

ICT for Planning and Optimization of Transport Routes with Time Windows

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Abstract. In the paper, authors analyze information and communication technology (ICT) for planning and optimization of transport routes with time windows. This analysis helps to choose the method for solving a vehicle routing problem with time windows (VRPTW) with optimal result for decision-maker, as well as determine the influence of the internal parameters of the selected method on the result of its application. Currently, there are several well-known methods and algorithms in ICT for planning and optimization of transport routes with time windows, in particular: saving and sweeping algorithms, ant colony optimization (ACO) method, artificial bee colony (ABC) method, etc. The result of the analysis showed that: a) the speed and quality of the search for solutions can be improved by adjusting internal parameters of researched methods, b) depending on the size and specificity of the in-coming data, different methods can be more or less suitable. In this paper, the authors discussed the features of using the ACO method and the ABC method to solve VRPTW and influence of their application on the optimality of the results. Simulation results show the need and feasibility of using ICT in VRPTW.

Keywords: Information and Communication Technology, Planning, Optimization, Transport Route, Time Window, Ant Colony Optimization Method, Artificial Bee Colony Method.

1 Introduction

The development and globalization of the market contributes to increased competition in it. That is why many companies have to expand their sphere of influence, expanding the sales area of their goods or services. Along with this, the delivery process is becoming more expensive. The share of logistics costs continues to grow, as supply chains are becoming more complicated, and requirements to the quality of service and the provision of the necessary service are growing [1-4].

The quality of customer service can also affect transportation planning. Each client also plans his day and work and is interested in the efficient use of his time. That is why, he wants to be served in a specific period of time. If the company cannot serve it

at this time (for those cases when the client and the carrier company have agreed on the delivery time), then the rating of the company drops sharply, which means that the company may lose the client and its profit [1].

Due to the large number of methods for planning and optimizing routes, the company is faced with the need to choose one of them. Depending on the initial conditions and factors that are taken into account, it is better to use different methods, since they give different percentages of accuracy and error of the results [3].

This paper is devoted to the analyze information and communication technology (ICT) for planning and optimization of Vehicle Routing Problem with Time Windows (VRPTW) using various meta-heuristic methods [5-7].

2 Related Works and Problem Statement

The problem of transportation planning has existed since the first vagrant merchants appeared who transported their goods from city to city. The first written mention of this problem dates back to 1882 in the book "Salesman – how he should behave and what he must do in order to be successful and mark success in business – the advice of the old courier" and it was first mathematically described in 1930 by Karl Menger. It was called Travelling Salesman Problem. It consisted of the formation of a minimum route along which all cities will be visited at least once and which will close in the first city [2].

But in the era of capitalization and globalization, the problem of transportation planning covered not only the sphere of trade and became much more complex than a traveling salesman problem. Routes can be formed not for one, but for several vehicles of one or different types, and other factors can be taken into account during their formation, except for the minimum path length [4].

So, vehicle routing problem (VRP) is a combinatorial optimization problem in which a set of routes to several remote points of consumption should be defined for a fleet of vehicles located in one or more depots [5].

The task refers to NP-hard classes, that is, the number of options for solving the problem and the time to find the best option with an increase in the number of nodes grows exponentially [2, 4].

Methods of forming transport routes are divided into several groups. They include [8-10]:

1. Exact methods - give the greatest accuracy of the result, but require a lot of time and resources. These include: the branch and bound method, the clipping branch method, the exhaustive search method [8];
2. Heuristic methods - require less time, but do not give such accuracy, but it is quite large. Among them: Clark-Wright algorithm, a method based on coincidences; sweeping algorithm and the like [2, 7];
3. Metaheuristic methods - based on a more thorough study of the most promising parts of the solution space. They give greater accuracy than heuristic methods. The following algorithms exist: ant algorithm, wolf pack algorithm, genetic algorithm, bee colony algorithm, swarm of particles, taboo search [3, 10].

The probabilistic component of metaheuristic methods gives them a significant advantage when choosing them for solving a VRPTW, since they also allow to take into account those solutions that in other methods can be truncated by the indicated restrictions, because, despite this, they may be in part of the solution domain with target function with the best value [11-15].

