Crowdsourced-Focused Redistribution Operations in Free-Floating Scooter Systems

Lacy Greening, Alan Erera
lacy.greening@gatech.edu, alan.erera@isye.gatech.edu,
H. Milton Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology

1. Introduction

Shared mobility systems have the potential to contribute greatly to the first- and last-mile problem by bridging the gaps in existing transportation networks and encouraging multimodality. Within all shared mobility systems, operators are challenged by the problem of providing riders with adequate vehicle or ride availability within a convenient distance from their origin and destination, while also adhering to budget and space constraints. Two critical decisions that must be made are how and when to distribute these fleet vehicles throughout a city. There has been research addressing these decisions for many such systems, including micromobility platforms like station-based bike sharing systems. However, the complexity and novelty of free-floating systems that rely on crowdsourced repositioning lead to new and interesting problems.

2. Problem Description

The major difference between station-based systems and free-floating systems is the customer experience of finding a suitable vehicle. In free-floating systems, a customer looks for a vehicle in a general area, where the size of the area and amount of time spent searching are dependent on the customer. Thus, the placement of vehicles clearly affects system performance. The transition to free-floating systems has also increased the complexity of vehicle recovery and repositioning operations compared to station-based systems. Vehicles are no longer at fixed locations and can be scattered throughout a service region.

Free-floating fleet redistribution is more flexible than that for station-based systems. Importantly, an interesting tradeoff exists for any vehicle reallocation: some configurations may lead to higher ridership, while others may be achievable at a lower redistribution cost. The redistribution problem becomes even more interesting when independent contractors are used to charge, maintain, and reposition the fleet, which is the case for many free-floating scooter systems (FFSS). Operators using contractors do not require trucks and employees to distribute scooters. However, it may be more difficult to redistribute vehicles to desired locations since independent contractors have capabilities and preferences that may significantly constrain these decisions.

In this study, we focus first on a redistribution problem where company drivers or independent contractors will place scooters exactly where the operator specifies and our goal is to maximize ridership. We develop and test heuristics for allocating scooters in a geographic service region as our primary contribution. A secondary contribution will be to introduce a redistribution planning problem that balances the ridership benefits of a configuration with the costs required to achieve it feasibly using independent contractors.

3. Methodology

We outline our roadmap for improving crowdsource-dependent FFSS as follows:

1. *Determine fleet configurations that attempt to nearly maximize expected rides served (or revenue generated).*
2. *Optimize the contractor distribution plan to feasibly redistribute vehicles while balancing potentially competing objectives of the operator and the contractors.*

In this paper, we focus on (1) and propose some initial ideas for (2). The stochastic nature of FFSS motivates the use of simulation-based optimization heuristics to determine a configuration that maximizes the expected number of rides served in an operating day. Our approach utilizes a construction heuristic and a number of different solution improvement heuristics to determine such a configuration; Algorithm 1 below outlines the structure of this approach. All heuristics rely on a detailed simulation to determine the increase in benefit of the new configuration, where benefit is defined as the average number of rides served across all sample days. Both the construction heuristic and the improvement heuristics make decisions to maximize *marginal benefits* realized from changing a configuration. In the construction phase, we seek to add one or more vehicles to the region with largest marginal benefit. We develop improvement heuristics that use either swap-type neighborhoods or faster gradient-based improvement schemes that move scooters from least attractive to most attractive (marginally) regions.

Algorithm 1: Construction Heuristic

Input : fleet size, regions, step size n
Output: Starting configuration
Initialize all regions to have 0 scooters;
while *the total number of scooters distributed* $<$ *fleet size* **do**
  for *each region* **do**
    use a simulation to determine the value gained when adding n scooters
  end
  add n scooters to the region that benefited the most
end

To establish the quality of our heuristic results, we also formulate a novel upper bounding problem that still can account for the probability of a rider finding a nearby scooter using a network-based integer programming model (NB-IP), depicted in Figure 1, for the special case where the ride

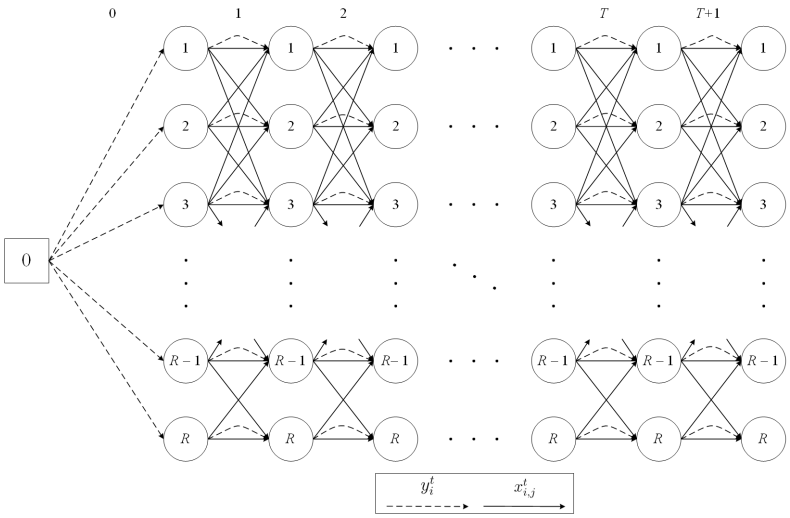


Figure 1 **Network structure for optimizing the starting configuration for a given day.**

demand by region and time is known *a priori*. The optimal objective value for this model is used to create a sample-average upper bound on the ride-maximizing fleet configuration. We also adapt the structure of this bounding model to formulate a two-stage stochastic integer programming (SIP) model for the true configuration problem that uses a simplification of the demand fulfillment process as an alternative heuristic.

