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The concept and impact analysis of a flexible mobility on demand system

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ABSTRACT

This paper introduces an innovative transportation concept called Flexible Mobility on Demand (FMOD), which provides personalized services to passengers. FMOD is a demand responsive system in which a list of travel options is provided in real-time to each passenger request. The system provides passengers with flexibility to choose from a menu that is optimized in an assortment optimization framework. For operators, there is flexibility in terms of vehicle allocation to different service types: taxi, shared-taxi and mini-bus. The allocation of the available fleet to these three services is carried out dynamically so that vehicles can change roles during the day. The FMOD system is built based on a choice model and consumer surplus is taken into account in order to improve passenger satisfaction. Furthermore, profits of the operators are expected to increase since the system adapts to changing demand patterns. In this paper, we introduce the concept of FMOD and present preliminary simulation results. It is shown that the dynamic allocation of the vehicles to different services provides significant benefits over static allocation. Furthermore, it is observed that the trade-off between consumer surplus and operator's profit is critical. The optimization model is adapted in order to take into account this trade-off by controlling the level of passenger satisfaction. It is shown that with such control mechanisms FMOD provides improved results in terms of both profit and consumer surplus.

1. Introduction and motivation

Flexible forms of transportation are of interest to both passengers and transportation operators for many reasons. A survey in the San Francisco Bay Area revealed that 60% of the respondents were willing to consider personalized demand responsive transit systems as reported by Khattak and Yim (2004). Many individuals, such as elderly and disabled passengers, have difficulty using conventional public transportation services. Additionally, conventional public services may be inconvenient since they are not personalized and may not meet the needs of the passenger's intended trip. Public transportation services have fixed routes and schedules, and they may have low frequency during certain times of the day or in some parts of the transportation network. Conversely, taxis tend to provide greater flexibility but they are unaffordable on a regular basis for many individuals.

From the perspective of transportation operators, while fixed-route services are cost-effective in urban areas, they become less effective in low-density areas as mentioned by Goodwill and Carapella (2008). Therefore, it is economically

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inefficient for transportation operators to provide higher frequency or better coverage in those areas. As a result they cannot offer a high quality of service. A vicious cycle is created where low ridership leads to lower profit for operators and decreased quality of service, which in turn results in lower passenger satisfaction and ridership.

In order to break this vicious cycle, innovative transportation alternatives with higher profitability and greater flexibility must be developed. Several alternatives, such as dial-a-ride services, have been introduced around the world. These services are usually provided to elderly and handicapped people who cannot use regular public transportation alternatives. The need for such flexible services is expected to increase due to the aging population and the increased importance given to equity and quality of life issues. As flexible services are being introduced, a critical issue is how best to ensure the profitability of transport operators while providing a high quality of service.

In this paper, we introduce the Flexible Mobility on Demand (FMOD) system, which provides flexibility to both passengers and transportation operators. FMOD provides different levels of service to each passenger request; passengers are presented with a menu of choices from which they make a selection based on their preferences. This menu of travel options is an optimized menu which is one distinction of the FMOD system. The flexibility provided to the operators is based on the dynamic allocation of the vehicles to different services depending on the received request. The allocation is such that a vehicle changes its role among different services during the day and this is another distinction of the FMOD system.

FMOD utilizes three services: taxi, shared-taxi and mini-bus. A list of travel options is designed in real-time and includes these three types of services. These services vary in regard to flexibility and cost. For instance, while taxi services are convenient for passengers because they provide door-to-door service at the passenger's desired time, they are also expensive to operate and not an affordable mode of regular transportation for many passengers. Conversely, fixed-route mini-bus services can be cheaper to operate because passengers and origin–destination pairs can be pooled together. However, fixed routes and schedules may not be as convenient as taxi service, especially for passengers who are elderly, disabled, or traveling to outlying areas during off-peak times. The flexible nature of FMOD aims to improve the sustainability of transportation systems while simultaneously improving convenience for passengers and profitability for operators.

This paper introduces the concept of FMOD and provides preliminary analysis that serves as a proof of concept. An optimization framework has been developed; when a request is received, the menu of choices offered is optimized by taking into account passenger preferences and operational constraints related to schedule and capacity. Preliminary results have been obtained for a network in Tokyo under different scenarios. The main contribution of this paper is that it provides a proof of concept for the FMOD system using appropriate methodologies. FMOD itself is an innovative concept and the nature of FMOD brings the need for a new modeling framework. The scheduling, routing and assortment optimization models are brought together in order to design such a system which is unique in the context of transportation.

The rest of the paper is organized as follows: Section 2 presents related literature and Section 3 introduces the FMOD system. Section 4 presents the methodology for the operation of the FMOD system. Section 5 presents preliminary results and evaluation of the system based on simulation experiments. Finally, we conclude the paper in Section 6.

2. Related literature

Demand Responsive Transit (DRT) has been increasingly studied and applied in the last decade. DRT is a user-oriented form of public transport with flexible routing and scheduling based on passenger needs. DRT is usually operated in a shared-ride mode between requested pick-up and drop-off locations. The most well known version of DRT is called *dial-a-ride* where door-to-door transportation services are provided using mini-buses and taxis. A fully automated version has been introduced by Dial (1995) and is called Autonomous Dial-A-Ride Transit (ADART).

The routing and scheduling of the vehicles in dial-a-ride systems is referred to as dial-a-ride problem (DARP), and it is addressed by various operations research techniques in the literature. We refer to the paper by Cordeau and Laporte (2007) for a comprehensive review of models and algorithms developed for DARP in the literature. In general, the optimization problem aims to find the set of minimum cost vehicle routes while accommodating as many requests as possible under a set of operational and quality of service constraints. We cite a few operations research approaches for the solution of DARP; Cordeau and Laporte (2003) address the problem with a tabu search heuristic, Coslovich et al. (2006) propose a two-phase insertion heuristic for the solution of the version with time windows, and Parragh et al. (2010) present a variable neighborhood search approach. DARP is similar to a number of vehicle routing problems in the literature. We refer to Toth and Vigo (2001) for a review on the vehicle routing problems. The main distinction of DARP from vehicle routing problems is that incorporating the users perspective when providing a convenient service is an important objective along with minimizing the operating costs.

The considered DRT systems are mostly studied or applied to a niche market for elderly or disabled people, especially in rural areas where the demand is typically low and spread over a large area. More recently, the concept of DRT has been broadened to go beyond its niche market and is referred to as Flexible Transport Services (FTSs). Mulley and Nelson (2009) provide an overview of FTS stating that the scope is to improve the flexibility and convenience of public transport and to keep a comparable price to existing public transport services. Brake et al. (2007) analyze the recent experiences with FTS in the US and Europe where they come up with policy insights regarding the design, operation and the technology to be used in the context of FTS.