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Mathematical modelling of traveling salesman problem (TSP) by implementing simulated annealing and genetic algorithms

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Abstract. The Traveling Salesman Problem (TSP) is very well known as one of the optimization problems of circuit of Hamiltonian , which will seek for the shortest route that must be passed by a number of city salesmen exactly once and will return to the initial city. Genetic Algorithm (GA) and Simulated Annealing (SA) are one method that can be used in TSP case. Fertilizer distribution at PT. Sahabat Mewah dan Makmur (SMM) in Belitung which is one of the branches of PT. Austindo Nusantara Jaya Group does not yet have an optimal fertilizer distribution schedule, where when fertilizer will be distributed from the starting point of distribution to the location of storage warehouses, it is not determined which location points will receive delivery, shipments are made to warehouse locations that still have enough storage space or stacked in the nearest warehouse. PT.SMM distributes fertilizer from Port of Tanjung Pandan to warehouses in Jangkang, Balok, Ladang Jaya, Sari Bunga, and Aik Ruak. The results show that in the GA of 120 routes, there are 8 routes with a distance of 175 km; In SA, the shortest distance is equal to GA, which is 175 km.

1. Introduction
Optimization is the process of making something better than before or the process of finding the best solution (the optimal value) from the optimization problem [1,2]. One optimization problem is determining the shortest route. In general, determining the shortest route can use conventional methods [3, 4] and heuristic methods. Conventional methods are easier to understand than heuristic methods, because in the conventional method only comparing the distance and finding the shortest distance while in the heuristic method the results obtained are more varied, more accurate, the error rate is smaller, and the calculation time is more short [5].

Traveling Salesman Problem (TSP) is one form of optimization problem from the Hamiltonian circuit (the path that passes every point exactly once, except the origin and end points that are passed twice) [6], where the shortest route to be passed by a number of city salesmen exactly one time and returned to the city early (starting point of distribution) [7,8].

The heuristic method consists of various kinds of algorithms, one of which are genetic algorithm and simulated annealing [5-9]. Genetic Algorithm (GA) branch of the evolution algorithm which can be said as an adaptive method commonly used to solve value search problems in an optimization problem [7-10]. GA is based on genetic processes that exist in living things [7-11], in this study based on the distribution route and distance traveled. GA can be used to find solutions to problems in the real world whether simple or complex problems, if well designed it will produce an optimum solution [8, 9]. In this study, the GA stage includes determining a possible distribution route to be a solution, evaluating

distribution routes, calculating convergent percentages of distribution routes, checking stop conditions, selecting distribution routes, exchanging selected distribution routes, mutating selected distribution routes, checking again the distribution route chosen was the final solution [7].

Simulated Annealing (SA) is an algorithm that is applied with the aim of finding an approach to the global optimum solution of a combinatorial problem, where the existing search space for solutions is too broad, so there is no way to find exact solutions to these problems [12-16]. SA was developed based on the idea of the mechanism of cooling behavior and the process of crystallization (annealing) of hot material [12-17]. In this article, the SA stage is to bring up the initial state which is the distribution route, calculate the amount of distance traveled, update the distribution route, calculate the number of mileage distribution routes that have been updated, choose a random number (0,1], calculate the probability based on Boltzmann distribution, compare the value of Boltzmann probability calculation and random generated value [18].

Previously, research on GA and SA had been carried out by Widyadana and Pamungkas [12], which concluded that in terms of performance and processing time SA was superior to GA. In general, the advantages of GA include optimizing variables, can be used on extensive data searches, providing a list of optimal variables not only a single solution, can be used on flexible data [19,20]. In general, the advantages of SA are being able to avoid local minimum traps [21].

At present, the oil palm plantation industry has mushroomed in almost all regions in Indonesia. With the many companies and communities that have oil palm plantations, of course competition in the number of production, quality of production and human resources is increasingly stringent from day to day. Good and correct management of oil palm plants will produce good quality production, in managing oil palm plantations fertilizers are usually needed as a source of nutrients needed by plants that lack nutrients. Fertilizer distribution at PT. Sahabat Mewah dan Makmur (SMM) in Belitung which is one of the branches of PT. Austindo Nusantara Jaya Group does not yet have an optimal fertilizer distribution schedule, where when fertilizer will be distributed from the starting point of distribution to the location of storage warehouses it is not determined which location points will receive delivery, shipments are made to warehouse locations that still have enough storage space or stacked in the nearest warehouse. Optimal fertilizer distribution is expected to make it easier for employees to distribute fertilizer from the distribution starting point to the intended distribution points and reduce fertilizer delivery costs. That is why the research on designing the mathematical modelling of distribution routes of this company is crucial to be conducted.

