A Hybrid Approach to Matching Taxis and Customers

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***Abstract*—We propose a Hybrid method for a computationally efficient matching between taxis and customers in a Mobility on Demand System. Our framework explores a hybrid path search for the assignment in order to minimize the total travel cost with a limited knowledge of the network. To validate the Hybrid method, two assignment techniques are compared: Greedy and Bipartite. The Hybrid method is a two stage process, where we first use the Euclidean distance-based travel cost for fast pairing between the taxis and customers. In the second stage, we iteratively unfold the street distance-based travel cost for the least cost path in the Euclidean metric. The outcome of the proposed framework is a fast and efficient taxi to customer assignment with the optimal total travel cost.**

***Keywords*-Transportation Technologies; Assignment Methods; Mobility on Demand; Computational Intelligence;**

I. Introduction

We are observing a disruption in urban mobility services worldwide. New, shared forms of transportation are growing rapidly and becoming a daily life for many commuters. With this growth in the shared mobility industry, it becomes crucial to provide systems, which are reliable and fast for the growing number of users. One of the bottlenecks for such systems is the efficiency to assign customers to vehicles. In this work, we propose a hybrid path search for fast, efficient and reliable assignment to minimize the total travel cost with a limited knowledge of the network.

The assignment problem attempts to solve a maximum or minimum weight matching in a weighted bipartite graph. In case of mobility on demand (MoD) systems (similar to the example illustrated in Fig. 1), the problem is to match customers to vehicles while minimizing the total cost of assignment. We build upon studies [1], [2] and extend presented assignment techniques to a hybrid method described in [3]. We introduce a methodology to solve matching problem optimally and efficiently with a limited number of queries to the street network database.

Limiting the number of queries to the database is important to reduce the communication and planning cost. In addition, it also helps in efficiently dealing with slow and expensive access to the database servers. Our proposed hybrid method uses fast matching based on Euclidean distance measurements to guide the search for optimal matching in real street distance network space. We iteratively query the network only for the real street distances corresponding to the least cost matches in the Euclidean space. This provides us optimal matches between customers and taxis while saving on the communication and planning costs of the system. We present our proposed approach for assignment techniques with hybrid computation method in Section II. The experimental results are discussed in Section III and conclusion along with future directions are highlighted in Section IV.

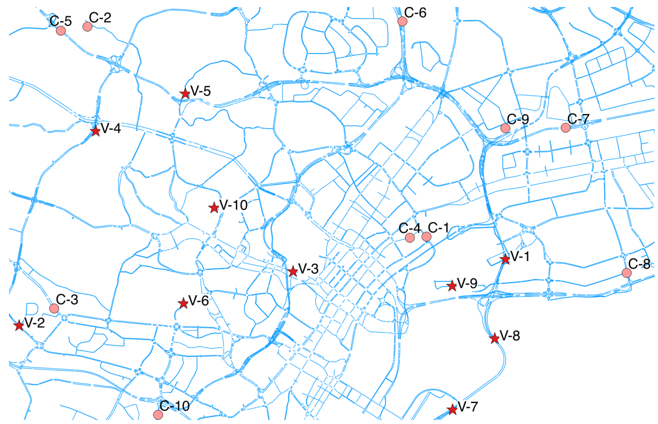

Figure 1: Customer requests (circles) and locations of available vehicles (stars). Given this knowledge our goal is to solve the customer to vehicle matching problem using a *hybrid route choice* model. Note, that if customer 1 (C-1) is the first in queue then according to Greedy assignment, it would be matched to vehicle 1 (V-9). Otherwise, when optimizing for the total assignment cost for Bipartite matching, (C-1) is assigned to vehicle 2 (V-2) and (V-9) is assigned to (C-4).

II. Proposed Approach

Our proposed framework for matching taxis to customers, involves two major components. The first component provides optimal assignment technique given a particular scenario and the second component helps in finding this optimal assignment, rapidly and efficiently. The assignment problem of passenger-to-vehicle in our application is formulated in the following two ways: Greedy Assignment and Bipartite Assignment.

