

# Spreading peak demand for urban rail transit through differential fare policy: A review of empirical evidence

Yulin Liu, Phil Charles

School of Civil Engineering, The University of Queensland, Brisbane St Lucia QLD 4072, Australia

Email for correspondence: [y.liu24@uq.edu.au](mailto:y.liu24@uq.edu.au)

## Abstract

More evenly spread demand for public transport throughout a day can reduce transit service provider's total asset and labour costs. A plausible peak spreading strategy is to increase peak fare and/or to reduce off-peak fare. This paper reviews relevant empirical studies for urban rail systems, as rail transit plays a key role in Australian urban passenger transport and experiences severe peak loading variability. The literature is categorised into four groups: a) passenger opinions on willingness to change time for travel, b) valuations of displacement time using stated preference technique, c) simulations of peak spreading based on trip scheduling models, and d) real-world cases of peak spreading using differential fare. Policy prescription is advised to take into account impacts of traveller's time flexibility and joint effects of mode shifting and peak spreading. Although focusing on urban rail, arguments in this paper are relevant to public transport in general with values to researchers and practitioners.

## 1. Background and Introduction

Rapid growth of public transport patronage in Australian cities has created both opportunities and challenges. One of the most significant challenges is considerable pressure on funding. Research (LEK, 2010) estimates that only 36% of total annual operating costs of around \$5.2 billion for public transport in Australia's five major cities are recovered by revenue and the balance is subsidised by government. Given the increasing competition for government funds, closing the funding gap is of great importance to ensure a sustainable public transport system for Australia into the future. Since the operating costs are nearly three times greater than the revenue for public transport in Australia, 1% reduction in operating costs have three times impact on cost position as 1% increase in revenue (LEK, 2010). It is therefore critical to reasonably maximise the number of passenger-kilometre for a given level of operation costs.

Across Australia, public transport networks encounter systematic peaks in demand during weekday mornings and afternoons. The total capacity requirements of a public transport system are generally dictated by the needs to service the peaks, which are usually a couple of hours in duration. With patronage levels much lower outside peak periods, capacity tends to be poorly utilised throughout the majority of a day. It is clearly in an operator's best interest to spread demand over a larger time period in order to reduce maximum capacity requirements. One of the plausible strategies is increasing peak fare and/or reducing off-peak fare in order to encourage peak travellers to travel in off-peak.

This paper reviews empirical studies on spreading peak demand for urban rail through fare differentiation. Rail is the largest mode of urban public transport in Australia with 60% of passenger kilometres and dominates in the three most populous cities. From 2004 to 2008, metropolitan rail patronage had grown at approximately 11% p.a. in Melbourne, 8% p.a. in Perth, and 6% p.a. in Brisbane. Rail will still play a key role in Australian urban passenger transport in the years to come (LEK, 2010). Peak overcrowding of rail services has now become an endemic problem for many major cities around the world, including Australian urban railways. In Sydney, the share of trains above their 135% load factor standard increased from 6% in January 2004 to 16% in July 2008. In Melbourne, the number of trains that breached peak contract loading standards increased by 500% between 2005 and 2007 (Currie, 2010a). It is not always feasible to increase capacity due to financial and/or technical

constraints, particularly in short term for rail systems. Peak spreading through differential fare holds promise, as it may partially and temporarily address peak overloading and related problems with service provision for urban rail.

The rest of this paper is structured as follows. The next section clarifies the concept of peak spreading for urban public transport and discusses fare differentiation as a tool for peak management and travellers' responses. Then, it examines the methodologies and main findings of the empirical studies classified into four groups. Finally, advice to policy prescription is provided, followed by conclusions. The arguments in this paper are not unique to urban rail but relevant to public transport in general, with reference values to researchers and practitioners in transport policy.

## **2. Transit Peak Spreading and Fare Differentiation**

### **2.1. Peak management and spreading in public transport**

Imbalance of demand levels between peak and off-peak periods leads to a series of negative impacts on both public transit service providers and users. The capacity geared toward peak demand level is inefficiently utilised during off-peak periods. Whereas the peak direction cost per passenger may look attractive, the whole picture is far from ideal (Hale & Charles, 2009). Peak overcrowding and resulting poor reliability sabotages customer satisfaction and attractiveness of public transport (see Li & Hensher, 2011, for valuations of crowding). Therefore, *peak management* in public transit may have various policy objectives, such as balancing loading between peak and off-peak, improving peak passengers' satisfaction, lifting peak operating cost recovery, enhancing capacity utilisation (see e.g., Hale & Charles, 2009; Henn et al., 2010).

The basic ideas of peak management are of two types: increasing peak service supply and reducing peak travel demand. Options by increasing peak capacity are often limited because transit lines with peak overcrowding are usually operating at maximum capacity. As argued by Currie (2010a), finding feasible solutions to peak rail overcrowding is a significant challenge for rail service providers because it requires substantial funding and years to implement. Whelan & Johnson (2004) also noted that difficulties in procuring additional stock, restrictions to train length, and capacity constraints on track mean that the provision of additional peak capacity is not always feasible. Cheaper and shorter term solutions to peak overcrowding therefore must be sought.

Changing peak travellers' time for travel is the key to relieving peak overcrowding. Using pricing and/or non-pricing tools to intervene with travel behaviour, e.g., choices of timing, destination, route and/or mode belongs to *travel demand management*. Shifting travellers from peak to off-peak is associated with the concept of (active) peak spreading. *Peak spreading* is a dynamic process whereby the pattern of travel demand changes over time from one where there is heavy peaking to one where the demand spreads out over a longer period (Bolland & Ashmore, 2002). Hounsell (1991) identified two mechanisms of peak spreading, '*passive*' *peak spreading* (i.e., a natural increase in the duration of a peak period as a result of congested/crowded network conditions) and '*active*' *peak spreading* (i.e., travellers deliberately change their time for travel to avoid peak periods, or public policies are enacted to encourage this trip timing change).