2. Method

The methods used are Genetic Algorithm and Simulated Annealing. The data used in this study was obtained from one of the branches of the ANJ Group in Belitung, namely PT. Sahabat Mewah dan Makmur (SMM). The data used is secondary data (is from PT. SMM in 2016) about the starting point of the location and the location of the destination for the distribution of fertilizers along with the distance traveled. The research was conducted at the Mathematics Department, Faculty of Mathematics and Natural Sciences, Sriwijaya University.

Implementation of TSP with GA and SA on the problem of fertilizer distribution at PT. SMM, where with the starting point of distribution is Port of Tanjung Pandan, Belitung and distribution points for warehouse purposes in Jangkang, Balok, Ladang Jaya, Sari Bunga, and Aik Ruak.

3. Result and Discussion

3.1. Genetic Algorithm (GA)

Some terms that must be understood in GA are Genotype (Genes), Allele, Chromosome, Individual, Population and Fitness Value [22]. In this study, genes are sequences of vertex numbers (position) from the intended distribution and location of warehouses, alleles are numbers given at vertex, Chromosomes are fertilizer distribution routes of PT. SMM, Individuals are distances that may be a solution, Population is a set of distances travel that might be a solution, and fitness value is the number of mileage of the distribution route.

Table 1 states the distribution location where vertex 1 states Port of Tanjung Pandan as the starting point for distribution, vertex 2 is warehouse location in Jangkang, vertex 3 explains warehouse location in Balok, vertex 4is warehouse location in Ladang Jaya, vertex 5 describes the warehouse location in Sari Bunga, and vertex 6 denotes the warehouse location in Aik Ruak.

Table 1. Distribution location.

Number of vertex	Distribution location
1	Port of Tanjung Pandan
2	Jangkang Estate
3	Balok Estate
4	Ladang Jaya Estate
5	Sari Bunga Estate
6	Aik Ruak Estate

Then, Table 2 states the distance between distribution locations where 1-2 states the distance from the Port of Tanjung Pandan to the warehouse location in Jangkang and 2-1 states the distance from the warehouse location in Jangkang to Tanjung Pandan Port with the same distance of 45 km, and so on until the route sequence number 5-6 and 6-has the same distribution distance of 22 km.

Table 2. Distance between distribution location.

Route Sequence Number		Distance Between Distribution Location (Km)
$1-2$	$2-1$	45
$1-3$	$3-1$	55
$1-4$	$4-1$	58
$1-5$	$5-1$	65
$1-6$	$6-1$	70
$2-3$	$3-2$	10
$2-4$	$4-2$	13
$2-5$	$5-2$	20
$2-6$	$6-2$	25
$3-4$	$4-3$	23
$3-5$	$5-3$	35
$3-6$	$6-3$	33
$4-5$	$5-4$	7
$4-6$	$6-4$	15
$5-6$	$6-5$	22

After describing the data, it is continued by determining the distribution route. In the TSP coding used is permutation encoding, the distribution route is permutation *vertex* 1, 2, 3, 4, 5, and 6. Where the distribution route consists of:

$$(n-1)! = (6-1)! = 5! = 5 \times 4 \times 3 \times 2 \times 1 = 120 \text{ routes}$$

Distribution routes are formed randomly, expressed as vector *v*:

$$v_k = [g_1, g_2, \dots, g_n] \text{ with } 1 \leq k \leq size \ of \ population$$

With:

v_k : Distribution route to $- k$

$g_1, g_2, \dots, g_n$: *vertex* to 1, 2, …, n

From the 120 routes that might be the solution, 15 routes with different amounts of mileage, are randomly selected using Microsoft Excel (in Table 3) were obtained. Table 3 shows the distribution

routes and the number of distances, as number 1 (v_1) the distribution routes is $1 - 4 - 5 - 6 - 3 - 2 - 1$ state the distribution route from Port of Tanjung Pandang – Ladang Jaya – Sari Bunga – Aik Ruak – Balok – Jangkang – Port of Tanjung Pandan with a total distance of 175 km, and so on until v_{15} (as described in the same way as v_1).