For further research were selected Ant Colony Optimization method (ACO), Artificial Bee Colony method (ABC) [16-18, 21, 22].

3 Using of ACO and ABC methods for solving VRPTW

The principle of the ACO method (Fig. 1) is based on the behavior of the ant colony in nature, namely the labeling of more successful pathways with a large amount of pheromone [16, 17].

In general, ants move in search of food in random order. If one of them finds food, then he goes back to the anthill, marking the path with pheromones. Other ants, finding a trail of pheromones, go to the place of discovery, following the path and supplementing it with their pheromones. If there are two paths from the find point, then more ants will have time to go along the short path, which means that more pheromones will remain on it, and it will be more attractive. Over time, the pheromones erode and the trail loses its appeal [18-20].

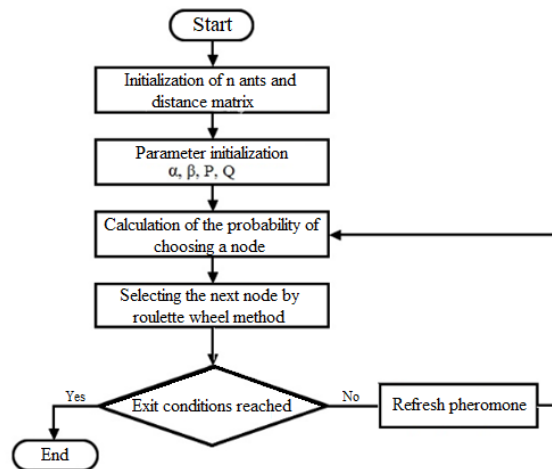


Fig. 1. ACO method.

The ABC method (Fig. 2) operates on the principle of the behavior of a bee colony in nature, namely the exploration of the space around the hive in order to search for nectar with its subsequent collection. For this, there are various types of bees in the colony: scout bees and working forager bees (in addition to them, there are drones and a uterus in the colony that are not involved in the collection of nectar). Scouts conduct

research on the space surrounding the hive and report information on promising places where the largest amount of nectar was found (there is a special mechanism called bee dance for exchanging information in the hive). Then, in the most promising areas, worker bees fly out, which collect nectar, while simultaneously updating the information of scouts on the amount of nectar in a certain area indicated by the scout. The work of these types of bees in the hive provides effective exploration of the surrounding space and the collection of nectar [21, 22].

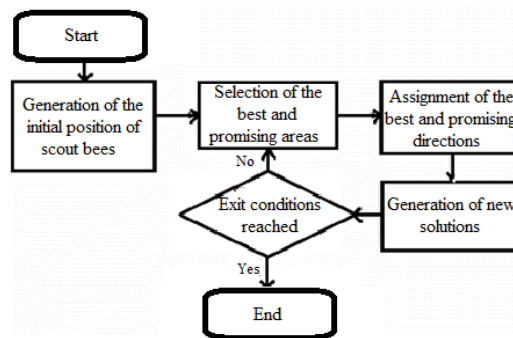


Fig. 2. ABC method.

According to the ABC method, each scout bee finds a certain random solution, and depending on whether this area is assigned to the best or promising areas, forager bees search in the vicinity of these solutions [4, 21, 22].

4 Modeling Results and Comparative Analysis of ACO and ABC Methods

For the test, a task with eleven nodes was selected: one “zero” storage and ten nodes to which it was necessary to deliver the ordered quantity of goods in a specific period of time.

ACO method. The so-called “greed” parameter α of ACO method is a parameter that determines the degree of influence of the pheromone concentration when choosing the next node [16-20].

The larger the parameter α , the greater the influence of pheromone concentration on the edge when calculating the probability of choosing a particular node (Fig. 3).

Thus, on Fig. 3, e it is seen that the larger the parameter α , the faster the search for the optimal solution is performed. It is clearly seen that the best average time use efficiency (percentage of time spent on the journey and for unloading and placing orders) was obtained at $\alpha = 0$, but the smallest deviation from the best found path length and the least time was obtained at $\alpha = 0.3$, therefore, for further testing decided to leave it.

