A Novel Optimization Framework for Dynamic Capacitated Arc Routing Problems

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A Novel Generalized Metaheuristic Framework for Dynamic Capacitated Arc Routing Problems

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ABSTRACT

The capacitated arc routing problem (CARP) aims at scheduling a fleet of vehicles with limited capacities to serve a set of tasks in a graph. The dynamic CARP (DCARP) optimization focuses on updating the vehicles' service routes when unpredicted dynamic events happen and deteriorate the current service plan. Due to the outside vehicles are still being in their service when dynamic events happen and being located at different positions of the graph with different remaining capacities, the optimization algorithms for static CARP are unsuitable for solving the DCARP instance. However, in the existing literature, almost all proposed algorithms for DCARP were designed only for specific dynamic events instead of generic dynamic events such as the changing of traversing costs, the changing of the task's demand, and the changing of the task's number. Moreover, these algorithms are unable to benefit from the wealth of contributions provided by the existing CARP literature. In this work, we proposed a novel generalized meta-heuristic framework which enables all algorithms designed for static CARP to be capable of solving DCARP instances. Our experimental results demonstrated that the proposed framework significantly improves over state-of-the-art dynamic optimization algorithms in terms of the quality of obtained solution within the limited computational time.

This paper for the Hot-off-the-Press track at GECCO 2023 summarizes the work *Hao Tong, Leandro L. Minku, Stefan Menzel, Bernhard Sendhoff, and Xin Yao: A Novel Generalized Meta-heuristic Framework for Dynamic Capacitated Arc Routing Problems* published in *IEEE Transactions on Evolutionary Computation* [10].

KEYWORDS

Dynamic Capacitated Arc Routing Problem, Meta-heuristic Algorithms, Routing Optimization, Evolutionary Algorithms

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1 INTRODUCTION

The Capacitated Arc Routing Problem (CARP) is a classical and important combinatorial optimization problem with a range of applications in the real world, such as winter gritting [1]. It targets to assign a number of vehicles with limited capacities to serve all tasks in a graph spending the lowest possible total costs.

In the literature, most existing studies concentrated on static CARP. In real applications, dynamic changes usually happen and influence the vehicles' service when vehicles are in service [2]. When that happens, a new problem instance is formed, in which vehicles stop at different locations, labeled as outside vehicles, with various amounts of remaining capacities. We aimed at re-scheduling the service plan when dynamic events happen that have influence on the current schedule. This is referred to as Dynamic CARP (DCARP) in our work.

Only few studies in the literature have focused on DCARP so far [3, 6–8]. However, these algorithms have two serious shortcomings: 1) Almost all of them only deal with one specific dynamic event, such as newly added tasks [7] or the failure of vehicles [6]; 2) These algorithms required the design of special operators or representations to tackle the constraints of DCARP.

Even though there is a rich literature on CARP optimization algorithms, so far it has not been possible to benefit from such algorithms for optimizing DCARP instances. Therefore, we provided two main contributions in this work:

- We proposed a novel framework which allows to generalize almost all existing algorithms designed for static CARP to the DCARP context. The framework converts a DCARP instance into a "static" CARP instance by introducing the idea of "virtual tasks", which enables outside vehicles (with potentially partial capacity) to be interpreted as vehicles located at the depot (with full capacity).
- We performed extensive experiments with a variety of DCARP instances, demonstrating the effectiveness of the proposed framework. We show that valuable research progress achieved by the static CARP literature can contribute towards optimization results that significantly outperform the existing algorithms [3] that were specifically designed for DCARP.

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2 THE GERENALIZED META-HEURISTIC FRAMEWORK

For DCARP, to deal with the different starting positions and capacity violation of the routes corresponding to the outside vehicles, we proposed a virtual task strategy that forces all outside vehicles to virtually return to the depot for optimization purposes, such that all vehicles (some virtually) start at the depot during the optimization.

A virtual task is interpreted as a representation of an outside vehicle's previous serving status, including the total cost, served demand and stop location before the occurrence of the dynamic events. For an outside vehicle k locating at v_k of the map with q_k remaining capacity in a DCARP instance, the virtual task is constructed with the following steps:

1. Connect the depot v_0 and the vehicle's location v_k as virtual task arc required to be served;
2. The service cost of the virtual task edge is set to the shortest traversing costs from v_0 to v_k;
3. The traversing cost of the virtual task is set to infinity;
4. The demand of the virtual task is set to $Q - q_k$, where Q is the full capacity of an empty vehicle.

During the optimization, the virtual tasks are regarded as arcs to be assigned to routes when being rescheduled. Once a depot vehicle serves a virtual task, its remaining capacity will become the same as the remaining capacity of the corresponding outside vehicle, and so will its stop location. After the optimization, the obtained solution with routes starting from the depot will be converted to an executable solution according to the locations of outside vehicles.

On the basis of the virtual-task strategy, we proposed a generalized optimization framework to generalize static CARP algorithms to dynamic scenarios, which comprises four main steps:

1. Construct virtual tasks;
2. Apply the initialization strategy to obtain a population of initial solutions (restart strategy or sequence transfer strategy);
3. Apply the meta-heuristic algorithm to optimize the converted "static" CARP instance;
4. Convert the obtained solution with virtual tasks to an executable solution without virtual tasks.

3 SUMMARY OF RESULTS

In our computational study, the necessity of directly optimizing DCARP together with outside vehicles was first demonstrated by comparing the virtual-task strategy with a return-first strategy. The results indicated that it would be more efficient to optimize the DCARP instance by using the virtual-task strategy when the outside vehicles' remaining capacities were sufficiently large to serve more tasks. Then, the efficiency of the virtual-task strategy was demonstrated by embedding it into an existing algorithm and comparing it to the original version of the existing algorithm. Finally, our generalized optimization framework's efficiency was analyzed by integrating a set of optimization algorithms that were designed for static CARPs, and the constructed algorithms performed significantly better than state-of-the-art algorithms for DCARP. The experimental results over 120 testing instances after statistical tests are presented in Figure 1, where MAENS [9], ILMA [5] and RTS [4] are effective meta-heuristic algorithms for static CARP, and MASDC is the state-of-the-art algorithm for DCARP [3]. All algorithms are embedded with the virtual task strategy and algorithms with "VTtr" prefix denotes algorithms which are embedded with the sequence transfer strategy instead of the restart strategy.

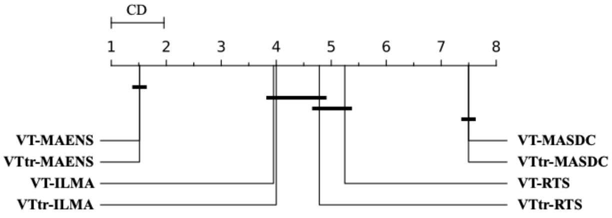

Figure 1: Critical difference diagram for the comparison of 8 algorithms against each other on the benchmark with Friedman test and Nemenyi test. Groups of algorithms which are not significantly different at the level of 0.05 are connected.

4 FUTURE WORK

In the future, we target to focus on the dynamic optimization for DCARP scenarios which consist of a series of DCARP instances. By extracting the experience which is stored in the process data collected during the optimization for previous DCARP instances, we can promote the efficiency of the optimization for new DCARP instances.

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