Table 3. Distribution routes with different amounts of mileage once randomly selected using Microsoft Excel from 120 routes that might be solutions.

Number	Distribution Routes (v_k)	Amount of Mileage $f(v_k)$ (km)
$1 = v_1$	$1 - 4 - 5 - 6 - 3 - 2 - 1$	$58 + 7 + 22 + 33 + 10 + 45 = 175$
$2 = v_2$	$1 - 6 - 4 - 5 - 2 - 3 - 1$	$70 + 15 + 7 + 20 + 10 + 55 = 177$
$3 = v_3$	$1 - 4 - 6 - 5 - 2 - 3 - 1$	$58 + 15 + 22 + 20 + 10 + 55 = 180$
$4 = v_4$	$1 - 6 - 4 - 5 - 3 - 2 - 1$	$70 + 15 + 7 + 35 + 10 + 45 = 182$
$5 = v_5$	$1 - 4 - 6 - 5 - 3 - 2 - 1$	$58 + 15 + 22 + 35 + 10 + 45 = 185$
$6 = v_6$	$1 - 2 - 5 - 4 - 3 - 6 - 1$	$45 + 20 + 7 + 23 + 33 + 70 = 198$
$7 = v_7$	$1 - 5 - 4 - 3 - 2 - 6 - 1$	$65 + 7 + 23 + 10 + 25 + 70 = 200$
$8 = v_8$	$1 - 2 - 4 - 3 - 6 - 5 - 1$	$45 + 13 + 23 + 33 + 22 + 65 = 201$
$9 = v_9$	$1 - 3 - 4 - 2 - 6 - 5 - 1$	$55 + 23 + 13 + 25 + 22 + 65 = 203$
$10 = v_{10}$	$1 - 4 - 5 - 3 - 2 - 6 - 1$	$58 + 7 + 35 + 10 + 25 + 70 = 205$
$11 = v_{11}$	$1 - 2 - 5 - 3 - 6 - 4 - 1$	$45 + 20 + 35 + 33 + 15 + 58 = 206$
$12 = v_{12}$	$1 - 2 - 6 - 5 - 3 - 4 - 1$	$45 + 25 + 22 + 35 + 23 + 58 = 208$
$13 = v_{13}$	$1 - 4 - 3 - 6 - 2 - 5 - 1$	$58 + 23 + 33 + 25 + 20 + 65 = 224$
$14 = v_{14}$	$1 - 6 - 3 - 5 - 2 - 4 - 1$	$70 + 33 + 35 + 20 + 13 + 58 = 229$
$15 = v_{15}$	$1 - 5 - 3 - 4 - 2 - 6 - 1$	$65 + 35 + 23 + 13 + 25 + 70 = 231$

After determining the distribution route, continue the GA stage by evaluating the distribution route selected in Table 3, so that the number of mileage $f(vk)$ is obtained (in Table 3). Based on Table 3 and evaluation of the distribution route above, the distribution route v_1 is the best distribution route with the smallest mileage.

Then proceed with distribution route selection using the roulette wheel, with the roulette wheel stage (determine the minimum function of each distribution route mileage, determine the total evaluation of the distribution route mileage, determine the probability value for each distribution route, determine the cumulative probability value of each route distribution) based on the conditions at that stage, the distribution route v_1 obtained through selection is the same as the v_8 distribution route before being selected. New distribution route after going through the roulette wheel selection stages, is presented in Table 4.

Table 4. New distribution route after going through the roulette wheel selection stages.

