Dynamic Taxi-sharing Service Using Intelligent Transportation System Technologies

Chi-Chung Tao
Dept. of Transportation Management
Tamkang University
Taipei County, Taiwan
cctao@mail.tku.edu.tw

Abstract—**A practical and applicable taxi-sharing system based on the use of Intelligent Transportation System (ITS) technologies has been developed in Taipei City. This system is easy for members to use and inexpensive for the service provider to operate. This paper gives an overview of the taxi-sharing service, presents key algorithms for dynamic rideshare matching processes, describes the field trial operation of the system in Taipei Nei-Hu Science and Technology Park and discusses empirical results to provide valuable implications for better taxi-sharing service in the future.**

Keywords-ITS; Rideshare matching; Taxi-sharing

I. Introduction

The convergence of the Intelligent Transportation System (ITS) technologies, including the Internet, wireless communications, geographic information system (GIS), positioning technologies, and mobile devices, has given rise to new opportunities for taxi services. With ITS technologies taxi operators can monitor their entire fleet and track mobile user's location and movement on GIS-based maps. Due to any information or message about each taxi or user can be provided visually and interactively, taxi-sharing has become a new public transportation system which has high mobility and high accessibility in the same manner as privately owned cars.

In Japan, the public and private sectors have jointly conducted field trials of taxi-sharing systems using electric vehicles at several locations around the country in recent years [1]. In Switzerland, England and Germany, taxi-sharing systems are already being operated successfully as businesses [2]. It has been demonstrated that joint use of taxis by multiple members is fully feasible by suitably managing the number of vehicles and participating members.

According to the statistics report [3], the amount of taxies in Taipei city has reached 32,824 vehicles up to the end of 2006. The average daily working time per taxi driver is 10 hours, but the vacancy time is 3 hours. Most of taxi drivers are willing to take incentive measures such as taxi-sharing to improve the average level of occupancy. Taxi-sharing is similar to carpooling which is based on the idea that sets of users having the same travel destination and sharing vehicles. Previous work suggests that dynamic ride matching differs from regular carpooling and taxi-sharing in that ridesharing is arranged for individual trips rather than for trips made on a regular basis and requests for ridesharing can be made close to the time when travel is desired [4].

Dynamic rideshare matching differs from traditional rideshare matching in following ways: Traditional systems assume the traveler has a fixed schedule and a fixed set of origins and destinations [5]. A dynamic system must take into account each trip individually and be able to adjust trips to arbitrary origins and destinations at anytime by matching users' individual trips. The other major difference is that dynamic ride matching systems must offer the real-time match information to the user to accommodate short-term (e.g. same day) travel as well as long-term (e.g. future days or weeks) trips [6]. Using ITS technologies the requirements of dynamic rideshare matching are easier to meet than those of for traditional rideshare applications [7].

This paper is aimed on modeling a dynamic rideshare matching application of taking into account the Internet and wireless communication network infrastructure to meet the requirements of taxi passengers from one origin to many destinations ("one-to-many") and from many origins to one destination ("many-to-one"). First, the specific taxi-sharing problem is addressed and the conceptual framework of the dynamic taxi-sharing system is also introduced. Then, a field trial for two cases of "one-to-many" and "many-to-one" is conducted. Finally, empirical results are analyzed and the conclusion follows.

II. System Overview

The problem being considered in this paper is defined around a situation in which a number of potential passengers that daily commute between their house and workplace. These commuters need taxi-sharing services with the type of "many-to-one" in the morning peak hour and the type of "one-to-many" in the afternoon peak hour. Passengers can access the taxi call center either through a World Wide Web (WWW) browser or via mobile phones at any time. Given this situation, the problem at hand is deciding which passengers should be matched and assigned to a taxi in a way of minimizing the distance traveled and time of both passengers and taxi. Before we proceed to a general overview of the system, the core module of the system is the dynamic rideshare matching algorithm procedure which can be described as follows:

Although the capacity constraint is set to be four passengers for the taxi-sharing service, it is also suitable for over four persons if the pooling vehicle larger than a car. The algorithm procedure is shown in Fig. 1.

