artificial intelligence, artificial immune systems, clonal selection,
evolutionary algorithm, waste disposal garbage trucks, optimisation

Bogna MRÓWCZYŃSKA
Silesian University of Technology, Faculty of Transport
Krasińskiego st. 8, 40-019 Katowice, Poland
Corresponding author. E-mail: bogna.mrowczynska@polsl.pl

OPTIMAL ROUTES SCHEDULING FOR MUNICIPAL WASTE DISPOSAL GARBAGE TRUCKS USING EVOLUTIONARY ALGORITHM AND ARTIFICIAL IMMUNE SYSTEM

Summary. This paper describes an application of an evolutionary algorithm and an artificial immune systems to solve a problem of scheduling an optimal route for waste disposal garbage trucks in its daily operation. Problem of an optimisation is formulated and solved using both methods. The results are presented for an area in one of the Polish cities.

PLANOWANIE OPTYMALNYCH TRAS DLA ŚMIECIAREK SAMOCHODOWYCH PRZY POMOCY ALGORYTMU EWOLUCYJNEGO I SZTUCZNYCH SYSTEMÓW IMMUNOLOGICZNYCH

Streszczenie. W artykule przedstawiono zastosowanie algorytmu ewolucyjnego i sztucznych systemów immunologicznych do zaplanowania optymalnych tras śmieciarek samochodowych. W artykule sformułowano zadanie optymalizacji tras i rozwiązano przy pomocy dwóch metod: algorytmu ewolucyjnego i algorytmu immunologicznego. Omówiono wyniki otrzymane dla jednego z polskich osiedli.

1. INTRODUCTION

One of the main problems of residential areas is waste removal. Rational handling of waste should take into account both the demands of ecology and the principles of logistics in planning, organising and implementing the necessary actions. In accordance with EU directives it is considered a priority for prevention of rubbish production and its recovery, processing, utilisation and storage.

There are two models of segregation of waste [6, 9]:

1. Separate collection of waste, which consists of collecting pre-sorted rubbish into separate containers or bags, taking some to the point of purchase, etc.
2. Waste collection in a communal container and then separation and sorting recyclable materials.

The result of selective waste collection is reduction of weight and volume of waste in landfills up to 60% [4]. It is very important because the costs of building new landfills that meet EU standards are very high. Due to the impact on the environment, it is also difficult to find a suitable location, especially in heavily urbanised areas. Acquisition of secondary raw materials by way of selective waste collection reduces of primary raw materials production. It results in lower energy consumption in comparison to primary raw materials use and reduces environmental pollution. It also decreases production costs, charges and penalties for environmental funds.

Separate collection of municipal waste may include personal collection of resources on each property and usually includes the residents of housing estates [7, 10]. In neighbourhoods with high and multifamily building containers for recycling paper, glass and plastic were within easy access from the settlements.

In the case of separate collection of waste from an economic point of view following factors are important:

- location of containers, transfer stations, processing facilities,
- capability of these objects,
- selection of containers,
- number of employees of municipal companies,
- collection schedule of the containers.

Optimal planning of rubbish disposal vans' routes have a major impact on fuel consumption and operating costs of vehicles and is one of the key elements affecting the economics of waste management system. The aim of this paper is to present two methods to support the process of planning routes of rubbish disposal vans.

2. NUMERICAL MODEL

The routes scheduling model was carried out for multi-family housing estates in Tychy, where the separate system collection of the waste is kept. Location of waste containers is shown in Fig. 1.