Distribution Routes (v_k)	Distribution Routes on Table 4 are the same with Distribution Route on Table 3
$1 - 2 - 4 - 3 - 6 - 5 - 1$	$v_1 = v_8$
$1 - 4 - 6 - 5 - 2 - 3 - 1$	$v_2 = v_3$
$1 - 2 - 6 - 5 - 3 - 4 - 1$	$v_3 = v_{12}$
$1 - 4 - 5 - 3 - 2 - 6 - 1$	$v_4 = v_{10}$
$1 - 6 - 4 - 5 - 3 - 2 - 1$	$v_5 = v_4$
$1 - 4 - 5 - 6 - 3 - 2 - 1$	$v_6 = v_1$
$1 - 5 - 4 - 3 - 2 - 6 - 1$	$v_7 = v_7$
$1 - 4 - 6 - 5 - 3 - 2 - 1$	$v_8 = v_5$
$1 - 6 - 4 - 5 - 2 - 3 - 1$	$v_9 = v_2$
$1 - 2 - 5 - 4 - 3 - 6 - 1$	$v_{10} = v_6$
$1 - 3 - 4 - 2 - 6 - 5 - 1$	$v_{11} = v_9$
$1 - 5 - 3 - 4 - 2 - 6 - 1$	$v_{12} = v_{15}$
$1 - 2 - 5 - 3 - 6 - 4 - 1$	$v_{13} = v_{11}$
$1 - 4 - 3 - 6 - 2 - 5 - 1$	$v_{14} = v_{13}$
$1 - 6 - 3 - 5 - 2 - 4 - 1$	$v_{15} = v_{14}$

After the distribution route selection, the GA stage is continued with cross-breeding. In this study, the process of interbreeding uses the Single-Point Crossover (SPX) method. In the SPX stage, the crossover (pc) probability is assumed to be 0.25. After the SPX stage is complete the distribution route chosen is the distribution route v_{11} and v_{15}. Distribution routes after crossing using the SPX method are as follows.

Table 5. Distribution routes after crossing using the SPX method.

Distribution Routes (v_k)
$1 - 2 - 4 - 3 - 6 - 5 - 1$
$1 - 4 - 6 - 5 - 2 - 3 - 1$
$1 - 2 - 6 - 5 - 3 - 4 - 1$
$1 - 4 - 5 - 3 - 2 - 6 - 1$
$1 - 6 - 4 - 5 - 3 - 2 - 1$
$1 - 4 - 5 - 6 - 3 - 2 - 1$
$1 - 5 - 4 - 3 - 2 - 6 - 1$
$1 - 4 - 6 - 5 - 3 - 2 - 1$
$1 - 6 - 4 - 5 - 2 - 3 - 1$
$1 - 2 - 5 - 4 - 3 - 6 - 1$
$1 - 3 - \mathbf{3} - \mathbf{5} - \mathbf{2} - \mathbf{4} - \mathbf{1}$
$1 - 5 - 3 - 4 - 2 - 6 - 1$
$1 - 2 - 5 - 3 - 6 - 4 - 1$
$1 - 4 - 3 - 6 - 2 - 5 - 1$
$1 - 6 - \mathbf{4} - \mathbf{2} - \mathbf{6} - \mathbf{5} - \mathbf{1}$

After the crossing process is complete, the GA stage is followed by a mutation on the distribution route using Microsoft Excel randomized distribution points so that it is obtained:

Table 6. Result of randomization vertex.

Vertex	Result of randomization vertex
1	3
2	1
3	4
4	6
5	2
6	5

From table 6 after vertex is randomized, vertex 1 is replaced by vertex 3, vertex 2 is replaced by vertex 1, and so on. The number of distribution routes that have mutated in one generation is $n*$ *pop_size* = $6(15) = 90$ routes. If the specified mutation probability value (*pm*) is 0.01 then it is expected that $0.9 \approx$ 1 mutation per route. Each distribution route has the same opportunity to experience mutations, therefore random numbers that have a range (0,1] will be selected using Microsoft Excel as many as 90. Distribution routes that have random numbers smaller than pm = 0.01 are chosen as mutations. The distribution routes selected are shown in Table 7.

Table 7. Distribution routes chosen to be moved.

Sequence Position of Random Numbers	Distribution route to -	Numbering Route to -	Random Numbers
13	12	3	0.001087

From Table 7, the position of a random number sequence that has a value of 0.001087 which is randomized using Microsoft Excel is number 13, with the distribution route that experiences mutations is the 12th distribution route in Table 3 and the randomized distribution point is the 3rd point, so that the distribution route is obtained after the mutation:

Table 8. Distribution routes after the mutation.

