顧客のパンクチュアリティ予測を備えた MaaS 共有バスシステムの設計

MaaS Shared Bus System Design with Customer Punctuality Prediction

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1 Abstract

Nowadays, Mobility as a Service (MaaS) as a novel idea of urban mobility framework has been widely developed and provides convenience for multiple transportation ways. However, though among all sorts of transportation, subway takes on the most travel pressure, and commuters still face with difficulties concerning methods to efficiently move between homes and subway stations with less transportation pollution.

To address these challenges, in this paper, we propose a novel MaaS shared bus sub-system framework, which can optimize an integrated subway station nearby shuttle bus route based on passengers' travel demands, meanwhile adequately taking the punctuality of the passengers into account. Considering different business scenarios, the route planning is solved by proposed methods based on ant colony optimization. A real case experiment is applied to test the efficiency of the shared bus system, which can be served as a benchmark. Through the real case, the ability of the system to reduce environmental pollution is also demonstrated.

Keywords: Big Data, Bus Sharing, MaaS, Vehicle Routing Problem

2 Introduction

Nowadays, Mobility as a Service (MaaS), a new idea of urban mobility framework, has been extensively discussed and studied, which provides convenience for users through fast response to instant travel requests and efficient transportation planning. In traditional MaaS systems, smart phone plays a significant role, which helps with ordering new trips, checking for timetables and paying for fares. Smart phone is also able to collect real-time location information and movement trajectory continuously. Such mobility big data can be utilized for local passenger flow analysis and travel demand prediction, which can help transportation service providers automatically allocate capacities in specific time and locations. Thus, with the assistance of mobility big data, the MaaS system can be designed more ingeniously. By extracting travel demands from real human mobility data based on GPS records, in this paper, we propose a novel MaaS shared bus system framework. Inspired by the "last mile" scene, the system provides an efficient and environment-friendly solution for the short-distance movement around the subway station by arranging shared bus for different passengers. To be more specific, optimal route of each shared bus is planned by establishing midway bus stations, which takes operating costs, the majority of the customers' demands and the uncertainty of punctual arrival into account. An ant colony optimization algorithm based method is developed to solve the route planning problem. The system is also capable to receive temporary requests raised by users through smartphone application.

More than this, we provide a real case experiment to test the efficiency of the shared bus system. We extract commuting demands between communities around subway stations and the stations. Based on the real travel demands, we analyze the environmental pollution that can be reduced to demonstrate the significance of our proposed system.

The Vehicle Routing Problems (VRPs) help identifying routes for a set of customers with fixed positions, and on this basis some further problems like the Vehicle Routing Problem with Time Windows (VRPTW) and The Dial-a-Ride Problem (DARP) derive from the original VRP. The series problems first started with the famous Travelling Salesman Problem(TSP), described as given a list of cities and their distance graph, find a shortest route to cross all the cities then returns to the place of departure with no other repetitive visit. Tadei *et al.* and Huang *et al.* explored stochastic conditions of TSP and VRP respectively, showing the path selection leads to significant savings of costs. Then with the rise of more customer requests and travel demands, new problems and solutions generated in the fields of time constraints, travel economy and order appointed multiple destinations, etc. In 2010s, the sharing economy soon spawned the appearance of new public transportation methods like hitch rides and the shared taxi. Nasser summarized the exact, heuristic and metaheuristic methods to solve VRPTW. In the field of customized bus service, with multiple starting points and a single destination, typically the problem can be summarized as a School Bus Routing Problem. However, the researches on customized bus for subway shuttle scenarios are rare particularly considering the high standard of customer comfort, let alone the emission analysis comparing to typical transportations. These elements are vital in the development of modern MaaS system and urban transportation construction, which is exactly emphasized in our article.

3 Problem Description and Methodology

Our goal is to provide shared-bus service for dense passenger flows to efficiently commute from subway stations to their destinations. Passengers getting off from trains in subway stations can take our service for the rest parts of their trips by providing their destinations and expected arrival time. We assume that each bus serves in a certain period.

Figure 1: Overview of the MaaS Bus Sharing System.

