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ROUTE PLANNING OF SEPARATE WASTE COLLECTION ON A SMALL SETTLEMENT

Summary. Waste collection problems are one of the most important logistic tasks to solve. The paper deals with the optimization of vehicle routes, which is one of the ways of reducing costs of waste collection. In this paper it was formulated the problem of optimization for a single vehicle.

This task can be reduced to the Euler's problem in the mathematical sense. The task was resolved using artificial immune systems. The methods have been adapted to solve real problems of selective waste collection on a small settlement. The solutions were discussed. It was described further plans for the development of methods for waste collection needs.

PLANOWANIE TRASY DLA SELEKTYWNEJ ZBIÓRKI ODPADÓW NA MAŁYM OSIEDLU

Streszczenie. Problem zbiórki odpadów jest jednym z najważniejszych logistycznych zadań. Celem artykułu jest optymalizacja tras pojazdów odbierających odpady, która jest jednym ze sposobów redukcji kosztów ich zbiórki. W artykule sformułowano kwestię optymalizacji trasy pojedynczego samochodu.

Przedstawiony problem może być zredukowany w sensie matematycznym do zadania Eulera. Problem został rozwiązany metodą sztucznych systemów. Metody zostały zaadaptowane do potrzeb rozwiązania rzeczywistego problemu selektywnej zbiórki odpadów na małym osiedlu. Otrzymane wyniki przeanalizowano. Przedstawiono dalsze plany rozwoju metody na potrzeby selektywnej zbiórki odpadów.

1. INTRODUCTION

This paper presents a method for planning routes for garbage trucks collecting rubbish on the settlement of one of the cities in Poland. This settlement consists of individual buildings and cottages. The garbage truck is passing along all streets and is taking all garbage bags. After filling the vehicle the rubbish is exported to landfill or to waste processing plant. Empty vehicle returns to the point, which it left.

When planning the route should be taken into account various factors, such as traffic management (in particular, one-way streets), temporary traffic congestion (road works, accidents), changes in the volume of traffic at different times of the day. As the garbage truck must pass all settlement roads, length of roads to handle not change. Optimization will therefore be consisted in minimizing empty runs, i.e. rides on the road, on which the waste was collected, but it is necessary to cross it during

driving from one street to another or on the way to the landfill waste. The optimal solution is one in which the sum made empty journeys and journeys to landfill is minimal.

This paper presents a solution of the key element of the optimization, i.e. to plan one cycle of route of rubbish disposal van: from the entrance to the estate, filling van by collecting rubbish and return to the landfill.

2. CHINESE POSTMAN PROBLEM IN THE SELECTIVE COLLECTION OF WASTE

A described task is one of the types of arc routing problems (ARP), where the vehicle has to cross determined network of roads. Plowing streets [13], sprinkle sand [5], delivering mail, inspection of ventilation pipes by a mobile robot - all examples are the same type. In the literature this problem can also be encountered as the Chinese Postman Problem (CPP) [6].

The task becomes more complicated when considering the additional conditions, such as taking into account the time window receiving / sending the goods, in problems where the cost function has been replaced by other parameters (e.g. time of execution, the length of the routes of transported cargo), taking into account the capacity of means of transport and the size of the traffic load.

3. MATHEMATICAL MODEL OF TASK

At the considered estate was selected road network with a total length of 3969 m. Along the streets are 400 houses. All roads are two-way. Each cottage has the ability to issue four sacks, one for paper, plastic, glass and non-ferrous metals. Garbage collection is done once a month. It is clear that each of the cottages issue a different amount of garbage. This is a random quantity. But the estate is operated for several years and can estimate the average number of bags of garbage for each street.

In sense of mathematical settlement is represented by an unoriented graph G = (V, E), where V is the set of vertices and E – a set of edges of the graph [1, 2]. The vertices of the graph correspond to the selected crossroads. Most are crossroads of at least three streets, none of which is blind. The edges of the graph correspond to the settlement streets that connect the vertices, and blind streets extending from the streets. Such procedures are used to simplify the task. At Fig. 1 on the map of settlement there were drawn vertices numbers (in circles) and edge numbers (in rectangles). Fig. 2 shows a graph representing such model of the settlement.

