Mobility on Demand for Improving Business Profits and User Satisfaction

● Takuro Ikeda ● Takushi Fujita ● Moshe E. Ben-Akiva

For a sustainable society, we need to design a mobility management system that does not excessively depend on private vehicles. To achieve this goal, an innovative transportation system is required that provides high user satisfaction in terms of both convenience and fares and is viable as a profit-making business. Recently on-demand transportation, which makes use of information and communications technology (ICT), has been growing and may be a viable solution to the challenges mentioned above. We are developing an innovative on-demand transportation system that has flexibility in terms of vehicle allocation and provides a menu of travel options to users. The system dynamically allocates a fleet of vehicles owned by a business to different transportation services such as taxi, shared taxi, and minibus. It offers convenient and reasonably priced transportation services through an optimization framework where services are assigned on the basis of a choice model in order to maximize profit. The system is expected to improve both user satisfaction and business profits as compared to conventional means of transportation. This paper presents the concept of the system and provides experimental results as a proof of concept using a simulation framework.

1. Introduction

A number of mobility issues need to be addressed to achieve a sustainable society. These include the mitigation of traffic congestion, reduction of CO_2 emissions generated by transportation, and provision of a means of transportation for mobility-challenged users such as the elderly and disabled. The preferred approach to resolving these issues is to establish a mobility environment centered about public transportation conducive to everyday activities instead of heavy reliance on private cars. The key to creating such an environment is the provision of local and user-friendly transportation services, which would target, for example, a trip from one's home to a comparatively close destination or a "first-and-last-mile" trip between one's home and a transit station and between a transit station and one's final destination. Making such services convenient and reasonably priced to improve user satisfaction should lead to a transportation modal shift from private cars to public transportation for both short-range and long-range trips while helping to find solutions to the above issues. The problem, however, is how to make such services profitable for operators.

Against the above background, Fujitsu Laboratories came to propose a new mobility on demand system through joint research with the Massachusetts Institute of Technology (MIT) with the objective of improving both operator profit and user satisfaction with local transportation services.[1),2)] In this paper, we provide an overview of the proposed system, which we call Flexible Mobility on Demand (FMOD), and present the results of evaluating its effectiveness by simulation.

2. Local transportation services and issues

To date, buses and taxis have been the main means of providing local transportation services. However, it is difficult for conventional bus services that operate on fixed routes and schedules to achieve a high level of user satisfaction in terms of convenience while keeping operating costs down and ensuring a profit for the operator. Recent years have seen a drop in convenience owing to lower frequency of services and the termination of routes due to reduced ridership. Taxis, on the other hand, provide a highly convenient means of transportation as a door-to-door service, but the relatively high fares that they charge make it difficult to raise user satisfaction any further.

In response to these issues, a variety of demand responsive transportation services are now being commercialized with the aim of providing means of transportation with a high degree of user satisfaction. For example, demand responsive community buses and shared taxis are being introduced to ensure a means of transportation for mobility-challenged users with a focus on areas with no transportation service. At the same time, app-driven real-time taxi reservation systems using the GPS function of smartphones are expanding in urban areas. In particular, novel transportation services that include ride sharing such as Uber, Lyft, and SideCar are attracting attention. One reason that can be given for the emergence of these services is that the use of information and communications technology (ICT) has simplified reservation processing, automated scheduling, smoothed out the payment process, and facilitated the matching of drivers and passengers and the matching of passengers for ride sharing.

These transportation services are helping to improve user satisfaction and attract new users, but they are still insufficient in terms of maximizing operator profit. For example, the reservation systems of current transportation services generally offer the user with a list of ride alternatives that match the conditions specified by the user (place of departure, place of arrival, departure time, arrival time, etc.). Of concern here, however, is that the choices made by users may deplete available vehicles in the operator's fleet, thereby preventing services from being provided to subsequent users and profits from being made. On the other hand, if ride alternatives that prioritize operator convenience deviate much from the conditions specified by the user, none may be acceptable to the user, with the result that the operator again loses out on profits.