Distribution Routes (v_k)
$1 - 2 - 4 - 3 - 6 - 5 - 1$
$1 - 4 - 6 - 5 - 2 - 3 - 1$
$1 - 2 - 6 - 5 - 3 - 4 - 1$
$1 - 4 - 5 - 3 - 2 - 6 - 1$
$1 - 6 - 4 - 5 - 3 - 2 - 1$
$1 - 4 - 5 - 6 - 3 - 2 - 1$
$1 - 5 - 4 - 3 - 2 - 6 - 1$
$1 - 4 - 6 - 5 - 3 - 2 - 1$
$1 - 6 - 4 - 5 - 2 - 3 - 1$
$1 - 2 - 5 - 4 - 3 - 6 - 1$
$1 - 3 - 3 - 5 - 2 - 4 - 1$
$1 - 5 - \mathbf{4} - \mathbf{3} - 2 - 6 - 1$
$1 - 2 - 5 - 3 - 6 - 4 - 1$
$1 - 4 - 3 - 6 - 2 - 5 - 1$
$1 - 6 - 4 - 2 - 6 - 5 - 1$

The last stage of GA is decoding, where recalculation is carried out on the number of distribution routes that have gone through the stages of selection, crossing and mutation. The decoding result is v_{11}

and v_{15} which is not Hamiltonian (one vertex is passed twice and there is another vertex that is not skipped).

3.2. Simulated Annealing (SA)

The Simulated Annealing steps are as follows:

1) Select the initial *state* S_0, for example is $1 - 2 - 3 - 6 - 4 - 5 - 1$

2) Calculate *energy* E_0 *pada* S_0, is $1 - 2 - 3 - 6 - 4 - 5 - 1 = 45 + 10 + 33 + 15 + 7 + 65 = 175$ km.

3) State S updates with the update rules according to the problem being S_i, is:

    a. Choose randomly r_1 dan r_2 with points (1,6], using Microsoft Excel.

    b. For *state* values at position r_1 until position r_2 is exchanged. Obtained $r_1 = 2$ and $r_2 = 3$

       State before being *update* $1 - 2 - 3 - 6 - 4 - 5 - 1$

       State after being *update* $1 - 3 - 2 - 6 - 4 - 5 - 1$

    c. Calculate *energy* E_i, $1 - 3 - 2 - 6 - 4 - 5 - 1 = 55 + 10 + 25 + 15 + 7 + 65 = 177$ km.

4) Select uniform distribution random number $p = (0.1]$; $p = 0.396478$ (using Microsoft Excel)

5) Ifa $p < e^{-\frac{\Delta E}{kT}}$, the *state* is accepted; if doesn't, the *state* is rejected. Calculate *Boltzmann* probability with T = 0,2; obtained:

$$p(E) = e^{-\frac{E_i - E_0}{kT}} = e^{-\frac{177 - 175}{(1,380658 \times 10^{-23})0,2}} = e^{-\frac{2}{2,761316 \times 10^{-24}}} = 1$$

because $p < e^{-\frac{\Delta E}{kT}}$, so the *state* is accepted.

6) Back to step 3, because the updated state distance is not the shortest route, repeat until the updated route is the shortest route, so the shortest route in SA is route $1 - 2 - 3 - 6 - 5 - 4 - 1$ with mileage of 175 km.

From the 120 possible routes can be solution, there are 15 different distances are 8 routes with mileage of 175 km, 12 routes with mileage of 177 km, 8 routes with mileage of 180 km, 4 routes with mileage of 182 km, 4 routes with mileage of 185 km, 12 routes with mileage of 198 km, 4 routes with mileage of 200 km, 12 routes with mileage of 201 km, 16 routes with mileage of 203 km, 4 routes with mileage of 205 km, 4 routes with mileage of 206 km, 20 routes with mileage of 208 km, 4 routes with mileage of 224 km, 4 routes with mileage of 229 km, and 4 routes with mileage of 231 km.

Based on Table 3, as for the shortest route obtained from GA with a distance of 175 km, namely:

1) Port of Tanjung Pandan - Jangkang - Balok - Aik Ruak - Sari Bunga - Ladang Jaya – Port of Tanjung Pandan;

2) Port of Tanjung Pandan - Jangkang - Balok - Aik Ruak - Ladang Jaya - Sari Bunga – Port of Tanjung Pandan;

3) Port of Tanjung Pandan - Jangkang - Ladang Jaya - Sari Bunga - Aik Ruak - Balok – Port of Tanjung Pandan;

4) Port of Tanjung Pandan - Jangkang - Sari Bunga - Ladang Jaya - Aik Ruak - Balok – Port of Tanjung Pandan;

