Strategies for on-line management of a Multi-Layered Personal Transit System

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INTRODUCTION

In recent years, a new trend in transportation has aimed at developing shared mobility on-demand transportation systems that preserve the advantages of classical transportation means and mitigate their downsides. A Multi-Layered Personal Transit System (MLPTS) is an innovative last-mile on-demand public transit system consisting of convoys of electric vehicles circulating over a network of stations. Each of these convoys is composed of a human-driven head vehicle followed by one to several cabins that can autonomously travel short distances at the proximity of stations. That is, cabins can attach and detach from head vehicles as they pass nearby stations while heads cycle non-stop in the system. A passenger completes his/her entire journey on-board the same cabin, while the cabin may switch between several heads along its path. The system is highly capacitated: stations have a limited number of platforms for cabins, length of convoys is limited to a head followed by a small number (three to five) of vehicles and cabins embark a maximum of six people at a time. These features generate strong dependencies between the head-cabin-passenger layers. Namely, passenger movements are restricted by cabin movements, which in turn are restricted by head movements. Operationally, this results with a complicated routing and assignment problem where many decisions have to be taken concurrently.

RELATED LITERATURE

The design and management of an MLPTS have strong relations with many problems in the transportation literature. MLPTS is essentially a public transit system [Desaulniers (2007)] where vehicle routes can be dynamically adapted. In terms of fleet structure, the use of convoys composed of heads and cabins connects MLPTS to passenger railway optimization [Cordeau (1998)], though passenger trains have significantly larger capacities. At an urban scale, the circulation of cabins with small capacities over a network of stations resembles also the operation of Personal Rapid Transit systems [Anderson (2000), Andreasson (1994)]. Furthermore, on-demand and ride-sharing features relates the planning of MLPTS to dynamic Dial-a-Ride Problems [Pillac (2013), Berbeglia (2010)]. Beyond the scope of public transit, similar fleet scheduling and demand assignment issues exist in elevator optimization [Friese (2006)]. The design and operations of an MLPTS generalize many of the above hard planning problems. Specifically, the three-layer structure makes it more difficult as compared to the common vehicle-passenger structure that characterizes many of these problems.

PROPOSED MANAGEMENT FRAMEWORK

We propose a global management framework for MLPTS that takes care of the system's operations in a dynamic setting. It consists of several interconnected modules for head routing, cabin routing and passenger assignment.

As head vehicles are human-driven and in order to simplify dynamic decisions for the cabin-passenger layers, head routes are predefined. To provide a good service, the assignment of heads to routes should be adapted to the observed passenger demand patterns. For this purpose, we disregard the cabin layer and formulate the head route-planning problem as an Integer Linear Programming problem where the objective is to minimize the total travel time of passengers. Specifically, travel times are calculated as the sum of waiting times and riding times, which are functions of the selected routes and the number of heads assigned to each route. Due to lack of space, the formulation is not included in this abstract but will be provided in the full paper. We use Benders decomposition to solve the problem.

Given the head routes, cabin paths are dynamically modified throughout the operations based on the destinations of on board passengers. The decision to join a convoy is based on the position, route and available capacity of the head, the elapsed time of on board passengers and the number of cabins at stations. The assignment of passengers to cabins is done as soon as possible after their arrival. Given the position of cabins and occupancies, passengers are assigned to the cabins with the earliest estimated arrival times to their destinations. Passengers who wait too long at their origin are assumed to opt-out.

SIMULATION AND RESULTS

The proposed management framework has been embedded in a purpose-built simulation that replicates heads, cabins and passengers movements. We measure the performance of the system by the mean passenger delay time (as compared to direct taxi service) and by the opt-out fraction. The simulation is run on a case study network of 20 stations to be implemented in a real-world area of approximately 3 km^2 in an Asian city. Interstation distance varies from 200 to 800 meters. The daily demand is in average 2400 passengers.

We tested the system performance for several combinations of number of cabins (10-90), number of heads (20,40,60) and different head route plans. Specifically, we examined two head route plans designed by the operator (R2,R3) and the route plans resulting from the head routing optimization model (Opt). In addition, in terms of station capacities, 60 platforms in total are distributed in the system's stations. For any tested configuration, output values are averaged over 100 different demand realizations generated using a Poisson process based on hourly demand rates.