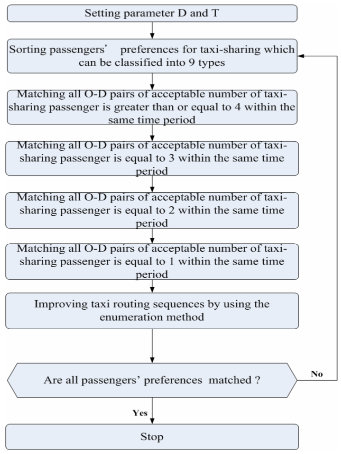

Figure 1. The algorithm procedure

Step0: Setting parameter D and T.

1) D is used to restrict the searchable scope that prevents routing distance from being too long.
2) T means the maximum passenger waiting time.

Step1: Sorting by taxi-sharing passengers' preferences which can be classified into following 9 types:

1) Acceptable number of taxi-sharing passenger is two and female only.
2) Acceptable number of taxi-sharing passenger is two and male only.
3) Acceptable number of taxi-sharing passenger for is two and no request for male or female preference.
4) Acceptable number of taxi-sharing passenger is three and female only.
5) Acceptable number of taxi-sharing passenger is three and male only.
6) Acceptable number of taxi-sharing passenger is three and no request for male or female preference.
7) Only female taxi-sharing passengers are acceptable.
8) Only male taxi-sharing passengers are acceptable.
9) No request.

The matching process will continue from type 1 to type 9 till the major candidate passengers are matched by considering the strictest constraint of preference with the first priority. If they can not be matched, step 2 will not be taken.

Step2: Matching all O-D pairs of acceptable number of taxi-sharing passenger is greater than or equal to four within the same time period. A simple example is shown as follows:

6:30		6:35		6:40
O→D1	~~5~~ 1	O→D1	2	....
O→D2	1	O→D2	~~5~~ 1	....
O→D3	3	O→D3	~~5~~ 1	....
O→D4	~~8~~ 0	O→D4	1	....
O→D5	1	O→D5	~~7~~ 3	....
O→D6	1	O→D6	1	....
O→D7	1	O→D7	1	....

Step3: Matching all O-D pairs of acceptable number of taxi-sharing passenger is equal to three within the same time period.

Step4: Matching all O-D pairs of acceptable number of taxi-sharing passenger is equal to two within the same time period.

Step5: Matching all O-D pairs of acceptable number of passenger for taxi-sharing is equal to one within the same time period.

Step6: Improving taxi routing sequences by using the enumeration method. For example, if the original route is O→D1→D2→D3, all possible sequences of O→D1→D3→D2, O→D2→D1→D3, O→D2→D3→D1, O→D3→D1→D2, and O→D3→D2→D1 will be searched to identify the shortest route.

Step7: If all passengers' preferences are matched, then stop; else, go to step 1.

A conceptual framework of the dynamic taxi-sharing system is shown in Fig. 2 and a general overview of the system follows.

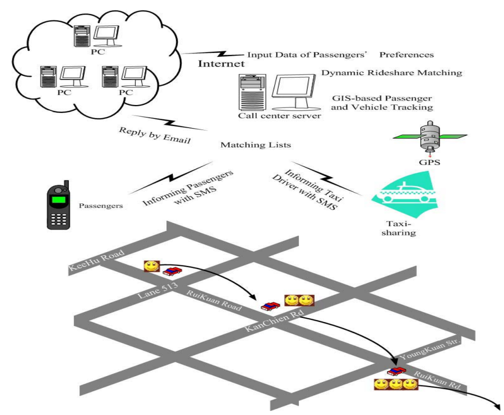

Figure 2. The framework of the taxi-sharing system

1) The positions of all taxis in the system are tracked and monitored by GPS. When a taxi moves a predetermined distance, information is sent via GPRS network to the taxis fleet management database in the call center.
2) Passengers order taxi-sharing service via Internet or by cellular phones. The host computer begins to process their O-D data to generate rideshare matching lists by using the "many-to-one" or the "one-to-many" algorithm.
3) The generated matching lists are compared with the taxi positional information that was monitored in GIS-based server, and a search is made to find the taxi that can move most quickly to the first passenger's location. The sequence of the taxi-sharing route to pick up other passengers is also determined.
4) The taxi driver is informed by the call center via GPRS to confirm his tasks with an on-board unit (OBU) shown in Fig. 3. The detailed passengers' information including names, on-off locations, route and fees are transmitted to the OBU which can be checked with different buttons.