Research on peak spreading has focused more on road than on transit networks, due to the scale of traffic congestion problems on the road in peak periods and the availability of off-peak capacity. As summarised by Daniels & Mulley (2013), the wide range of research on time for travel includes understanding peak travel, understanding departure time choices, modelling peak spreading, jointly modelling time and mode choice, active and passive peak spreading, network equilibrium effects, influence of road pricing on time for travel, and the role of flexible work hours. Most public transport providers still tend to meet peak demand through investment in infrastructure, vehicles, and provision of services. However, facing the

recently rapid increase in demand for public transport, it is time for public transport providers to consider active peak spreading strategies to better utilise capacity and to save investment.

Nevertheless, as Faber Maunsell (2007) pointed out, it is extremely important to clarify the significant differences in scenarios for peak spreading between road and public transport networks. This is not saying that road and public transport travellers behave in intrinsically different ways to peak spreading incentive (e.g., pricing) but that the conditions and options they face have very significant differences:

- Road capacity is essentially the same at all times of a day, while capacity in peak shoulders is usually constrained in public transport systems. Hence, there is greater potential for moving peak road traffic to a less congested period;
- The mixture of journey purposes on road over peak period is often more varied. There is therefore potentially more time flexibility among automobile users;
- Drivers have greater flexibility to decide when to go than transit users who are constrained by service schedules;
- There can be significant savings in time, fuel costs, and stress on a road journey out of peaks. For transit users, crowding is often the only factor of travelling out of peaks;
- In terms of road traffic, a reduction in demand by encouraging modal transfer is a desirable policy outcome. For public transport this would be an undesirable outcome.

## 2.2. Fare differentiation for peak management

The basic idea of peak/off-peak fare differentiation is to charge passengers different prices between peak and off-peak, namely to increase peak fare, to discount off peak fare, or both in combination. Peak/off-peak fare differentiation is common around the world. A recent review by LEK (2010) finds that around 40% of major urban rail networks worldwide, including all of the Australian networks, provide some form of peak surcharge and/or off-peak discount. Meanwhile, despite the availability of technology enabling dynamic pricing, including electronic payment options, transit organisations often continue to favour 'simplified fare structures'. It was found in the US that the percentage of agencies using fare differentials had actually declined by 2003 (TCRP 2003, as cited in Henn et al., 2010).

As summarized by McCollom & Pratt (2004), transit fare changes can have various purposes, such as to increase revenue, to stimulate transit usage, and sustainability objectives. Specifically, they indicated that the differential fares between peak and off-peak, with lower fare charged in off-peak periods than in peak periods can be introduced for the following reasons:

- To better reflect the higher costs of providing service in peak periods;
- To promote ridership growth in underutilized off-peak periods; and
- To shift riders from crowded peak period services to less crowded off-peak services.

Noticeably, although spreading peak demand to peak shoulders or off-peak is the key to address peak overloading, most differential fare policies so far seem to emphasise more on cost efficiency and equity concerns than on peak spreading. For example, Cervero (1990) stated that differentiating fares by peak and off-peak periods represented potentially the most effective way to capture the higher marginal cost of providing rush-hour services. Streeting & Charles (2006) argued that "pricing is one the most effective options that rail agencies have in meeting the challenges of overcrowding and peak period congestion... the concept of rail pricing includes but seldom meets the premise that the full cost of service provision should be reflected in the cost to passengers...fares differentiated by both distance and time-of-day appear to provide a balance of efficiency, equity and revenue benefits". Henn et al (2010) consulted a group of experts in Australian urban rail industry and authority on the peak/off-

peak fare differential policy. Their consultation results showed that increasing peak fares was believed easy to implement, but politically unpopular; increase needed to be significant enough to be effective, but needed to control to avoid mode shift to car; all market segments should be considered within the context of social inclusiveness; reducing shoulder fares was expected to have mixed success in Australian cities, in view of low fare sensitivity; reducing shoulder fares was less objectionable than increasing peak fares.

The potential of differential fare as economic incentive and disincentive ('carrot and stick') to encourage active peak spreading is theoretically plausible. Small (1982) introduced the concept of *schedule delay costs* for work trips. If a consumer wants to undertake certain activities during a day, s/he will schedule them according to his/her preferences, taking into consideration external constraints. Deviating from these scheduling preferences will result in disutility, i.e. schedule delay costs. Schedule delay costs is an important concept in the research focused on alleviation of congested transport networks because they indicate the costs travellers attribute to changing their preferred time for travel. Recently, more attention is being paid to differential fare as a policy tool to achieve peak spreading.

### **2.3. Traveller responses to fare changes**

Transit fare change can impact travel behaviour. The most commonly used measure of travellers' sensitivity to fare changes is fare elasticity of ridership, i.e., the ratio of percentage change in ridership in response to the percentage change in fare. Fare elasticity of ridership varies considerably under different situations, but exhibits relative consistency when expressed as averages. A frequently used rule of thumb, known as the Simpson-Curtin Rule, is that each 3% fare price reduction increases ridership by 1% (LEK, 2010). This elasticity value may vary by transit modes, location, and time frame. The effect of heavy rail transit fare changes is typically about half the bus fare elasticities in the same cities (McCullom & Pratt, 2004). Elasticity of demand on transit in the outer suburban areas is likely to be higher than in city centre locations (Litman, 2012). Ridership appears to be less sensitive to fare changes where transit is in a strong competitive service and price position vis-a-vis auto travel than it is where transit service is marginal (McCullom & Pratt, 2004). Fare elasticities tend to increase over time with the change in fares, i.e.,  $-0.3$  to  $-0.5$  in the short run (first year) and  $-0.6$  to  $-0.9$  over the long run (five to ten years) (Litman, 2013).