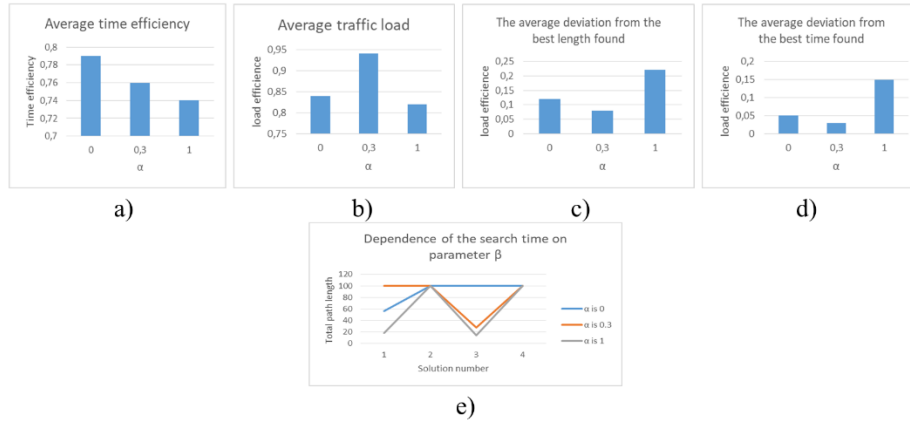


Fig. 3. The dependence of the results on α : a) the effectiveness of the use of spring; b) transport load efficiency; c) deviations from the best found length; d) deviation from the best found time; e) search time.

The larger the parameter β , the more the time spent on its maintenance with the corresponding fines affects the probability of choosing a node.

The Fig. 4, e shows that the faster the search is performed at $\beta = 0.75$ and the highest accuracy of the results is achieved when $\beta = 0.6$.

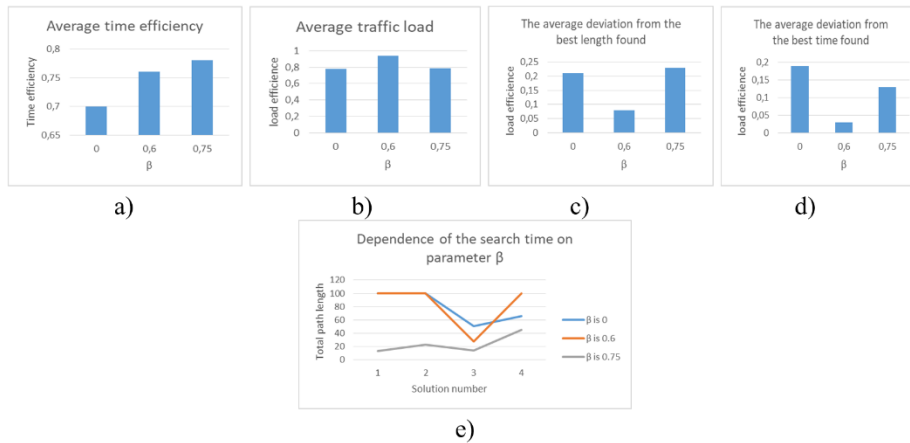


Fig. 4. The dependence of the results on β : a) the effectiveness of the use of spring; b) transport load efficiency; c) deviations from the best found length; d) deviation from the best found time; e) search time.

ABC method. In different sources and for different types of combinatorial optimization problems, a different ratio of different types of bees in the colony is recommended. For the transport task in [4, 7, 23-25] it is recommended to choose the following ratio: 20% inactive bees, 50% active and 30% scout bees.

Fig. 5 shows that the most suitable number of bees in the colony for the given test data is 100 bees, because with it the result is the most accurate.

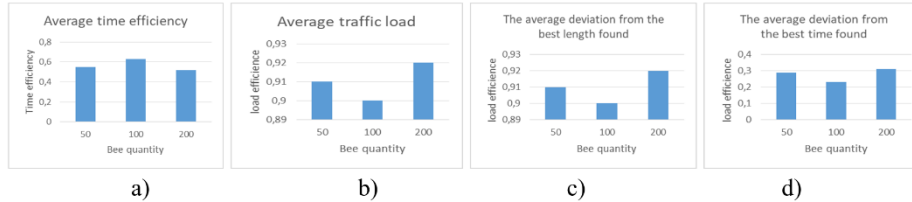


Fig. 5. The dependence of the results on the total number of bees in the colony: a) the effectiveness of the use of spring; b) transport load efficiency; c) deviations from the best found length; d) deviation from the best found time.

