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Urban bus network of priority lanes: A combined multi-objective, multi-criteria and group decision-making approach

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ABSTRACT

This study presents a multi-objective approach for selecting an optimal network of public transport (PT) priority lanes. Bus priority schemes and techniques on urban roads and highways have proven effective for increasing reliability, efficiency, and faster travel times. This study develops a multi-objective model for selecting an optimal PT priority lanes network that 1) maximizes total travel time savings; 2) maintains balanced origin and destination terminals; and 3) minimizes the construction budget. In contrast to commonly used single objective models, which must be executed numerous times in order to provide the decision-maker with feasible solutions, multi-objective models exhibit a complete set of feasible and optimal solutions with a single execution. Since the major disadvantage of a multi-objective model is the need to select a preferred solution from a set, a multi-criteria approach was developed for: 1) ranking each decision-maker's solutions; and 2) selecting a compromise solution acceptable to a group of decision-makers. This methodology is demonstrated with a case study of Petah Tikva, a medium-sized city in Israel.

1. Introduction

Public transport priority schemes are used to "reduce or eliminate certain types of general traffic interference that can slow down transit service, make it less reliable, or reduce its capacity" (Kittelson & Associates. et al., 2003). This priority can be both spatial (dedicated lanes) and temporal (traffic signal priority). Spatial schemes can be classified as: mixed traffic (no priority to public transport vehicles); semi-exclusive (a lane partially reserved for public transport but also available, based on time or location, to other types of vehicles); exclusive (a fully reserved lane, but interaction with other modes of transport occurs at intersections, turnings, etc.), and grade separated (exclusively dedicated for public transport vehicles).

Ceder (2004), investigated several priority schemes in Europe (Athens, Dublin, Munich, Turin, Vienna, and Zurich) and concluded that they have a positive effect on reducing travel times and increasing average speed, patronage and revenues. Mesbah, Sarvi, and Currie (Mesbah et al., 2008, 2010, 2011b) were the first to introduce a system-wide approach for designing priority lanes based on a bi-level model comprising priority lane selection and traffic assignment. A model was recently developed for optimal construction of a connected network of bus priority lanes (Hadas and Ceder, 2014). This optimization model presented an algorithm for maximizing the travel time reduction resulting from the use of priority lanes given a predefined budget. However, the major disadvantage in investigating a wide range of scenarios is that the policymaker is required to execute the algorithm multiple times with different budget constraints, as larger budgets lead to the construction of more priority lanes and increased travel time reduction. The repeated executions are time consuming and cumbersome.

This paper introduces a multi-objective and multi-criteria framework with three components: 1) a multi-objective algorithm that with one execution provides a set of solutions for the decision-maker to choose from; 2) a multi-criteria model that assists the decision-maker to rank a solution based on specific preferences; (3) joint group ranking for selecting the solution ranked highest by all decision-makers.

2. Literature review

2.1. Public transport network design

Numerous studies have been published regarding the design of public transport networks. Baaj and Mahmassani (1991, 1992,

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1995) developed methods based on artificial intelligence with minimum frequency, load-factor, and fleet-size constraints. Ramirez and Seneviratne (1996), proposed models with multiple objectives, taking into account passenger flow and distance travelled. Yan and Chen (2002) developed a model for designing routes and timetables that optimizes the correlation between supply and demand. Bagloee and Ceder (2011) developed a heuristic model in order to solve realistically sized road networks. The model takes into account budget constraints, level of service and attractiveness of the system.

All these models and approaches neglect to incorporate priority schemes as an integral part of PT network design. Many bus priority strategies have been demonstrated worldwide. Traditionally, priority is granted for bus operation at stops, intersections, and by preferential/exclusive lanes. It is known that bus travel times, reliability of service, and vehicle productivity improve when buses are able to use higher-speed, uncongested lanes. These improvements make the bus systems more attractive and thus increase the potential to gain new riders (Kittelson & Associates. et al., 2003).

Skabardonis (2000) reviewed existing control strategies, evaluated them on an actual arterial corridor, identified the major factors affecting transit priority, and formulated both passive and active transit priority strategies. According to the review, both the passive and active priority strategies placed major emphasis on system-wide improvements to transit movements and on minimizing any adverse impact on the rest of the traffic stream. An evaluation technique was also developed to assist in designing signal priority strategies and to predict the impact of the transit priority measures. Turnquist and Bowman (1980) used a set of simulation experiments to investigate the effect on service reliability of several characteristics of network structure in urban bus systems. These experiments primarily focused on the factors which lead to vehicle bunching and on the effect of network form and route density on transfers. The results of these experiments highlight the importance of controlling link travel time variability and of scheduling to expedite transfers, especially in radial networks. Yao et al. (2014) presented a tabu search-based transit network optimization method that considers travel time reliability. The optimization model seeks to maximize the efficiency of passenger trips in the transit network. The results show that the proposed method can effectively improve the reliability of a transit network and reduce the travel time of passengers in general.

