vehicle routing problem; multi-vehicle; artificial intelligence;
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MULTICRITERIA VEHICLE ROUTING PROBLEM SOLVED BY ARTIFICIAL IMMUNE SYSTEM

Summary. Vehicles route planning in large transportation companies, where drivers are workers, usually takes place on the basis of experience or intuition of the employees. Because of the cost and environmental protection, it is important to save fuel, thus planning routes in an optimal way. In this article an example of the problem is presented solving delivery vans route planning taking into account the distance and travel time within the constraints of vehicle capacities, restrictions on working time of drivers and having varying degrees of movement. An artificial immune system was used for the calculations.

WIELOKRYTERIALNY PROBLEM MARSZRUTYZACJI ROZWIĄZYWANY METODĄ SZTUCZNEGO SYSTEMU IMMUNOLOGICZNEGO

Streszczenie. Planowanie tras samochodów dostawczych w dużych firmach transportowych, w których kierowcy są pracownikami najemnymi, najczęściej odbywa się na podstawie doświadczeń lub intuicji pracowników. Ze względu na koszty i na ochronę środowiska ważne jest oszczędzanie paliwa, a więc układanie tras w sposób optymalny. W artykule rozwiązano przykładowy problem planowania trasy samochodów dostawczych ze względu na długość drogi i czas przejazdu przy ograniczeniach ładowności pojazdów, ograniczeniach czasu pracy kierowców i przy uwzględnieniu zmiennego natężenia ruchu. W obliczeniach zastosowano sztuczny system immunologiczny.

1. INTRODUCTION

Usually, transport companies are establishing routes basing on the intuition and experience of drivers. Truck drivers are usually paid employees. For them, the main criterion when driving a covering longer distances is travel time. Minimizing the distance is often a less important criterion. Order processing with a range of local transport is based on the criterion of minimum distance and a minimum of time (multi-criteria optimization). This leads to the costs generation associated with the increased number of kilometers traveled, fleet consumption etc. The operating time can also be subject to restrictions depending on the regulations on drivers' hours and overtime hours are additional costs for the employer.

Optimizing the way in which a vehicle travels through a predetermined route is therefore economically significant. It also has an impact on the degree of pollution. In proportion to fuel consumption occurs emission to the environment.

The paper presents the problem of optimizing deliveries in the case of a warehouse that supplies multiple recipients. Due to the volume of supplies and working time for drivers to handle the customers involved a sufficient number of vehicles. Each car handles assigned customers. Each driver therefore has to arrange the route in such a way that the entire route from the warehouse, through the recipients, and back to the warehouse is minimal. The problem of customer service by a single car is also considered. Every time after delivery of part of the goods the vehicle returns to the warehouse to download another goods. The change in traffic during the day are taken into account.

There are some limitations. Delivery plan is made for a fixed number of customers, each of which is expected of different size deliveries. For every customer time intervals shall be determined, which is the expected delivery and estimated time of unloading. Therefore limit on driver working time is imposed. The driver must supply merchandise to customers during their 8-hour working day. Therefore, the route designing takes into account not only the distance but also the duration of the individual sections of the route depending on the time of day.

As can be seen the task is complex. For a single driver it is a typical traveling salesman problem, which is the task of visiting all clients while overcoming the shortest path length, while meeting adopted restrictions. But after adding the results for all drivers the results may not be optimal. High impact may have a way to divide buyers between drivers.

Existing solutions rely therefore at the appropriate collection points division between cars. At this stage, the capacity of vehicles serving a group of points have to be taken into account.

To divide delivery points into groups, one of the methods of clustering can be used. They belong to the data mining methods. Rely on classifying data and creating clusters of similar data. The approach focus on hierarchical methods, k-means and fuzzy cluster analysis [11].

Then the so obtained clusters delivery points you can use one of the traveling salesman problem solving methods. The strict method consists in determining all Hamilton cycles in the graph, which form the delivery points, and the route between them. For more points, this method becomes ineffective. The most common is the branch and bound method [9]. Often used artificial intelligence methods such as evolutionary algorithms, simulated annealing method, ant colony optimization and others [3, 7, 8, 10].

This paper proposes a direct approach, without first grouping. Formulated objective function takes into account all the criteria and limitations. To solve the task artificial immune system was used [4, 5].

2. TASK FORMULATION

The problem, considered in the article, may relate to any transport company. The company described here is engaged in supplying retail stores both non-alcoholic and alcoholic beverages. It has many trusted, loyal customers, which has been cooperating with the firm for a long time. The company is developing dynamically and has rapidly growing number of customers. To carry out their tasks it should have well organized logistics system. The company is equipped with a well-managed warehouses. With such a large number of customers it is very important to supply a competently organized schedule eliminating unnecessary costs as much as possible.

