 0,08, 2 – 0,07, 3 – 0,05, 4 – 0,09, 5 – 0,03, 6 – 0,02, 7 – 0,01, 8 – 0,04, 9 – 0,05, 10 – 0,02, 11 – 0,03, 12 – 0,02).

The first step of implementation of the ant algorithm was to find the set of the best parameters which characterizes this algorithm (i.e. $\alpha = 1$, $\beta = 0{,}5$, $\rho = 0{,}6$). The number of iterations was set to 200. The size of population (ants) was set to 600.

In order to verify the correctness of the ant algorithm (AA), its results were compared with random values (RA). The ant algorithm in each case generated a better solution than the random algorithm. The results are shown in Tab. 1. The heuristic information (for a total route of the ant) in the case of the ant algorithm is greater than the random algorithm. On the basis on the route of the ant one can designate the number of vehicles which realizes the given route. In the case , when the ant goes to the municipal plant because of working time, another vehicle starts the realization of routes.

Table 1. Comparison of algorithms
Tabela 1. Porównanie algorytmów

No.	The number of vehicle [AA]	η [AA]	The number of vehicle [RA]	η [RA]
1	2	7,62	6	2,4
2	3	8,01	5	1,4
3	2	7,99	7	3,0
4	3	8,0	8	4
5	4	9,01	5	1,9
6	3	7,89	7	3,4
7	2	7,98	6	2,7
8	3	8,90	7	3,4
9	4	9,0	5	1,8
10	2	7,98	8	4
11	3	8,98	6	2,8
12	4	9,0	7	3,2

Source: own development

5. Conclusion

The aim of the paper is to present the decision model of the organization of municipal waste collection. This model bases on multi-criteria optimization. The optimization algorithm in this case is the ant algorithm.

It should be emphasized that ant belongs to heuristic algorithms. The solution generated by these algorithms for complex decision problems is a sub-optimal solution. However, considering the complexity of the organization of municipal waste collection, the solution is accepted from a practical point of view. The further step is to use Anti-colonial systems in the organization of municipal waste collection. The early convergence to the sub-optimal solution is blocked by the use of the update pheromone ant – cycle in the ant algorithm.

The optimal results generated by the algorithm depend on many factors, e.g.: parameters of the algorithm, the number of iterations or ants in population.

It should be underlined that results of the ant algorithm depend on the type of the data input which are taken into account in the mathematical model. This algorithm was implemented by the use of the fixed data input, e.g. the average driving time. The presented model does not take into account the random values of the input data. Further research in the context of the presented problem will be conducted taking into account random character of transport process.

The developed algorithm can be used in municipal companies to develop, e.g. the driver's working schedules. The main advantage of this algorithm is that the results are generated in a quick way, what is very important for this companies.

The processes occurring in the municipal companies are the dynamic processes. For this reason, the algorithm must be started a few times depending on the volume of waste, vehicle capacities. In this case, the calculation speed plays the huge role what underlines utility of this algorithm in the municipal companies.

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Organizacja zbiórki odpadów komunalnych: Model decyzyjny

Streszczenie

W pracy przedstawiono problem organizacji zbiórki odpadów komunalnych od indywidualnych mieszkańców. Organizacja zbiórki odpadów jest zdefiniowana jako wyznaczenie tras jazdy pojazdów realizujących daną zbiórkę. W celu rozwiązania tego problemu zaproponowano model decyzyjny wyznaczania tras jazdy pojazdów.

Organizacja zbiórki odpadów komunalnych może być rozpatrywany w ujęciu jedno lub wielokryterialnym. W niniejszym opracowaniu przedstawiono zbiórkę odpadów komunalnych w kontekście wielokryterialnego problemu decyzyjnego. W niniejszej pracy model decyzyjny organizacji zbiórki odpadów komunalnych opiera się na optymalizacji wielokryterialnej. W tym przypadku algorytm optymalizacji był algorytmem mrówkowym. Algorytm ten został specjalnie zmodyfikowany w celu rozwiązania problemu podejmowania decyzji w oparciu o wiele kryteriów. Autorzy tej publikacji nie znaleźli zastosowania tego podejścia i tego algorytmu w literaturze do wyznaczenia organizacji zbiórki odpadów komunalnych.