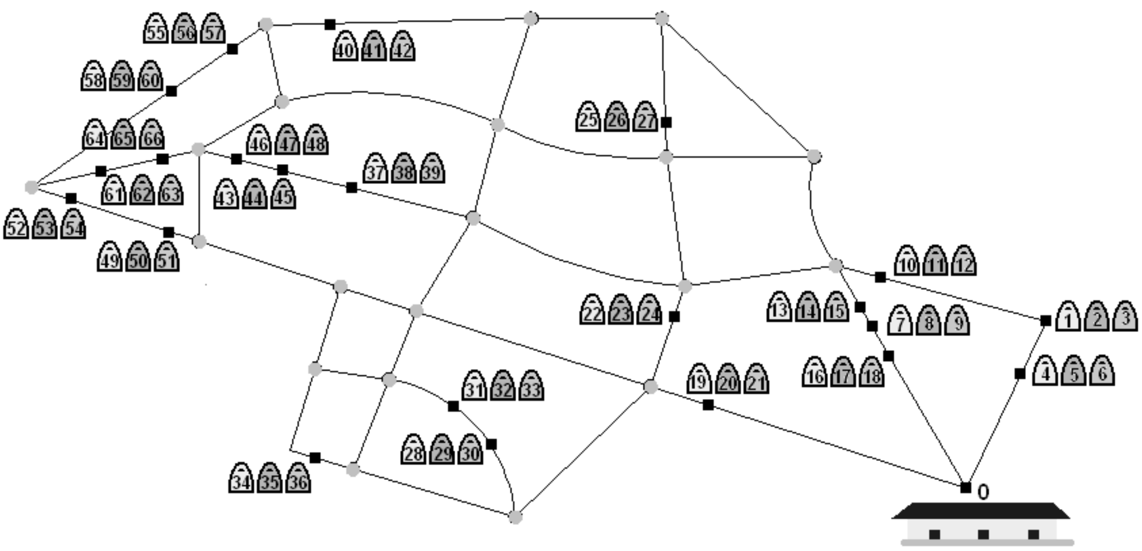

Fig. 1. The container sets distribution in estate
Rys. 1. Rozmieszczenie zestawów kontenerów na osiedlu

23 sets of containers (Fig. 2a) with a capacity of 1.4 m^3 each are placed on the estate. Each set consists of three containers for: paper, glass and plastic (Fig. 2a) collection. The technical vehicle Volvo FL 6 / K equipped with a HDS crane, which can accommodate at one time 7 m^3 of waste (Fig. 2b) was used to empty containers.

The waste is transported to the hub. The vehicle must return to the hub after emptying the five containers due to the limited capacity and not to mix the waste. With these assumptions, the problem is in finding the possible shortest route to empty all of 66 containers set in 22 places. The problem takes also into account the return to base after loading the contents of the next five containers. Table 1 shows the distances in km between the containers and the distances in km of these containers from the hub.

Fig. 2. a) Set of containers for rubbish disposal; b) container replacement
Rys. 2. a) Zestaw kontenerów na segregowane śmieci; b) opróżnianie kontenera

Table 1

The distances between containers for disposal rubbish (in km)

z/do	0	1	2	3	4	5	6	7	8	9	10	11	...	66
0	0	7.288	7.288	7.288	7.257	7.257	7.257	7.278	7.278	7.278	7.519	7.519	...	8.151
1	7.288	0	0.001	0.001	0.031	0.031	0.031	0.366	0.366	0.366	0.231	0.231	...	1.127
2	7.288	0.001	0	0.001	0.031	0.031	0.031	0.366	0.366	0.366	0.231	0.231	...	1.127
3	7.288	0.001	0.001	0	0.031	0.031	0.031	0.366	0.366	0.366	0.231	0.231	...	1.127
4	7.257	0.031	0.031	0.031	0	0.001	0.001	0.335	0.335	0.335	0.262	0.262	...	1.169
5	7.257	0.031	0.031	0.031	0.001	0	0.001	0.335	0.335	0.335	0.262	0.262	...	1.169
6	7.257	0.031	0.031	0.031	0.001	0.001	0	0.335	0.335	0.335	0.262	0.262	...	1.169
7	7.278	0.366	0.366	0.366	0.335	0.335	0.335	0	0.001	0.001	0.093	0.093	...	1.005
8	7.278	0.366	0.366	0.366	0.335	0.335	0.335	0.001	0	0.001	0.093	0.093	...	1.005
9	7.278	0.366	0.366	0.366	0.335	0.335	0.335	0.001	0.001	0	0.093	0.093	...	1.005
10	7.519	0.231	0.231	0.231	0.262	0.262	0.262	0.093	0.093	0.093	0	0.001	...	1.012
11	7.519	0.231	0.231	0.231	0.262	0.262	0.262	0.093	0.093	0.093	0.001	0	...	1.012
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
66	8.151	1.127	1.127	1.127	1.169	1.169	1.169	1.005	1.005	1.005	1.012	1.012	...	0