Wholesale is designed to deliver 49 recipients of the goods with a total weight of 4675 kg. To do this there are four vans available of loading capacity given in Tab. 1.

Tab. 2 contains a description of the sections of the roads connecting the nodes. In the present case, all roads are two-way. This road network is represented by graph G (Fig.1). The graph G is an ordered pair:

$$G=(V, E) \tag{1}$$

where: V is a set of vertices (delivery points) and E is a set of edges (sections of roads directly connecting the delivery points), $E \subseteq \{\{u,v\}: u, v \in V, u \neq v\}$. It is a weighted graph - a weight as a distance and the average traveling times in three intervals (it allows to take into account the changes in traffic during the day), is assigned to each edge.

Table 1

Delivery trucks serving area under consideration

ordinal number	Del ivery truck	capacity [kg]
1	*2*	*3*
1	Peugeot Boxer 3.0 hdi 180 KM	1150
2	Fiat Ducato 2.3 130 KM	1300
3	Volkswagen T5 Doka 140 K	1100
4	Mercedes-Benz Sprinter 313 Cdi Furgon	1312

Table 2

Description of edges of the graph G

			route	Route travel time [min:ss]						route	Route travel time [min:ss]		
No route	starting point	end point	length [km]	hours 10 - 14	hours 14 - 18	hours 18 - 24	No route	starting point	end point	length [km]	hours 10 - 14	hours 14 - 18	hours 18 - 24
1	*2*	*3*	*4*	*5*	*6*	*7*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1	1	3	0.8	01:28	01:42	01:16	**53**	5	38	2.5	05:33	06:29	03:46
2	1	2	1	01:39	02:14	01:31	**54**	4	38	3	05:52	06:44	04:01
3	2	10	3	05:04	07:55	04:07	**55**	4	34	2.1	03:55	04:38	02:44
4	1	9	2.1	03:36	05:22	02:47	**56**	34	38	1.5	02:23	02:50	01:36
5	1	7	2.2	04:14	04:41	03:17	**57**	36	39	3.8	07:59	09:32	06:11
6	1	44	3.1	07:15	08:05	05:25	**58**	35	36	2	04:12	04:55	03:15
7	1	43	4.6	10:25	12:01	07:43	**59**	35	39	3.2	07:58	09:22	05:57
8	1	42	3.1	06:21	07:27	04:40	**60**	37	39	1.8	03:56	04:33	02:55
9	2	5	2.1	04:32	05:26	03:16	**61**	35	37	2	04:07	04:45	03:02
10	3	5	2.2	04:45	05:41	03:38	**62**	37	38	2	05:29	06:29	03:57
11	3	4	0.6	01:20	01:34	01:00	**63**	37	6	5.9	11:23	13:28	08:41
12	4	5	2	03:56	04:35	02:53	**64**	38	45	3.3	06:51	08:08	05:07
13	2	9	2.6	05:51	06:50	04:30	**65**	45	49	1.5	03:22	04:00	02:28
14	2	8	2.8	05:49	06:45	04:06	**66**	48	45	4.8	11:53	14:04	09:09
15	8	9	1.2	02:19	02:44	01:39	**67**	47	49	2	05:23	06:12	03:47
16	8	21	1.8	04:11	05:00	03:02	**68**	46	47	2.8	05:25	06:15	03:50
17	9	21	0.7	01:40	01:59	01:10	**69**	43	46	2.6	06:12	07:20	04:30
18	7	9	2	04:07	04:49	02:39	**70**	46	48	4.1	08:55	10:34	06:12
19	9	23	1.1	02:26	02:49	01:36	**71**	43	44	2	04:14	05:03	02:44
20	21	23	1.5	03:31	04:07	02:23	**72**	44	50	1.2	03:02	03:33	02:01
21	22	23	1.2	03:18	03:48	02:15	**73**	22	50	3.8	08:52	10:19	06:02
22	20	22	3.2	07:51	09:17	05:23	**74**	8	17	2.9	05:45	06:46	03:55
23	19	21	3.2	06:47	08:08	04:44	**75**	17	19	1.3	03:00	03:27	02:03
24	19	20	1.5	03:22	04:00	02:16	**76**	19	22	2.2	04:16	05:02	02:59
25	18	20	1.6	02:58	03:29	01:55	**77**	21	22	1.9	04:07	04:55	02:46
26	18	19	1	01:48	02:04	01:11	**78**	17	18	2	05:00	05:56	03:13
27	16	18	1.6	03:03	03:34	02:04	**79**	8	10	2.1	04:10	04:53	02:45
28	16	17	1.2	02:19	02:40	01:35	**80**	43	50	2	03:58	04:35	02:42
29	15	17	3.8	05:07	06:05	03:30	**81**	23	44	2.3	05:31	06:27	03:45
30	10	15	1.1	01:16	01:31	01:01	**82**	43	48	6.2	08:01	09:15	05:30
31	13	28	3.2	03:50	04:33	03:04	**83**	47	48	5.7	11:56	14:11	08:20
32	13	15	1	01:46	02:04	01:18	**84**	49	48	4.8	09:41	11:33	06:30
33	13	14	1.6	02:58	03:27	02:11	**85**	42	48	1.7	03:25	04:03	02:32
34	14	32	4.3	05:45	06:44	04:09	**86**	42	45	2.4	04:48	05:44	03:32
35	32	33	1.7	02:19	02:40	01:46	**87**	34	45	4.5	09:35	11:17	06:54
36	31	33	3.6	04:21	05:05	03:15	**88**	38	41	7.5	09:32	11:14	07:16
37	31	32	4.4	05:44	06:50	04:11	**89**	35	41	5.1	07:53	09:04	05:53

