kCW-rTS: a new efficient meta-heuristic algorithm for the Inventory Routing Problem

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Abstract

The current paper introduces kCW-rTS, an effective, fast and scalable meta-heuristic optimization algorithm for the NP-hard Inventory Routing Problem (IRP). IRP is a well-known -for Operations Research field- rich vehicle routing problem that incorporates the centralized inventory handling on top of the classic routing problem. Specifically, it is a complicated distribution and inventory management optimization problem, in which a product is shipped from a supplier to a network of customers that preserve inventories using a vehicle for multiple time periods. The supplier is responsible for replenishing the inventory of the geographically dispersed customers (Vendor Managed Inventory, VMI) over a specific horizon of time while preventing stock-outs. This VMI policy offers cost reductions in comparison to the classic approach where the customers independently monitor their inventories and place orders. The problem is to determine at each discrete time step which customers should be visited, in what order and what quantity to be delivered to them in order to minimize the inventory and transportation costs simultaneously.

We propose kCW-rTS, a new fast meta-heuristic algorithm with two phases. Initially, a greedy constructive cost saving algorithm (kCW) constructs a feasible solution of good quality. The algorithm is based on the known Clarke and Wright algorithm (CW) with the addition of a tuning hyper-parameter k which allows to construct feasible solutions. In the second phase, the solution is iteratively improved by Local Search. We implement a Tabu Search algorithm with a new feature for the problem that we call reductive Tabu Search (rTS). rTS features a novel reductive mechanism that unlike common meta-heuristics allows the algorithm to massively reduce costs and converge to optimal without strong dependency on the initial solution. Usually, in integrated and rich routing problems TS algorithms are mainly used for solution exploration and not optimization. However, the reductive mechanism allows rTS to efficiently optimize while searching without need for combining other methods as it currently happens. This is due to each ability to remove solution elements by readjusting the remaining solution to avoid infeasibilities.

The IRP classification as NP-hard suggests that there is no dominant solution algorithm. All of them can be evaluated towards: scalability, computational time and optimality. kCW-rTS proves to be scalable and capable of solving problems of realistically large size and copes with well-known benchmarking instances. It is fast and unlike most meta-heuristics it preserves its speed for problem sets of bigger size as its complexity is significantly lower that the IRP complexity. The algorithm was extensively tested and managed to achieve satisfactory optimal gap. It was tested on 160 problem instances with an average optimal gap of just 3.64% and benchmarked against a known Branch and Cut algorithm in IRP literature. For the 80 high inventory costs instances it achieves an optimal gap of 1.88%. kCW-rTS manages to solve realistic industry size instances rapidly with only a small impact on optimality and therefore it can become a useful tool in supply chain management.