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An ant colony system empowered variable neighborhood search algorithm for the vehicle routing problem with simultaneous pickup and delivery

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A R T I C L E I N F O

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A B S T R A C T

Along with the progress in computer hardware architecture and computational power, in order to overcome technological bottlenecks, software applications that make use of expert and intelligent systems must race against time where nanoseconds matter in the long-awaited future. This is possible with the integration of excellent solvers to software engineering methodologies that provide optimization-based decision support for planning. Since the logistics market is growing rapidly, the optimization of routing systems is of primary concern that motivates the use of vehicle routing problem (VRP) solvers as software components integrated as an optimization engine. A critical success factor of routing optimization is quality vs. response time performance. Less time-consuming and more efficient automated processes can be achieved by employing stronger solution algorithms. This study aims to solve the Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD) which is a popular extension of the basic Vehicle Routing Problem arising in real world applications where pickup and delivery operations are simultaneously taken into account to satisfy the vehicle capacity constraint with the objective of total travelled distance minimization. Since the problem is known to be NP-hard, a hybrid metaheuristic algorithm based on an ant colony system (ACS) and a variable neighborhood search (VNS) is developed for its solution. VNS is a powerful optimization algorithm that provides intensive local search. However, it lacks a memory structure. This weakness can be minimized by utilizing long term memory structure of ACS and hence the overall performance of the algorithm can be boosted. In the proposed algorithm, instead of ants, VNS releases pheromones on the edges while ants provide a perturbation mechanism for the integrated algorithm using the pheromone information in order to explore search space further and jump from local optima. The performance of the proposed ACS empowered VNS algorithm is studied on well-known benchmarks test problems taken from the open literature of VRPSPD for comparison purposes. Numerical results confirm that the developed approach is robust and very efficient in terms of both solution quality and CPU time since better results provided in a shorter time on benchmark data sets is a good performance indicator.

1. Introduction

Vehicle routing problem (VRP) variants arising in real world applications are considered to be highly complex combinatorial optimization problems that require improved automation and high-quality software tools for decision support since human planning is inadequate for most applications and occupation of valuable human resources is undesired. Computerized planning not only reduces risk of error, but also improves the utilization of transportation resources and provides more efficient planning processes with respect to manual planning. As efficiency and sustainability grows in importance, significant cost savings and a better utilization of resources serving to environmental benefits can be achieved via the combination of powerful computers and high performance solvers integrated to expert and intelligent software systems. A key strength of excellent solvers comes from the better optimization performance yielding to better solutions with substantial savings. Gap between the requirements and the performance of today's optimization-based decision support systems is quite large. The evolving optimization technology of tomorrow may be greatly enhanced by improved solution algorithms that play an essential role in finding high-quality feasible solutions even for more complex and larger sized real-life instances. Therefore, there is a huge potential of improvement and hence an exciting work ahead.

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Companies must wisely optimize their decisions in every aspect in order to survive in today's competitive environment. The optimization of logistic systems is of primary and shared concern for many companies since it serves not only to reduced transportation costs and improved service quality, but also to environmental protection. A critical step of this optimization process is to solve the vehicle routing problem (VRP) introduced by Dantzig and Ramser (1959). The VRP that is concerned with the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of clients. A widely studied generalization of VRP, the vehicle routing problem with simultaneous pickup and delivery (VRPSPD), proposed by Min (1989), requires simultaneous consideration of both pickup and delivery demands. This causes a fluctuation in the current load of the vehicle which results in increased difficulty in checking the feasibility of the solutions. Therefore, a key aspect is to check the current load of the vehicle(s) at each client since the vehicle capacity cannot not be exceeded. A well-known example occurs in the soft drink industry where the operations of delivering full bottles and picking empty ones up are performed by the same vehicle. A further extension of VRPSPD, vehicle routing problem with simultaneous pickup and delivery with time limit (VRPSPDTL), additionally requires the vehicles to return to the central depot before a time deadline is reached. A real life example occurs in milk transportation since there is a limited time to carry such sensitive goods on the route before turning bad. Mathematical formulation of VRPSPD and VRPSPDTL can be found in Alfredo Tang Montané and Galvão (2006) and Polat, Kalayci, Kulak, and Günther (2015), respectively.

Since VRPSPD works were started by Min (1989) with a case study of a small sized book distribution problem that requires book delivery and pick-up operations between a central library and twenty-two local libraries, several studies have been published on this problem. These studies in the literature can be categorized as exact, heuristic, single solution based and population based metaheuristic algorithms.