5) Port of Tanjung Pandan - Balok - Aik Ruak - Ladang Jaya - Sari Bunga - Jangkang – Port of Tanjung Pandan;

6) Port of Tanjung Pandan - Balok - Aik Ruak - Sari Bunga - Ladang Jaya - Jangkang – Port of Tanjung Pandan;

7) Port of Tanjung Pandan - Ladang Jaya - Sari Bunga - Aik Ruak - Balok - Jangkang – Port of Tanjung Pandan;

8) Port of Tanjung Pandan Port - Sari Bunga - Ladang Jaya - Aik Ruak - Balok - Jangkang – Port of Tanjung Pandan;

4. Conclusion

From the calculations in SA, the shortest route for the distribution of fertilizer PT. SMM is the Port of Tanjung Pandan - Jangkang - Balok - Aik Ruak - Sari Bunga - Ladang Jaya - Port of Tanjung Pandan with a distance of 175 km.

The results of calculations in GA and SA are the same as the results, the shortest route of fertilizer distribution is obtained in PT. SMM with a distance of 175 km. From the length of time spent to calculate the shortest route with GA and SA, the calculation using SA is faster than GA.

5. References

[1]   Haupt R L and Haupt S E 2004 *Practical Genetic Algorithms Second Edition* (New Yersey: Jon Wiley and Sons, Inc)

[2]   Gunantara N 2018 *Teknik Optimasi* (Bali: Udayana University Press)

[3]   Puspita F M, Cahyono E S, Rahayu S and Sintia B L 2018 *The E3S Web of Conferences* **68** 01025

[4]   Puspita F M, Hartono Y, Syaputri N Z, Yuliza E and Pratiwi W D 2018 *IJECE* **8** 4382

[5]   Hardjasutanto F O 2011 *Penerapan Algoritma Semut untuk Pencarian Jalur Terpendek* (Bandung: Institut Teknologi Bandung)

[6]   Wilson R J 2016 *Pengantar Teori* Graf Ed 5 (Jakarta: Erlangga)

[7]   Fanggidae A and Lado F R 2015 *Algoritma Genetika dan Penerapannya* (Yogyakarta: Teknosain)

[8]   Kusrini and Istiyanto J E 2007 *Jurnal Informatika* **8** 109

[9]   Mahmudy W F 2013 *Algoritma Evolusi* (Malang: Brawijaya University)

[10]   Sari F H, Sugiharti E, and Dwijanto 2013 *UNNES Journal of Mathematics* **2** 116

[11]   Shukla A, Tiwari R, and Kala R 2010 *Real Life Applications of Soft Computing* (London: CRC Press)

[12]   Widyadana I G A and Pamungkas A 2002 *Jurnal Teknik Industri* **4** 26

[13]   Corana A, Marchesi M, Martini C, and Ridella S 1987 *ACM Transactions on Mathematical Software (TOMS)* **13** 262

[14]   Kirkpatrick S, Gelatt CD, and Vecchi MP 1983 *Science* **220** 671

[15]   Miki M, Hiroyasu T, and Ono K 2002 *Simulated Annealing with Advanced Adaptive Neighborhood* In Second international workshop on Intelligent systems design and application (Georgia: Dynamic Publishers, Inc) pp 113-118

[16]   Miki M, Hiwa S, and Hiroyasu T 2006 *Simulated Annealing using an Adaptive Search Vector* In Conference on Cybernetics and Intelligent Systems (Thailand: IEEE) pp 1-6

[17]   Ingber L and Rosen B 1992 *Mathematics and Computer Modelling* **16** 87

[18]   Basuki A, Huda M, and Santoso T B 2004 *Modeling dan Simulasi* (Jakarta: IPTAQ Mulia Media)

[19]   Haupt R L and Haupt S E 2004 *Practical Genetic Algorithms* Second Edition (New Yersey: Jon Wiley and Sons, Inc)

[20]   Gen M and Cheng R 2000 *Genetic Algorithms and Engineering Optimization* (New York: John Wiley & Sons, Inc)

[21]   Chibante R 2010 *Simulated Annealing Theory with Applications* (Croatia: Sciyo)

[22]   Weise T 2009 *Global Optimization Algorithms Theory and Application Second Edition* online: http://www.it-weise.de