The weights are assigned to the edge. They correspond to a total length of street, which is represented by that edge. The length of each blind street is counted twice because the rubbish disposal van has to pass it twice. The van have to pass once other streets, taking garbage, but it can pass them any number of times passing to other streets. Such transfers have been called empty journeys. As mentioned above, the optimal solution is one in which the sum made empty journeys and journeys to landfill is minimal, because the length of the path travelled by the garbage truck affect on transport costs and pollution of exhaust gases [11].

The entire route of the truck, which is carrying rubbish, consists of the road from its base to the settlements, the road from the settlement to the landfill and back, routes between successive sections of the road. The estate adheres to the expressway. Therefore, as a point of departure from the settlement taken the vertex 0 and a distance from the base and into the base, as well as to and from stockyard of rubbish shall be taken as the distance from the point 0.

The considered task can be reduced to designate roads in the graph, which passes through all the edges of the graph. This path is called the Euler way, and if the first vertex of the road is also the last one, it is a cycle of Euler. According to the theorem of Euler consistent graph G has cycle of Euler if and only if the degree of each vertex is even [2].

Graph in Fig. 2 does not satisfy this condition. In practical terms, this means it is impossible to pass all settlement roads, not passing some twice. In that case, we would point out the road sections where the sum of the length is minimized. It is therefore necessary to add edges corresponding to those

sections of roads to the graph representing the task. As a result of this the Euler graph is obtained for which there is cycle of Euler.

Fig. 1. The numbering of vertices and edges of the settlement plan
Rys. 1. Numeracja wierzchołków i krawędzi na planie osiedla

Table 1 lists the edges of the graph. For each edge is given the number of the initial vertex, the number of the end vertex and the length of the road represented by the edge.

To solve this task is most commonly used heuristic methods [7, 10], such as the nearest neighbour method, evolutionary algorithms [3, 9]. The task is solved by artificial immune system [4, 12]. It is a method of artificial intelligence that mimics the human immune system. The body attacked by foreign arms first mechanically and chemically (skin, tears, temperature). In spite of these barriers microbes penetrate into the body, the immune system starts to work [13, 14].

Antibodies acts better, the more fit to antigens attacking the body. They are developing and improving by mutation. Best of antibodies are cloned. An expansion of antibodies occurs to fight against the antigens. After successful defense suppression occurs. Part of antibodies is preserved by creating a base from which the body will draw patterns of antibodies during the next antigens attack. In this entire process, the immune system can effectively distinguish its own cells from foreign attacking organism. The mechanism of selection of the best antibodies is called clonal selection. Distinguishing between their cells from strangers - negative selection.
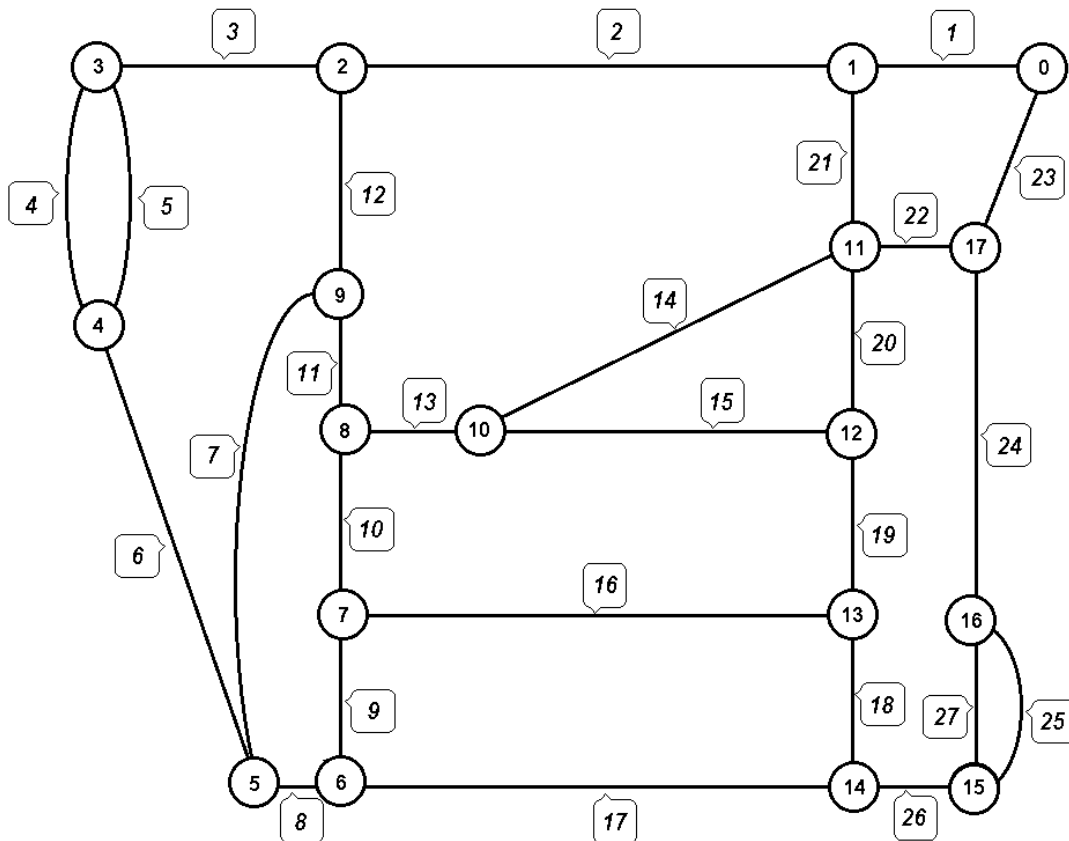
Fig. 2. Graph representing the settlement
Rys. 2. Graf reprezentujący osiedle

