An Optimization Framework for One-way Carsharing Systems with User Acceptance Probabilities

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1 INTRODUCTION

Carsharing refers to a type of car rental system in which the users have temporary access to a private vehicle fleet and are charged by the distance traveled or minutes spent. Similar to sharing economy focusing on underutilized assets to increase efficiency and sustainability (Hossain, 2020), carsharing systems aim to improve the utilization of vehicles.

One-way carsharing systems offer more flexible journeys by allowing users to pick up and leave the vehicles at stations that are not necessarily the same. As the demand for different stations varies throughout the day, one-way carsharing systems suffer from imbalances between vehicle supply and trip demands. In such systems, the availability of vehicles and parking spots is the key component that determines the level of service (Boyacı & Zografos, 2019). This is mainly ensured by a team of dedicated personnel to relocate vehicles between stations. The involvement of personnel for relocation of the vehicles creates a major operational cost. One alternative way of dealing with the mismatches between stock of the vehicles and the demand at the stations is to provide incentives to certain users for alterations within their original trip requests (Boyacı & Zografos, 2019, Correia *et al.*, 2014). Studies considering user-based relocations are mainly assuming the offered trips are accepted by the users. However, in reality, an offer that does not coincide with the user's preferences may be declined. Therefore, in this study, we considered a decision framework that incorporates the acceptance and rejection rates of the offers provided to the users.

The contribution of our research is two-fold. First, we introduce a mixed integer linear programming (MILP) model that considers the offers' rejection rates by the users. Second, we introduce a graph-spanner based heuristic approach which reduces the relocation arcs created within the MILP. Note that the proposed heuristic mimics the real-life operations by creating multiple stops along the way of the personnel, allowing them to change route once the need for initial relocation is eliminated.

2 FRAMEWORK AND SOLUTION ALGORITHMS

2.1 Framework

In this study, we present a decision framework for obtaining the most profitable offer that is provided to the user at each trip request. It is assumed that each user specifies their journey preferences including origin and destination stations, start and end time intervals. Upon receiving the trip request details, an optimization module evaluates the request and generates counteroffers (including the original request) within a predefined “distance” to the original offer. The most profitable offer is then presented to the user. The process is followed by a simulator module, deciding whether the counteroffer is accepted by the user considering the acceptance/rejection rates. If the user accepts the offer, then the offer is inserted to the accepted trips list and is considered as an input for the upcoming cycles within the framework. Figure 1 illustrates the proposed framework.

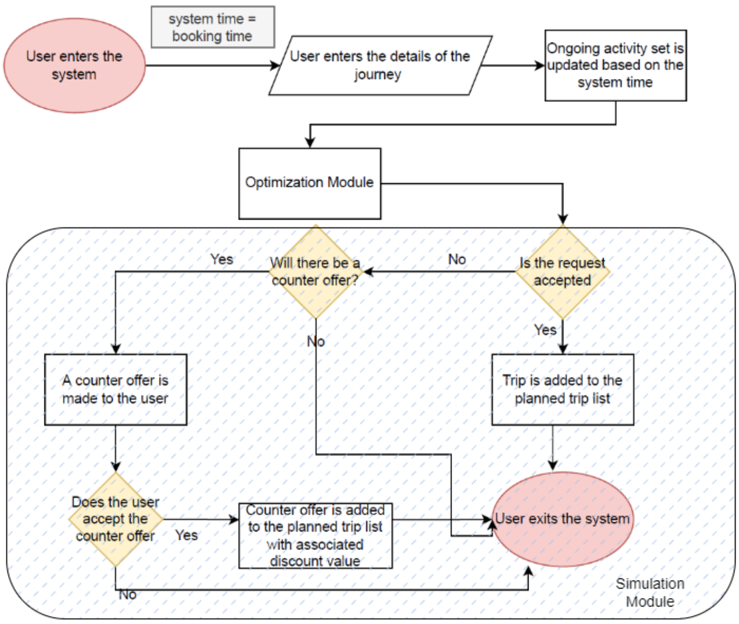

Figure 1 – *Proposed Optimization Framework*

2.2 Mathematical Model and Solution Algorithms

In this section, we briefly present the mathematical model that is used in the optimization module. At each iteration, the mathematical model aims to identify the most profitable offer to be offered to the user. The users are notified with a counteroffer (either their original offer or an offer that is different from the original offer spatially and/or temporally) along with price information, or they are informed of offer rejections. The mathematical model first generates a list of probable counteroffers which are associated with acceptance probabilities dependent on the distance from the original offer. Note that a binary logit function is used to express the consumer behavior in such systems taking explanatory variables as the distance differences from the requested and offered origin and destination stations (in km), time differences from the requested and offered start time (in minutes) and price.