In this paper the problem was formulated as a travelling salesman problem (TSP). The travelling salesman problem is one of the most known combinatorial optimisation problem. It was formulated at the turn of eighteenth and nineteenth centuries. The algebraic methods of solving this problem were involved in 50ths years of XX century [1]. The integer programming and dynamic programming were used among other methods. In 1972 R. M. Karp proved that the TSP is NP- hard. For such tasks, there are strict solutions for small dimension tasks. The large tasks are solved using heuristic methods. In recent years they were successfully used artificial intelligence methods, such as ants systems [3], simulated annealing methods, the nearest neighbouring method, genetic algorithms [8], artificial immune systems [11], and others. These methods don't find optimal solutions in the strict mathematical sense, but the obtained solutions are adequate exact approximations. They are always better than intuitive solutions. An application of the evolutionary algorithm and the immune system to solve this problem is presented in this paper.

The solved problem can be formulated as follows: 66 containers should be emptied. One rubbish disposal van can take 5 numbers of them in the same tour. The rubbish disposal van has to do 14 tours for emptying containers. The van starts and ends every tour in point 0.

All containers are numbered. An order of taking containers is according to his number position in the following sequence of numbers:

$$[\ n_1\ ,\ n_2\ ,\ \ldots\ ,\ n_{66}\ ] \tag{1}$$

The first 5 numbers are the containers, which are taken by the van in its first tour. The second 5 numbers are the containers, which are taken by the van in its second tour etc.. The van takes the other containers in its 14 tour.

An objective function for this problem is formulated as follows:

$$f = \sum_{k=1}^{66} \left(d_{0i_k} + \sum_{i=i_k}^{j_k} d_{ij} + d_{j_k 0} \right) \tag{2}$$

where:
d_{ij} – distance between the i-th and j-th containers, d_{0j} – distance between the hub and j-th containers, d_{j0} – distance between the j-th containers and the hub, i_k – number of the first container taken in k-th route of the van,
j_k – number of the last container taken in k-th route of the van.

The solution will be obtained by minimising the function:

$$F = \frac{1}{f} \tag{3}$$

with respect to an order of taking containers (1). The f is always positive because it is the length of the van's route.

3. SOLUTION USING EVOLUTIONARY ALGORITHM

The problem of the optimisation the route scheduling of the waste collecting vehicles is solved by the evolutionary algorithm at first. It simulates the mechanisms of natural evolution. Each generation consists of a number of individuals that reproduce through crossover or mutation. Those best suited mostly go to the next generation. The worst can be eliminated.

Artificial evolution is modelled in the manner described below. The algorithm of the evolutionary optimisation is presented in Fig.3.

Environment

Defining the environment is constructing of an appropriate model of solving problem. It is determined by objective function, boundaries for parameters, maximal length of life and probabilities of mutations or crossovers. A population and a fitness function are determined.

Population is a set of chromosomes. The *k-th* chromosome from the population represents the possible solution in the form (1), which takes the form:

$$N_k=[\ n_{k1}\ ,\ n_{k2}\ ,\ \ldots\ ,\ n_{k66}\ ] \tag{4}$$

where n_{ki} – i-th gene in the *k-th* chromosome. In other words it is *k-th* proposed solution, in which n_{ki} is i-th emptied container.

The worth of function (3) is calculated for every chromosome N_k. The function (3) is here called the fitness function. The target of the evolutionary algorithm is to find chromosome N_k, for which the fitness function reaches the highest value.

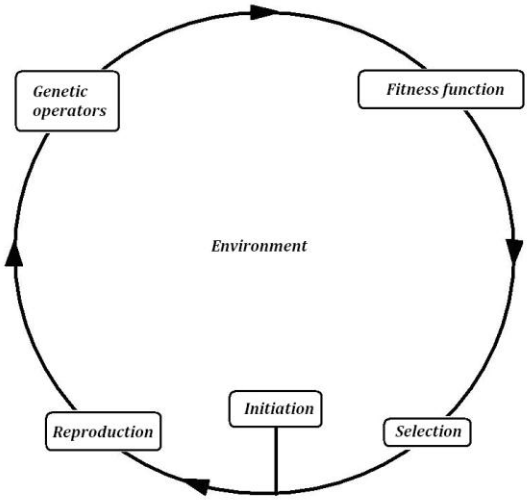

Fig. 3. The algorithm of the evolutionary optimisation
Rys. 3. Algorytm ewolucyjnej optymalizacji

Initiation

The chromosomes are randomised at first. Each chromosome is permutation of numbers {1, 2, ..., 66} picked at random. The fitness function is calculated for every chromosome.