The described mechanism has been used successfully for artificial immune systems in various applications. Artificial immune systems are used in some computer antivirus software. The paradigm of clonal selection is used for optimization. For this purpose it is used in the presented calculations.

4. NUMERICAL CALCULATIONS

First of all the distances between each two nodes of the graph have been designated. For this purpose, the Dijkstra algorithm was used [2]. The results are shown in Table 2.

To bring a graph representing the settlement to the graph of Euler was the first step in the calculation. This was done using the paradigm of clonal selection. In the graph that represents settlement was isolated set of vertices of odd degree. In this way, was created a set of 16 vertices of the third degree. Each antibody is composed of a finite sequence of numbers of those vertices. The next two numbers are the numbers of vertices, between which is to be created additional, possibly the shortest route. The value of fitness function is the sum of the smallest distances such routes for all occurring consecutively in the antibody pairs of these vertices.

The graph of Euler, shown in Fig. 3, was obtained as a result of the calculations. Additional edges between the vertices are marked by dashed lines.

Table 1

The list the edges of the graph

No of edge	Initial vertex	Final vertex	Weight of edge (Length in meters)	No of edge	Initial vertex	Final vertex	Weight of edge (Length in meters)
1	0	1	106	19	13	12	68
2	1	2	287	20	12	11	77
3	2	3	132	21	11	1	87
4	3	4	295	22	11	17	81
5	3	4	126	23	17	0	135
6	4	5	264	24	17	16	152
7	5	9	229	25	15	16	187
8	5	6	41	26	14	15	65
9	6	7	68	27	16	15	87
10	7	8	65	28	1	11	87
11	8	9	61	29	11	17	81
12	9	2	100	30	4	3	126
13	8	10	87	31	5	6	41
14	10	11	300	32	9	2	100
15	10	12	203	33	13	14	81
16	7	13	284	34	8	7	65
17	6	14	481	35	12	10	203
18	14	13	81	36	15	16	87