3. FMOD features

The key feature of the FMOD system that we propose is dynamic allocation of each vehicle in an operator's fleet to different types of transportation services, such as taxi, shared taxi, and mini-bus. FMOD uses a choice model to optimize the menu of rides offered to the user and maximizes operator profit (**Figure 1**). This choice model is a mathematical model that estimates the probability that the user will choose any of the rides offered. Although each of the services offered has a different fare structure, all services can be provided through dynamic use of identical vehicles in the operator's fleet. For example, we can envision an operator that uses a fleet of vehicles, each with a capacity of 6–8 passengers. This being the case, each type of service takes on the following features.

1) Taxi

This service provides a door-to-door means of transportation in response to a single ride request. The passenger may board or alight at any location.

2) Shared taxi

This service provides a door-to-door means of transportation in response to multiple ride requests. In this case, while each passenger may board or alight at any location, detours are bound to occur to accommodate other passengers, so the travel time of each passenger may be longer than that of a taxi service.

3) Mini-bus

This service provides a means of transportation on a fixed route in response to multiple ride requests. A passenger may board or alight at any location on the route. Since there is no deviation from the route with this type of service, the travel time of each passenger will not increase to accommodate other passengers, but additional trips will be required between the passenger's place of departure and boarding point and between the alighting point and passenger's destination. In contrast to conventional fixed-route bus services, the mini-bus service has no timetable—it does not begin operating until that mini-bus is allocated to its first passenger.

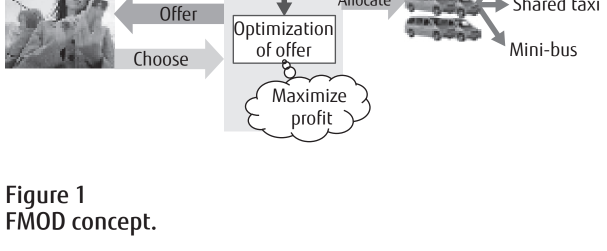


Figure 1
FMOD concept.

As described above, FMOD enables the same vehicle to be dynamically allocated to different services in accordance with current conditions, thereby providing flexibility to meet temporal and spatial fluctuations in demand. For example, allocating more vehicles to the shared-taxi and mini-bus services than the taxi service during peak times when demand is high can prevent a situation in which service cannot be provided due to a depletion of available vehicles. Furthermore, for users traveling from a high-demand area to a low-demand area, transport could be provided by shared taxi or mini-bus while the return trip could be provided by taxi. These forms of vehicle allocation make for efficient operation of an operator's fleet in accordance with supply and demand. Compared to conventional transportation systems, FMOD can be expected to improve both operator profitability and user satisfaction.

4. Reservation process

FMOD is a reservation-based transportation system. The flow of the reservation process is shown in **Figure 2**. To begin with, the user sends a ride request to the FMOD server using a smartphone app (step 1). This ride request can include various types of information such as origin and destination, preferred departure and arrival time window, and number of seats needed. A user may also request that a ride be provided as soon as possible ("immediate ride").

Next, the FMOD server offers a menu of rides by different services in response to the user's ride request (step 2). Each one includes various types of information such as service type (taxi, shared taxi, mini-bus), pick-up location, drop-off location, scheduled pick-up time, scheduled drop-off time, and fare.

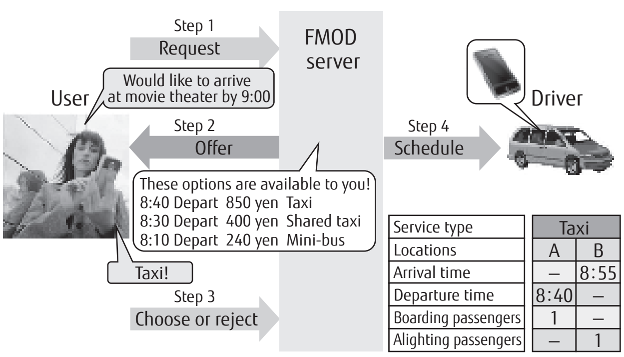


Figure 2
Reservation process.