Reproduction

Elitist model is used for this purpose [8]**.** The best chromosome replaces the worst of all the population.

Genetic operators

The chromosomes are changed a little by crossing and mutate during their all life. This evolutionary algorithm uses operators of the crossover (an one-point crossover, a two-point crossover [8]). Operators of the mutation (a position based mutation, an order based mutation, an adjacent two-job exchange [8]) were also used. They map the successive numbers to the set of permutation these numbers. So the every result of genetic operators gives the acceptable solution.

Selection

The better chromosomes remain for another life cycle. This evolutionary algorithm uses operators of the proportional selection in order to select better solutions.

There were several calculations made in this study and they are presented in table 2.

4. SOLUTION USING ARTIFICIAL IMMUNE SYSTEM

The problem of the optimisation of the route scheduling of the waste collection vehicle was also solved by the artificial immune system in this paper. The artificial immune systems are based on the defence system of living organism [2, 11].

Natural immune system reacts on attacks of antigens. It distinguishes between pathogens and own cells and eliminates pathogens. Possibility to store pathogens accelerates the body's mobilisation in the event of another attack. There are few kinds of immune cells (lymphocytes), which take part in the process of the recognition and elimination of the antigens. The B cells produce antibodies, which recognises specific group of antigens. The T cells recognise pathogens and eliminate them. They stimulate B cells and prevent the over-stimulation [5].

Each lymphocyte can recognise one kind of antigen. The B cells, which recognise antigens, are activated to proliferate rapidly. The clones can mutate. The new B cell can recognise antigens better than their parent cells. The suppression mechanism prevent over-stimulation of B cells. This process is called “a clonal selection” and is presented in the Fig. 4.

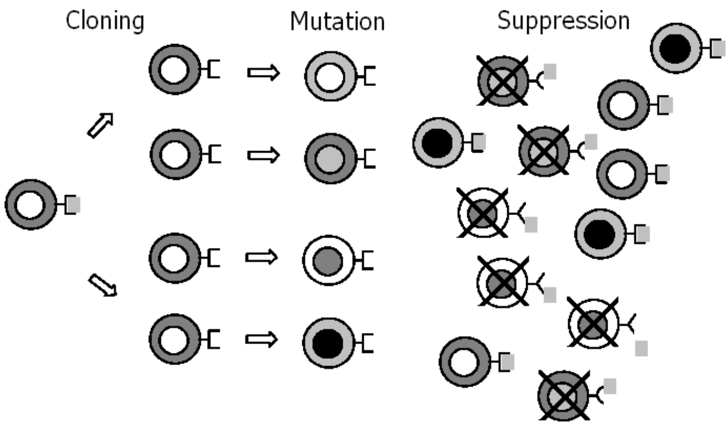

Fig. 4. Clonal selection
Rys. 4. Selekcja klonalna

Algorithm of clonal selection (Fig. 5) is used to solve optimisation problems.

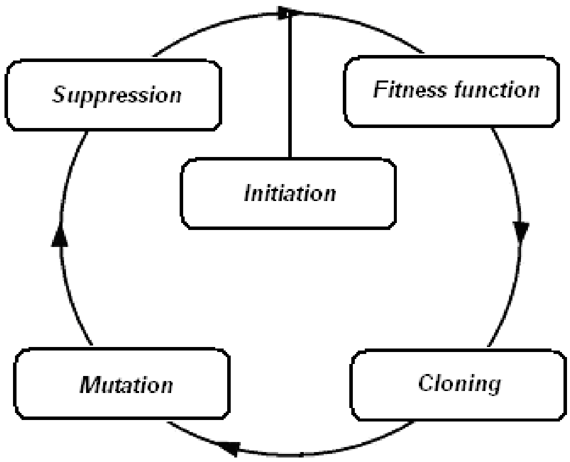

Fig. 5. The clonal selection's algorithm
Rys. 5. Algorytm selekcji klonalnej

Variables of optimisation are genes of chromosomes of antibody cells. They are also represented in the way described in formula (4). The measure of matching antibodies to the antigen is a fitness function (3).

