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Station choice for Australian commuter rail lines: Equilibrium and optimal fare design

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ABSTRACT

We examine how park-and-ride commuters living along a rail line compete for seats when they travel to their workplace in Australian metropolitan areas. First, we prove that at user equilibrium in which each commuter minimizes her expected travel cost, there exists one station on the rail line at which some commuters could find a seat and the others have to stand; all of the commuters boarding at its upstream stations have seats and all of the commuters boarding at its downstream stations must stand in the train. We derive a solution algorithm for obtaining a user equilibrium, which involves solving an equation with only one variable. We demonstrate that more than one user equilibrium may exist. Second, we examine the system optimal station choice that assumes all of the commuters cooperate and minimizes their total travel cost. An analytical solution approach is proposed based on the structure of the problem. Third, we investigate the optimal train fare design that leads to the system optimal station choice. We prove that the optimal train fare satisfies: there exists a particular train station that has some seats and the train is full after this station. All of its upstream stations have the same fare, which is higher than or equal to the fare of this particular station; and all of its downstream stations have the same fare, which is lower than the fare of this particular station.

1. Introduction

Commuter rail (suburban rail) is a passenger rail transport service that primarily operates between a city center (central business district, or CBD) and the middle to outer suburbs. People using commuter rail services usually travel on a daily basis: from home to workplace in the morning and from workplace back home in the evening. In Australia, commuters use cars to get to train stations more than almost any others in the world (Department of Infrastructure, 2005) because of a high rate of car ownership and poor coverage of the broad urban areas by conventional public transport modes (e.g., buses and trams). Commuter rail forms a vital part of public transportation in major Australian cities. For instance, around 1 million people travel in the New South Wales commuter rail system every day, covering Sydney, New Castle, and Wollongong, amongst others; the daily ridership of the Melbourne railway system is 0.8 million (Commuter Rail in Australia, 2015).

Fig. 1 shows the South Coast Line of the New South Wales commuter rail system, where "Central" is the Central Railway Station of Sydney (Sydney CBD). People living along the south coast of New South Wales, mainly including cities and suburbs of Nowra (Bomaderry), Kiama, Albion Park, Dapto, Port Kembla, Wollongong, Thirroul, and Helensburgh, travel on this line to their workplace in Sydney CBD. The trip is long, for instance, it takes about 1 hour and 50 minutes from Nowra (Bomaderry) to Sydney CBD, and 1 hour 30 minutes from Wollongong to Sydney CBD. Therefore, the commuters have to wake up very early in order to arrive at their workplaces on time. As a result, they are still very sleepy when they get on the train and most people choose to sleep for half an hour to two in the train. This is in contrast to the evening trip from workplace back home during which most people play with their electronic devices such as iPad's and smart phones. An important precondition for sleeping in trains in the morning is having a seat. Commuters could not sleep without a seat. Due to peak demand and limited train capacity, commuters who get on trains at downstream stations may not have a seat and hence could not sleep in trains. Some commuters therefore drive to upstream stations so that they could find a seat and then sleep during the trip. Our study hence aims to analyze how commuters choose stations to compete for seats when traveling to workplaces in the morning and the resulting implications for transport authorities.

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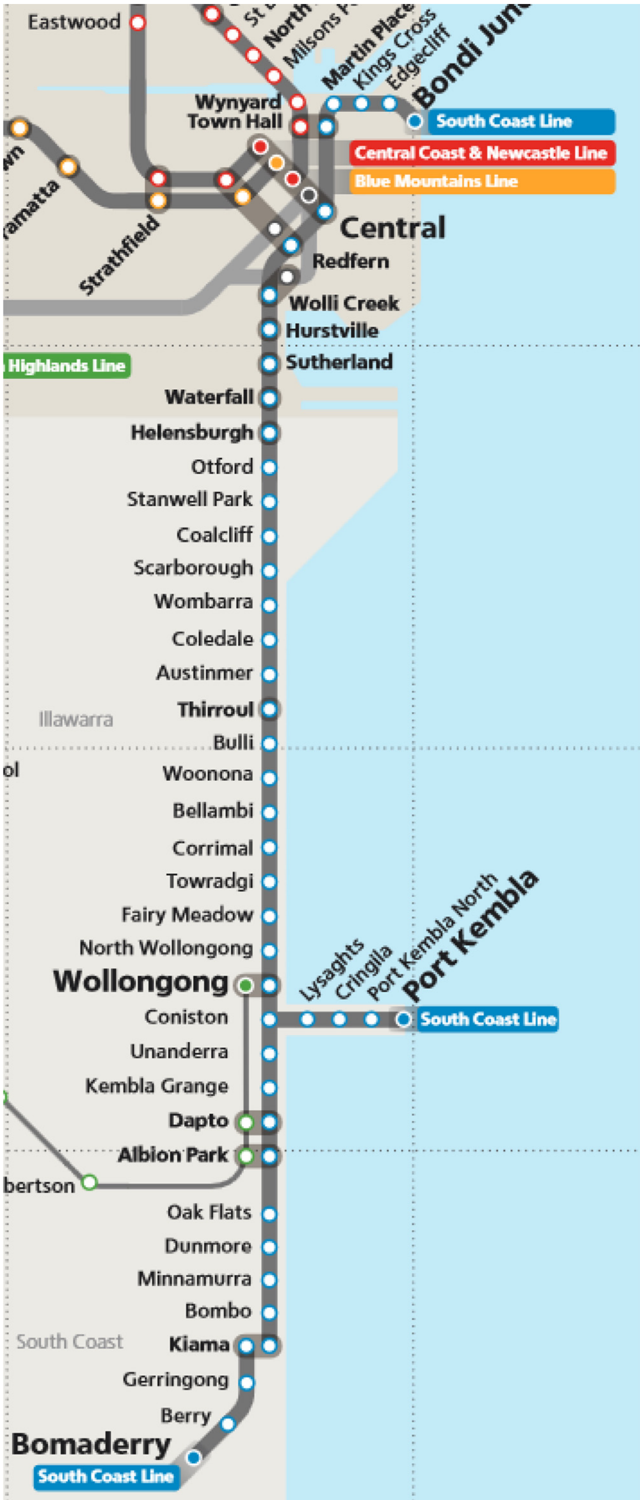

