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AN APPROACH TO THE WASTE COLLECTION ROUTING PROBLEM IN THE MUNICIPAL SERVICES COMPANIES

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Summary: This article solves the waste collection routing problem from individual inhabitants. This type of waste collection routing problems is determined as kerbside collection. This problem was modified to the problem of the assignment of vehicles to tasks (in the litereture it is presented as the vehicle scheduling problem). In order to designate the assignment problem a method was developed. The presented method designates the set of tasks which are assigned to each vehicle, so it designates the routes of vehicles. The method consists of two stages. In the first stage the tasks were designated, whereas in the second stage the assignment of vehicles to tasks was made. Each stage consists of three phases: the preparatory phase, the optimization phase, the generation task or the generation assignment phase. Each phase was characterized.
In this paper the block scheme of constructing the hybrid algorithm solving optimization problem of the method was presented. The application TransMar solving the waste collection routing problem was characterized.
Keywords: the municipal services companies, the collection routing problem, the assignment

1. INTRODUCTION

Collection routing problems are the complex decisional problems [3]. In essence the collection of waste is a vehicle routing problem (VRP). The most famous problems of a vehicle routing problems are the Travelling Salesman Problems (TSP) and the Chinese Postman Problem (CPP). TSP belongs to the set of NP-hard problems. In collecting routing problems the CPP turns in a capacitated-CPP, which is NP-hard too. As NP-hard problems are difficult to solve, many publications rely on heuristics e.g. genetic, ant algorithms, a simulated annealing to solve this type of the problem [2],[6],[12],[16],[17],[20]. This article presents the collection routing problem from individual inhabitants. This type of waste collection routing problems is determined as kerbside collection. Householders put out their waste bins, the collection vehicles pass every street to pick up the garbage [18]. In kerbside collection every house needs to be visited. The model that most closely resembles kerbside collection is the Capacitated Arc Routing Problem (CARP) [13],[15],[19]. In this problem, a certain demand (in our case the size of waste) is specified for each arc. CARP belongs to the class of NP-hard problems too.

Transport in a large degree affects the atmosphere [1],[8],[10],[11],[14]. Solving collection routing problems is one of the ways which can decrease air pollution in cities.

In the article the collection routing problem was modified to the assignment problem of vehicles to tasks. The solution of the assignment problem proposed in the article is a comprehensive approach designating the waste collection routes for each vehicle and it will allow to designate not only the minimal loading route (on this route the vehicles pick up the garbage) but also the total waste collection route taking into account the minimal access roads to the beginning loading points of each loading route. These access roads in some degree decide about the lenght of all wast collection route (e.g the beginning loading points of each loading route can be serviced by the vehicles which leave the base or after unloading waste in the waste management facility, designating access roads is the optimization problem).

The assignment problem in the municipal service company belongs to the general assignment problem defined in the literature as vehicle scheduling problems [4]. The task in this problem is interpreted as the driving route to which the vehicle needs to be assigned in order to realize this route. The municipal service company is a specific transport company, where the assignment problem is the difficult issue to realize. Difficulty lies in the fact that the tasks are not defined as it is in the transport companies. The task in the municipal service company is interpreted as waste collection on the specific loading route so the indication of these routes is tantamount to designating the tasks. The problem of designating the loading route is complex optimization problem referring to CARP.

The measure of the correctly generated assignment is the minimum cost of the realization of all contracted tasks. Determining the optimal allocation relies on indicating the minimum route for the vehicles which realize the contracted tasks. In order to solve this problem the method designating the assignment of vehicles to tasks in this type of companies was proposed. The developed method allows to assign vehicles to tasks in the municipal services companies taking into account the limited availability of vehicles and drivers performing waste collection and the limits of the driving time of the driver, the limits of the working time of the driver and the time limits of the task realization. The method consists of two stages. In the first stage the tasks were designated, whereas in the second stage the assignment of vehicles to tasks was made. In the submitted method the assignment of vehicles to tasks is determined in such a way to minimize the length of access roads to all contracted tasks and total costs of the performed service of waste collection.

The reference of the assignment vehicle problem to tasks in the municipal services companies in the aspect of vehicle routing problem requires the allocation of the transportation means to the handling of individual entities generating the waste (the garbage), taking into account the availability of the transportation means and the size of reported tasks in the range of waste collection.

2. THE ASSIGNMENT PROBLEM IN THE MUNICIPAL SERVICES COMPANIES

Generally, the assignment problem in municipal services companies relies on assigning collection vehicles to the tasks in such a way that the costs of the realization of all tasks were as small as possible. It means that the route of the realization of tasks must be the shortest.