Step 1. Initiation

Initiation is done exactly the same way as in the evolutionary algorithm.

Step 2. Cloning

The better antibodies are rapidly cloned. Number of clones was proportional to

$$\frac{F}{F_{max}} \tag{5}$$

where F_{max} – maximal value of fitness function for all population.

Step 3. Mutation

Antibodies are mutated. Part of them becomes more fitted to antigen. They will better recognise antigens. The same mutation operators, like in the evolutionary algorithm, have been used in this algorithm.

Step 4. Suppression

A suppression mechanism controls number of antibodies in the system. The most similar chromosome is selected for every chromosome. The second-best is replaced by sampling.

The steps from 2 to 4 of algorithm are repeated until satisfactory results. Calculations can also be interrupted after a given period of time.

5. CALCULATIONS

The calculations were performed on a computer equipped with an Intel Celeron CPU 3.33 GHz. This allowed to compare the calculation time for both methods.

Table 2

Solutions by evolutionary algorithm and artificial immune system

SOLUTION NUMBER	LENGTH OF ALL ROUTE OF RUBBISH DISPOSAL VAN [KM]	SOLUTION IN STEP	SOLUTION IN TIME	SEQUENCE OF EMPTYING THE CONTAINER OF GARBAGE BIN
1	218.47	72200	44	49 51 61 63 62 15 27 26 25 14 18 7 9 16 17 20 29 33 32 31 8 11 12 10 13 38 44 42 41 40 6 1 2 3 4 66 64 65 52 50 19 34 35 36 21 53 60 59 58 54 37 48 46 47 39 24 22 23 28 30 43 57 55 56 45 5
2	218.89	47233	30	24 62 61 47 37 20 34 35 36 21 8 25 27 26 13 43 45 42 41 40 49 63 65 64 66 29 28 30 23 19 51 50 32 31 33 16 9 15 14 7 53 60 58 59 52 5 2 3 1 6 54 56 57 55 44 17 10 12 11 18 39 48 46 38 22 4
3	218.79	404688	156	18 16 8 9 17 27 25 40 41 26 39 46 47 50 49 7 12 10 11 13 21 24 23 22 20 36 34 35 30 29 44 55 56 57 42 51 52 66 62 14 53 58 60 59 54 15 61 65 64 63 38 48 43 45 37 19 28 31 33 32 6 1 3 2 5 4
4	218.62	347657	134	38 47 63 61 46 37 62 66 64 65 17 16 7 9 18 21 35 34 36 20 22 24 25 27 26 15 12 10 11 13 53 60 58 59 54 30 28 23 14 8 4 2 1 3 5 40 42 41 44 45 43 56 55 57 52 39 48 50 51 49 19 29 31 33 32 6
5	218.91	436556	171	19 61 65 66 64 39 46 62 63 48 21 24 23 25 27 44 57 55 56 43 17 16 8 9 18 47 40 42 41 26 13 10 11 12 14 51 59 60 58 45 28 32 33 31 30 7 15 37 38 22 20 29 35 34 36 6 2 1 3 5 49 53 52 54 50 4
6	**217.92**	**964**	**29**	**34 35 36 30 20 13 12 11 10 14 5 3 2 1 4 52 59 58 60 54 19 24 22 23 21 61 64 65 66 62 38 48 47 46 37 18 17 8 9 16 41 40 42 43 45 28 33 32 31 29 15 25 27 26 7 53 55 56 57 44 39 63 51 49 50 6**
7	218.167	846	29	27 25 26 23 20 17 16 7 8 18 37 48 46 47 39 51 54 53 59 52 40 42 41 45 43 30 33 32 31 29 14 10 12 11 13 63 64 65 66 61 4 2 1 3 5 9 15 22 24 19 57 55 60 58 56 50 49 62 44 38 21 28 35 36 34 6
8	218.607	806	29	30 33 31 32 28 6 3 1 2 4 47 56 57 55 53 21 29 35 36 34 18 17 8 9 16 7 13 37 39 38 20 49 51 50 19 22 61 40 41 42 24 23 26 25 27 62 64 65 66 63 52 58 60 59 54 48 45 43 44 46 14 10 12 11 15 5
9	218.72	570	24	19 61 62 63 23 13 10 11 12 15 6 3 2 1 4 55 57 56 58 52 17 16 8 9 18 48 42 40 41 25 20 22 24 27 26 34 35 36 28 21 7 14 39 38 37 51 54 65 66 64 29 31 33 32 30 50 53 59 60 49 46 43 45 44 47 5
10	218.78	610	28	41 55 56 57 45 62 63 61 42 40 37 48 47 51 50 16 18 7 8 17 29 31 33 32 30 1 3 10 11 2 49 54 66 65 64 9 13 15 12 14 53 58 59 60 52 39 46 44 43 38 20 21 19 4 5 26 27 25 24 22 23 28 34 36 35 6