Currie and Lai (2008), who investigated dynamic priority lanes, reviewed a variation of the intermittent bus lanes (IBL) and dynamic transit lanes concept, in the dynamic fairway (DF) adopted for trams in Melbourne, Australia. Their paper documents the world's first practical, ongoing experience with IBL-DF operation. It also presents future plans for a Melbourne bus-based IBL, referred to as the “moving bus lane.” Significantly, both applications found good driver compliance with transit lanes, suggesting the IBL-DF concept has practical performance benefits. Eichler and Daganzo (2006) described strategies for operating buses on signal-controlled arterials using special lanes that are made intermittently available to general traffic. According to their paper, bus lanes with intermittent priority (BLIPs) do not significantly reduce street capacity. Intermittence, however, increases the average traffic density at which the demand is served and as a result traffic delay increases. The main factors determining whether an intermittent system saves time are: the traffic saturation level, the bus frequency, the improvement in bus travel time achieved by the special lane, and the ratio of bus and car occupant flows. In some cases, where a dedicated bus lane cannot be operated, a BLIP can save bus and car occupants together as much as 20 persons-min of travel per bus-km. Xie et al. (2012) describe how dynamic bus lanes with BLIP allocation strategies may improve bus transit. These strategies consist of intermittently opening the bus lane to general traffic when not in use by a bus. Simulated results are consistent with analytical results.

The first to introduce a system-wide approach for designing priority lanes were Mesbah, Sarvi, and Currie (Mesbah et al., 2008, 2011a, 2010, 2011b) who proposed a bi-level model combining priority lane selection and traffic assignment. The model assesses the impact of exclusive lanes on private car travel time and optimizes the overall weighted travel times and distances. Due to the complexity of the model, heuristics are introduced, such as genetic algorithms. However detailed and innovative the model may be, the following issues have to be considered. a) The model considers two alternatives, exclusive or mixed, while it is possible to consider other alternatives which differ in cost, flow, travel time reduction, etc. b) The priority lanes presented in the model are not necessarily connected (or continuous). It is possible to add explicit constraints, which further increase complexity and model size. c) The priority lanes do not necessarily cover the network efficiently since as the model only takes into account travel time reduction. Hadas and Ceder (2014) recently introduced a new approach and modelling for selecting an optimal network of public transport (PT) priority lanes. Their approach is based on a system-wide concept that results in optimal PT network coverage. It develops a model for optimally selecting a set of PT priority lanes that maximizes total travel time savings while also maintaining balanced origin and destination terminals given a budget constraint.

2.2. Multi-objective optimization

Many problems have multiple conflicting objectives, for which there is no single best solution. For example, solution x_1 is said to dominate solution x_2 if x_1 is better than x_2 when measured on all objectives. If x_1 does not dominate x_2 and x_2 also does not dominate x_1, they are referred to as non-dominated solutions. Various multi-objective optimization algorithms provide a set of non-dominated solutions. If the set of non-dominated solutions represents the entire search space, it is called the global Pareto optimal set (or the Pareto set). Otherwise it is called the local Pareto optimal set (Coello Coello, 2006).

Fig. 1 presents an example of a Pareto front. The various points represent feasible choices in which smaller values are preferred to larger ones. Points C and D are not on the Pareto front because point C is dominated by both points A and B, while point D is dominated by point B. Points A and B are not strictly dominated by any other point, and hence lie on the frontier.

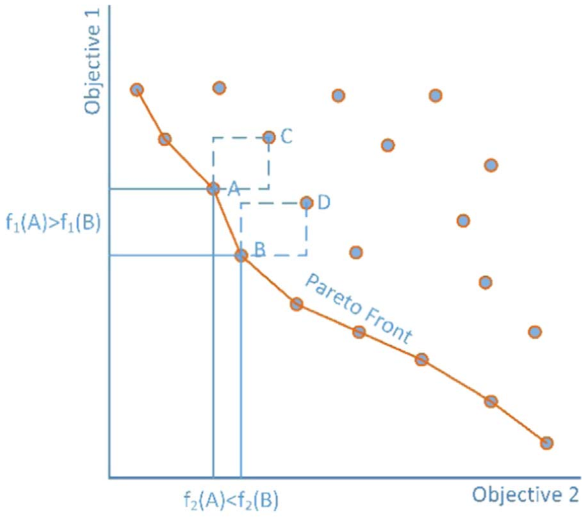

Fig. 1. Example of a Pareto front.