No significant differences in elasticities for fare increases versus decreases, or for large versus small changes, have been consistently discerned within the range of normal experience. However, the experience with across-the-board fare changes (i.e., not involving peak/off-peak fare differentials) suggests that much of the ridership change occurs during off-peak periods (McCullom & Pratt, 2004). Litman (2012) suggested that fare elasticities for off-peak travel are typically 1.5 to 2 times higher in magnitude than peak-period elasticities. As noted by McCullom & Pratt (2004), the differences in rider responses in peak and off-peak means that even without a change in the proportional relationship of peak and off-peak fares, fare changes will affect the distribution of transit riding over the hours of the day. Fare increases heighten the differences between the daily peaks and valleys of transit usage, while fare decreases diminish the differences. Charging lower fares in the off-peak periods relative to peak periods further enhances off-peak usage relative to peak usage. McCullom & Pratt also pointed out that most of this ridership increase is the result of off-peak trips new to transit. Peak period riders show only extremely limited propensity to shift to off-peak riding in response to off-peak fare reductions.

All the observed fare elasticities of transit demand fall in the inelastic range between  $-1$  and  $0$ , which means that the percentage change in quantity demanded is smaller than the percentage change in fare price. Thus if a transit system wants to increase total fare revenues, it should increase fare levels, but expect some ridership loss. It is hoped that targeting larger fare increases to users with low fare sensitivities (i.e., small absolute values of elasticity) will result in smaller losses of riders than would result from imposing a uniform fare increase on all riders. Likewise, reducing fare levels will almost always increase

ridership, but at a cost of revenue loss. The new rides due to fare reduction or elimination come from two sources: 1) Existing riders who decide to take more trips, and 2) New riders who either divert from other modes such as automobile, or did not make the trip before the fare reduction. In the context of travel mode competition, fare changes can impact car usage, i.e., automobile demand cross elasticity to transit fare. Litman (2012) gave this cross elasticity values as 0.03 to 0.1 for short term and 0.15 to 0.3 for long term.

Theoretically, increasing peak fare would increase revenue but with peak ridership loss (most probably diverting to other modes and limited cancelling the trip after the fare increase or hopefully shifting to off-peak). Noticeably, even small peak-of-the-peak demand reduction might help save operation costs, i.e., maximum track capacity/fleet/labour for peaks. On the other hand, reducing off-peak fare would increase off-peak ridership but with revenue loss. The additional off-peak ridership would mostly be from new transit users who either divert from other modes or did not make the trip before the fare reduction, plus limited demand shifted from peak and existing off-peak riders who take more trips than before. This theory needs to be backed up by empirical evidence.

### 3. Evidence from Empirical Studies

#### 3.1. Data requirements and categorization of studies

The potential effects of fare changes on ridership are often estimated using fare elasticities. However, elasticities may mask extensive variability among results for differing operating environments, types of services, and market groups (McCollom & Pratt, 2004). Balcombe et al. (2004) pointed out that elasticities convey limited information about demand structure and should only be used to provide preliminary estimates rather than precise prediction.

McCollom & Pratt (2004) suggested that the more robust analysis of demand's response to fare changes should utilise 'before-and-after' approach, as contrasted to cross-sectional analysis. Before-and-after analyses require data on the number of existing riders subjected to change ('before' data) and the response of riders to change ('after' data). This quasi-experimental data ideally should cover a time span free of significant confounding events. e.g., concurrent service changes, or at least be accompanied by before-and-after quantification of confounding events. Most available before-and-after data pertains to overall fare level changes and are collected based on tallies. In contrast, analyses of relative fare changes for different hours of the day are scarce. This scarcity is understandable since this type of analysis requires estimating not only the number of riders shifting between transit and other modes but also the number of riders shifting between peak and off-peak, in response to fare change. Such analyses involve more detailed data collection like passenger survey.

Due to the scarcity of actual before-and-after data on demand response to differential fare, most of the primary studies reviewed are based on the surveys of public opinions toward hypothetical schemes and/or potential behaviour in response to supposed situations. The most straight forward approach is to ask passengers' opinions (via focus group, interview, or questionnaire) on a proposal of peak surcharge and/or off-peak discount aimed to shift travel time and thus reduce peak overcrowding. This approach is simple and fast to collect market information for decision making and thus popular in practice.

Some studies employed *stated preference* (SP) techniques to investigate differential fare's impacts on individuals' behaviour. SP techniques are the state of art and practice to investigate consumer's behavioural responses towards a hypothetical product or policy. SP approach typically suits the situations in which a test alternative is either not currently available or lack of variation in attribute levels. In an SP experiment, respondents are asked to choose or rank or rate the most preferred alternative, defined in terms of a set of attribute levels which vary according to a statistical design. Disaggregate models of choice behaviour under these combinations of attribute levels can then be estimated. As noted by Li & Hensher (2012), SP approach is powerful for revealing the underlying preferences of choice

behaviour, and more importantly, is capable of delivering empirical estimates of willingness to pay for specific attributes and associated levels which is the key to project appraisal and demand forecasting. Li & Hensher also clarified that some studies use a simpler method in which respondents are asked to provide their opinions and behaviour responses towards specific policies where the attribute levels are predefined by the analyst but not statistically designed to maximise the precision of parameter estimates as in SP approach. This simpler method is fundamentally different from a standard SP approach, and is more correctly called a *stated opinion* approach.

Further, based on the choice models estimated with SP data, simulation can be performed to examine the aggregate impacts of peak/off-peak differential fare on a transit or multi-modal transport network with respect to peak spreading, capacity utilisation, route competition, mode split, revenue change, etc. The functionality of a simulation system depends on its core choice model and its assumptions of individuals' travel behaviour, e.g., a traveller's response and sensitivity to peak fare surcharge alone or combined with changes in other service attributes, such as onboard crowding, service frequency, etc.