A. Greedy Assignment

The Greedy assignment is an approximation of the minimum cost generalized assignment problem [1]. We assign customers to vehicles in a greedy (first-in first-out) order using a residual profit concept, that is, the first customer in the queue is assigned to the nearest vehicle, as illustrated in Fig. 1. For the subsequent customers we look for the nearest vehicle in an iterative manner (with no option for assigning previously assigned vehicles).

B. Bipartite Assignment

In the Bipartite assignment, we attempt to solve the minimum weight bipartite matching problem for a set of vehicles and a set of customers at one iteration and minimize the total travel cost of assignment, as presented in Fig. 1. Let us assume *P* is a set of booking requests (customers), where each individual p_j is described by its current location (*x, y*). Let us assume *V* is a set of available vehicles, where each vehicle v_i is described by its current location (*x, y*) and status, e.g., free, passenger on board. The cost of picking up passenger *j* by vehicle *i*, c_{ij} is expressed in terms of the travel distance. The decision variables x_{ij} describe whether or not vehicle *i* is assigned to passenger *j*. The objective is to minimize the total distance traveled by all the vehicles to pick up all passengers. This cost function is formulated as below, where $R = max(c_{ij}) + 1$:

$$\begin{aligned} \text{minimize} \quad & \sum_{ij}(c_{ij}x_{ij} - R) \\ \text{subject to} \quad & \sum_{i} x_{ji} \leq 1 \; j \in P \\ & \sum_{j} x_{ji} \leq 1 \; i \in V \\ & x_{ij} \geq 0, integer \end{aligned} \tag{1}$$

Given the two assignment techniques we know that the Greedy assignment method is faster to compute than the Bipartite assignment. However, the Greedy assignment provides a larger total distance traveled to pick up all customers. Both assignment techniques rely heavily on the accuracy of distances. If the distances based on the real network are available, the algorithms will give an optimal solution to the matching problem. However, it can be expensive to access the street network database. Hence, if the network information is not exact and incomplete, then we may not always get the optimal solution. We propose a hybrid method to find the optimal cost path while efficiently querying to the database server.

C. Hybrid Method for Cost Computation

We apply the hybrid cost computation method from [3] to the Greedy and Bipartite assignment techniques for obtaining fast and cost optimal matches between customers and vehicles. This method is based on a heuristic that the Euclidean distance measures are a good first approximation of the real street distance measurements. Using this heuristic, we guide and speed up the search for finding optimal assignments based on the Euclidean distance measurements. Consequently, we require only a few measurements to be retrieved in real street distance metric to obtain an optimal assignment matching.

A description of our hybrid cost computation method when implemented with the two assignment techniques is presented in the Algorithm 1 and 2. Our goal in these algorithms is to achieve an optimal assignment matching cost $m_{ij} \in M$ for the vehicle to passenger pair (v_i, p_j).

```
Input: Set of passenger P and vehicle V locations.
Initialize cost matrix C in Euclidean space
foreach (p_j ∈ P) do
    do
        Compute Greedy Assignment cost, m_ij ∈ M
        if (m_ij ∈ ℝ) then
            Repeat for next p_j
        else
            Replace c_ij ∈ C with m_ij ∈ ℝ
        end
    while (M ∉ ℝ);
end
```

Algorithm 1: Hybrid Method for Greedy Assignment

```
Input: Set of passenger P and vehicle V locations.
Initialize cost matrix C in Euclidean space
do
    Compute Bipartite Assignment cost, m_ij ∈ M.
    foreach (p_j ∈ P) do
        if (m_ij ∈ ℝ) then
            Repeat for next p_j
        else
            Replace c_ij ∈ C with m_ij ∈ ℝ
        end
    end
while (M ∉ ℝ);
```

Algorithm 2: Hybrid Method for Bipartite Assignment

III. SIMULATION RESULTS

In our experiment we attempt to match 10 vehicles and 10 customers within the Central Business District in Singapore. The locations of the vehicles and the customers are distributed as shown in Fig. 1. We compare our proposed hybrid method with two benchmark cost computation methods used for obtaining travel cost of vehicle assignment *i* to customer *j*. These include: Euclidean and Real distance-based cost metrics.