In one-way carsharing systems, the relocation activities include both the movement of the personnel to the vehicle (relocation without the vehicle) and relocating the vehicle with personnel (relocation with the vehicle). Therefore, the MILP model creates variables related to relocation activities (with and without vehicles) for all origin-destination station pairs and start time intervals even though such variables generally take the value of zero. The MILP model is computationally intractable due to the high number of variables created. This is why, we have considered heuristic algorithms that are reducing the number of relocation variables. The first heuristic algorithm we apply is an adoption of the Relocation Restriction algorithm proposed by Bekli *et al.* (2021). The algorithm creates relocation variables based on the potential need for relocation at the stations. The second heuristic algorithm that we propose uses graph-spanners to create relocation arcs related to the relocation activities of personnel without vehicles. Instead of direct arcs between any station pair, we propose reaching a target station through multiple stations. The second heuristic allows personnel to dynamically change their previous route assignment on the road with each new request.

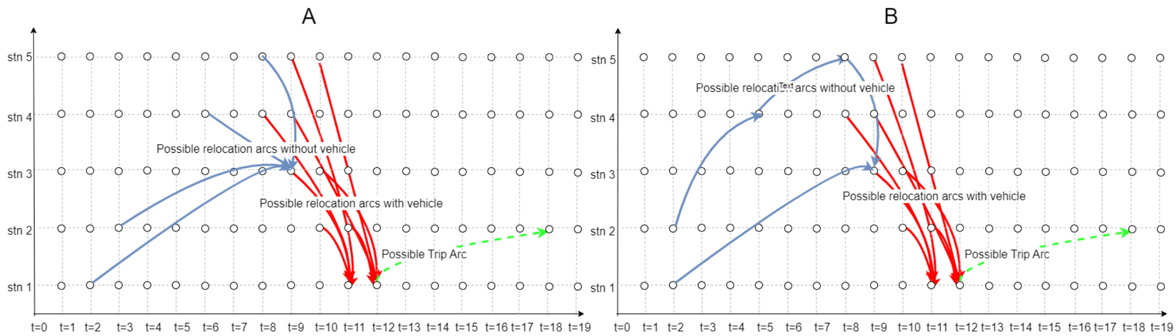

Figure 2 – *Illustration of Relocation Restriction (A) and Graph-spanner Based (B) Heuristics*

Figure 2 illustrates both heuristics when a counteroffer from Station 1 to Station 2 starting at Time 12 is created. Considering the need for a vehicle at time 11 or 12 at Station 1, possible relocation with vehicle arcs are created. To provide personnel at the start of these relocation arcs, possible direct relocation arcs without vehicle (in the Relocation Restriction heuristic) or possible relocation paths (in the Graph-spanner Based heuristic) are created.

3 COMPUTATIONAL RESULTS

We have tested the framework using the MILP model and both heuristic algorithms on a one-way carsharing system data from Nice, France. First, we have considered the busiest 10 stations to be able to compare the heuristics with the proposed MILP. The analysis on the 10-station network with 100 or 150 demands per day shows that the generated profit values of both of the heuristics at the end of the day are similar to what we have obtained by solving MILP model exactly.

We conducted a sensitivity analysis on spatial and temporal flexibility using both of the heuristic algorithms. In line with existing literature, spatial flexibility yields better values compared to temporal flexibility. Additionally, the analysis shows that integrating operator- and user-based relocations leads to notable profit increments.

We have also explored the impact of the number of personnel on the system with 20-node instances. The analysis reveals that the profit increases substantially when the number of personnel is increased, until a certain number at which further increases in the number of personnel yield negligible improvements in profits. The profit generated by both of the heuristics show similar patterns.

Finally, we have compared the CPU times required to solve the heuristics algorithms, finding that the required time for the Relocation Restriction Algorithm is significantly greater than that of Graph-spanner-based algorithm for most of the cases.

4 CONCLUSION

In this work, we take the users' acceptance probabilities to the alternative offers into the decision framework. By considering the acceptance probabilities, which depend on the offered trip to the user, real-life operational decisions are better reflected in the proposed framework.

Two heuristic algorithms are proposed for solving the mathematical model. Both heuristic algorithms decrease the number of variables created significantly without compromising the quality of the model.

The study can be further enhanced by integrating the historical demand data and predicting the states of the stations.

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