Individuals do not have to back up their statements or choices with real commitments when they participate in an opinion survey or SP experiment, to some extent, they might behave inconsistently when the hypothetical situation really happens. Therefore, the major drawback of hypothetical approach is that it is not built upon the observed data of actual behaviour, which are always hard to obtain, particularly the cases of peak/off-peak differential fare. Nevertheless, real world data should be becoming more and more obtainable since peak/off-peak fare differentiation is increasingly being considered as a potential tool for peak demand management. Moreover, the rapid proliferation of electronic ticketing technology (e.g., smart card systems) is making it much easier to track transit users' travel behaviour.

This paper groups the reviewed empirical studies on peak spreading using differential fare into four categories, according to their data's nature and methodology: a) passenger opinions on willingness to change time for travel, b) valuations of displacement time using SP technique, c) simulations of peak spreading based on trip scheduling models, and d) real-world cases. In general, the empirical research relevant to transit peak spreading using fare adjustment is becoming increasingly active in the past five years, though the body of literature is still very limited compared to that on overall transit demand forecasting and fare elasticity. The primary studies reviewed are from UK and Australia, as summarised in Table A in Appendix, where their key characteristics are provided, such as study location, year of data, collection approach, respondents, and analysis methodology.

## **3.2. Passenger opinions on willingness to change time for travel**

### **3.2.1. Focus groups, interviews, and questionnaire surveys mainly in London, UK**

According to Transport for London (2004, as cited in Faber Maunsell, 2007 and Currie, 2010a), large fare differentials would be necessary in order to induce even a small transfer of passengers from the peak to the off-peak period; on the basis of a neutral revenue assumption, to obtain a 3% switch in time travel to central London, 40% differentiation in fare would be necessary for passengers from inner suburban stations and 100% for passengers from outer suburban stations.

Passenger Focus (2006a; 2006b) conducted a series of qualitative and quantitative research in 2006 to investigate the feasibility of differential fare to achieve peak spreading for London commuting trains. 173 passenger intercept interviews were taken over three days in morning peak at Waterloo Station. 41% of passengers interviewed said that they could arrive outside of peak times and the majority would prefer to arrive earlier rather than after the morning peak. Work and education commitments were the most significant factor stopping interviewees from shifting out of peak period. Reduced fare, higher service frequency, and more seats were identified as the three biggest motivations to travel in off-peak.

Later, Passenger Focus (2006a) ran five focus groups of passengers currently arriving into the Waterloo Station during morning peak and having flexibility to change time for travel. The five focus groups are commuters within and over one hour to Waterloo, less and more affluent commuters, and students. It was found that

- Some passengers in each focus group could be incentivised to change time for travel;
- Work and education commitments were the most important factor of trip timing;
- It was harder to persuade passengers with longer journeys to reschedule their trips;
- Passengers were less willing to travel earlier in the dark winter months;
- Passengers would not shift to off-peak if off-peak services were unreliable to them;
- Security at railway stations was a deterrent to travelling at off-peak times;
- Off-peak fare discounts in the region of 25%-30% were sought by passengers;
- Off-peak discounts would be more acceptable than peak surcharges;
- Time would be needed for travellers to adjust travel behaviour after any fare changes.

Passenger Focus (2006b) then surveyed commuters during peak periods across Great Britain on the likelihoods that they would shift their travel times to avoid morning and evening peaks, under the circumstances of no financial compensation, 10% travel cost discount, and 20% discount respectively. As shown in Table 1, 20% reduction in travel cost could substantially increase travellers' likelihood to shift time for travel to avoid peak periods.

**Table 1: Potential for Shifting Travel Times (modified based on Passenger Focus, 2006b)**

Likelihood of travelling earlier / later to avoid busiest periods	Percentage of likelihood given travel cost discount* (%)		
	No discount	10% discount	20% discount
Very likely	5	10	24
Fairly likely	14	7	24
Neither	9	8	10
Fairly unlikely	32	34	12
Very unlikely	41	40	27
No. of respondents	N= 487	N= 358	N= 278

\*Note: sum of percentages under every discount level not equal to 100% in the original literature, possibly due to rounding.

Faber Mausell (2007) held six focus groups (four at London and two at Birmingham) and questionnaire surveys of commuters on a rail line between London and Birmingham to explore the issue of peak spreading and to collect feedback on a proposed new ticket, a reduced price season ticket stored on a smart card valid for off-peak travel. If you make a journey that finishes in central London during pre-defined morning peak period, there will be a peak surcharge. The same will apply for journeys that start from central London during pre-defined evening peak period. The focus groups found that:

- In morning peak, most travellers caught a particular train with some buffer time; Although some passengers travelled earlier to avoid overcrowding, many did not want to get in workplace early because they would not necessarily be allowed to leave early thus would have a longer work day;
- Travel conditions in evening peak were worse because everyone was getting on at

once, going for the first train available rather than a specific service;

- There existed a very strong '9-to-5' culture in working hours;
- Childcare was an reason for some people to travel during peak hours;
- Security was a concern for people not wanting to set off too early or arrive back late;
- Crowding was a major issue especially when people could not get on train; when they could, overcrowding onboard could result in comfort and safety concerns;
- London travellers felt the fare they paid was excessive given the quality of the service but Birmingham travellers felt ticket prices were acceptable;
- Peak surcharge was felt as unfair punishment on people without a choice of time for travel, e.g., people with low-paid jobs;
- Pricing up peak travellers might encourage more people to use their car;
- A substantial off-peak discount rather than a peak surcharge was better received;
- Two other concerns with the new ticket option: first, the last off peak train before the surcharge kicked in would be horrendously busy; second, smartcards should be clever enough to automatically correct the peak surcharge as a result of service delay.