It is firstly caused by the selection of the task which has to be realized as a first one when the vehicle starts work and secondly how to choose a following task, at the moment when vehicle ends the realization of the current task, unloads waste in the landfill and then the problem appears, we can ask the question which task has to be performed next.

It is assumed that all tasks must be realized in a given working day, the vehicles must be assigned to the tasks in such a way that the route of the realization of these tasks was as small as possible.

The assignment problem requires designating the tasks to the realization by vehicles. In this case we must indicate: the starting point of waste collection which is simultaneously the beginning of the task, the ending point of waste collection in which the vehicle ends waste collection and goes to the unloading point, the intermediate points of the waste collection route.

In the situation where waste are collected in the container, the transport task can be defined as the collection of the container and transport to the unloading point (the landfill). In case of containers of small capacities (bins) the collection vehicle visits individual places (households) and collects waste. After the vehicle is loaded, it goes to the unloading point.

Therefore, in order to designate the tasks for this waste collection when the vehicle does not collect the container from one point only, as it takes place in case of small container (bins), the minimum route of driving vehicles (so-called the loading route) between individual loading points (houses of inhabitants) must be determined.

Generally the task in the transport companies can be defined as transport of the cargo from the loading point to the unloading point. In the municipal services companies the loading point is problematic because it may be but has not to be in one place. The unloading point is located in one place (the landfill). The indication of the first loading point in the loading route of waste collection which can, but has not to be in one place, the indication of the intermediate points, and the point where vehicle leaves the route and goes to the unloading point is the difficult problem in designating the tasks. The incorrect indication of these points influences the length of the loading route that is realized by vehicles. The task is designated when all presented points are known. Thus the solution of the assignment problem will allow to designate not only the minimum loading route of the vehicle, but also the total route of vehicles taking into account the minimization of the access roads to the first loading points of each task, so costs of performed tasks.

The model of the assignment problem is described by following variables [9]:

– the set of nodes: bases, unloading points (the landfill), the beginning points of the loading route, the intermediate points of the loading route, the ending points of the loading route,

- the set of the type of cargo e.g. glass, paper,
- the matrix of the size of waste,
- the vector of the waiting time for unloading in unloading point,
- the matrix of the distance between the points of the transportation network,
- the set of drivers performing tasks in a working day,
- the vector of the hourly rate for each driver,
- the set of numbers of transportation means,
- the vector of the capacity of transportation means,
- the matrix of costs of the fuel consumption,
- the matrix of the driving time of each driver in the task,
- the matrix of the working time of each driver in the task,
- the vector of the working time of drivers in a working day,
- the matrix of the driving time between the points of the transportation network,
- the vector of the expected unloading time,
- the matrix of the unloading time.

The problem is to find such connections (binary decision variables) beetwen: the beginning point of the task (of the loading route) - the ending point of the loading route, the beginning point of the task - the intermediate points, the intermediate point - the intermediate point, the intermediate point - the ending point of the loading route, the unloading point - the beginning point of the task, the base - the beginning point of the task, the ending point of the loading route - the unloading point, the unloading point – the base in such a way to the cost of the realization of the waste collection was minimal.

The searched solution must take into account the following constraints:

- The limits of capacity of the vehicle. The size of collected waste in the loading route of the task cannot exceed capacity of the vehicle. The model takes into account three types of the loading route i.e. the route consisting of the beginning point and the ending point, the route consisting of the beginning point, the intermediate point and the ending point, the route consisting of the beginning point, the intermediate points and the ending point.
- The limits of the driving time of the driver: The sum of travel times to the task both from the base and directly from the unloading point, the sum of travel times between the ending point of the loading route and the unloading point, the sum of travel times between the unloading point and the base, travel times in the tasks (travel times between the points of the loading route):
  - The limits of the working time of the driver. The driving time of the driver is increased by the working time in tasks (i.e. the loading time of bins), the expected time for unloading, the time of unloading and the rest time of the driver in the route.
  - The limit time of the realization of tasks.