Cont. table 2

38	29	32	2.7	02:58	03:33	02:22	**90**	40	41	6.1	12:46	14:43	09:19
39	27	30	5.6	06:20	07:36	05:04	**91**	36	40	2.5	05:13	06:10	04:01
40	26	27	2.1	02:42	03:06	01:55	**92**	16	32	4.1	05:35	06:37	03:56
41	24	26	2.9	03:40	04:15	02:40	**93**	13	32	3.1	04:15	05:04	03:01
42	24	29	4.3	05:08	06:02	04:07	**94**	11	28	2.6	03:15	03:49	02:21
43	12	28	2.9	03:47	04:31	03:02	**95**	28	29	2.4	02:40	03:09	02:01
44	12	24	2.5	02:31	03:03	02:17	**96**	29	30	1	01:10	01:21	00:56
45	24	25	2.2	02:16	02:43	01:49	**97**	12	25	6.2	06:33	07:34	05:14
46	25	39	6.9	07:24	08:37	05:55	**98**	26	30	4.2	09:41	11:33	06:30
47	10	11	3.4	03:12	03:38	02:55	**99**	30	31	3	03:25	04:03	02:32
48	11	12	1	01:03	01:14	00:51	**100**	16	33	5.3	04:48	05:44	03:32
49	6	11	3.9	05:23	06:19	04:19	**101**	14	29	2.5	09:35	11:17	06:54
50	5	10	4.1	08:23	09:56	07:37	**102**	25	40	6.5	09:32	11:14	07:16
51	5	6	2	04:14	05:03	02:48	**103**	7	44	1.6	07:53	09:04	05:53
52	6	38	3.8	07:13	08:40	04:55							