Fig. 1. South Coast Line (Source: Intercity Trains Network, 2015).

1.1. Literature review

Our study is related to the stream of works on park-and-ride (P&R). A large amount of research on P&R investigates the factors that affect the percentage of P&R commuters such as train/parking fare, availability of parking facilities at train stations and at workplaces, frequency of train services, and culture (Duncan & Christensen, 2013; Habib et al., 2013; Li, Gao, Li, & Wang, 2012; Liu & Meng, 2014; Mingardo, 2013). Once the factors are identified, effective policies for promoting the usage of P&R could be initiated. Some efforts are devoted to the location of P&R facilities (i.e., car parks) as well as the capacities of the facilities (Liu, Huang, Yang, & Zhang, 2009; Wang, Yang, & Lindsey, 2004). Discrete choice models and transit assignment models are usually used to formulate transport mode split and commuters' route choice behavior (Aros-Vera, Marianov, & Mitchell, 2013; Farhan & Murray, 2008). Our study differs from the above-mentioned works as we focus on one rail line along which all of the potential commuters park and ride as they all live far away from their workplaces. We further assume that parking slots are always available, which is the case for most train stations in remote suburbs of Australia. Moreover, in our model commuters choose stations based on the generalized cost that incorporates the availability of seats.

Another relevant category of research is transit assignment considering passenger congestion. An implicit approach is derived from road network modeling, for which strictly non-decreasing continuous disutility functions with respect to the number of commuters in trains are defined (Wong & Tong, 1999; Nuzzolo, Russo, & Crisalli, 2001; Wu et al., 2013). The main drawback of this approach is the approximation in assessing the disutility for boarding users at stops with respect to users already on board. In other words, the effect of congestion is the same for both standing passengers and sitting passengers. Another approach is to impose a strict vehicle capacity constraint and passengers are rejected if the vehicles are full (Hamdouch & Lawphongpanich, 2008; Poon, Wong, & Tong, 2004). The third approach differentiates the discomfort level experienced by sitting and standing passengers (Hamdouch, Ho, Sumalee, & Wang, 2011; Leurent, 2012; Palma, Kilani, & Proost, 2015; Schmöcker et al., 2011; Sumalee, Tan, & Lam, 2009; Tian, Huang, & Yang, 2007). Nevertheless, models in these studies generally consider only the public transport mode. In our research, we analyze a single line and develop analytical models to gain deeper insights into the problem. Moreover, we consider a park-and-ride system consisting of both private car mode and public transport, rather than just public transport.

1.2. Objectives and contributions

We conduct an in-depth analysis of how P&R commuters compete for seats when they travel to their workplace in the morning. We use the words "commuters" and "passengers" interchangeably. In our setting, all of the commuters live along a rail line and are homogeneous in that they have the same unit travel cost by train with a seat and the same unit travel cost by train without a seat. Our major findings are threefold. First, we prove that at user equilibrium (UE) in which each commuter minimizes her expected travel cost, there exists one station on the line at which some commuters could find a seat and the others have to stand; all of the commuters boarding at its upstream stations have seats and all of the commuters boarding at its downstream stations must stand in the train. It is possible, in extreme cases, that some stations are not used. We derive a solution algorithm for obtaining a user equilibrium, which involves solving an equation in one unknown. We demonstrate that more than one user equilibrium may exist. Second, we examine the system optimal (SO) station choice that assumes all of the commuters cooperate and minimizes their total travel cost. An analytical solution approach is proposed based on the structure of the problem. Third, we investigate the optimal train fare design that leads to the system optimal station choice. We prove that the optimal train fare satisfies: there exists a particular train station that has some seats and the train is full after this station. All of its upstream stations have the same fare, which is higher than or equal to the fare of this particular station; and

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