The general function of the criterion takes into account the costs related to the fuel consumption and the hourly rate of a driver. Lets assume that $\boldsymbol{X},\boldsymbol{Y}$ are the decision variables, so the function of the criterion minimizing the cost of loading routes in all tasks and all costs on the access roads to tasks was defined:

$$\mathrm{F}(\boldsymbol{X},\boldsymbol{Y}) = \mathrm{KZZ}(\boldsymbol{X}) + \mathrm{KZP}(\boldsymbol{X}) + \mathrm{KPZ}(\boldsymbol{Y}) + \mathrm{KPP}(\boldsymbol{Y}) \to \mathbf{min} \tag{1}$$

where:

$\mathrm{KZZ}(\boldsymbol{X})$ - the costs related to the fuel consumption in the tasks,

$\mathrm{KZP}(\boldsymbol{X})$ - the costs related to the hourly rate of a driver,

$\mathrm{KPZ}(\boldsymbol{Y})$ - the costs related to the fuel consumption in the assignment route,

$\mathrm{KPP}(\boldsymbol{Y})$ - the costs related to the hourly rate of a driver in the assignment route.

3. THE METHOD OF DESIGNATING THE ASSIGNMENT

The method designates the set of tasks reported to the realization and the minimum number of vehicles performing these tasks. The method consists of two stages: the tasks in the first stages are designated, the assignment of vehicles to these tasks in the second stage. Each stage consists of three phases. The stage of designating the tasks consists of the preparatory phase in which the input data are determined e.g. the distance between the loading points. In this phase the so – called collective loading points are designated.

The concept of the collective loading points should be understood as the set of individual loading points (small containers/bins) which are assigned to the street, on which the vehicle has not the possibility to change the driving direction. At the moment of waste collection the decision of the selection of loading points to the loading route follows then, when the vehicle reaches the place in which it can change the driving direction (e.g. the junctions). The length of the generated route depends on the further decision of the driver.

The main aim of the optimisation phase in the first stage is to designete the minimum task route. This route conists of all collective loding points. In order to designate this route the hybrid algorithm was proposed. The task of the hybrid algorithm is to find the setting of the collective loading points which will generate the minimum route. In the optimisation phase the correctness and effectiveness of the hybrid algorithm were verified by comparing the results of the hybrid algorithm with the results of the search random algorithm, the ant and genetic algorithms. The search random algorithm generates a certain number of random solutions and chooses the best one. In this phase the best parameters of the algorithm were found and the costs of the realization of the tasks were calculated.

The consequence of designating the minimum task route is the realization of the generation task phase. The minimum task route is divided into small sections which are interpreted as tasks.

In the preparatory phase of the stage designating the assignment the input data which are needed to realize the assignment are introduced e.g. the working and driving time of the driver, the speed of the vehicles, the loading and unloading time of bins, a number of vehices of a given capacity.

The optimisation phase of the method of designating the assignment contains indicating the so-called minimum assignment route which consists of tasks, and the base. Designating the minimum assignment route is equivalent with designating the minimum access roads to tasks. The problem of designating the assignment route needs to be presented as the permutation of points of the assignment route (tasks, the base). The task of the hybrid algorithm is to set and check the configuration of the base and tasks in such a way that the designated assignments (base-the task, the task-the task) will generate the minimum assignment route. The problem of designating the assignment route is a complex optimisation problem. In this phase the best parameters of the algorithm were found. The results of the hybrid algorithm with the results of the search random algorithm, the ant and genetic algorithms were compared.

The consequence of designating the minimum assignment route is the realization of the generation assignment phase. Each vehicle in this phase is assigned to the tasks. More detail description of this method one can find in [7].

The method of determining assignment of means to tasks was implemented in the form of the computer application TransMar. The graphical presentation of the application TransMar was shown in Fig 1.

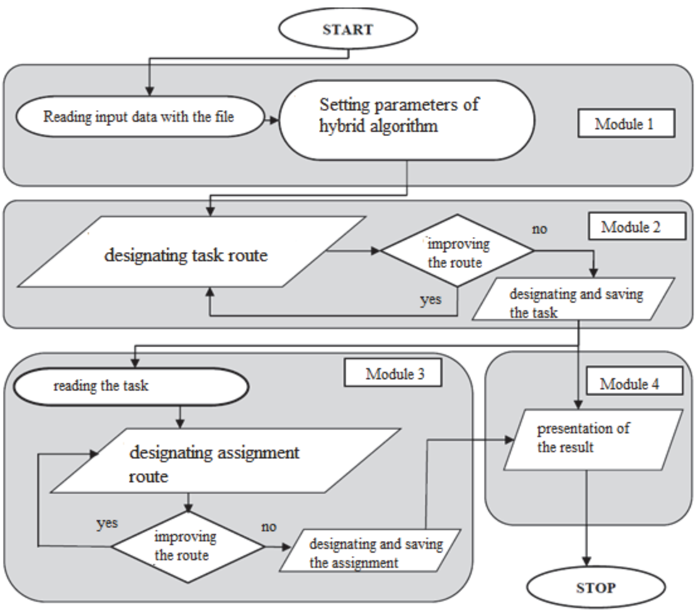

Fig 1. The scheme of the application TransMar
Source: compiled by authors.