The Euclidean distance-based metric, measures the cost in the Euclidean space without requiring any network information and purely based on the location of the passengers and vehicles. Whereas, the real distance-based cost computation metric requires full network information to find the optimal matches. Our goal is to combine these two metrics using the Hybrid method to obtain optimal cost with minimal number of queries.

Customers ID	1	2	3	4	5	6	7	8	9	10
Euclidean	9	4	2	1	5	10	8	7	3	6
Real	3	10	2	1	4	5	9	6	7	8
Hybrid	3	10	2	1	4	5	9	6	7	8

Table I: **Greedy Assignment** where columns represent the vehicle IDs matched to customer IDs.

Customers ID	1	2	3	4	5	6	7	8	9	10
Euclidean	9	5	2	3	4	10	7	8	1	6
Real	3	4	2	7	10	5	8	1	9	6
Hybrid	3	4	2	7	10	5	8	1	9	6

Table II: **Bipartite Assignment** where columns represent the vehicle IDs matched to customer IDs.

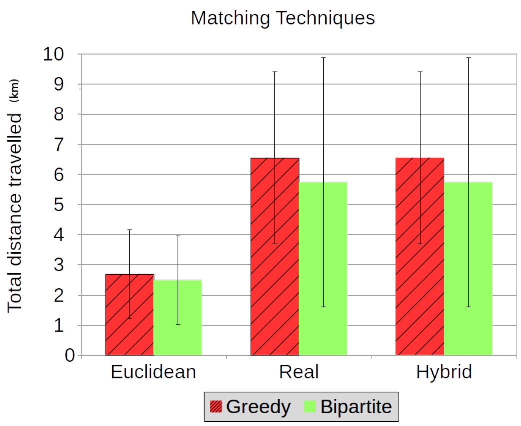

Figure 2: Total distance traveled for the Greedy and Bipartite matching techniques using three different travel cost assessment methods.

We apply the Euclidean, Real and Hybrid cost computation methods to the Greedy and Bipartite assignment techniques. The matches obtained by using these two assignment techniques are shown in Table I and II. It can be observed that the Hybrid method provides the same optimal matches as the real distance-based method. The number of queries saved by using the Hybrid method with incomplete network information, over the real distance-based method, requiring the complete network information, is 38% for Greedy and 50% for Bipartite matching.

Fig. 2 shows a cost comparison of two assignment techniques and three cost computation methods. The cost is expressed in terms of the total distance traveled by all the vehicles to pick-up passengers. From the plot, we observe that the Euclidean distance-based algorithm provides an underestimate of the real street distances and has the least total distance traveled. The real distance-based cost computation method provides the total distance traveled that is required for an optimal match. The Hybrid cost computation method provides the same total distance traveled however with lesser number of queries to the database server. A comparison between the two assignment techniques reveals that we could save 12% of the total distance traveled by using Bipartite over Greedy assignment. However, this would be at the expense of increase in the total number of queries by 32% and increase in the waiting time of the queued customers.

In summary, we achieve optimal matching using Hybrid method for both Greedy and Bipartite assignment techniques while reducing the total number of queries to the database server. We can apply either of the two matching techniques depending upon the desired application of either providing greedy service for the incoming demand of the customers or queuing the passengers for a batch assignment using Bipartite matching.

IV. Conclusion and Future Work

In this work we present a Hybrid method for assigning taxis to customers. We presented the two assignment techniques namely, Greedy and Bipartite matching and validated our Hybrid algorithm on them. Our results for applying Hybrid algorithm to the two matching techniques, illustrate that we can achieve fast and optimal matches by using Euclidean distance-based cost measurements for guiding the search for finding optimal cost in real street distance space. In addition, we also save the total number of queries to the street network database server.

For our future work, we would like to extend our matching techniques and cost computation methods to the ride-sharing application, wherein, a group of passengers in the vicinity of each other can share a ride together. In this case, we would require to find an optimal match that not only considers the start locations of the passengers but also their desired destinations.

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