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Meta-heuristics for vehicle routing and inventory routing problems

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Citation

Yang, Z. (2016, September 20). *Meta-heuristics for vehicle routing and inventory routing problems*. Retrieved from <https://hdl.handle.net/1887/43073>

Version: Not Applicable (or Unknown)

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Note: To cite this publication please use the final published version (if applicable).

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Issue Date: 2016-09-20

Introduction

1.1 • Background

With the rapid development of electronic commerce, logistics management has become more and more important in the procedure of supply chain management. The goal of logistics management is to satisfy the demands of customers while minimizing the use of resources of the whole process in logistics management from the point of origin to the point of consumption. The logistics management technology has been widely used in the field of engineering and contributes to reducing the total logistics cost. In this thesis, we focus on algorithms based on nature-inspired paradigms to solve dynamic logistics management problems.

Vehicle routing problems (VRP) have been studied for several decades. However, some information of customers are not known in advance in real world applications. The problem which combines dynamic information is called the dynamic vehicle routing problem (DVRP). Ant colony optimization algorithms show their strength on solving routing problems. The search mechanism based on a pheromone matrix makes it easier to adjust the ant-based solver to deal with a dynamic routing problem. Hence, we developed an improved ant-base solver to solve dynamic vehicle routing problems as they occur in practice. The proposed algorithm is also applied within the “Deliver” Project, a project co-founded by the EU and “Agentschap NL”. The aim of the “Deliver” Project is to design a platform to deal with dynamic routing problems. For instance, this routing problem occurs in the security company named “Trigion”. As another partner, Almende B.V., an IT company, focuses on designing the platform to make the human-machine interface more convenient. Leiden Institute of Advanced Computer Science (LIACS), as a member of the “Deliver” Project, provides an efficient algorithm for the

routing problem. The ant-based solver is successfully implemented on the platform and a test case is derived in cooperation with the company to demonstrate the performance of the algorithm.

The inventory routing problem (IRP) is an extension of the vehicle routing problem which also integrates inventory management. With the improvement of computing power and newly developed technologies, it is possible to solve the inventory management and routing problems together which could optimize conflicting objectives of the inventory routing problem simultaneously rather than solving the inventory management and routing problem separately. Hence, heuristic algorithms are proposed to deal with this logistics management problem.

1.2 · Research Goals and Contribution of this Thesis

The main goal of this research is to model problems derived from the real world logistics problem and propose heuristic algorithms which can provide a high quality solution for the theoretical benchmark as well as the practical problem. The problem is first modeled as a dynamic vehicle routing problem with time windows and an ant-based solver called Multiple Ant Colony System (MACS) is proposed to solve this problem. Since customers have different priority levels, the customers with higher priority level should have a higher probability to be served earlier. The concept of priority levels is integrated into the model which creates a new problem, namely the dynamic vehicle routing problem with time windows and multiple priorities. The ant-based solver is also adapted to solve this problem.

The solver is tested on a real-world case which is derived from the daily jobs of the Dutch company “Trigion”. The pilots are run iteratively and a survey is done for the drivers’ experiences in order to adjust the algorithm to the problem. Results show that the proposed ant-based solver is able to deal with the routing problem in practice.

A second part of the thesis deals with the more complex inventory routing problem. The inventory routing problem is an extension of the vehicle routing problem which takes the inventory management problem into account. The decision maker has to minimize the inventory cost and routing cost simultaneously. A multi-objective meta-heuristic algorithm is proposed to generate several alternative solutions to the decision makers, namely a Pareto front set in which no solution is equal or better than the other solution in all objectives and better in one objective (Pareto dominated). The proposed multi-objective cooperative particle swarm can produce a Pareto front of high quality

solutions for this tri-objective inventory routing problem.