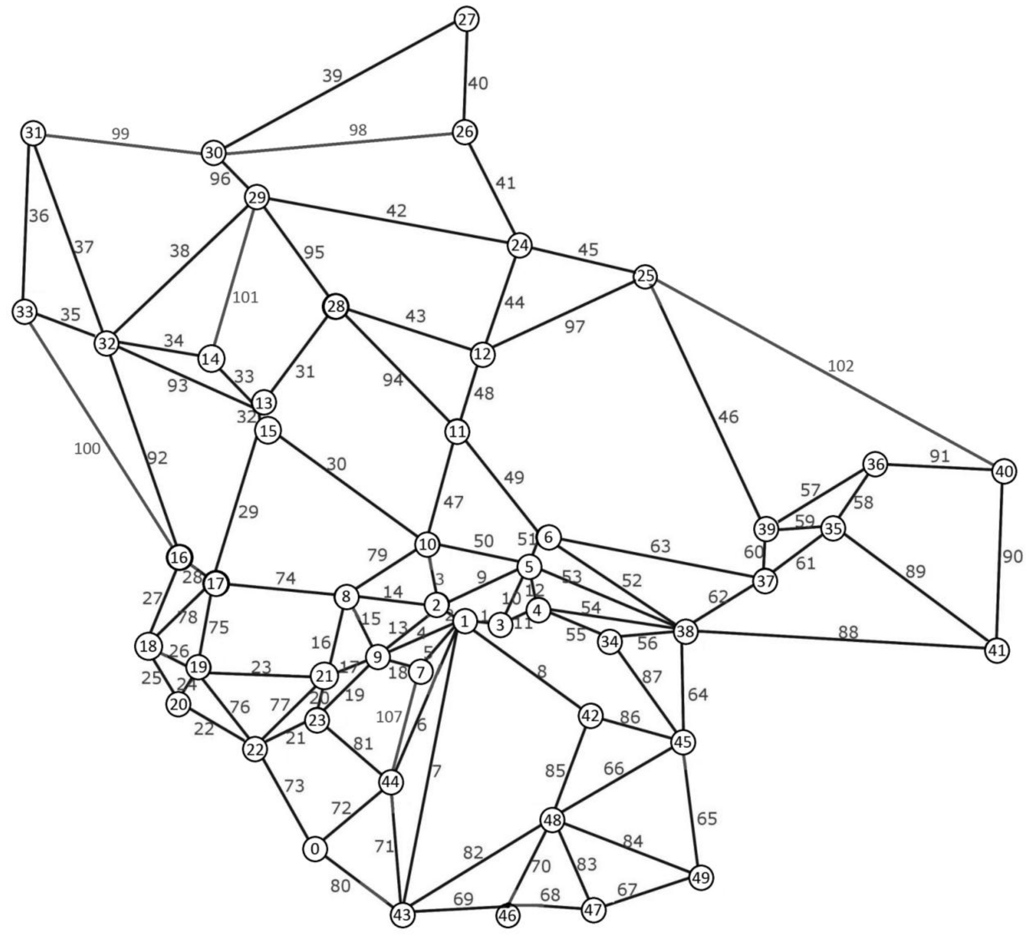

Fig. 1. The graph G representing the road connections of delivery points
Rys. 1. Graf G reprezentujący połączenia drogowe punktów odbioru

Tab.3 contains the requirements of each of the delivery points. In column 2 and 3 there are time windows: time, from which the product can be received, time till which the goods can be delivered. When it does not matter, it is inscribed 0. The average time of unloading of the goods is inscribed in column 4 and the weight of the goods received by a given point is in column 5. On the basis of this table are calculated distances (Tab. 4) and travel times or fastest shortest paths between any two nodes. The calculations are carried out with Dijkstra method [1, 2].

Table 3

Description of the nodes of the graph G

number of delivery point	time windows in which delivery is expected		unloading time [min]	weight of load [kg]	number of delivery point	time windows in which delivery is expected		unloading time [min]	weight of load [kg]
	start time [h:min]	finish time [h:min]				start time [h:min]	finish time [h:min]		
1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
0	0	0	5	80	25	0	0	3	80
1	0	0	7	90	26	0	0	7	90
2	0	0	15	75	27	0	0	5	60
3	0	0	3	155	28	0	0	9	90
4	0	0	7	70	29	07:30	8:00	4	60
5	0	0	7	90	30	0	0	8	80
6	0	0	9	60	31	0	0	5	90
7	0	0	4	150	32	0	0	5	65
8	0	0	8	150	33	0	0	4	55
9	07:30	8:00	5	70	34	0	0	3	70
10	0	0	6	80	35	0	0	6	150
11	0	0	6	90	36	0	0	4	60
12	08:00	10:00	3	75	37	0	0	11	150
13	0	0	5	90	38	0	0	5	80
14	0	0	7	160	39	07:30	9:00	7	70
15	0	0	10	80	40	0	0	12	80
16	0	0	3	90	41	0	0	3	90
17	0	0	7	60	42	0	0	7	75
18	0	0	7	145	43	0	0	4	90
19	07:30	9:00	9	70	44	0	0	9	60
20	0	0	4	155	45	0	0	4	95
21	0	0	8	160	46	0	0	8	145
22	0	0	5	150	47	0	0	5	95
23	0	0	7	80	48	0	0	7	150
24	0	0	13	70					

The task is to minimize the total distance and travel time of all delivery vans, taking into account the working time of drivers, vehicle capacity, time windows in which they must deliver the goods to certain points and major changes in traffic during the day on some sections of the route.