The computer application TransMar is the tool which can be used both by the dispatcher at the moment of making a decision in the aspect of the allocation of the transportation means for the handling of the municipal waste in the municipal services companies as well as the managers of these companies. The program was developed in C#. Computational implementation of the method in the form of application TransMar enables elaboration of the assignment vehicles to tasks in the municipal services companies for the fixed the region of the transport network.

The application TransMar consists of four modules. The module 1 and 2 designates the tasks, whereas the modules 3 and 4 are responsible for designating the assignment of tasks to vehicles:

- Module 1, Module 2 – In these modules input data with the file are read e.g. the distance between the points of the transportation network. The optimal parameters of the hybrid algorithm in the case of designating the task route were set experimentally. After determining the parameters one can go to designate the task route and the tasks. It is possible to improve the task route. All results can present in the graphical way.
- Module 3, Module 4 – The main task of these modules is to designate the assignment. The optimal parameters of the hybrid algorithm in the case of designating the assignment route were also set experimentally.

The main optimisation tool of the application is the hybrid algorithm. This application designates the minimal collection routes and the minimal number of vehicles which perform these routes.

4. THE HYBRID ALGORITHM OF THE OPTIMISATION PHASE OF THE METHOD

In order to implementing the hybrid algorithm in program C# as a optimisation tool of the method the block scheme was developed. The hybrid algorithm for the task route was presented in Fig 2. The hybrid algorithm for the assignment route works on the same rules.

Operation of the algorithm is presented in following steps:

- Step 1 – The data are read: the set of starts of algorithm ($\boldsymbol{I}^{\boldsymbol{Pr}}$), the set of iterations ($\boldsymbol{I}^{\boldsymbol{T}}$), the set of loading points ($\boldsymbol{Z}$), the distance between the loading points ($\boldsymbol{D}$), the initial population for the hybrid algorithm ($\boldsymbol{POP}^{\boldsymbol{HYBZ}}$).
- Step 2 – Creating second copy of the initial population for the hybrid algorithm which is generated by the ant algorithm ($\boldsymbol{POP}^{\boldsymbol{HYBZ\_BIS}}$). This copy is processed by the algorithm. The set of ants is described as $\boldsymbol{MR}$.
- Step 3-6: Operation of selection, crossing and mutation, PMX – the operator of crossing [5].
- Step 7 – Put chromosome from the matrix of the minimum chromosomes in given iteration ($\boldsymbol{CH}^{\boldsymbol{HB}}$) to the matrix of the minimum chromosomes in the single start ($\boldsymbol{CH}^{\boldsymbol{H}}$) with the iteration $i^t = \overline{I^T} - 1$. The main aim of this step is to designate the minimum chromosome with the all starts of the algorithm.
- Step 8 – Designating the value of each chromosome in single start ($ch^{h\min\_p}$) from matrix $\boldsymbol{CH}^{\boldsymbol{H}}$ and putting all values of chromosomes in $\boldsymbol{X}^{\boldsymbol{HCH}}$ - the minimum value of chromosomes in given start.

