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Reducing the wasted transportation capacity of Personal Rapid Transit systems: An integrated model and multi-objective optimization approach

Olfa Chebbi [a,*], Jouhaina Chaouachi [b,1]

[a] Institut Supérieur de Gestion de Tunis, Tunis University, Tunisia
[b] Institut des Hautes Etudes Commerciales, Carthage, Carthage University, Tunisia

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ABSTRACT

This study addresses the problem of wasted transportation capacity in Personal Rapid Transit (PRT) systems. We propose a two-tier transportation model that integrates PRT and capillary transportation systems. We study a related multi-objective empty vehicle redistribution problem that attempts to minimize empty movement and the number of vehicles used. Furthermore, we design a hybrid multi-objective genetic algorithm that integrates multiple crossover operators and linear programming techniques to solve the proposed problem. Evaluations indicate that our algorithm produces satisfactory results, and simulations confirm the efficiency of our proposed two-tier transportation system.

1. Introduction

1.1. Personal Rapid Transit: Background, current progress, and advantages

Personal Rapid Transit (PRT) is an automated transportation system that uses a set of small electric automatic vehicles to continuously move groups of passengers between stations (Carnegie and Hoffman, 2007). PRT systems have the advantages of offering a taxi-like service while remaining a part of public transportation, and of providing an on-demand service (Vahle, 2014). Specifically, a group of passengers at a given PRT station selects a destination station on the PRT network. The central control system automatically dispatches an empty vehicle to the given station to transport the passengers to their destination. The stations in a PRT system are located off the main line. This allows vehicles to bypass intermediate stations and proceed to their destinations without unnecessary stops. PRT is considered to be an environmentally friendly and sustainable transportation tool, and has the potential to solve multiple problems associated with urban transportation. Furthermore, using clean sources of energy to power the PRT pods will reduce carbon emissions in urban areas. Various studies have estimated that PRT systems offer energy savings of up to 75% compared with private vehicles (Lowson, 2003; Anderson, 2006; Carnegie and Hoffman, 2007). More details about the PRT system could be found in McDonald (2013).

* Corresponding author at: Institut Supérieur de Gestion de Tunis, Tunis University, 41 Rue de la liberté, Le Bardo 2000, Tunisia. Tel.: +216 95 294158.
E-mail addresses: olfaa.chebbi@gmail.com (O. Chebbi), siala.jouhaina@gmail.com (J. Chaouachi).
[1] Tel.: +216 71 678901; fax: +216 71 678907.

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1.2. Issues with PRT systems

Although PRT is a viable alternative to private automobiles, its development remains limited. A primary restriction on PRT development is its wasted capacity. Studies have shown that PRT systems have an average vehicle loading of between 1.1 and 1.3 persons per six-person vehicle (Carnegie and Hoffman, 2007). This is aggravated for three- or four-passenger PRT vehicles, in which the load factor is 0.3–0.4 (Anderson, 2000).

PRT also suffers from wasted transportation capacity in terms of empty vehicle movements. Because different stations have uneven levels of passenger demand, the number of trips requested from one PRT station may exceed the number of trips terminating there. Hence, PRT control systems must balance the number of vehicles by moving empty PRT pods in response to requests for different stations.

1.3. Proposals

Determining when and where empty vehicles should move is known as the empty vehicle redistribution (EVR) problem (Lees-Miller et al., 2010). Studies addressing this problem focus on minimizing passenger wait time (Lees-Miller, 2013), energy consumption (Mrad and Hidri, 2015; Mrad et al., 2014), network design (Zheng and Peeta, 2015), and capacity analysis (Mueller and Sgouridis, 2011; Lees-Miller et al., 2010). This paper differs from these previous studies on PRT optimization in a number of ways.

Since we aim at reducing PRT wasted transportation capacity, a focus could be given to the emergence of new planning practices for urban transportation tools. An increased emphasis has been placed on efficient and effective mobility tools for transporting goods and passengers in urban areas. Using multiple vehicles to move persons and goods contributes to congestion and air and noise pollution in urban areas. Thus, shared transportation tools provide an alternative that may overcome various issues. The effective implementation of shared transportation has two main aspects: consolidation and coordination between the flow of goods and passengers. These features allow a small number of vehicles to be effectively used in urban areas. Furthermore, integrating goods and passengers into a unique transportation tool significantly increases capacity and promotes new urban mobility options for transportation managers. Within such an option, the movement of goods and mail on the system will be swift and easy, making it much more efficient than a simple PRT system.

This study addresses the wasted transportation capacity of PRT vehicles by coordinating the flow of people and goods in the same PRT vehicles. We believe that PRT systems can profit from their sparse capacity by transporting more than just passengers. We also predict the future integration of PRT systems with smaller transportation tools, such as bicycle sharing systems for passengers or city freighters for goods, to complete the last mile of a journey. Indeed, previous studies have proposed integrating PRT with other forms of transportation, including larger transportation tools such as trains (Andreasson, 2012) and buses. Using simulations, we compare our transportation model with a classic transportation system, and demonstrate the efficiency and advantages of the proposed system.

Also wasted transportation capacity of PRT systems are dealt with by studying a multi-objective EVR with the aim of minimizing total travel time and the number of vehicles used in the PRT system. Although previous studies consider single-objective EVR, none has addressed a multi-objective version. EVR can be modeled as a combinatorial optimization (CO) problem. Exact methods such as branch-and-bound and constraint generation are able to solve smaller CO problems. However, as the problem size increases, the number of constraints and decision variables increases exponentially, making the problem intractable for exact methods. Hence, heuristic approaches such as genetic algorithms (GAs) and simulated annealing are becoming more common. Heuristic methods produce good-quality solutions within a reasonable amount of time. Genetic algorithms form a branch of metaheuristics, and are widely used because of their robustness and ease of implementation. However, few studies have used GAs, especially multi-objective GAs, to solve the CO problems that concern intelligent transportation systems such as PRT. Therefore, we attempt to integrate a multi-objective GA into PRT-related problems.

We introduce a hybrid multi-objective GA by incorporating linear programming techniques and a multiple crossover operator into the multi-objective EVR problem. The computational performance of this hybrid multi-objective GA is measured experimentally and compared with that of the original multi-objective GA. This indicates that the hybrid GA outperforms the classic version, producing good results within a reasonable time period for large problem sizes.

1.4. Contributions

In this paper, we emphasize the joint usage of urban transportation tools for people and goods. We also focus on reducing wasted PRT transportation capacity. Based on the assumption that PRT systems are generally underused, this paper makes the following contributions:

1. We define and propose a two-tier shared global transportation system. We attempt to combine the flow of goods and persons within the same PRT vehicle to exploit the available capacity and increase the load factor. Goods collected at different distribution centers are loaded into the spare capacity of the PRT vehicles. The PRT system prioritizes passengers to ensure a high level of service, and moves goods and people to their final destination using a smaller capillary transportation system.