Faber Maunsell (2007) also carried out a questionnaire survey among passengers boarding trains at eight rail stations in London in evening peak. Analysis was performed on 2360 responses from passengers making a trip between 7:45 and 9:15am. This survey revealed:

- 33% of respondents arrived at their ideal arrival time, 19% up to half an hour earlier, and 35% up to half an hour later;
- The reasons for not arriving at ideal time include: no available train in preferred time (30%), to avoid overcrowding (13%), missed train/late leaving home/delayed on route (12%), train delayed/cancelled (8%); and to get on direct/faster train (7%);
- 43% of respondents had no flexibility in the time they travelled; just over 35% could travel up to half an hour earlier; and 24% could travel up to half an hour later;
- For passengers to central London with limited mode alternatives, pricing strategies for peak spreading would be more likely to be successful, whereas for passengers to other areas any increased fares would be more likely to lead to modal shift;
- There was strong linkage between workplace arrival time in morning and departure time from work in evening;
- Respondents with higher earnings had far more flexibility in time than those with lower level of income, which posed a potential social equity issue.

### **3.2.2. Questionnaire surveys in Sydney and Melbourne, Australia**

To try a fare with 50% discount on trains arriving in central Sydney before 7:15am as well as between 9:15 and 10:15am, Sydney rail operator, RailCorp (2008, as cited in Henn et al., 2011) added questions on travel time flexibility to its customer survey in February 2008:

- '*Are you able to change your travel arrangements?*' - approximately two thirds of just over 1,000 respondents had some flexibility in their daily travel routine, with the biggest potential for changing the time of travel being arrivals in the CBD before 7:45am (41%) and departing after 6:00pm (43%);
- '*Regarding trips where you are able to change your time of arrival or departure to/from the CBD: what would make you change your travel arrangements?*' - just over

one half of respondents considered improved service frequency to be the main motivation, with improved seat availability (35%) and a change in fares (32%) also being significant (faster journey like express trains was not offered as an incentive);

- 'Regarding trips where you are not able to change your time of arrival or departure to/from the CBD: what are your main constraints?' - work commitments emerged as the dominant constraint, with family commitments as the second;
- The survey also found that combining peak fare surcharges with off-peak discounts increased the willingness to travel in the off-peak from 43% to 53%.

Henn et al (2011) reported an evaluation study of peak spreading potential of a Sydney urban rail corridor experiencing high peak loading. A self-completion questionnaire survey was carried out in September 2009 to assess the willingness of rail commuters to travel earlier or later in morning peak to take advantage of a hypothetical fare discount or a faster train trip. In total, 1,807 questionnaires completed by adult passengers (except RailCorp employees) were obtained from 43 services. Figure 1 shows a time displacement question.

**Figure 1: Example of a time displacement question of the passenger survey in Sydney (Source: Henn et al., 2011)**

11. Would you use a train that departs 30 minutes **EARLIER** than now, if you received a 10% discount? Please tick one only

<input type="checkbox"/> 1. Yes	<input type="checkbox"/> 4. No- fixed appointment	<input type="checkbox"/> 7. No- discount not large enough to make up for time shift
<input type="checkbox"/> 2. No- train too crowded	<input type="checkbox"/> 5. No- too hard to get out of bed earlier	<input type="checkbox"/> 8. No- other Please specify: .....
<input type="checkbox"/> 3. No- other family commitments	<input type="checkbox"/> 6. No- no flexibility in work/ study hours	

12. If you departed **EARLIER** in the morning, would you leave the city **EARLIER** in the afternoon?  1. Yes  2. No

This example question asks whether a passenger would travel 30 minutes earlier if a 10% fare discount was offered. It then asks whether the passenger would travel earlier in the afternoon. The question will then be repeated, but with the respondent asked whether they would travel 30 minutes later. A set of five questionnaires was developed that varied the nature and extent of the incentive (Table 2). The average fare per trip was estimated at \$3.31, thus a 10% reduction would be 33 cents and a 30% reduction would be 99 cents.

**Table 2: Displacement incentives of the passenger survey in Sydney (source: Henn et al., 2011)**

Set	Incentive	Displacement (travel earlier or later)
1	10% fare discount	30 minutes
2	30% fare discount	30 minutes
3	30% fare discount	60 minutes
4	5 minutes faster train trip	30 minutes
5	10 minutes faster train trip	30 minutes

Responses were aggregated by time period and by distance. Three time periods were defined: early peak (trains arriving at Sydney Central Station between 6:00 and 7:59am), peak hour (8:00 - 9:00am), and late peak (9:01 -10:30am). Three trip length groups were: short trips (up to 25 minutes), medium (26 - 50 minutes), and long (over 50 minutes). Each passenger was asked to respond to only one type of incentive. By comparing the response to Sets 1 and 2 in Table 2, it was possible to assess the effect of fare discount (10% versus 30%). Likewise, by comparing the response to Sets 4 and 5, it was possible to assess the impact of varying trip time (five versus ten minutes); and by comparing Sets 2 and 3 it was

possible to assess the impact of the degree of displacement (30 minutes versus 60 minutes). Survey results (see Table 3) showed that:

- 37% were willing to travel 30 minutes earlier for a 10% fare discount offering an average saving of 33 cents per trip on average; by contrast, passengers were much less willing to displace later with only 15% willing to shift 30 minutes later. Increasing the fare discount to 30% increased the displacement to 52% earlier and 25% later. Increasing the displacement time to an hour, the willingness to displace for a 30% fare discount reduced to 35% (willing to travel earlier) and 13% (willing to travel later);
- 24% of respondents were willing to travel 30 minutes earlier to take advantage of a five minute faster train time. Increasing the saving to ten minutes increased the percentage to 39%. Thus, a five minute faster train trip was less motivating than a 10% fare reduction (37%), whereas a ten minute reduction was comparable;
- Faster trains provided an inducement to travel later. For a five minute saving, 19% of passengers were willing to travel 30 minutes later, which increased to around a 34% for a ten minute saving. Thus, compared to a fare discount, faster trains encouraged travelling later.
- Passengers unwilling to displace travel time were asked why they would not take advantage of the incentive. At 30%, 'sleep' was the most often cited reason for not travelling earlier; a lack of flexibility in work/education hours was given by 15%; 'fixed appointments' by 10% and 'family commitments' by 12%; train crowding was given by 12% of respondents; 13% considered the fare discount or travel time saving was insufficient. The most often cited (37%) reason for not travelling later was 'could not leave later in the evening'. Lack of travel time flexibility accounted for 28%;
- A link between morning and evening displacement was established, with 45% of passengers willing to depart earlier in morning peak also being willing to depart earlier in evening peak. For departing later, the percentage reached 60%;
- In total, 97% (including 80% at their ideal times) were travelling within 15 minutes of their ideal time and only 3% were travelling outside of 15 minutes of their ideal time. The reasons for not travelling at their ideal time are: no train service (37%), overcrowding (24%), unable to access the departure station at required time (23%);
- 37% had no flexibility in their travel time, with a further 33% only being able to vary their travel time by up to 15 minutes. Thus, a combined percentage of 70% unable to vary their travel time by more than 15 minutes;

**Table 3: willingness to displace for a fare or travel time incentive**

Respondent Group	Fare Discount						Faster Train			
	10% cheaper		30% cheaper		30% cheaper		5 mins faster		10 mins faster	
	30 mins disp.	30 mins disp.	30 mins disp.	60 mins disp.	30 mins disp.	30 mins disp.	Earlier	Later	Earlier	Later
All	37%	15%	52%	25%	35%	13%	24%	19%	39%	34%
Flexible	13%	6%	19%	13%	7%	4%	13%	8%	17%	12%

As reported by Webb et al. (2010), in March 2009 Metlink (the former marketing body and umbrella brand for public train, tram, and bus transport operators in Greater Melbourne) undertook research to provide an evidence base about the capacity to manage peak demand using price or other levers. An online survey was conducted to investigate the peak period train passengers' propensity to shift out of peak travel times for a better service.

Respondents were 942 adult passengers commuting during peak period for work on a metropolitan rail line. The survey results showed that:

- 50% of the respondents would consider travelling earlier in morning-peak for cheaper fare. The main reasons for not travelling earlier in morning were ‘no flexibility in work arrangements’ and ‘a discount was not enough to change to catch an earlier train’;
- 20% of the respondents would consider travelling later in morning-peak for cheaper fare. The main barrier to travelling later in morning was ‘no flexibility in work time’;
- When asked about the afternoon-peak, a similar proportion of commuters indicated they would consider to travel earlier (34%) and later (38%) for cheaper fares;
- Of those respondents who indicated they would consider travelling earlier in the morning-peak for a discount, 35% would change their evening travel time;
- Conversely, the majority (79%) of the respondents who would catch a later train in the morning would change their afternoon travel time;
- On average, respondents who indicated they were willing to change their travel for a discount would change their time of travel by a maximum of 30 minutes. At least 70% of the respondents willing to change their travel could do so by 30 minutes or less.

### 3.3. Valuations of displacement time using stated preference technique

#### 3.3.1. Stated choice experiment of arrival time by train in London, UK

Faber Maunsell (2007) used a SP experiment in London and Birmingham, UK to explore rail passengers’ propensity to change arrival time in morning peak based on alternative scenarios of fare and crowding levels. Self-completion questionnaires were distributed in evening peak to passengers boarding trains between 4:00 and 7:00pm at seven railway stations in London and one station in Birmingham. 2,360 respondents were identified as ‘in scope’ passengers making a train trip into London between 7:45 and 9:15am.

The stated choice experiment followed an orthogonal partial factorial design. Table 4 shows the levels of attributes in the design. Each respondent was asked to trade off between combinations of displacement time, crowding level, and fare. The respondents were explicitly told to assume that all other factors such as journey time and frequency would be the same in each time period. There were three versions of questionnaire depending on whether the respondent arrived at: 08:00am (07:45~08:14am); 08:30am (08:15~08:44am); or 09:00am (08:45~09:15am). Figure 2 shows a choice task presented to respondents arriving at 8:00am.

**Table 4: attributer levels used in stated choice experiment of arrival time by train in London**

Displacement Time	Crowding Levels	Fare Levels
60 minutes earlier	Seat 1: seats available - no standing;	As now
30 minutes earlier	Seat 2: a few seats available - a few standing	25% less
Current arrival time	Stand 1: no seats available - standing around doors	50% less
30 minutes later	Stand 2: no seats available - standing around doors and in the aisle	25% more
60 minutes later	Stand 3: no seats available - densely packed.	-

**Figure 2: A choice task in the SP experiment in London (source: Faber Maunsell, 2007)**

D2 If you had the following six options for your journey into Central London, which option would you choose? Please tick one only				
	Arrive	Seating	Fare Level	Choice
A	07:00 am	SEATS AVAILABLE - No Standing	25% Less	<input type="checkbox"/> <sub>1</sub>
B	07:30 am	A FEW SEATS AVAILABLE - A Few Standing	25% Less	<input type="checkbox"/> <sub>2</sub>
C	08:00 am	NO SEATS AVAILABLE - Standing Around Doors and in the Aisle	As Now	<input type="checkbox"/> <sub>3</sub>
D	08:30 am	NO SEATS AVAILABLE - Densely Packed	As Now	<input type="checkbox"/> <sub>4</sub>
E	09:00 am	NO SEATS AVAILABLE - Standing Around Doors	25% Less	<input type="checkbox"/> <sub>5</sub>
F	I would not travel by train if these were the only options			<input type="checkbox"/> <sub>6</sub>

Multinomial logit models were estimated using the SP data. The cost parameter was measured in terms of British pound (£). The ticket cost given by the respondent was converted into an equivalent single ticket cost depending on the type of ticket used. The crowding parameters measured the value in pound per minute of the crowding level compared with the base which was ‘Seat 1: seats available - no standing’. The time displacement variable measured the value per minute of arriving earlier or later than usual. The alternative of ‘I would not travel by train’ was tested in models. However, ‘policy bias’ responses were found, i.e., some respondents reacted to the scenarios with fare increases in an illogical manner by choosing ‘I would not travel by train’ regardless of the relative times and costs of the alternatives presented.