The solved problem can be formulated as follows: m=49 points should be served. One van can take no more than their loading capacity in the one tour. Every van starts and ends every tour in point 0 (warehouse). All delivery points are numbered. An order of visiting them is according to its number position in the following sequence of numbers:

$$[\, n_1 , n_2 , \ldots , n_m \,] \tag{2}$$

Table 4

Fragment of array of distances (in kilometers)

		node number												
		1	**2**	**3**	**4**	**5**	**6**		**44**	**45**	**46**	**47**	**48**	**49**
node number	**1**	0	4.3	5.3	5.1	5.7	7.4	…	1.2	12	4.6	7.4	8.2	9.4
	2	4.3	0	1	0.8	1.4	3	…	3.1	7.7	7.2	10	4.8	9.2
	3	5.3	1	0	1.8	2.4	2.1	…	4.1	6.5	8.2	11	11.8	8
		…	…	…	…	…	…	…	…	…	…	…	…	…
	47	7.4	10	11	10.8	11.4	9.3	…	7.4	3.5	2.8	0	5.7	2
	48	8.2	4.8	5.8	5.6	6.2	7.8	…	7.9	4.1	4.1	5.7	0	4.8
	49	9.4	7	8	7.8	8.4	7.3	…	9.4	1.5	4.8	2	4.8	0

The first van serves points from n_1 to n_k. It returns to the base after delivering of goods. Next points from n_{k+1} to n_q are supported by another van. And so on until all points are handled. The vans can handle their points simultaneously. It is also considered the case when one van serves the entire route.

The order of the points is variable. Optimization consists in determining the order of points to achieve the minimum of objective function. An objective function for this problem is formulated as follows:

$$F_c = w_1 \frac{\sum_{k=1}^{m}(d_{0k_s} + d_{j_{k_s} j_{k_s+1}} + ... + d_{j_{k_e-1} j_{k_e}} + d_{k_e 0})}{d_{max}} + w_2 \frac{\sum_{k=1}^{m}(t_{0k_s} + t_{j_{k_s} j_{k_s+1}} + ... + t_{j_{k_e-1} j_{k_e}} + t_{k_e 0}) + t_{op}}{t_{max}} + \\ + w_3 \cdot \frac{\sum_{k=1}^{m}(q_{max_k} - \sum_{j=j_{k_s}}^{j_{k_e}} q_j)}{q_{max}} \quad (3)$$

where: n – the number of points served, m – number of vans serving these points, j_{ks} – the starting point number supported by the k-van, j_{ke} – number of endpoint supported by the k-van, 0 – base, d_{ij} – the shortest distance between i and j point, t_{ij} – the shortest travel time from point i to j, q_j – the size of the load in the j node, w_1, w_2, w_3 - weighting factors, d_{max} - maximum distance; d_{max} = the sum of the values in column 5 of Table 2, t_{max} – maximum travel time; t_{max} = the sum of the values in column 7 of Table 2, q_{max} - maximum load, q_{max} = the sum of the values in column 3 of Table 1, q_{maxk} - load capacity of the k-van, t_{op} - total time which the van were late to delivery point about a specific time of receipt; this time is calculated as a sum of time for all vans.

For example, time windows in which consecutive points are to be handled are taken into account in such a way that in case of delays the penalty for being late is being added to the function, and in the case of early arrival of a supplier to the point, it is assumed that the driver is in this point until departure according to the scheduled plan. The restrictions have been taken into account in the form of a penalty function, which is the size beyond the limits multiplied by factors of large numerical values. The model included an 8-hour driver working time and a break after 4 hours. When a working time is exceeded the punishment must be added to function.

The solution will be obtained by maximizing the function:

$$f = \frac{1}{F_c} \quad (4)$$

with respect to an order of delivery points. The F_c *is* always positive because it is the sum of the length of the van's route, travelling time and the remaining load capacity of vans.

Calculations were carried out using artificial immune system [4 - 6]. It is a defense mechanism designed to mimic the living human body. As a result of the attack on the body of foreign bodies and penetration of the mechanical barriers such as the skin, and chemical, for example: tears, microbes stimulate the immune system. Antibodies are being produced that recognize and dispose of antigens. Those which recognizes the best cloned, then are developing and improving by mutations. And again, the best are cloned. Released into the blood they are searching for antigens in the bloodstream. After eradication of antigen suppression occurs, resulting in the reduction of antibodies and converting some of the plasma cells and memory. Schematically described process called clonal selection is shown in Fig. 2.