1.3 · Thesis Outline

This thesis consists of eight chapters. Most of them have associated publications which are shown in the following brief descriptions:

- Chapter 2 defines the problem of different variations of vehicle routing problems, which are modeled based on the real-world problem. Part of the problem definitions are published in papers [Yang et al., 2015a, Yang et al., 2015b, Yang et al., 2016c]. The complexity of the vehicle routing problem is also analyzed in this chapter which is published in [van Stein et al., 2013]:

van Stein, B., Emmerich, M. and Yang, Z. (2013). Fitness landscape analysis of NK Landscapes and vehicle routing problems by expanded barrier trees. In: Emmerich M., Deutz A., Schuetze O., Bäck T., Tantar E., Tantar A., Moral D., Legrand P., Bouvry P., Coello A., editors. *EVOLVE-A Bridge between Probability, Set Oriented Numerics, and Evolutionary Computation IV*, AISC 227, pages 75–89. Springer International Publishing.

- Chapter 3 describes the canonical ant colony optimization algorithms and its variants. The proposed ant-based solver is based on the concept of ant colony techniques. The mechanism of preserving the pheromone matrix gives the solver some advanced knowledge which can make the solver more efficient. Part of this chapter is published in the following articles [van Veen et al., 2013, Yang et al., 2016c]:

van Veen, B., Emmerich, M., Yang, Z., Bäck, T., and Kok, J. (2013). Ant colony algorithms for the dynamic vehicle routing problem with time windows. In: Ferrández Vicente, J.M., Álvarez Sánchez, J.R., de la Paz López, F., Toledo Moreo, F.J., editors. In *Proceedings of the 5th International Work-Conference on the Interplay Between Natural and Artificial Computation, IWINAC '2013*, LNCS 7931, pages 1–10. Springer Berlin Heidelberg.

Yang, Z., van Osta, J., van Veen, B., van Krevelen, R., van Klaveren, R., Stam, A., Kok, J., Bäck, T., and Emmerich, M. (2016). Dynamic vehicle

routing with time windows in theory and practice. *Natural Computing*, Accepted, Preprint Published Online: 1–16. Springer Netherlands.

- Chapter 4 looks into the dynamic vehicle routing problem with time windows which is even more relevant to most companies in logistics and transportation than the static vehicle routing problem. In this problem, a fleet of vehicles will service a number of customers with time windows. But part of the customers are unknown and revealed dynamically during the execution of the routes. An ant colony optimization algorithm is proposed to solve this problem. Customers and time windows are inserted during the working day and need to be integrated in partially committed solutions. Results are varying degrees of dynamicity and different variants, including pheromone preservation and the min-max ant system. This work is published in the following article [Yang et al., 2016c]:

Yang, Z., van Osta, J., van Veen, B., van Krevelen, R., van Klaveren, R., Stam, A., Kok, J., Bäck, T., and Emmerich, M. (2016). Dynamic vehicle routing with time windows in theory and practice. *Natural Computing*, Accepted, Preprint Published Online: 1–16. Springer Netherlands.

- Chapter 5 proposes an ant based solver to solve the dynamic vehicle routing problem with time windows and multiple priorities. For this problem, customers have different priority levels. Customers with higher priority should have a higher quality of service. The quality of service is measured by the sum of the expected delay time between the arrival time and the earliest available beginning service time of all customers. The goal is to minimize the traveling distance while minimizing the total delay time of customers. First, a new benchmark is generated for the solver based on van Veen's benchmark which is a dynamical extension of Solomon's 100 customers benchmark. Then, the ant based solver is introduced and two strategies based on the ant colony algorithm are proposed to deal with priorities of customers. One is servicing high priority level customers immediately using the nearest vehicle. The other is giving a penalty to the delay time, combining the penalty and traveling distance and minimizing them together. Finally, the results show that the second strategy performs better than the first one. This work is published in the following article [Yang et al., 2015a]:

Yang, Z., Emmerich, M., and Bäck, T. (2015). Ant based solver for dynamic vehicle routing problem with time windows and multiple priorities. In 2015 IEEE Congress on Evolutionary Computation, CEC '2015, pages 2813–2819. IEEE.

- Chapter 6 explains the details of a case study conducted with real drivers in a company. First the test case which was used for the pilots is discussed. Then the initially implemented algorithm is described. Finally, the execution of real-world pilots will be discussed, including the intermediate revisions of the algorithms that were motivated by problems encountered in real-world testing. This work is published in the second part of the following article [Yang et al., 2016c]:

Yang, Z., van Osta, J., van Veen, B., van Krevelen, R., van Klaveren, R., Stam, A., Kok, J., Bäck, T., and Emmerich, M. (2016). Dynamic vehicle routing with time windows in theory and practice. *Natural Computing*, Accepted, Preprint Published Online: 1–16. Springer Netherlands.

