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Conclusions and Outlook

This thesis is concerned with problems of vehicle routing and inventory routing management, as well as their combination. The main contributions of this thesis to this research topic are:

- the proposal of new ant colony based algorithms for the dynamic vehicle routing problem with time windows (DVRPTW).
- its extension to the problem of dynamic vehicle routing problem with two priority levels and the comparison of two strategies for achieving these solutions.
- the implementation and evaluation of real world pilots with real drivers for the DVRPTW problem.
- the design and evaluation of multi-objective optimization algorithms for the inventory routing problem with demand uncertainty.

In Section 8.1 we will describe these results in more detail and thereafter provide a brief outlook in Section 8.2.

8.1 Conclusions

For dynamic vehicle routing problem with time windows, some orders are not known in advance but given during the execution of routes. When new orders come, they have to be merged into routes that are currently executed. As time passes by, some orders which have been served or are currently being served cannot be changed anymore, which makes it more difficult to find a high quality solution for the whole working day. The whole working day is divided into several time slides. When a slide begins,
the algorithm needs to check whether there are some new coming orders needed to be served and some orders have to be committed to the controller. If there are some new coming orders, the algorithm has to integrate these orders and rearranges routes. The biggest challenge is the efficiency of the algorithm, that is, the algorithm has to find a feasible solution quickly and then improve it by finding a better solution with less vehicles and shorter distance whereas the priority is on finding feasible solutions with less vehicles. The mechanism of preserving pheromone trails in ant colony optimization algorithms makes it easier to use the advanced knowledge to generate a high quality feasible solution for the routing problems.

In order to solve this problem, the multiple ant colony system which works with two colonies (one for vehicles, one for time minimization) is used and extended to the dynamic case. In this algorithm, a controller is used to initialize the solutions for ant colonies. The newly proposed Ranking Time Windows Based Nearest Neighbor algorithm is implemented which establishes good initial solutions for the ant colony algorithm especially for the problem with time windows. A range of benchmark problems with different dynamicity are generated from Solomon’s vehicle routing problem benchmark. Results show that the algorithm performs good for all these benchmarks. Moreover, as the dynamicity increases from 0% to 50%, the traveling distance becomes 17.63% longer and two more vehicles are needed to handle the incidents.

For the newly proposed dynamic vehicle routing problem with time windows and multiple priorities, the main difference is the attribute called priority. Customers have different priorities in many real world problems. The customers with high priorities should be served first and the delay time for the high priority customers should be minimized. The multiple ant colony system is proposed and evaluated to solve the dynamic vehicle routing problem with two priorities. Such problems occur for instance in scenarios where emergencies can occur that need to be served urgently. To deal with the priorities of customers, two strategies are proposed. One is serving the high priority customers first and then serving the customers with low priorities. The other is giving a penalty to the delay time of servicing each customer. The penalty for high priority customers is higher than the one for low priority customers. The attribute of priority is added to the previous dynamic vehicle routing problem with time windows benchmark. The final results show that the second strategy performs much better than the first strategy which has been opposite to our intuitive ideas.
The real world problem studied in this thesis can be modeled as a dynamic vehicle routing problem with time windows and multiple priorities. The problem is derived from a Dutch company which serves customers located all over in the Netherlands. In order to scale down the problem, a test case with a reduced number of customers and drivers in the Rotterdam area is generated. The gaps between the theoretical benchmark problem and the real world problem are analyzed. The ant-based solver is adjusted to replace the manual control system used in the company. Results show that the ant-based solver can produce solutions that are equally good or even better than the manual control system. Meanwhile, some lessons are also learned from the implementation of the algorithm. The three key points are: Iteration works, which means it takes several iterations of real world experiments to adapt the theoretical algorithm to the real world problem due to unforeseen requirements and adaptations of algorithm parameters; Communication is key, namely in order to find real needs of the real world problem, accurate communication is needed to make computer scientists fully understand the requirements of industries and drivers understand the details of the routing schedule; People are important, which means a successful implementation of an algorithm should pay most of its attention to the needs of end-users rather than theoretical assumptions. The survey of the driver experiences also gives us some ideas of how to improve the model of the real world vehicle routing problem.