Table 2

The shortest distances in meters between the vertices of the graph of Euler

No vertex	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0	106	393	525	651	850	891	625	560	621	473	193	270	520	439	374	287	135
1	106	0	287	419	545	809	794	516	581	642	367	87	164	232	313	378	465	168
2	393	287	0	132	593	329	294	226	161	100	248	548	578	510	775	767	680	528
3	525	419	132	0	126	390	431	499	564	619	651	506	583	651	732	797	884	587
4	651	545	258	126	0	264	305	373	419	358	506	786	709	657	738	803	890	1042
5	722	616	329	461	264	0	41	109	174	229	261	703	464	393	474	539	626	778
6	713	584	370	502	305	41	0	68	331	270	418	497	420	352	433	817	730	578
7	645	513	226	358	484	355	68	0	65	126	152	429	352	284	549	614	662	510
8	554	448	161	293	419	290	331	65	0	61	87	387	417	349	430	707	620	468
9	493	387	100	619	493	229	194	126	61	0	148	474	351	410	491	556	643	555
10	496	367	248	380	506	377	418	152	87	148	0	280	203	436	517	600	513	361
11	216	87	374	506	802	538	497	429	535	474	280	0	77	145	226	291	378	81
12	270	164	451	583	725	461	420	352	612	551	203	77	0	68	149	214	301	453
13	361	232	519	651	657	393	352	284	680	619	271	145	68	0	81	146	233	226
14	439	472	591	723	849	720	433	365	430	491	517	385	462	81	0	65	152	304
15	507	378	665	797	803	539	498	430	826	765	417	291	214	146	65	0	87	372
16	287	393	680	812	890	626	585	517	841	780	504	378	301	233	152	87	0	152
17	135	168	736	868	994	829	788	510	575	636	361	81	158	226	307	372	152	0

These edges represent the road in which the car, that receives waste from the settlement, will have to pass a second time, now without collecting of garbage. According to the optimization's criterion the best solution offers the shortest route, the length of which is 871 m.
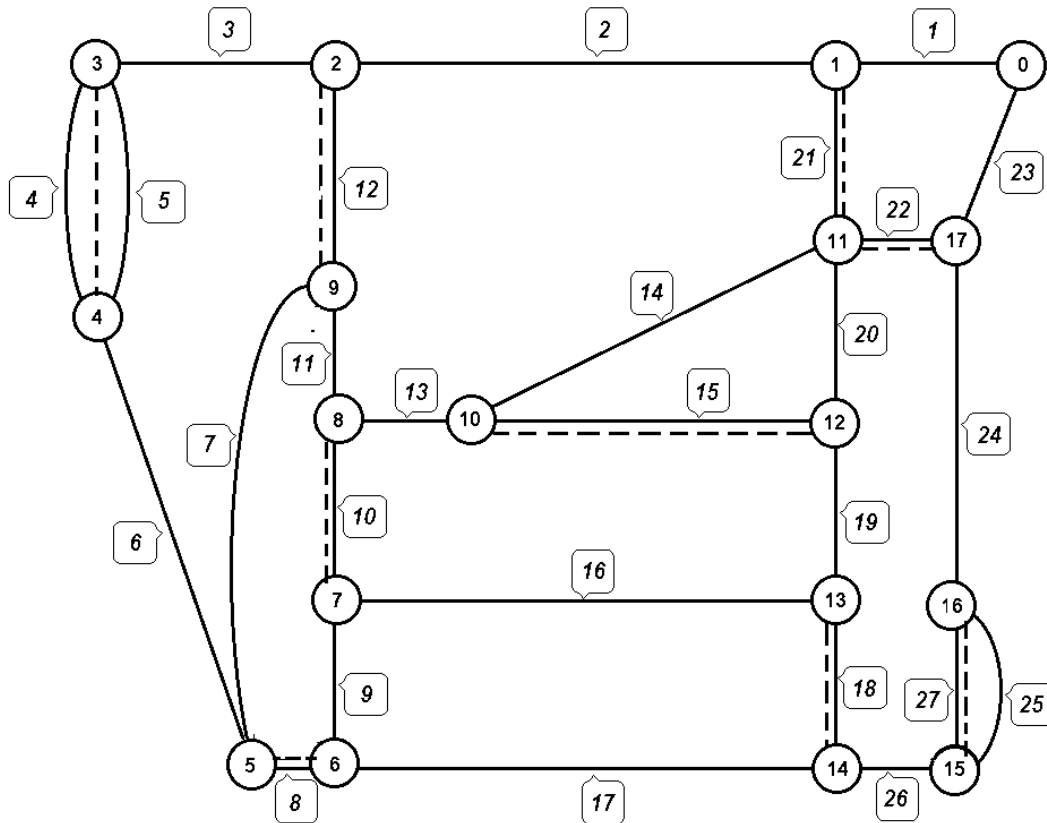

Fig. 3. Optimal graph of Euler representing the settlement
Rys. 3. Optymalny graf Eulera reprezentujący osiedle

The next step is to determine the plan of the road passing through the estate. For Euler's graph it is the simple task using the algorithm of Fleury [1] or of Hierholzer [8]. For this purpose can also use heuristic algorithms, including artificial immune systems. The result was obtained using the algorithm of Hierholzer. The finished graph is shown in Fig. 4.