To demonstrate the merit of using simulation-based optimization heuristics to increase the usage of scooters throughout a city, Atlanta, Georgia was used as a case study. The layouts analyzed, shown in Figure 2, and simulation data were based on Atlanta population densities and travel patterns. The upper bound for the average number of rides served for each layout was calculated by taking the average of the NB-IP objective functions for 100 sample days. The percent of satisfied demand (% SD) when using the heuristic and SIP model outputs were then compared.

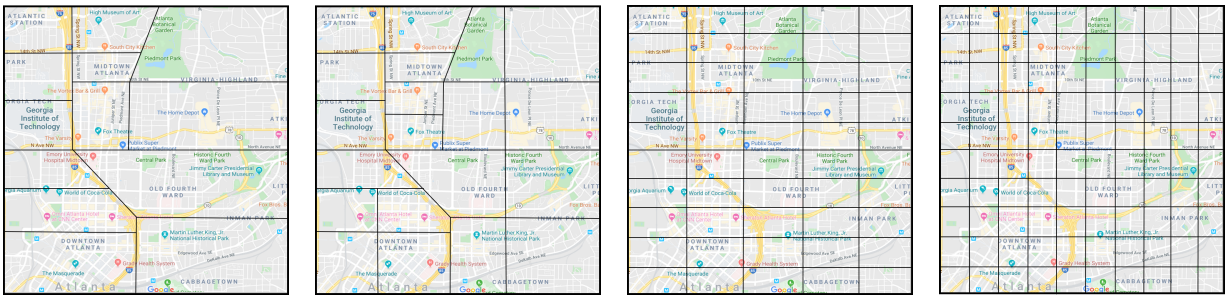


Figure 2 **The four Atlanta, GA model layouts with 13, 20, 50, and 100 regions, respectively.**

To begin the study of the contractor distribution planning problem, we first focus on a simplification where we seek to achieve a given scooter configuration feasibly while minimizing the average time required to redistribute each scooter. This problem can be formulated as a variant

of the multi-depot split-delivery vehicle routing problem (MDSDVRP) where each contractor's home location is a depot and each contractor has a given initial quantity of scooters to return and (potentially) different maximum available time to return scooters. We propose an arc-based MIP for the problem, and we are developing computational approaches to solve realistic-scale problem instances within reasonable compute times.

4. Results

We present results for the fleet configuration heuristics in Table 1. The table aggregates the results for all tested layouts and uses a realistic fleet size of 1000 scooters and 100 sample days of demand. We express the results as a percentage of the sample average ridership upper bound generated by the NB-IP models. We also include a column representing a simple heuristic, denoted "User", where scooters are placed into regions in proportion to the fraction of total demand generated. The simulation-based construction heuristic and the improvement heuristic perform similarly, regardless of whether the improvement heuristic starts with the "User" or "Constructed" solution. Interestingly, the SIP approach produces configurations that are somewhat worse due to the simplifications required in the model of demand fulfillment.

	User	**Constructed**		**Improved Constructed**		**Improved User**		**SP**	
Layouts	% SD	% SD	Time (hrs)	% SD	Time (hrs)	% SD	Time (hrs)	% SD	Time (hrs)
13	86.2%	89.3%	0.7	89.4%	0.9	89.4%	1.5	87.9%	3.0
20	81.3%	86.0%	0.9	86.3%	2.1	86.4%	2.0	80.4%	3.0
50	64.9%	69.4%	1.1	69.5%	3.5	68.9%	3.5	61.5%	3.0
100	62.5%	67.6%	2.0	65.0%	2.8	63.8%	3.5	64.5%	3.0

Table 1 Comparison of heuristic-generated, user-generated, and SP configurations when $F = 1000$.

The results indicate that using simulation-based heuristics to increase the amount of satisfied demand is useful and practical; improvements over the simpler user configuration were found using total compute time less than 3.5 hours. For the largest, most realistic instances with many subregions, the construction heuristic was particularly effective and produced better solutions faster than the improvement heuristics.

5. Conclusions

This work is one of the first to begin to address problems faced by FFSS that must effectively utilize and maintain the continued participation of crowdsourced contractors. We have shown the value of using simulation-based heuristics to improve fleet utilization and introduced the problem of assigning contractor repositioning tasks in such a way that encourages positive placement decisions. We have also begun an investigation of distribution planning methods that seek to place vehicles into a high-quality configuration feasibly and at low costs for a set of independent contractors.