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Environmental impacts of public transport systems using real-time control method

Mahmood Mahmoodi Nesheli [a], Avishai (Avi) Ceder [a,*], Farzan Ghavamirad [b], Scott Thacker [c]

[a] Transportation Research Centre, Department of Civil and Environmental Engineering, 20 Symonds Street, University of Auckland, New Zealand
[b] School of Engineering, Deakin University, Waurn Ponds, Victoria 3216, Australia
[c] Environmental Change Institute, University of Oxford, South Parks Road, Oxford OX1 3QY, UK

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ABSTRACT

Public Transport (PT) systems rely more and more on online information extracted from both operator's intelligent equipment and user's smartphone applications. This allows for a better fit between supply and demand of the multimodal PT system, especially through the use of PT real-time control actions/tactics. In doing so there is also an opportunity to consider environmental-related issues to approach energy saving and reduced pollution. This study investigates and analyses the benefits of using real-time PT operational tactics in reducing the undesirable environmental impacts. A tactic-based control (TBC) optimization model is used to minimize total passenger travel time and maximize direct transfers (without waiting). The model consists of a control policy built upon a combination of three tactics: holding, skip-stops, and boarding limit. The environmental-related measure is the global warming potential (GWP) using the life cycle assessment technique. The methodology developed is applied to a real life case study in Auckland, New Zealand. Results show that TBC could reduce the GWP by means of reduction of total passenger travel times and vehicle travel cycle time. That is, the TBC model results in a 5.6% reduction in total GWP per day compared with an existing no-tactic scenario. This study supports the use of real-time control actions to maintain a reliable PT service, reducing greenhouse gas emissions and subsequently moving towards greener PT systems.

1. Introduction

On the global scale, transport activity for both passengers and freight is growing rapidly and is expected to double by 2050 (IEA, 2009). Internationally, increased attention has been directed towards green transportation as governments are faced with the onset of climate change. The environmental impacts of transportation systems are considerable, accounting for 20–25% of the world's energy consumption yearly (Zhou et al., 2010). Energy use in the transportation sector (i.e., gasoline, diesel, or liquefied petroleum gas, with most vehicles being operated with gasoline or diesel), has made a major contribution to the deterioration of urban air quality and is responsible for a significant amount of greenhouse gas (GHG) emissions, which include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and sulfur hexaflouride (SF6).

* Corresponding author.
E-mail addresses: m.mahmoodi@auckland.ac.nz (M.M. Nesheli), a.ceder@auckland.ac.nz (A. (Avi) Ceder), Fghavami@deakin.edu.edu.au (F. Ghavamirad), scott.thacker@ouce.ox.ac.uk (S. Thacker).

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The rise in transport use of energy has resulted primarily from increased use of the private car for personal transport (Potter, 2003). Technological developments such as fuel-efficient vehicles and alternative energy sources provide a means to address this concern, though current efforts fall short of counterbalancing the impacts of this growth (Rode and Burdett, 2011). Therefore, it is desirable to provide travelers with a viable alternative to private cars. Undoubtedly, the use of public transport (PT), being accountable for only a fraction of the total emissions, can help make transportation more economical and efficient in terms of use of resources (Hassold and Ceder, 2014). However, in terms of reliability, efficiency, and environmental impacts, PT itself has great potential for improvement. (Beirão and Sarsfield Cabral, 2007; Hassold and Ceder, 2014; Keirstead et al., 2012; Kimball et al., 2013; Nesheli and Ceder, 2014)

Due to the fact that most PT attributes (travel time, dwell time, demand, etc.) are stochastic, the passenger is likely to experience unplanned waiting and trip times. This uncertainty (especially for buses) will create the undesirable vehicle-bunching phenomenon, unproductive service, increase of passenger waiting and travel times, and of passenger frustration. Inefficient PT operation not only causes a loss of existing and potential passengers, but also leads to major detrimental impacts on environmental aspects and resources.

