A Hybrid Local Search Framework for the Dynamic Capacitated Arc Routing Problem

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ABSTRACT

The static capacitated arc routing problem (CARP) is a challenging combinatorial problem, where vehicles need to be scheduled efficiently for serving a set of tasks with minimal travelling costs. Dynamic CARP (DCARP) considers the occurence of dynamic events during the service process, e.g. traffic congestion, which reduce the quality of the currently applied schedule. Existing research mainly focused on scenarios with large changes but neglected the time limitations of the rescheduling process. In this paper, we investigate DCARP scenarios with small dynamic changes in which events only affect the properties of a few edges. We propose an efficient hybrid local search framework (HyLS) to reschedule the service plan in a short time for a DCARP instance. HyLS maintains an archive that enables it to cover more search areas than single local search algorithms, while its local search mechanisms enable it to find better solutions than meta-heuristic re-optimisation from scratch when restricted to a tight time budget. Our experiments demonstrate HyLS' effectiveness compared to existing local search strategies and meta-heuristic re-optimisation from scratch.

KEYWORDS

Dynamic capacitated arc routing problem, Hybrid local search.

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1 INTRODUCTION

The capacitated arc routing problem (CARP) is abstracted from a range of real world applications, e.g. mail delivery. Algorithms for solving CARP target to schedule vehicles with limited capacities for serving a set of tasks in a map with minimal travelling costs. However, dynamic events are common in real world applications and consequently affect the executed CARP solution's quality in practice. Therefore, solutions need to be rescheduled frequently and within a tight time budget. Existing research on Dynamic CARP (DCARP) is limited and mainly focused on dynamic scenarios where several larger changes occur on the map, drastically influencing the problem's condition [1]. Usually, a time-consuming strategy has been applied for these scenarios, utilizing meta-heuristic algorithms for re-optimising the new DCARP instance from scratch [4],[7]. One complete optimisation on a small test graph would consume hundreds of seconds as shown in [5]. Dynamic capacitated vehicle routing problem (DCVRP) is a related area that might offer alternatives, but the possible transformation from CVRP to CARP increases the problem's dimension, discouraging attempts to use capacitated VRP algorithms to solve CARP. Therefore, in this paper:

- we propose a novel hybrid local search framework for DCARP (HyLS) which is able to reschedule solutions in a very short time in response to small dynamic changes;
- we demonstrate the efficiency of the proposed HyLS by evaluating our framework against existing meta-heuristics and local search strategies, showing its effectiveness.

2 HYBRID LOCAL SEARCH FRAMEWORK

Our proposed HyLS framework (Algorithm 1) can find an improved solution for DCARP with a fast response time by removing the crossover operators existing in meta-heuristic algorithms and promoting the neighbourhood of the current solutions. It adopts three effective strategies as follows. The *parallel neighbourhood moves strategy* allows for an efficient use of multiple parallel processes where each slave process computes one neighbourhood move on one solution independently. Five neighbourhood moves (Single Insertion, Double Insertion, Swap, Reverse and Cross [2]) are adopted. The master process collects the improved solutions potentially leading to the optimal solution and maintains an archive to store them (*archive strategy*). For each solution in the archive, the *exhaustive one-step move strategy* is utilized, which optimises a solution until no further neighborhood move improves the solution quality, to find the best neighbour for the solution, thus focusing on the local area. The framework terminates once the optimisation exceeds the time limitation or all solutions in the archive have been optimised.

3 EXPERIMENTS AND ANALYSIS

We compare HyLS with re-optimisation from scratch and other 3 local search algorithms in terms of final solution quality and algorithm efficiency on 72 DCARP instances (3 for each map), which

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Algorithm 1: The hybrid local search framework

Input: The updated graph data; Stop locations of outside vehicles; Remaining capacities of outside vehicles;

Re-construct the solution S_0 with explicit routes;
Initialize the solution archive (set) $SA = \{S_0\}$;
Set global best solution $S_{gb} \leftarrow S_0$;
for *each solution* S_i *in* SA **do**
  Local best solution $S_{lb} \leftarrow S_i$;
  while *true* **do**
    // Parallel for loop
    for *each neighborhood move* $Move_j$ **do**
      Solution $S_{mj} = OneStepMove_j(S_{lb})$;
      if *improve and archive is not full* **then**
        $SA \leftarrow SA \cup S_{mj}$;
    Update local best solution S_{lb} based on S_{mj};
    if *not improve or exceed time limitation* **then**
      break;
  if $S_{lb}.cost < S_{gb}.cost$ **then**
    $S_{gb} \leftarrow S_{lb}$;
  if *exceed time limitation* **then**
    break;

Output: The global best solution S_{gb}

are generated from the static CARP dataset *egl* [3] using the DCARP simulator from [7]. The time budget (i.e. termination criterion) for each algorithm in each experiment was set to 5 seconds. All algorithms were implemented in C and run on an Intel Core i7-8700 3.2GHZ.

For each experiment, we present a representative subset of our results in Tables 1 and 2 due to the page limit. Specifically, we highlight our results achieved with the instances from map S4 - C (best result of each instance in grey). We also provide the average ranking, p-value of the Friedman test, and the critical difference (CD) of the Nemenyi test with a level of significance of 0.05 across all 72 DCARP instances for each experiment.

Is HyLS more efficient than re-optimisation strategy? Two powerful meta-heuristic algorithms (MAENS [6] and MASDC [4]) using the re-optimization strategy have been applied and compared with our HyLS in the first experiment (Table 1). HyLS performed better than the other two algorithms on all DCARP instances, because the re-optimisation strategy is too complex to converge within a tight time budget. The provided maximum time limits the number of iterations of the meta-heuristic algorithms, preventing them from finding high-quality solutions when starting from scratch.

***Does HyLS improve the efficiency* of local search?** We compare HyLS with the local search strategy by sequentially using neighbourhood moves (SEQ) [2], SEQ with Iterative Local Search (ILSeq) and exhaustive local search strategy with Iterative Local Search (ILSex) in Table 2. HyLS and ILSex achieved the top rankings, which were not significantly different from each other, and were both significantly better than ILSeq's and SEQ's.

Table 1: The best result of HyLS, MAENS and MASDC on DCARP instances.

Map	Ins	HyLS	MAENS [6]	MASDC [4]
S4-C	1	***10052***	22159.0	42285.0
	2	***10601***	22101.0	42878.0
	3	***10457***	21031.0	42094.0
Avr.Ranking		1	2	3
Friedman test		p-value=5.32e-32		
Nemenyi test		CD = 0.3		

Table 2: The median results of HyLS, ILSex, ILSeq and SEQ.

Map	Ins	HyLS	ILSex	ILSeq	SEQ
S4-C	1	***14760***	***14760***	14913	14913
	2	***14410***	14445	14418	14418
	3	***14142***	***14142***	14465	14465
Avr.Ranking		0.46	0.63	1.96	2.96
Friedman test		p-value=5.63e-39			
Nemenyi test		CD = 0.43			

4 CONCLUSION

In this paper, we focus on dynamic scenarios with small changes for the capacitated arc routing problem (DCARP). We propose a hybrid local search framework (HyLS) to reschedule the CARP solution within a short time budget for DCARP instances. We compared our proposed framework with existing methods in two sets of experiments, first evaluating a re-optimisation strategy and second analyzing the local search capability. Our results demonstrate that HyLS is very efficient in providing a good schedule within a very short time for the dynamic scenario with small changes compared with existing meta-heuristics and local search strategies.

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