Fig. 6 shows that the best accuracy in length is obtained at $MV = 100$, but the search speed is better at $MV = 200$.

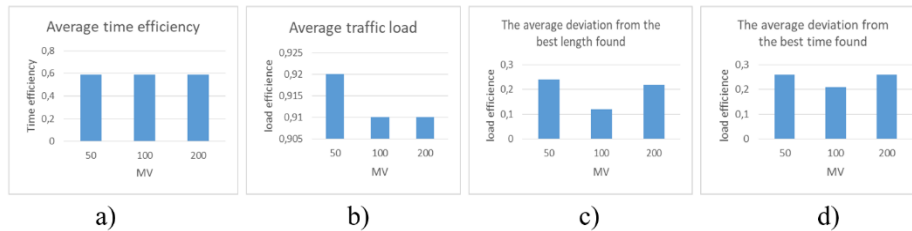


Fig. 6. The dependence of the results on the total number of bees in the colony: a) the effectiveness of the use of spring; b) transport load efficiency; c) deviations from the best found length; d) deviation from the best found time.

Next, these methods are compared according to criteria. Thus, the results of a comparison of the two methods can be seen in Table 1.

Table 1. The result of a pairwise comparison of ABC and ACO methods.

Criterion	ABC	ACO
Deviation of route lengths from the best solution found by both methods		*
Deviation of service time of routes from the best solution found by both methods	*	
Time efficiency in routes		*
Transport load efficiency	*	*
Solution search time		*

So, from the table it becomes clear that the ACO method for a number of parameters gives better results than the ABC method. These parameters are deviation of route lengths from the best solution found by both methods; time efficiency in routes, solution search time.

5 Conclusions

In this paper, the importance of considering customer service waiting times and the main factors that affect customer service time were considered.

The influence of the values of the main internal parameters of the ABC and ACO methods on the found solution was examined and a comparative analysis of both methods was performed. As a result of the analysis, it was found that the ACO method is more suitable for solving VRPTW according to most criteria.

References

1. Golden, B., Raghavan, S., Wasil, E.: *The Vehicle Routing Problem: Latest Advances and New Challenges*. Springer, Boston, MA (2008). DOI: 10.1007/978-0-387-77778-8.
2. Liu, B.: *Vehicle Routing Problem*. In: *Theory and Practice of Uncertain Programming. Studies in Fuzziness and Soft Computing*, vol. 239, pp. 147–155. Springer, Berlin, Heidelberg (2009). DOI: 10.1007/978-3-540-89484-1_10.
3. Pillay, N., Qu, R.: *Vehicle Routing Problems*. In: *Hyper-Heuristics: Theory and Applications. Natural Computing Series*, pp. 51–60. Springer, Cham (2018). DOI: 10.1007/978-3-319-96514-7_7.
4. Marinakis, Y.: *Metaheuristic Algorithms for the Vehicle Routing Problem*. In: Floudas, C., Pardalos, P. (eds.) *Encyclopedia of Optimization*. Springer, Boston, MA (2008). DOI: 10.1007/978-0-387-74759-0
5. Pisinger, D., Ropke, S.: A general heuristic for vehicle routing problems. *Computers, Operations Research* 34(8), 2403–2435 (2007). DOI: 10.1016/j.cor.2005.09.012.
6. Desrochers, M., Desrosiers, J., Solomon, M.: A Column Generation Algorithm for the Vehicle Routing Problem with Time Windows. In: Akgül, M., Hamacher, H.W., Tüfekçi, S. (eds.) *Combinatorial Optimization, NATO ASI Series*, vol. 82, pp. 249–252. Springer, Berlin, Heidelberg (1992). DOI: 10.1007/978-3-642-77489-8_17.
7. Samarov, K.L.: *Maths. The educational-methodical manual for students in the section "Transport task"*. Training center "Resolvent", Moscow, Russia (2009). (in Russian).
8. Kondratenko, Y.P., Encheva, S.B., Sidenko, E.V.: *Synthesis of Intelligent Decision Support Systems for Transport Logistic*. In: *Proceeding of the 6th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS*, vol. 2, pp. 642–646 (2011). DOI: 10.1109/IDAACS.2011.6072847.
9. Laporte, G.: The vehicle routing problem: An overview of exact and approximate algorithms. *European Journal of Operational Research* 59(3), 345–358 (1992).
10. Chen, H.-K., Hsueh C.-F., Chang, M.-S.: Production scheduling and vehicle routing with time windows for perishable food products. *Computers & operations research* 36(7), 2311–2319 (2009).
11. Arbelaitz, O., Rodriguez, C., Zamakola I.: Low cost parallel solutions for the VRPTW optimization problem. In: *Proceedings International Conference on Parallel Processing Workshops, Spain* (2002).
12. Werners, B., Kondratenko, Y.: Alternative Fuzzy Approaches for Efficiently Solving the Capacitated Vehicle Routing Problem in Conditions of Uncertain Demands. In: Berger-Vachon, C., Gil Lafuente, A., Kacprzyk, J., Kondratenko, Y., Merigó, J., Morabito, C. (eds.) *Complex Systems: Solutions and Challenges in Economics, Management and Engi-*