Since the core problem is known to be NP-hard, very few exact approaches have been developed for this problem. The first exact solution methodology based on branch-and-price approach with exact dynamic programming and state space relaxation procedures was developed by Dell'Amico, Righini, and Salani (2006) in which only instances up to 40 customers could be solved to optimality despite high computational time. Other exact solution approaches have been proposed by Subramanian, Uchoa, Pessoa, and Ochi (2011) based on branch-and-cut algorithm and Subramanian, Uchoa, Pessoa, and Ochi (2013) based on branch-cut-and-price algorithm which were able to solve instances up to 100 clients. Although exact methodologies are very useful to prove optimal solutions and to provide new lower bounds for well-known data instances, since the solution space grows exponentially when the problem size increases due to computational complexity (Tovey, 2002) which has a significant influence on the running time of algorithms, exact solution procedures may not be adequately efficient within reasonable time. Therefore, heuristic and metaheuristic approaches are commonly developed as solution methodologies.

Dethloff (2001) proposed a mathematical formulation for VRPSPD and developed an insertion-based heuristic by addressing the problem in reverse logistics operations. Salhi and Nagy (1999) studied a similar approach that combined Clarke and Wright saving heuristic (Clarke & Wright, 1964) with an insertion based heuristic that insert two customers at a time in the route. Nagy and Salhi (2005) developed a composite heuristic approach that temporarily allows a certain degree of infeasibility to occur at VRPSPD solutions and eliminates capacity infeasibilities using different sub-routines such as 2-opt, 3-opt, shift, exchange, reverse and perturb structures adapted for the problem. Heuristic approaches usually do not include an improvement routine and thus ends up with the same result for every run of the procedure unless a probabilistic mechanism is used. Therefore, heuristics are either used for initial solution construction in order to provide a better starting point compared to pure randomness or as an embedded constructive sub procedure of iterative search algorithms.

Single solution based metaheuristic algorithms have been commonly used for solving VRPSPD. Among the existing solution strategies, tabu search method is by far the most preferred approach applied for solving this problem. The first tabu search study is proposed by Crispim and Brandao (2005) which is a combination of tabu search and variable neighborhood descend approach with a sweep procedure that allows infeasibility to construct initial solution as well as insert and swap procedures to improve the incumbent solution until feasibility is established by penalizing according to the level of overloads. Chen and Wu (2005) proposed a tabu search algorithm that obtains initial solutions by an insertion-based procedure based on distance and load based criteria and then improves solutions with 2-exchange, swap, shift, 2-opt and Or-opt procedures and record-to-record travel strategies. Alfredo Tang Montané and Galvão (2006) proposed a tabu search algorithm that makes use of inter-route and intra-route neighborhood structures such as interchange, relocation, crossover and 2-opt procedures by controlling intensification and diversification scheme of the approach with a frequency penalization scheme. Bianchessi and Righini (2007) also proposed a tabu search algorithm with a variable neighborhood structure that makes use of node and arc exchange based local search heuristics. Wassan, Wassan, and Nagy (2008) proposed a tabu search algorithm with a mechanism that dynamically controls the tabu list size to achieve an effective balance between the intensification and diversification of the conducted search and makes use of neighborhood structures such as shift, swap, local shift and reverse procedures for improvement. Zachariadis, Tarantilis, and Kiranoudis (2009) presented a tabu search algorithm combined with guided local search strategies that iteratively improves the initial solution generated by a saving based constructive heuristic using neighborhood structures such as customer relocation, customer exchange, route interchange procedures. Zachariadis, Tarantilis, and Kiranoudis (2010) proposed a solution approach that stores the routes of high quality VRPSPD solutions in memory and makes use of an improvement procedure based on tabu search. Zachariadis and Kiranoudis (2011) utilize the weighted savings based heuristic approach to generate an initial solution and then a tabu search algorithm to improve the solutions. Ropke and Pisinger (2006) developed a large neighborhood search approach that selects a neighborhood method according to a probability depending on its success for solving several variants of vehicle routing problems with backhauls involving VRPSPD. A multi-start metaheuristic approach which consists of a variable neighborhood descent procedure, a random neighborhood ordering procedure and an iterated local search (ILS) framework is proposed by Subramanian, Drummond, Bentes, Ochi, and Farias (2010) who performed the experiments in a cluster with a multi-core architecture using up to 256 cores utilizing the parallel structure of the algorithm. Jun and Kim (2012), Li, Pardalos, Sun, Pei, and Zhang (2015) and Avci and Topaloglu (2015) proposed iterated local search algorithms with inter-route and intra-route operators and perturbation mechanisms to solve VRPSPD. Polat, Kalayci, Kulak, et al. (2015) recently proposed a perturbation based variable neighborhood search algorithm for solving VRPSPD with and without time limit restrictions.

Population based metaheuristic algorithms have also been applied for solving VRPSPD. Ai and Kachitvichyanukul (2009) and Goksal, Karaoglan, and Altiparmak (2013) proposed particle swarm optimization algorithms for solving VRPSPD. While Ai and Kachitvichyanukul (2009) used a real value encoding mechanism for representation of the solution, cheapest insertion heuristic and 2-