The user may then choose one of the offered rides and send that choice to the FMOD server or may reject all of the offered rides (step 3).

Upon receiving the user's choice (if a ride was chosen), the FMOD server updates the schedule block for a certain vehicle and sends that update to the smartphone app of the driver of that vehicle (step 4). Here, a "schedule block" ranges from the first passenger to board to the last passenger to alight for a certain type of service (taxi, shared taxi, or mini-bus). In general, more than one schedule block may be allocated to the same vehicle over the course of a day.

5. Selection of rides to be offered to user

In step 2 of the reservation process, the menu of rides to be offered to the user is selected in two phases: 1) generate feasible rides and 2) optimize offering of rides.

5.1 Phase 1: Generate feasible rides

Given that all vehicles in a fleet can provide taxi, shared taxi, or mini-bus services, FMOD generates all schedule blocks that could be offered to the user. Then the system generates a set of feasible rides for the user on the basis of those blocks.

Two cases can be considered in generating schedule blocks. In the first case, the system creates a new schedule block with the user being the first passenger. In the second case, which applies to a shared taxi or mini-bus service, the system adds the user to a schedule block for which other users have already been allocated.

A generated schedule block that satisfies the following constraints is considered to be feasible.

1) Constraint 1: Conflict with other schedule blocks

There must be no overlap with other schedule blocks, and some margin including travel time between schedule blocks must be provided.

2) Constraint 2: Seating capacity

The number of users allocated to a vehicle must not exceed the seating capacity of that vehicle.

3) Constraint 3: Maximum travel time

The travel time for any one passenger must not exceed a maximum value (e.g., twice the travel time by taxi).

4) Constraint 4: Committed departure/arrival time
The difference between departure/arrival times given to a user who has been allocated to a schedule block and new departure/arrival times in an updated schedule block must lie within an allowable range.

The feasible rides are determined on the basis of the feasible schedule blocks.

5.2 Phase 2: Optimize menu of rides

The system next selects the menu of rides to be offered to the user on the basis of the set of feasible rides obtained in phase 1, with the aim of maximizing the operator's expected profit. This optimization problem can be formalized as

$$\text{maximize} \sum_{n\in N}\sum_{m\in M}\sum_{l\in L} r_{n,m,l}\, Prob_{n,m,l}(X)$$

$$\text{subject to} \sum_{n\in N}\sum_{l\in L} x_{n,m,l} \leq 1 \quad \forall m\in M$$

$$X = (x_{n,m,l}),\ x_{n,m,l}\in\{0,1\} \quad \forall n\in N, m\in M, l\in L \quad ,$$

where N is the fleet of vehicles, M is the set of services, and L is the maximum number of rides for each vehicle-service pair. The l-th ride of service m provided by vehicle n is denoted as $p_{n,m,l}$. X is a matrix in which element $x_{n,m,l}$ is a decision variable indicating whether ride $p_{n,m,l}$ is to be offered to the user. The profit to be obtained from ride $p_{n,m,l}$ is denoted as $r_{n,m,l}$. Finally, $Prob_{n,m,l}$ (X) is the choice probability of ride $p_{n,m,l}$ when the user is offered the menu of rides represented by X.

The choice probability of a certain ride is calculated using a multinomial logit model based on *utility*, which in an index of user satisfaction with respect to that ride.[3] The utility of a ride is calculated on the basis of boarding time, fare, difference in preferred and scheduled times (with respect to departure or arrival time), and access/egress distance between departure/destination and boarding/alighting points.