- neering. *Studies in Systems, Decision and Control*, vol. 125, pp. 521–543. Springer, Cham (2018). DOI: 10.1007/978-3-319-69989-9_31.
13. Pureza, V.: Vehicle routing with multiple deliverymen: Modeling and heuristic approaches for the VRPTW. *European Journal of Operational Research* 218(3), 636–647 (2012).
 14. Schulze, J., Fahle, T.A.: A parallel algorithm for the vehicle routing problem with time window constraints. *Annals of Op. Research* 86, 585–607 (1999).
 15. Kondratenko, G.V., Kondratenko, Y.P., Romanov, D.O.: Fuzzy Models for Capacitive Vehicle Routing Problem in Uncertainty. In: Proc. 17th International DAAAM Symposium "Intelligent Manufacturing and Automation: Focus on Mechatronics & Robotics", pp. 205–206. Vienna, Austria (2006).
 16. Dorigo, M., Gambardella, L.M.: Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem. *IEEE Transactions on Evolutionary Computation* 1(1), 53–66 (1997).
 17. Dorigo, M., Maniezzo V., Colomi, A.: Ant System: Optimization by a Colony of Cooperating Agents. *IEEE Trans. Sys., Man, Cybernetics* 26, 29–41 (1996).
 18. Shi, W., Weise, T.: An Initialized ACO for the VRPTW. *Intelligent Data Engineering and Automated Learning*, 93–100 (2013).
 19. Wang, Y.: A Hybrid Approach Based on Ant Colony System for the VRPTW. *Advanced Technology in Teaching*. In: Proceedings of the 2009 3rd International Conference on Teaching and Computational Science (WTCS 2009), pp. 327–333 (2009).
 20. Qi, C., Sun, Y.: An improved ant colony algorithm for VRPTW. In: 2008 International Conference on Computer Science and Software Engineering, pp. 455–458 (2008).
 21. Basturk, B., Karaboga, D.: An Artificial Bee Colony (ABC) Algorithm for Numeric function Optimization. In: *IEEE Swarm Intelligence Symposium* (2006).
 22. Karaboga, D., Basturk, B.: A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. *Journal of Global Optimization* 39, 459–471 (2007).
 23. Kondratenko, Y.P., Klymenko, L.P., Sidenko, I.V.: Comparative Analysis of Evaluation Algorithms for Decision-Making in Transport Logistics. In: Jamshidi, M., Kreinovich, V., Kazprzyk, J. (eds.) *Advance Trends in Soft Computing, Series: Studies in Fuzziness and Soft Computing*, vol. 312, pp. 203–217 (2014). DOI: 10.1007/978-3-319-03674-8_20.
 24. Encheva, S., Kondratenko, Y., Solesvik, M.Z., Tumin, S. *Decision Support Systems in Logistics*. In: *AIP Conference Proceedings* 1060, 254–256 (2008). DOI: 10.1063/1.3037065.
 25. Teodorović, D., Dell’Orco, M.: Bee colony optimization - a cooperative learning approach to complex transportation problems. In: *Proceedings of the 10th EWGT Meeting, Poznan*, pp. 13–16 (2005).