Organizacja zbiórki odpadów komunalnych jest złożonym problemem decyzyjnym i odnosi się do problemu komiwojażera. Problem ten należy do problemów NP-trudnych. Aby rozwiązać problem komiwojażera, należy zastosować algorytm heurystycznych. Szybki czas generowania wyniku przez algorytm mrówkowy jest jego główną cechą, co jest pożądane w procesie wyznaczania organizacji zbiórki odpadów komunalnych. Proces ten zależy od wielu czynników, np. pojemność pojazdów, wielkość zadań. Algorytm wyznaczania tego typu problemu musi być dostosowany do częstych zmian tych czynników i szybkiego generowania rozwiązań. W firmach komunalnych najważniejszą rolę odgrywa czas generowania rozwiązania. Algorytm mrówkowy generuje

wyniki w szybki sposób i dlatego ten algorytm został wybrany w tym problemie. Przedstawiony model decyzyjny dotyczy zbiórki odpadów od poszczególnych mieszkańców. Samochód odwiedza punkty załadunku (mieszkańców) i zbiera odpady. Głównym celem jest wyznaczenie tej trasy. Fakt ten dodatkowo podkreśla zastosowanie algorytmu heurystycznego w tym problemie.

W pracy zdefiniowano model matematyczny problemu zbiórki odpadów komunalnych, podano dane wejściowe wprowadzane do modelu np. zdefiniowano odległości pomiędzy obiektami sieci transportowej, podano czasy jazdy pomiędzy tymi obiektami, czasy załadunku, wyładunku odpadów, czas przejazdu przez skrzyżowania. Zmienna decyzyjna określa połączenie pomiędzy poszczególnymi obiektami sieci realizowane przez pojazd w danej trasie. Zmienne decyzyjne są typu binarnego. Wprowadzono ograniczenia na czas pracy oraz na pojemność pojazdów realizujących zbiórkę odpadów. Funkcje kryteriów dotyczą minimalizacji czasu realizacji wszystkich tras oraz kosztów zużycia paliwa.

W pracy szczegółowo scharakteryzowano algorytm mrówkowy rozwiązujący wielokryterialny problem decyzyjny zbiórki odpadów komunalnych.

W celu sprawdzenia poprawności algorytmu mrówkowego jego wyniki porównano z wartościami losowymi. Algorytm mrówkowy w każdym przypadku generował lepsze rozwiązanie niż losowy algorytm.

Należy podkreślić, że algorytm mrówkowy należy do algorytmów heurystycznych. Rozwiązanie wygenerowane przez te algorytmy dla złożonych problemów decyzyjnych jest rozwiązaniem nieoptymalnym. Biorąc jednak pod uwagę złożoność organizacji zbiórki odpadów komunalnych, rozwiązanie jest akceptowane z praktycznego punktu widzenia.

Abstract

The paper presents the problem of organizing municipal waste collection from individual residents. A waste collection organization is defined as the designation of vehicle routes for a given collection. In order to solve this problem, a decision model for determining driving routes has been proposed. The organization of municipal waste collection may be considered in a single or multi-criteria approach. This study presents a collection of municipal waste in the context of a multi-criteria decision problem. In this work, the decision model of the municipal waste collection organization is based on multi-criteria optimization. In this case, the optimization algorithm was an ant algorithm. This algorithm has been specially modified to solve the problem of making decisions based on many criteria. The authors of this publication have not found application of this approach and this algorithm in the literature to designate the municipal waste collection organization.

The municipal waste collection organization is a complex decision problem and refers to the traveling salesman problem. This problem belongs to NP-hard problems. To solve the problem of the traveling salesman, a heuristic algorithm should be applied. Fast time of generating the result by the ant algorithm is its main feature, which is desirable in the process of designating the municipal waste collection organization. This process depends on many factors, e.g. vehicle capacity, size of tasks. The algorithm for determining this type of problem must be adapted to frequent changes of these factors and quick generation of solutions. The time of solution generation plays the most important role in municipal companies. The ant algorithm generates results in a quick way and therefore this algorithm was chosen in this problem. The presented decision model concerns the collection of waste from individual residents. The car visits the loading points (inhabitants) and collects waste. The main goal is to designate this route. This fact additionally emphasizes the use of the heuristic algorithm in this problem.

The work defines the mathematical model of the problem of municipal waste collection, the input data entered into the model are given, e.g. distances between objects of the transport network have been defined, driving times between these objects are given, loading times, unloading of waste, crossing time. The decision variable defines the connection between individual network objects implemented by the vehicle in a given route. Decision variables are binary type. Limitations have been introduced for working time and for the capacity of vehicles that collect waste. The criteria functions concern the minimization of the time of completion of all routes and the costs of fuel consumption.

In order to check the correctness of the ant algorithm, its results were compared with random values. The ant algorithm in each case generated a better solution than a random algorithm.

It should be emphasized that the form algorithm belongs to heuristic algorithms. The solution generated by these algorithms for complex decision problems is a suboptimal solution. However, taking into account the complexity of the municipal waste collection organization, the solution is accepted from a practical point of view.

Słowa kluczowe:
organizacja zbiórki odpadów komunalnych, optymalizacja wielokryterialna, algorytm mrówkowy

Keywords:
organization of municipal waste collection, multi-criteria optimization, ant algorithm