Assume that $U = u_1, u_2, ..., u_k$ denotes the group of k passengers that get off from trains and choose to take our service for the rest parts of their trips, their corresponding destinations $D = d_1, d_2, ..., d_k$ and expected arrival times $t_1, t_2, ..., t_k$ could be collected. A graph $G = (V, E)$ is utilized to represent distance relations between starting point of the bus and destinations, where $V = D \cup p_s$, p_s is the starting point of the bus and E is the shortest distance between two points on the road network. The bus route consists of n stations $S = s_1, s_2, ..., s_n, s_i \in V$. In particular, the first station and the last station are both the starting point, i.e., $s_1 = p_s, s_n = p_s$. The standard speed of each bus can be represented as v. For a given departure time t_0, the arrival time of each station $t_1, t_2, ..., t_n$ could be computed iteratively by:

$$t_i = t_{i-1} + \frac{E(s_{i-1}, s_i)}{v}, \forall i \in [1, n] \quad (1)$$

In addition, it is not proper to let passengers arrive too early or too late. We set a tolerance time Δt to represent the maximum difference time between the arrival time that passengers could tolerate and their expected arrival time. Then for any passenger u_i who expect to get off at station s_j at t'_{u_i}, we have:

$$t'_{u_i} - \Delta t \leq t_j \leq t'_{u_i} + \Delta t, \forall u_i \in U \quad (2)$$

We use a modified Ant Colony Optimization algorithm to solve our problem. We add the estimation of punctuality of each ant into calculation to guarantee the effectiveness.

4 Result and Analysis

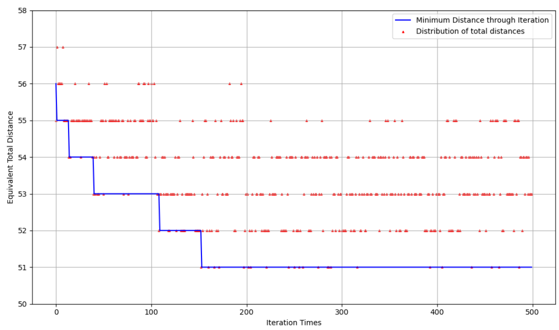

Figure 2: The results of ACO by iteration.

The Fig.2 reveals the convergence of our proposed ant colony optimization method. We recorded the outputs of 500 iterations with 50 ants generated in each run, and the input for our model are 20 requests, which was extracted randomly in the dataset of Ikebukuro station.

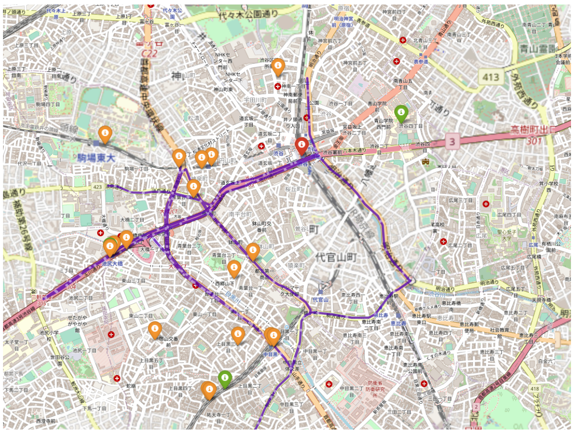

Figure 3: Example of planned real-world routes.

Fig.3 demonstrates the planned route of 20 real requests around Tokyo station. The red mark denotes the starting point of the bus, which is also the subway station. Each green and yellow mark represents a request from one person. The yellow marks are passengers that are successfully delivered, and the green marks represent people who cannot be sent in time and are not served. The purple line denotes the route of the bus.

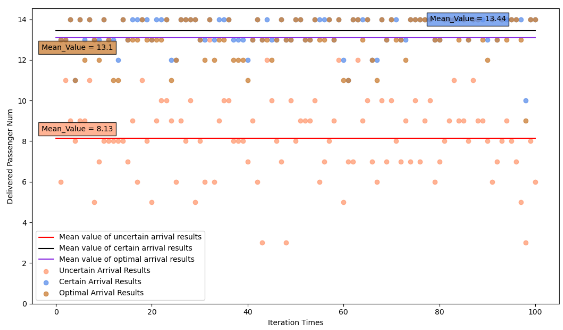

Figure 4: Distribution of results under uncertain passenger punctual arrivals and certain punctual arrivals.

We analyze the performance of our model in the dimension of passenger punctuality. The Fig. 4 reveals the distribution of the results with uncertain and certain punctual arrivals of the passengers. In Fig. 4, we tested the ridership of one bus with 40 passengers. The 40 passengers remain the same in each test as input. The certain punctual arrival denotes that the passengers can always arrive at the designated pick-up position, and in uncertain punctual arrival scenarios, we give each passenger a possibility of punctuality, a random number between 0.5 and 1.0. The blue dots in Fig. 4 represent the experiment result of certain punctual arrivals. We can see the delivered passenger number fall in between 10 and 14 when all passengers can arrive in time. But when the uncertainty is given, the ridership decrease sharply. The mean value of ridership decrease from 13.44 to 8.13. When we use the optimal ACO algorithm to take the uncertainty into account beforehand, the mean value rocket to 13.10, which was close to the result of certain punctual arrivals. This shows that our proposed method can effectively operate to deliver the most number of passengers under various real-world scenarios, bringing the best service quality for customers and the highest earnings for operators.