In the real world, decision makers do not only want a solution of the vehicle routing problem for one day, but in many cases also a win-win strategy for the inventory management and routing problem. As an extension of the vehicle routing problem, the inventory routing problem integrates inventory management. In this thesis, the inventory routing problem is handled as a tri-objective optimization problem rather than the classical bi-objective problem. In classical inventory problems, the goal is to minimize the inventory level and the routing cost in the given period simultaneously. Here, a scenario with uncertain demand is considered and the expected value of the stockout cost is also considered as an objective in the problem. Since it is not possible to know the coming demand of the customer, the stockout risk in this thesis has been modeled as a random variable.

To solve the inventory routing problem, multi-objective optimization cooperative particle swarm algorithm (MOCOPS) is proposed in this thesis. SMS-EMOA is a state-of-the-art multiple objective optimization algorithm which is used to compare with the newly proposed MOCOPS. The hypervolume contribution indicator is used as a
selection criterion for both algorithms which are aiming at maximizing the hypervolume performance indicator of the Pareto front approximation set of the inventory routing problem. The proposed algorithms are also compared with NSGA-II and HGS14 on the benchmark. For this, the HGS14 algorithm, which is a state-of-the-art algorithm for the bi-objective IRP, is extended to the tri-objective case by proposing a new scheme to generate 3-D reference points. The bi-objective inventory routing problem benchmark is used to test the efficiency of the proposed algorithm. Results show that the MOCOPS can produce similar good results to SMS-EMOA which are better than NSGA-II and HSG14. After applying to the tri-objective inventory routing problem, MOCOPS and SMS-EMOA also obtain similar attainment surfaces. However, it is difficult to figure out the difference between these attainment surfaces. In order to compare these algorithms, the hypervolume indicators are calculated. Based on the observation of results, we found empirical evidence that the HGS14 works better for solving the small scale inventory routing problems such as GS-01 and GS-02. However, the MOCOPS always performs best for the large scale problems such as GS-04 and GS-06.

8.2 · Outlook

Based on the results of this thesis, some important lessons were learned, but there are still many open questions for future research. Next, some important questions will be highlighted. In this thesis, a real world problem in a Dutch logistics company is modeled as a dynamic vehicle routing problem with time windows and multiple priorities. However, there are still some aspects in the real world that are not modeled. For instance, when running the pilot experiments, there was a traffic jam caused by a horse which made our algorithm fail to serve some orders. The possibility of unexpected traffic jams should be considered in the model. Moreover, based on the survey of the experiences of the drivers, we find that drivers want to know their schedule at the beginning of the day and never change their routes too much so that they will not feel stressed. Furthermore, some orders could be splittable orders and others could be canceled during the execution of the routing, which should also be considered in the model.

Besides, more components can be taken into account for modeling the problem, there are some desirable improvements for the proposed algorithms. Due to the rapid development of GPS technology and smart phone, it is possible to get first hand information from drivers about the incidents happening on the road. A protocol should
be designed to make the swift interaction between the drivers and the control center possible.

For the inventory routing problem, the savings algorithm used for subordinated vehicle routing problem is very fast but not precise enough compared to the state-of-the-art ant colony optimization algorithm or the genetic algorithm. However, the ant colony optimization and the genetic algorithm are time consuming compared to the savings algorithm. In the future, a fast and precise algorithm is desirable to solve this subproblem. For instance, one could consider surrogate modeling techniques, in order to reduce running times of such algorithms [Jin, 2011]. Last but not least, since more objectives of the inventory routing problem should be considered in the future, it makes the inventory routing problem a many-objective optimization problem. Alternatively, we may think about the green inventory routing problem, where an additional goal is to reduce the emission of Green House Gas (GHG) or other emissions that are harmful to the environment. As methods based on the hypervolume indicator tend to be very time consuming for many-objective problems, different types of indicators and/or methods need to be considered for solving such problems [Trautmann et al., 2013, Wang and Yao, 2014]. Moreover, the resulting high-dimensional Pareto front approximations will be difficult to be shown by simple scatterplots and include a large number of points. This might be solved by using interactive and preference handling methods [Zhou et al., 2011].

In this thesis for small problems of IRP reference point based methods performed better and for large problems the hypervolume based method was better. Perhaps the hybridization of hypervolume-based search and reference points based search can be considered as an interesting direction for the design of multi-objective optimization techniques, and first steps in this direction have already been published in [Yang et al., 2016d].