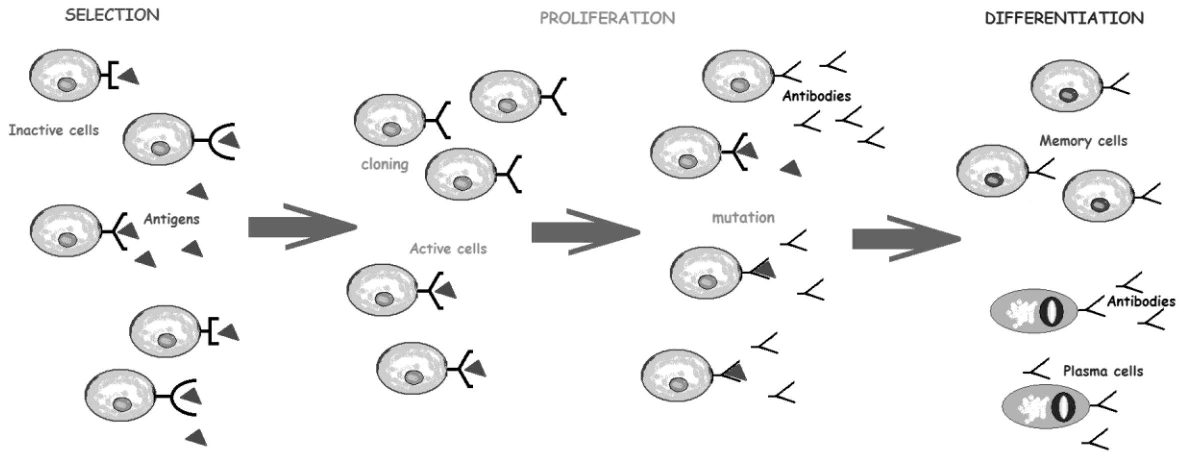

Fig. 2. Clonal selection
Rys. 2. Selekcja klonalna

In the problem presented in the article the antibody is defined as a finite sequence of numbers given by the formula (1) and the fitting of the antibody is measured by the function (3). The higher the value, the better the fit. The numerical algorithm of the clonal selection is presented at Fig. 3. The own implementation of AIS in C ++ was used for all calculations in this article.

3. CALCULATION RESULTS

Calculations were carried out for the two cases. In both cases, the aim was to deliver goods to recipients. In both cases, vans were leaving the warehouse at 7 o'clock in the morning. All the solutions meet all constraints on time deliveries and cargo volumes.

In the first case the delivery took place a single delivery van (van No. 4 of Table 1). In order to deliver the van had to do a four tours of receiving points, during which delivered the goods to all recipients. Due to the long delivery time was taken into account varying degrees of movement during the day. The model of a single car did not include drivers' hours as the sum of the operating times for each tour. Due to the long delivery time was taken into account traffic volume during the day. The model of a single car did not include drivers' hours as the sum of the operating times for each tour. Routes corresponding to the best solution results are indicated in Table 5. The best is 4 solution. In total, van defeated route of 216 km in the total of 11 hours and 17 minutes. Goods shipped accounted for even 99.84% of the total capacity of vehicles. The solution was obtained at 1286 generation, in a few seconds.