6. Simulation

To test the effectiveness of FMOD, we conducted a 24-hour simulation for the network of a city located in the Tokyo suburbs. We assumed a scenario in which operation by taxi is switched to operation by FMOD. That is, we compared operator profit and user satisfaction between the case in which all vehicles in an operator's fleet are operated only as a taxi service and the case in which different types of services are dynamically allocated to those vehicles under FMOD. As an index of satisfaction, we used the utility of rides chosen by users as represented by a monetary value.

For demand, we used synthetic data from the Tokyo Metropolitan Area Person Trip Survey, national census data, and other sources. For departure and destination points, we set arbitrary points within the city (selected in proportion to population distribution) and public facilities (stations, hospitals, city offices, etc.). For ridership, we used 4600 people/day as a base number, and, for FMOD, investigated the results when this number was increased by up to 40% in steps. This is because demand is expected to increase when operating the fleet by FMOD compared to a taxi-only service owing to the lower fares of the former.

The fleet size was varied from 25 to 150. We set the taxi fares by referring to actual taxi fare structures and set the shared-taxi fares to 50% that of taxis and set the mini-bus fares to 300 yen. The mini-bus routes were set the same as the actual bus routes. Operating costs comprised fixed costs per vehicle and variable costs proportional to travel distance.

Operator profit versus fleet size is shown in **Figure 3**. With no increase in ridership, maximum profit for taxi-only service exceeds that for FMOD provided that a sufficient fleet can be procured. The reason for this outcome is attributed to a shift by users to shared-taxi or mini-bus service with FMOD because of their lower fares. However, an increase in ridership by 20% causes the maximum profit for FMOD to exceed that for taxi-only service. This 20% increase is thought to be a realistic value. Additionally, for a limited fleet, FMOD

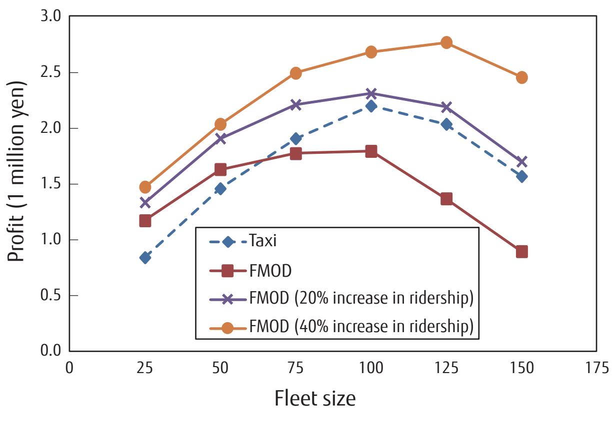


Figure 3
Operator profit.

produced a higher profit than the taxi-only service even without an increase in ridership.

The number of times each service was chosen against the time of day is shown in **Figure 4**. The total ridership and fleet size were set the same for all services (4600 people/day, 100 vehicles). With the taxi-only service, there were many cases in which service was unavailable during peak times due to a lack of vehicles. With the FMOD services, there were few such cases.

The sum total of user utility is shown in **Figure 5**. The ridership was set the same for all services (4600 people/day). It was assumed that utility for the case in which service was unavailable was equivalent to the minimum value of utility when the service was available. FMOD provided greater utility than the taxi-only service for any fleet size; the difference was particularly significant for a small fleet size because FMOD can accommodate more users than a taxi-only service when the fleet size is small.

In short, compared to taxi-only service, FMOD can improve operator profit and user satisfaction by accommodating more users through dynamic service allocation, particularly for a small fleet of vehicles.

7. Conclusion

We have described an innovative transportation system called Flexible Mobility on Demand (FMOD) and reported on its effectiveness based on simulation experiments.

In our study, we evaluated an approach that attempts to maximize operator profit for each user at the time of making a reservation. However, optimizing the system by predicting demand from both temporal and spatial perspectives holds the possibility of further improving both operator profit and user satisfaction. Since FMOD assumes the use of compact vehicles compared to conventional buses, it can operate on narrow streets not accessible to conventional buses and can therefore provide an even more convenient service.