Figure 3. The on-board unit on a shared taxi

5) Passengers who are matched successfully within predetermined time interval are informed via Internet or SMS with detailed information including shared taxis ID, driver's name, precise on-off locations and fees. The sharing fee of each passenger is computed on a distance-traveled basis. The fee increment (20 NT$) is set as a five-minute travel distance rectangle shown in Fig. 4. The final sharing fee of each passenger is computed according to number of sharing passengers, their O-D data and preferences.

Figure 4. The increment rectangle of sharing fees

6) While passengers riding on the shared taxi, the vehicle position information and the status information of passengers to get on and off are sent to the call center server so that the operator can track and confirm the service status at all times (see Fig. 5).

7) Passengers and the operator can check online the shared vehicle records stored on the service management server. Using a dedicated Web application installed on the server, the operator can tabulate and process taxi usage records. The resulting data can be used as reference information for revising the details of the service online at any time, including passengers' on-off locations, the service hours of shared vehicles and the detailed sharing fees.

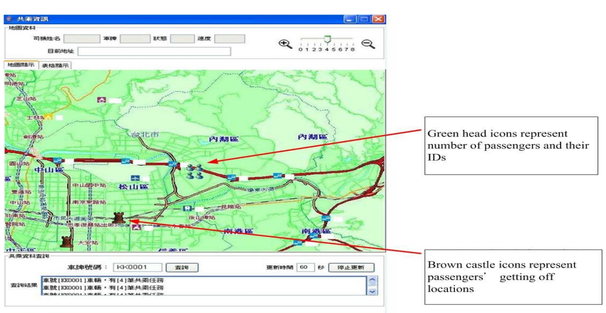

Figure 5. The GIS-based monitoring display for "one-to-many"

III. Empirical Study

To test how well the dynamic taxi-sharing system may be applied in the real world, a field trial of taxi-sharing service is conducted at Taipei Nei-Hu Science and Technology Park in Taiwan from October 26 to November 17 in 2006. There are 10 taxis and 798 passengers participating in this pilot project. The "one-to-many" algorithm is performed from 6:00 AM to 9:00 AM. The "many-to-one" algorithm is performed from 6:00PM to 9:00 PM.

As shown in Tab. 1, matching success rates for "many-to-one" and "one-to-many" are 53.9% and 53.6% respectively. There are 481 passengers have been matched in total, the matching success rate is 60.3% on the whole. In additional, the computation time of each test is less than 1 second. It is, of course, to be expected that the matching success rate is zero if number of passengers is too small or passenger locations are too dispersive. In Tab. 1 the matching success rate of the 2nd test in the afternoon, the 8th test all day and the 9th test in the morning are zero.

Table 1. Matching success rates of the field trial

	many-to-one (morning)			one-to-many (afternoon)		
Test	# join matching	# matching success	success rate	# join matching	# matching success	success rate
1st	-	-	-	15	9	60.0%
2nd	13	8	61.5%	3	0	0.0%
3rd	8	5	62.5%	12	7	58.3%
4th	19	13	68.4%	17	10	58.8%
5th	30	18	60.0%	35	22	62.9%
6th	25	14	56.0%	45	27	60.0%
7th	48	30	62.5%	38	24	63.2%
8th	3	0	0.0%	2	0	0.0%
9th	2	0	0.0%	42	24	57.1%
10th	36	23	63.9%	9	5	55.6%
11th	51	29	56.9%	40	23	57.5%
12th	31	20	64.5%	30	19	63.3%
13th	27	18	66.7%	26	16	61.5%
14th	20	12	60.0%	29	18	62.1%
15th	26	14	53.9%	17	11	64.7%
16th	20	13	65.0%	16	10	62.5%
17th	38	23	60.5%	25	16	64.0%
Average	23.35	14.12	53.9%	23.59	14.18	53.6%

As shown in Fig. 6, the average number of passenger per taxi (e.g. load factor) for "many-to-one" and "one-to-many" is 2.4 and 2.3 respectively. There is no significant difference in load factor between "many-to-one" and "one-to-many". The load factor will decrease if the demand for taxi-sharing declines.