Artificial immune system method performed 22 calculations. The maximum length of route was 220.65 km and minimum length 217.92 km. The average value was 219.35 km with a standard deviation equal 0.77 km. The average calculation time to obtain a solution was 27.82 s with a standard deviation equal 2.48 s.

Using evolutionary algorithm was performed on 36 calculations. The maximum length of route was 222.11 km and minimum length 218.47 km. The average value was 220.07 km with a standard deviation equal 0.97 km. The average calculation time to obtain a solution was 105.39 s with a standard deviation equal 59.65 s. The fastest solution was obtained after 8 s, and the longest at 179 s.

The table 2 shows the best results of the calculations for both algorithms. Solutions from 1 to 5 were obtained using evolutionary algorithm. In solutions from 3 to 5 there were used only mutation operators. Solutions from 6 to 10 were obtained using artificial immune system. As it can be seen the difference in length of routes in the solutions are not large. The shortest path obtained using artificial immune system (option 6) and it amounts to 217.92 km.

6. CONCLUSIONS

In this paper it was presented the application of the evolutionary algorithms and the artificial immune system for the optimization the route length for waste collecting vehicles. Immune system method has simpler structure and results can be obtained faster as indicated in the example described in this paper. The next generation is formed primarily by cross-breeding parents chromosomes, and mutations occur in the minimum percentage in the used evolutionary algorithms. The antibodies multiply by cloning, and clones are mutated in the artificial immune system used to calculations. In evolutionary algorithm, the size of the next generation is controlled in the exclusive selection process, which results in increasing the advantage of one, currently the best solution. The artificial immune system uses suppression mechanism for controlling the size of the population of antibodies. It provides a variety of solutions in each generation.

The artificial immune system is simpler; the time of calculation is a bit shorter. This seems to be more favorable for the solution presented here the task and was confirmed by the obtained results.

References

1. Applegate D.L., Bixby R.E., Chvátal V., Cook W.J.: *The Traveling Salesman Problem: A Computational Study.* Princeton University Press, 2006.
2. Castro L.N., Zuben F.J.: *Artificial Immune Systems, Part I – Basic Theory and Applications*. Technical Report, TR – DCA 01/99, December, 1999.
3. Dorigo M., Gambardella L.: *Ant Colony System: A Cooperative Learning Approach to the Travelling Salesman Problem.* IEEETrans, Evolutionary Computation, vol. 1, Issue 1, 1997, p. 53-66.
4. Dyrektywa Rady i Parlamentu Europejskiego 94/62/EC z 15 grudnia 1994 w sprawie opakowań i odpadów opakowaniowych (OJ L 365 31.12.1994).
5. Gołąb J., Jakóbisiak M., Lasek W., Stokłosa T.: *Immunologia.* PWN, 2008.
6. Korzeniowski A., Skrzypek M.: *Ekologistyka zużytych opakowań*. Instytut Logistyki i Magazynowania, Poznań, 1999.
7. Korzeń Z.: *Ekologistyka*. Instytut Logistyki i Magazynowania, Poznań, 2001.
8. Michalewicz Z.: *Genetic Algorithms + data Structures = Evolutionary Programs*. Springer-Verlag, Berlin, 1996.
9. Rosik-Dulewska Cz.: *Podstawy gospodarki odpadami.* PWN, Warszawa, 2007.
10. Skrzypek M.: *Ekologistyka stałych odpadów komunalnych.* Logistyka 5/2002, p. 18-20.
11. Wierzchoń S.T.: *Sztuczne systemy immunologiczne.* Teoria i zastosowania. Akademicka Oficyna Wydawnicza EXIT, Warszawa, 2001.

Received 12.04.2010; accepted in revised form 23.08.2011