Initial results (excluded from this abstract) have demonstrated that empty cabin relocation strategies must be applied to prevent significant deterioration of the system performance. In Figure 1, we present the delay time and opt-out fraction for the various combinations described above. As can be observed, the marginal effect of adding more heads in the system is positive but decreasing. As for cabin fleet size, the best results are obtained when the number of cabins is close to total platform capacity. In terms of head routing, the configuration resulting from the formulated head route-planning problem has shown to outperform operator-designed configurations, independently of the other system characteristics. In the best system settings, mean passenger delay time is less than 5 minutes while opt-out fraction is about 5%.

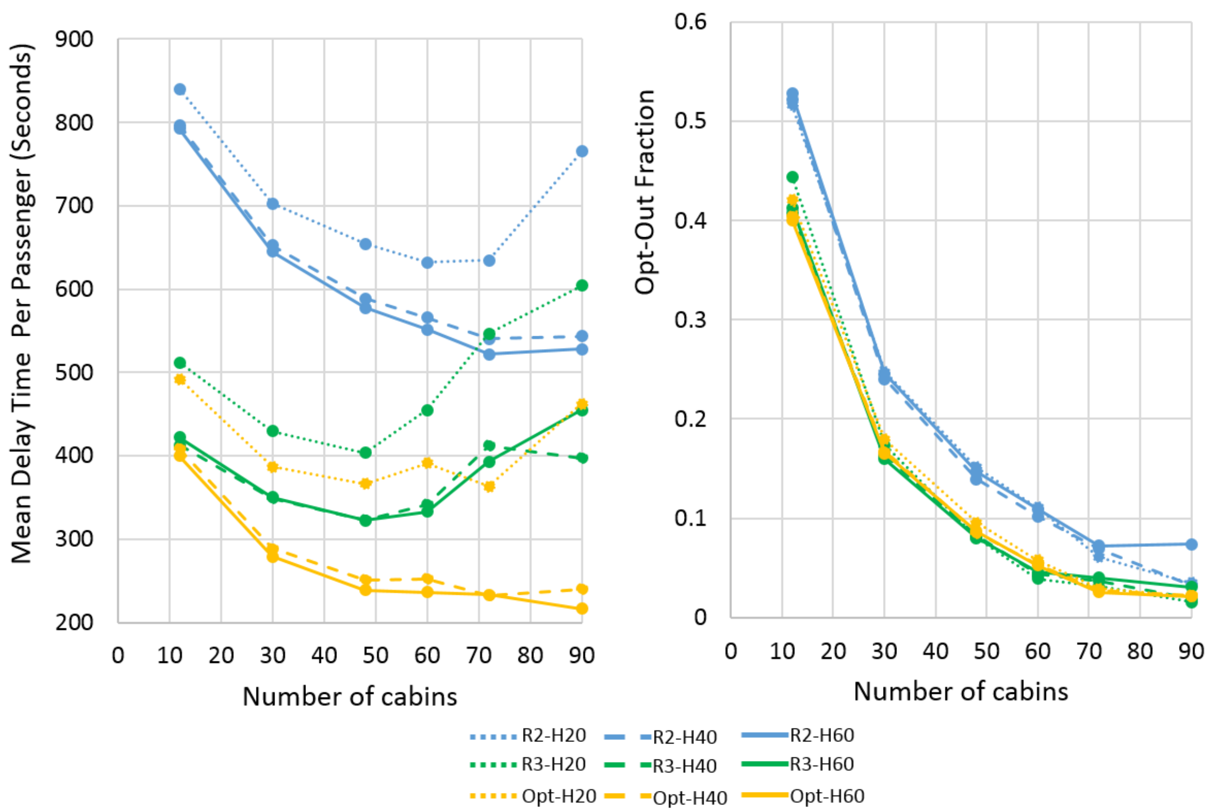

Figure 1: Performance measures obtained through simulation for various cabin, heads and route configurations

CONCLUSION AND ON-GOING WORK

In this work, we introduce the MLPTS, an innovative and complex public transportation system. We propose a method to manage real-time operations of the system. Through simulation, we demonstrate that proper configuration of the system enables handling the estimated demands very well. On-going work focuses on enhancing each of the decision modules by extending the information taken into account in the decision process. Specifically, better estimating the future state of the system will allow to plan and operate more efficiently. The final goal of this study is to build a coherent and effective framework for the on-line management of MLPTS.

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