- Chapter 7 studies a tri-objective formulation of the inventory routing problem, extending the recently studied bi-objective formulation. As compared to distance cost and inventory cost, which were discussed in previous work, it also considers stockout cost as a third objective. Demand is modeled as a Poisson random variable. State-of-the-art evolutionary multi-objective optimization algorithms and a new method based on swarm intelligence are used to compute an approximation of the 3-D Pareto front. A benchmark previously used in bi-objective inventory routing is extended by incorporating an uncertain demand model with an expected value that equals the average demand of the original benchmark. The results provide insights into the shape of the optimal trade-off surface. Based on this the dependencies between different objectives are clarified and discussed. Moreover, the performances of the four different algorithmic methods are compared and due to the consistency in the results, it can be concluded that a near optimal approximation to the Pareto front can be found for problems of practically relevant size. This work is published in the following articles [Yang et al., 2015b, Yang et al., 2016b]:

Yang, Z., Emmerich, M., Bäck, T., and Kok, J. (2015). Multicriteria inventory routing by cooperative swarms and evolutionary algorithms. In: Ferrández Vicente, J.M., Álvarez Sánchez, J.R., de la Paz López, F.,

Toledo Moreo, F.J., Adeli, H., editors. In Proceedings of the International Work-Conference on the Interplay Between Natural and Artificial Computation, IWINAC '2015, LNCS 9108, pages 127–137. Springer International Publishing.

Yang, Z., Emmerich, M., Bäck, T., and Kok, J. (2016). Multi-objective inventory routing with uncertain demand using population-based meta-heuristics. *Integrated Computer-Aided Engineering*, 23(3):205–220. IOS Press.

- Chapter 8 summarizes the thesis and provides some suggestions for the future work.
- In addition to the published full papers mentioned above, some results were also presented in international events as extended abstracts [Yang et al., 2015c, Emmerich and Yang, 2015, Yang et al., 2016f, Yang et al., 2016e]:

Yang, Z., van Osta, J.-P., van Veen, B., van Krevelen, R., van Klaveren, R., Stam, A., Kok, J., Bäck, T., and Emmerich, M. (2015). Solving dynamical vehicle routing in practice: Lessons learned and new challenges. In *International Conference on Multiple Criteria Decision Making, MCDM '2015*, page 80. MCDM Society.

Emmerich, M. and Yang, Z. (2015). Multicriteria optimization of inventory routing considering stock-out risk, distance cost, and inventory cost. In *International Conference on Multiple Criteria Decision Making, MCDM '2015*, page 135. MCDM Society.

Yang, Z., Yang, K., Bäck, T., and Emmerich, M. (2016). A cooperative swarms algorithm for inventory routing problem. In *Student Conference on Operational Research, SCOR '2016*, page 39. University of Nottingham, UK.

Yang, Z., Yang, K., Emmerich, M., and Bäck, T. (2016). A co-evolutionary algorithm for green inventory routing problem. In: Miłosz K., editor. *European Conference on Operational Research, EURO '2016*, pages 113. European Association of Operational Research Society.

- Other publications of the author are as follows [Yang et al., 2016d, Yang et al., 2016a, Liu et al., 2016]:

Yang, Z., Wang, H., Yang, K., Bäck, T., and Emmerich, M. (2016). SMS-EMOA with multiple dynamic reference points. In International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery, ICNC-FSKD '2016, pages 1–7. IEEE.

Yang, K., Deutz, A., Yang, Z., Bäck, T., and Emmerich, M. (2016). Truncated expected hypervolume improvement: Exact computation and application. In IEEE World Congress on Computational Intelligence, WCCI '2016, pages 1–8. IEEE.

Liu, X., Chen, C., He, R., Yao, F., Yang, Z., and Bäck, T. (2016). Maximizing the total net revenue for selection and scheduling problem with earliness-tardiness consideration using differential evolutionary algorithm. In: Miłosz K., editor. European Conference on Operational Research, EURO '2016, pages 140. European Association of Operational Research Society.