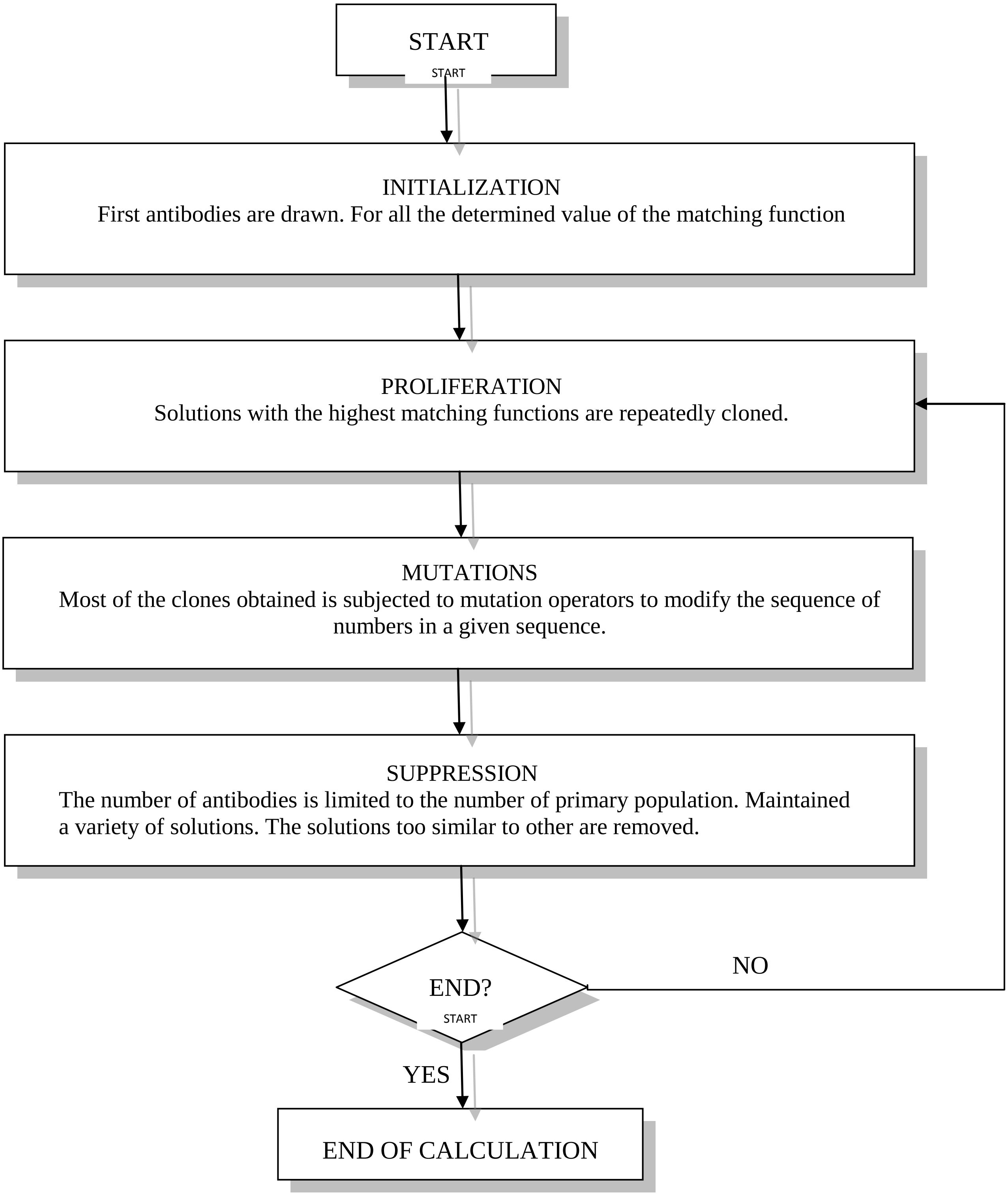

Fig. 3. Numerical algorithm of clonal selection
Rys. 3. Algorytm numeryczny selekcji klonalnej

In subsequent calculations we assume that the supplies are taking place by four vehicles (Table 1). Each of vans deliver goods to the intended recipients. Detailed results of the calculations and proposed route of vehicles in subsequent tours are summarized in table 6. The best is 3 solution. In total, van defeated route of 221 km in the total of 9 hours and 50 minutes. Significantly shorter delivery times results from the fact that in the proposed solution all deliveries ended no later than at 10 AM and driving took place with little traffic. Goods shipped accounted for even 100% of the total capacity of vehicles. The solution was obtained at 1769 generation, in a few seconds.

Table 5

Delivery of goods a single car in four runs

variant of calculations	**step of calculation**	**length of the route [km]**	**ending hour of work**	**variant of van**	**cargo size [kg]**	**cargo size [%]**	**delivery time [hh:min:ss]**	**order of service of the delivery points**																
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*																
1	738	249	19:02	4	1300	99,08	04:00	8	10	28	30	20	17	40	25	12	14	13	15	2	1	3		
				4	1300	99,08	03:45	44	7	9	43	46	48	42	33	31	29	27	26	11	6	5		
				4	1235	94,13	02:03	23	22	19	18	21	47	49	45	34	4							
				4	840	64,02	02:04	38	37	41	35	36	39	24	32	16								
2	1426	247	18:46	4	1305	99,46	03:28	23	21	8	10	30	20	18	40	25	24	28	13	17	19			
				4	1300	99,08	03:41	44	7	9	42	48	45	5	11	12	6	37	39	34	4	3		
				4	1290	98,32	02:40	43	46	47	49	1	2	16	32	33	31	29	14	15				
				4	780	59,45	01:57	38	41	35	36	27	26	22										
3	754	238	18:24	4	1280	97,56	04:22	7	10	28	30	40	32	20	18	16	14	13	5	37	34	4	3	1
				4	1295	98,7	02:39	44	23	21	9	8	2	6	11	12	24	27	26					
				4	1240	94,51	02:50	22	17	15	41	35	36	39	25	29	31	33	19					
				4	860	65,55	01:33	46	47	49	45	38	42	48	43									
4	1286	216	18:17	4	1310	99,84	03:43	23	21	8	10	30	13	20	40	36	35	41	45	49				
				4	1285	97,94	03:41	2	5	15	14	29	27	26	24	25	12	11	28	31	33	32		
				4	1290	98,32	02:32	44	22	19	18	16	17	3	4	34	38	39	37	6				
				4	790	60,21	01:21	43	46	47	48	42	1	9	7									