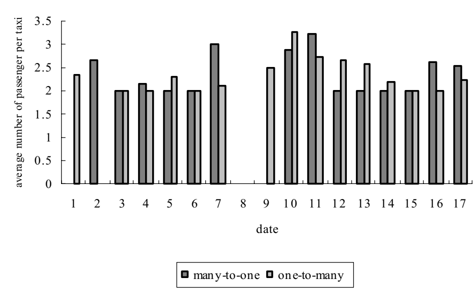

Figure 6. Average number of passenger per taxi of the field trial in Taipei

Some key findings are summarized as follows:

1) Approximately 70% of the taxi-sharing passengers are women, and abut 90% are in age from 20s to 40s, as young office ladies constitutes the main group. Most of them are transit captive riders.

2) The usage probability of private car before and after introducing the dynamic taxi-sharing service is 0.1139 and 0.9090, respectively. Because many employees in Taipei Nei-Hu Science and Technology Park have high income and high car ownership, the incentives of taxi-sharing are not significant to change their mode choice.

3) The success rate of rideshare matching is much higher when the passengers want to transfer to public transportation. It reveals that integration of the dynamic taxi-sharing system and public transportation will increase potential growth of taxi-sharing market.

4) The average saving travel time after using taxi-sharing system is 26.48 minutes, while the average travel cost increases 34.48 NT$ (about 1 US$).

5) Most of passengers are satisfied with prompt reply of reservation, taxi on-time arrival, driver's attitude, easy to get on and off…etc. The interface to Web service is, however, not user friendly and needs to be improved as soon as possible.

6) Approximately over 70% passengers are willing to pay taxi-sharing fees comparing with their original travel budgets when the maximal waiting time is guaranteed within 10 minutes and number of acceptable taxi-sharing passengers is three.

7) A qualitative analysis using Delphi method was conducted to survey degree of satisfaction among Taipei city government, taxi operators, taxi drivers and passengers. The results shown in Fig. 7 reveal that taxi operators are ready to accept ITS-based technologies because they think taxi-sharing service will help taxi drivers making more money than before. The passengers are not so satisfied with dynamic taxi-sharing service, for they still hesitate to ride with strangers. Lack of sufficient incentives for taxi-sharing can also discourage passengers from using taxi-sharing service.

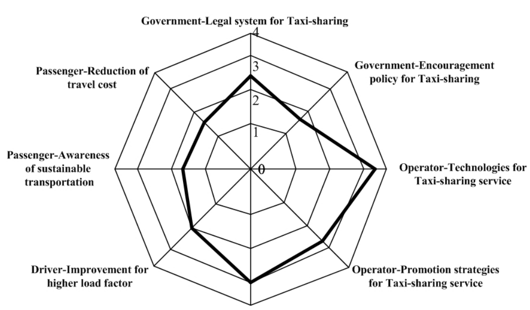

Figure 7. Qualitative results of the satisfaction survey for taxi-sharing among government, operators, drivers and passengers

IV. CONCLUSION

A dynamic taxi-sharing system is proposed to support a field trial at Taipei Nei-Hu Science and Technology Park in Taiwan. The results of numerical tests and user surveys demonstrated that the outcomes of these heuristic algorithms are fairly plausible. The average matching success rate is 60.3% on the whole.

However, the developed algorithms are applicable to the case of "one-to-many" and "many-to-one" which can more or less describe the commuter travel behavior for certain urban areas. The case of "many-to-many" which fully represents dynamic ride matching with any O-D pairs for taxi-sharing problem is under development. It is found that some advanced meta-heuristic techniques such as tabu search method, threshold accepting method, genetic algorithm, lagrangian relaxation or column generation may provide good solutions if the proposed heuristic algorithms are not able to cope with the large scale time-space network problems. This could be a direction of future work.

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