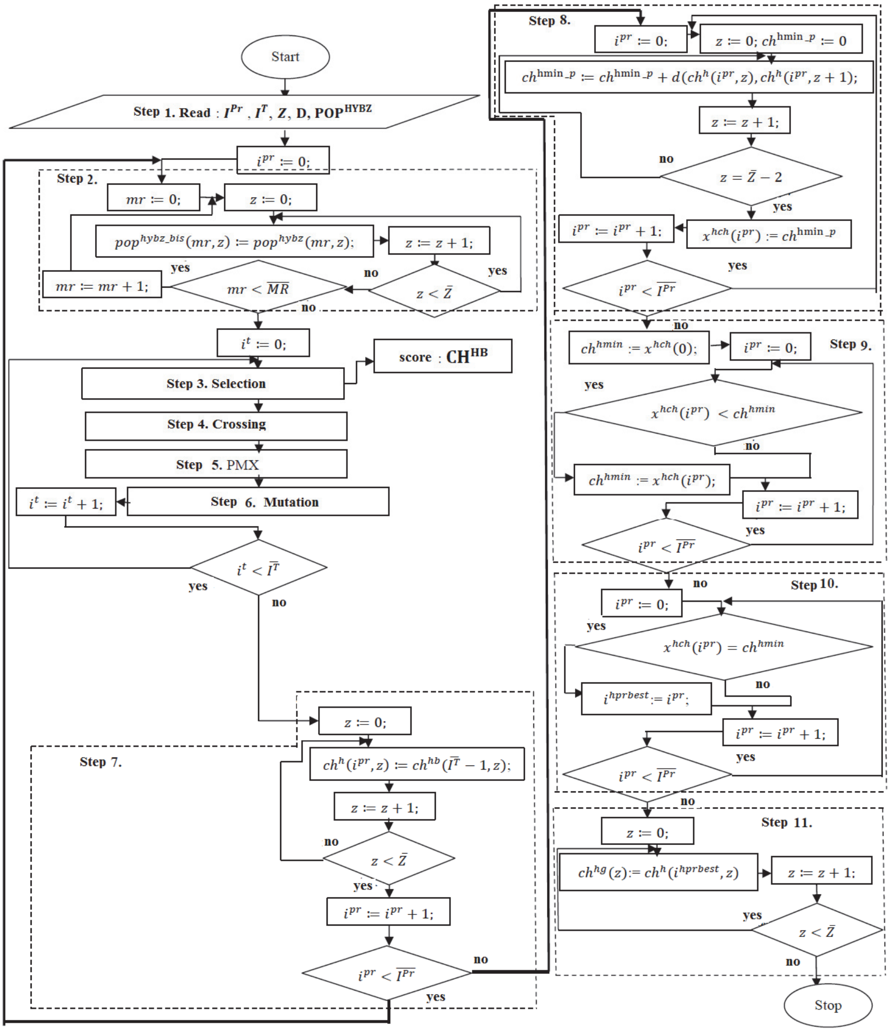

Fig 2. The scheme of hybrid algorithm for task route
Source: compiled by authors.

- Step 9 – Designating the minimum value of chromosome among all starts of hybrid algorithm ($ch^{h\min}$) among $\boldsymbol{X}^{\boldsymbol{HCH}}$.
- Step 10 – Designating the index of minimum chromosome among all starts of hybrid algorithm ($i^{hprbest}$). This index is indicated by the value $ch^{h\min}$ with $\boldsymbol{X}^{\boldsymbol{HCH}}$.

– Step 11 – From the matrix $\boldsymbol{CH}^{\boldsymbol{H}}$ with the index $i^{hprbest}$ one can designate the final chromosome $\boldsymbol{CH}^{\boldsymbol{HG}}$ which represents the minimum task route.

More detail description of this algorithm one can find in [7].

5. SUMMARY

The hybrid algorithms are the representatives of heuristics. Heuristics algorithms give a near-optimum solution, can find an optimal solution, but often confine themselves to the optimal solution in the local area of the search. Despite this inconvenience, heuristics algorithms are successfully used in optimisation problems. Taking into account the scale of the problem of designating the task and assignment route (92! possible task routes and 59! assignment routes) and the defects of the hybrid algorithms the method of the assignment generates a near-optimum solution. The further research can be conducted by the use of other algorithms in the optimisation phase and e.g. the Queueing Theory.

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PEWNE PODEJŚCIE DO WYZNACZANIA TRAS JAZDY POJAZDÓW W PRZEDSIĘBIORSTWACH KOMUNALNYCH

Streszczenie: W artykule rozwiązano problem zbiórki odpadów od indywidualnych mieszkańców. Problem został zmodyfikowany do zagadnienia przydziału pojazdów do zadań (w literaturze problem ten jest prezentowany jako problem harmonogramowania tras pojazdów). W celu wyznaczenia przydziału opracowano metodę. Przedstawiona metoda wyznacza zbiór zadań, które są przydzielane do pojazdów, więc metoda wyznacza trasy pojazdów. Metoda składa się z dwóch etapów. W pierwszym etapie są wyznaczane zadania, w drugi przydział pojazdów do zadań. Każdy etap składa się z trzech faz: fazy przygotowawczej, optymalizacyjnej oraz generowania zadań i przydziału. W pracy przedstawiono schemat blokowy konstruowania algorytmu hybrydowego rozwiązującego problem optymalizacyjny przedstawionej metody. Przedstawiono aplikację TransMar rozwiązującą problem trasowania pojazdów w przedsiębiorstwach komunalnych.
Słowa kluczowe: przedsiębiorstwo komunalne, problem zbiórki odpadów, przydział