In our simulation experiments, we evaluated the extent to which demand switched among various transportation modes assuming a number of patterns. It would be desirable, however, to use a model that includes selection of even more means of transport so that we can evaluate the extent to which demand switching may actually occur. To this end, we plan to apply a simulator developed by MIT.[4] We also plan to continue our evaluation of FMOD effectiveness through field testing.

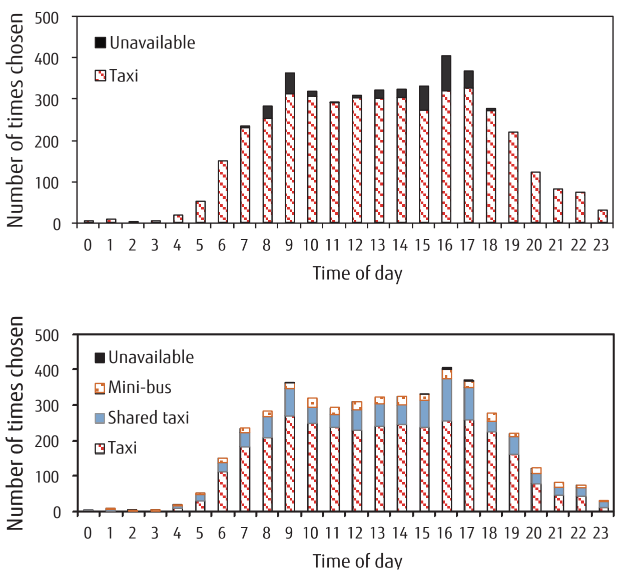


Figure 4
Number of times esch service was chosen (upper chart: taxi-only; lower chart: FMOD).

References

1) T. Ikeda et al.: Flexible Mobility On Demand (FMOD): Design and Evaluation of an On-demand Transportation System Featuring Dynamic Allocation of Vehicles to Multiple Transportation Services, 49th Conference of the Committee of Infrastructure Planning and Management, 2014 (in Japanese).

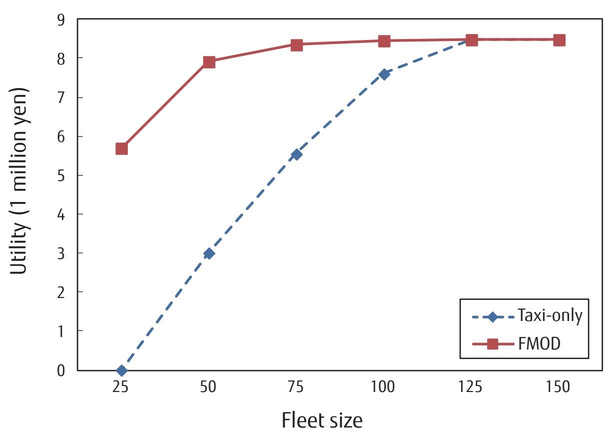
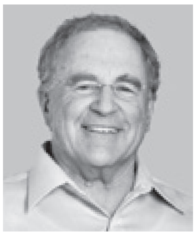


Figure 5
Sum total of user utility.

2) T. Ikeda et al.: The Concept and Impact Analysis of a Flexible Mobility on Demand System, Working Paper, Massachusetts Institute of Technology, 2014.
3) M. Ben-Akiva et al.: Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, 1985.
4) K. Basak et al.: SimMobility: Integrated activity based modeling. ITS World Congress, Tokyo, Japan, 2013.

Takuro Ikeda
Fujitsu Laboratories Ltd.
Mr. Ikeda is engaged in the research and development of transportation solutions technology.

Takushi Fujita
Fujitsu Laboratories Ltd.
Mr. Fujita is engaged in the research and development of transportation solutions technology.



Moshe E. Ben-Akiva
Dr. Ben-Akiva, Professor at Massachusetts Institute of Technology, is engaged in the research of behavioral modeling, econometrics, and transportation systems.