Separate models were estimated based on the overall sample and on sample segments according to reported flexibility in arrival time to examine the effect of flexibility in arrival time on the time displacement and crowding penalties. Table 5 presents a summary of overall costs of travelling at different times and under different conditions.

**Table 5: Valuations of crowding levels and displacement arrival times found in the SP study in London (source: Faber Maunsell, 2007)**

Factor	Levels	Perceived Cost (£ per minute)		
		Overall	Flexible	Inflexible
Crowding	Seat 2: a few seats available - a few standing	£0.01	£0.01	£0.04
	Stand 1: no seats available - standing around doors	£0.13	£0.08	£0.24
	Stand 3: no seats available - densely packed.	£0.17	£0.13	£0.24
Displacement time	Arrive 60 minutes earlier	£0.04	£0.03	£0.11
	Arrive 30 minutes earlier	-£0.06	-£0.04	-£0.13
	Arrive 30 minutes later	£0.13	£0.06	£0.44
	Arrive 60 minutes later	£0.20	£0.11	£0.49

Little difference was found between how respondents valued two crowding levels, ‘Stand 1’ and ‘Stand 2’. The results indicated that respondents would prefer to arrive 30 minutes earlier than their current time, since it had negative costs. This seemingly counter-intuitive finding was supported in the main survey (as introduced in Section 3.2.1) where over a third of respondents stated that they currently arrived up to half an hour later than their preferred arrival time (and would therefore prefer to arrive half an hour earlier). Respondents perceived costs of arriving 30 minutes earlier or later less than arriving 60 minutes earlier or later. People perceived costs of arriving later much more highly than early. The cost increased

where the crowding conditions worsen. Travellers reporting no flexibility generally valued time displacement and crowding much higher than those travellers reporting some flexibility in their arrival time.

### 3.3.2. Stated choice experiment of ‘off-peak train pass’ in the Netherlands

Bakens et al. (2010) presented a study on Dutch train commuters’ willingness to reschedule their trip to off-peak hours when given a positive price incentive. In the summer of 2009, 1,421 commuters selected from Dutch national railway company’s consumer panel, participated in an online survey. The commuters were selected for currently holding a pass for a specific route between 30 and 70 kilometres and had recently commuted on average a minimal of three times a week during morning peak hours (7:00–9:00 am).

The participants were introduced to a proposed ‘off-peak hours pass’ in the SP survey. That pass had the exact same features as the pass those participants were holding, except that it was not valid during a pre-indicated peak period and therefore was cheaper than their current pass (this is similar to the ‘new ticketing’ tested among focus groups in Faber Mausell, 2007). Only when combined with a peak supplement, a one-way specific ticket which travellers could buy on a daily basis, the off-peak hours pass was valid during peak hours. Respondents were asked about their preferences for keeping their current pass or purchasing the off-peak hours pass under different propositions. The propositions differed according to an orthogonal partial factorial design on the discount on the pass, the price (in Euro, €) of the peak supplement, and the length of the peak period during which the off-peak hours pass was not valid (Table 6).

**Table 6: Levels of attributes of the SP study in the Netherlands (source: Bakens et al., 2010)**

Factor Design	1 <sup>st</sup> Class			2 <sup>nd</sup> Class		
Peak surcharge (per day)	€2.5	€6.0	€9.5	€ 1.5	€3.5	€5.5
Discount (per month)	€50	€120	-	30€	€70	-
Length peak period	7:00am-9:00am	7:30am-8:30am	-	7:00am-9:00am	7:30am-8:30am	-

Because of the homogeneity in distance travelled, all respondents were presented with the same attributes that varied only by the class of their pass. All respondents choosing the off-peak hours pass were subsequently required to indicate how they would reschedule their commuting trips over a working week (i.e., number of days before, after, or during the peak). Figure 3 shows a choice screen for the SP experiment, where attributes of the choice set are in bold letters and attributes of the individual respondent are in italic letters.

**Figure 3: Example of choice task of a SP survey in the Netherlands (source: Bakens et al., 2010)**

You usually commute *5 days* a week between *Utrecht and The Hague*. The Dutch railway company offers you the following tickets for these trips:

A. A **monthly** season pass for the route *Utrecht-The Hague* for **€360**.

B. An **off-peak monthly** season pass for the route *Utrecht-The Hague* for **€330**. This pass gives you a discount of **€30** compared with option A, however, you are not allowed to travel with this pass from Monday to Friday between **7:00h-9:00h** unless you buy a peak supplement of **€3.50** per day.

Which pass would you purchase?

A

B

If you choose pass B:

Could you indicate when and how often you would commute during your *5-day working week* now that you have purchased an off-peak *monthly* season pass not valid between **7:00h-9:00h**?:

I would commute ..... days a week before the peak

I would commute ..... days a week after the peak

I would commute ..... days a week during the peak and buy a peak supplement of **€3.50** a piece.