Principally, one of the most challenging problems of transportation planning is how to shift a significant amount of car users (who consume the highest percentages of the energy used for transportation) to PT in a sustainable manner. Findings show that in order to increase PT usage, the service should be considered in a way that provides the levels of service required by passengers and by doing so, attract potential users (Beirão and Sarsfield Cabral, 2007). Following Hanaoka and Qadir, the need to attract people from personal automobiles to PT is vital for achieving a sustainable transport system (Hanaoka and Qadir, 2009). Levinson demonstrates that a reliable transit service is essential for attracting and retaining riders, principally in modern societies, which make many transportation options available (Levinson, 2005). As shown in Ceder, an attractive, advanced PT system that operates reliably and relatively rapidly, with smooth (ease of) synchronized transfers, constitutes part of the door-to-door passenger chain (Ceder, 2007, 2016).

A vast amount of research has been conducted on how to optimally or efficiently utilize the PT system. One efficient approach to alleviating the uncertainty of the PT service, such as simultaneous arrival of vehicles at a transfer point, and rectifying the service irregularity is to use real-time operational control actions (tactics), like holding, skip-stop, and short-turn. Daganzo showed that without interventions (i.e., control actions), bus bunching was almost inevitable regardless of the driver's or the passengers' behavior (Daganzo, 2009). With regard to transfer reliability, some recent studies show that applying certain operational tactics can significantly increase the number of direct (simultaneous) transfers and reduce total passenger travel time (Hadas and Ceder, 2010; Liu et al., 2014; Nesheli and Ceder, 2015, 2014).

With respect to using the intelligent transportation system (ITS) and environmental impacts, the European Commission published a comprehensive qualitative analysis of the potential of ITS technologies for reducing greenhouse gas emissions related to road transport and suggests that more research on the energy-reducing capacity of ITS applications is required (Bani et al., 2009). Dessouky et al. show the potential benefits of real-time control of timed transfers using intelligent transportation systems (Dessouky et al., 1999). The results showed that advanced technologies were most advantageous when there were many connecting buses - the schedule slack was then close to zero.

In New Zealand, the transportation sector is responsible for producing more than 40% of the CO_2 emissions and it is the fastest growing source of greenhouse gas (GHG) emissions (Andrew, 2004). A recent study shows that private vehicle transport in New Zealand is less energy-efficient and produces 65% of CO_2 emissions in comparison with 15.8% of CO_2 emissions from the whole PT sector (Ministry of Transport, 2014). The key findings of the Auckland Regional Council show that providing efficient PT system combined with some improvements to the road network will be a key element to limit growth in private care use and will be more effective in reducing growth in CO_2 emissions (Auckland Transport, 2010). More recently, the Auckland Transport Regional Public Transport Plan was created for the purpose of developing an integrated transport network to provide Aucklanders with a sustainable transport system in a safe, integrated and affordable manner (Auckland Transport, 2010). This plan shows the intensive discussion conducted on various issues relating to PT systems of the future. Indeed, a major focus over the next decade will be on enhancing the PT system. Thus, there is need to investigate the performance of Auckland's PT system to meet sustainability goals.

Although extensive research has been conducted to analyze PT movements at control points, there has been no specific analytical study dealing with environmental impacts related to real-time control actions. There is a need, then, to assess the effect of applying real-time tactics on environmental factors.

To date, life cycle assessment (LCA) tools have generally been used for knowledge generating studies either as standalone quantification tools or for comparisons of different alternatives. LCA is a systematic evaluation process of resource requirements and environmental impacts of given products from raw material acquisition to final disposal; it includes, for instance, global warming, ozone depletion, acidification, eutrophication, and human toxicity. The applicability and strengths of LCA in assessing environmental impacts have been proven in transportation engineering. Graedel (1998) defined LCA as "the examination, identification, and evaluation of the relevant environmental implications of a material, process, product or system across its lifespan from creation to waste, or preferably to re-creation in the same or another useful form". Azapagic and Clift (1999) indicate that LCA tool can be applied for evaluating alternative technology systems and optimization models. Chang and Kendall (2011) introduced a green method in rail-system planning for decision makers with the evaluation of life cycle GHG inventory for running high speed rail in the U.S. Recently, Matute and Chester (2015) conducted a study to find out the reduction cost per metric ton of greenhouse gases emission by comparing three urban transportation plans with California