Table 6

Delivery of goods using four car

variant of calculations	step of calculation	length of the route [km]	variant of van	cargo size [kg]	cargo size [%]	delivery time [hh:min:ss]	ending hour of work	order of service of the delivery points														
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*														
1	826	229	1	1140	99,13	03:58:24	10:58	48	42	10	28	30	40	25	12	20	18	15	13	11	6	
			2	1300	100,00	02:30:54	09:31	44	23	22	21	14	29	24	26	27	31	33	32	16		
			3	1095	99,55	02:19:04	09:19	46	47	49	45	34	38	39	37	5	2	1	7			
			4	1140	86,89	02:10:45	09:11	43	19	17	8	9	4	41	36	35	3					
2	2669	236	1	1125	97,83	03:10:47	10:11	43	2	10	30	24	40	35	37	34	20	8	11	28	13	7
			2	1285	98,85	03:25	10:25	46	48	42	32	33	31	29	25	39	36	41	5	17	16	18
			3	1055	95,91	01:51:47	08:52	44	21	9	1	3	38	45	49	47						
			4	1210	92,23	01:50:53	08:51	23	22	19	15	14	27	26	12	6	4					
3	1247	221	1	1150	100,00	02:59:36	10:00	7	9	10	29	30	40	31	33	20	17	13	14	2	44	
			2	1250	96,15	02:45:02	09:45	1	42	49	45	38	37	39	25	26	27	24	12	11	6	
			3	1065	96,82	02:29:54	09:30	43	46	47	48	3	4	34	41	36	35	5				
			4	1210	92,23	01:35:31	08:35	23	22	19	18	16	32	28	15	8	21					
4	1769	224	1	1150	100,00	03:05:23	10:05	28	29	30	11	10	13	17	20	24	40	36	39	37	34	7
			2	1280	98,46	02:31:55	09:32	21	15	14	25	26	27	31	33	16	8	2	1	44		
			3	1085	98,64	02:34:56	09:35	43	46	48	42	49	47	45	38	41	35	3				
			4	1160	88,41	01:43:51	08:44	23	9	4	5	6	12	32	18	19	22					

variant of calculations	step of calculation	length of the route [km]	variant of van	cargo size [kg]	cargo size [%]	delivery time [hh:min:ss]	ending hour of work	order of service of the delivery points														
1	2	3	4	5	6	7	8	9														
5	1061	235	1	1110	96,52	02:42:58	09:43	32	33	31	30	10	40	13	15	20	18	22	23			
			2	1265	97,31	03:03:24	10:03	3	5	38	41	35	36	24	27	26	25	39	37	34	4	
			3	1075	97,73	02:12:38	09:13	44	43	48	42	1	2	19	17	16	29	28	14			
			4	1225	93,37	01:58:20	08:58	7	9	21	8	11	12	6	45	49	47	46				
6	1235	232	1	1095	95,22	03:11:37	10:12	18	17	10	30	32	13	20	33	24	40	41	35	4	7	
			2	1280	98,46	03:15:44	10:16	1	3	37	39	36	25	26	27	31	29	14	48	47	46	
			3	1045	95,00	02:07:39	09:08	19	16	8	2	42	49	45	38	34	43					
			4	1255	95,66	01:41:39	08:42	44	23	22	21	9	15	28	12	11	6	5				
7	2444	236	1	1135	98,70	03:20:13	10:20	43	10	30	24	40	12	28	13	17	20	33	31	27	26	11
			2	1275	98,08	03:16:08	10:16	44	7	8	2	5	6	3	1	48	45	41	35	36	37	34
			3	1025	93,18	02:17:57	09:18	4	38	39	25	29	14	15	32	16	18					
			4	1240	94,51	01:31:58	08:32	23	22	19	21	9	42	49	47	46						

4. CONCLUSIONS

- In the case of the present business: in the event of simultaneous deliveries by 4 vans more effective is the tour in the morning, because it gives a chance for the supply with little traffic.
- Delivery by a single car with one driver is not the recommended solution, as the driver would have to work overtime.
- One can suggest a tour using two vans.
- Development of a favorable route for both the company and the customers is complex and requires numerical tool support.

- The method of artificial immune system is fast and efficient for solving traveling salesman task due to the route and travel time, the limits on the capacity, time windows of supplies and drivers' working time.
- As a result of the calculation may not be the optimal solution, but since it was obtained within a few seconds the solution achieved can be called quite good.
- Further work on the algorithm, especially for a much larger number of nodes, can produce even better results in the calculation.

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