5. CONCLUSIONS

Cost minimization is important when planning routes serving the waste collection vehicles. Influence on the amount of the costs of has among other length of the route. Garbage truck must pass all the planned streets. Some of them must overcome a second time to get to the next street, now without receiving waste.

This paper presents the method of determining the street, which must be passed more than one time and the sum of their length is the smallest possible, which significantly reduces costs. The method involves constructing a graph representing the streets of the settlement and extending it to the Euler's graph in such a way that the sum of the length of the edges is minimal. Purpose is achieved by using the theorem of Euler and clonal selection paradigm of artificial immune systems.
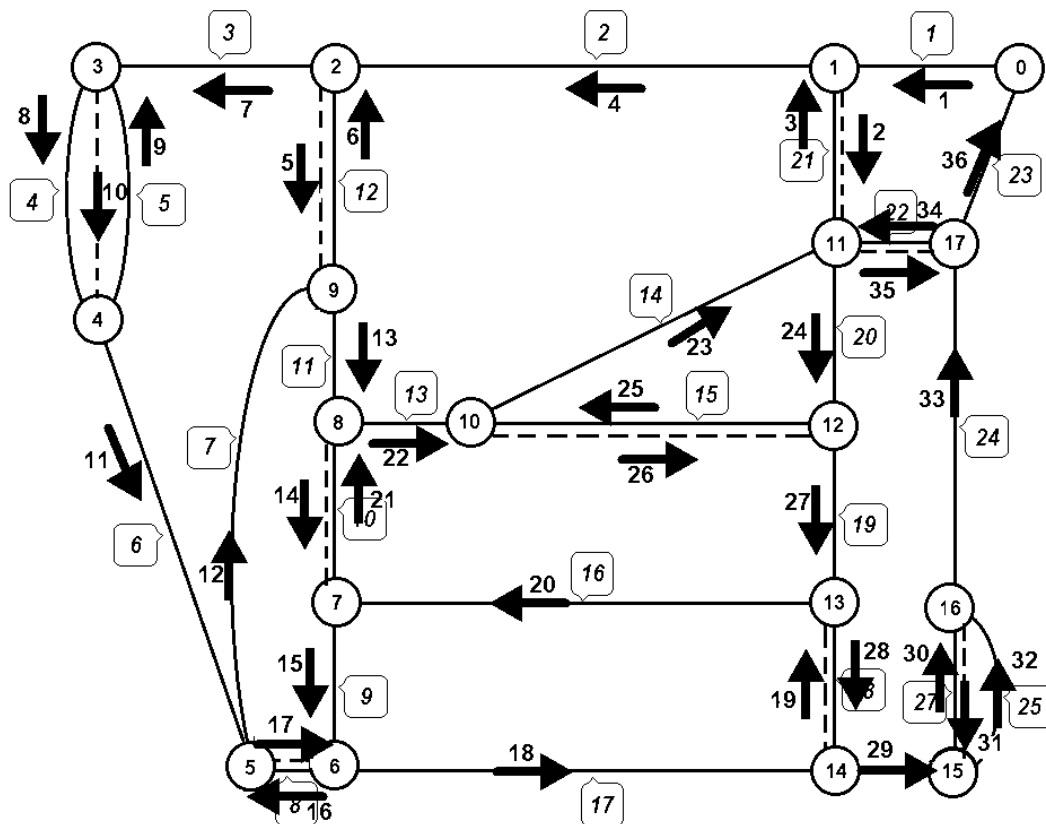
Fig. 4. The plan of the road passing through the estate

Rys. 4. Plan przejazdu śmieciarki przez osiedle

The next step in the planning garbage truck routes is an indication of the order of passing of the streets. According to Euler theorem, such solutions exist. They can be obtained using for example algorithms of Hierholzer or of Fleury or using the artificial immune systems. The presented algorithm applies algorithm of Hierholzer.

Another issue is the division of the land in areas serviced by a fleet of vehicles, taking into account their capacity and the amount of waste collected. This is a very important issue in connection to the statutory changes relating to waste collection, which came into force this year in Poland. This issue will be the target of further research of the author.

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