The SP experiment results showed that in 80% of the SP choice situations people chose not to change their current pass. Among the choices to purchase an off-peak hour pass, the majority preferred to reschedule their weekly trips to either all before or all after the peak; only 17% indicated to rescheduling work trips over a week as combinations of before and after peak hours.

To estimate the respondents' current train trip scheduling, an algorithm was employed to match their reported departure and arrival times of their commuting trips over a specific week (i.e. the reference week) to the published train timetables. Reported trips not resulting in a match were excluded from the dataset. In addition, travel and ticket information was gathered, including class, monthly or yearly costs, route specifications, onboard crowdedness and preferences for travelling before or after the peak hours. These data of the respondents' current trip conditions can be taken as revealed preference (RP) data.

Combining the SP and RP data, Bakens et al. (2010) estimated multinomial logit, cross-nested logit, and mixed logit models with three specifications of utility functions. Cross-nested logit models were applied to deal with potential substitution patterns across alternatives (the substitution between scheduling alternatives before peak were supposed to be higher than that between a before-peak and an after-peak alternatives). Mixed logit specifications were to account for possible correlations between repeated choice tasks a respondent faced in a SP survey. The possibility of an alternative mode of travel (such as car) or no travel at all could also be examined because the set-up of the SP experiment allowed for travelling less than five days by rail when choosing the off-peak hour pass; however, this could also be explained as an error by the respondent.

Modelling results showed that all other things being equal, commuters attributed a positive utility to their current travel behaviour, but a group of commuters was willing to travel during off-peak hours when given a positive price incentive; the values (costs) of schedule delay were between €4.20 (earlier than current) and €5.94 (later than current), which supported the idea that commuters tend to have less disutility from arriving early than from arriving late. The researchers did not find a very convincing relation between crowding in train and the choice considerations of commuters for travelling during or off-peak hours. It was suspected that the self-reported onboard crowding might be endogenous.

It seemed that respondents differed much in taste and personal preferences. Bakens et al. (2010) tested for socio-economic and demographic interaction variables on the monetary or time attributes in their models and only found weak effect of income level. The general pattern was that the value of schedule delay early was lower and the value of schedule delay late was higher for respondents with higher income than for those with lower income.

### **3.3.3. Stated choice experiment of arrival time by train in Melbourne, Australia**

According to Webb et al. (2010), the online passenger survey carried out by Metlink in March 2009 included two SP exercises (one for morning peak and one for afternoon peak), which varied (according to fractional factorial designs) time of travel, price, and service attributes to investigate a passenger's trade-offs between city arrival time, fare price, whether an express train service was available, crowding conditions (seated, standing but not cramped, and cramped), and service frequency (every 5, 10, and 15 minutes). Each respondent was presented with eight choice tasks for each peak. Figure 4 shows an example of choice task.

Figure 4: Example of choice task of a SP survey in Melbourne (source: Webb et al., 2010)

The table below is different again from those you have just seen. Again, please contrast the features of the time periods, and indicate in which time period you would generally choose to arrive at Melbourne Central station.

Scenario 3 of 8.

Based on this scenario, please indicate in which time period you would generally choose to arrive at Melbourne Central station.

Time your train arrives at Melbourne Central station in the morning	Price of train ticket, relative to current price	Is there an express train available leaving from Narrewarren?	The expected conditions on the train	The frequency of trains during the time period	Select:
Before 7.00am	Decrease by 60%	Express not available	Standing but not cramped	Every 10 minutes	<input type="radio"/>
7.00am to 7.30am	Decrease by 40%	Express Available	Seats available	Every 10 minutes	<input type="radio"/>
7.30am to 7.45am	Decrease by 40%	Express Available	Standing but not cramped	Every 5 minutes	<input checked="" type="radio"/>
7.45am to 9.00am	Increase by 20%	Express not available	Standing but not cramped	Every 5 minutes	<input type="radio"/>
9.00am to 9.15am	Increase by 20%	Express not available	Seats available	Every 5 minutes	<input type="radio"/>
9.15am to 9.30am	Increase by 10%	Express Available	Standing but not cramped	Every 5 minutes	<input type="radio"/>
After 9.30am	Same Price	Express not available	Cramped	Every 5 minutes	<input type="radio"/>
I would travel by another method of transport					<input type="radio"/>

Type of ticket: Weekly Zone 1 & 2	
	Price
Increase by 20%	\$59.52
Increase by 10%	\$54.56
Current Price	\$49.60
Decrease by 20%	\$39.68
Decrease by 40%	\$29.76
Decrease by 60%	\$19.84
Decrease by 80%	\$9.92
Decrease by 100%	\$0.00

PREVIOUS    NEXT

Progress

Respondents were also able to opt out of the options provided and select 'I would travel by another method of transport'. This provided the ability to measure under what conditions customers would abandon the train network in favour of travelling by another mode or not travelling at all. To help respondents understand the dollar savings of percentage discounts or increments, a reference table was provided with each choice task showing the price of the ticket they currently purchase and the value of each discount and increment.

Discrete choice modelling based on the SP data suggested that a 10% price increase during the high-peak (7:45-9:00am) would shift 7% of passengers out of the high-peak. A 20% price increase would result in a 13% decrease in high-peak travel. Similar results were also found for the afternoon-peak, with a price increase of 10% moving 8% of passengers and a price increase of 20% moving 13% of passengers.

Price decreases during non-high-peak time bands had a similar impact on shifting peak demand as price increases during the peak. Reducing non-high-peak prices by 10% would shift 6% of passengers out of the high-peak. A decrease of 40% would move 19% of passengers out of the high-peak. Results for the afternoon peak showed a similar pattern of travel behaviour, with a 10% decrease in non-high-peak prices shifting 7% of passengers out of the afternoon peak.

Passengers tended to move to the closest time bands, like peak shoulders, where the discounts were available, thus minimising changes to their travel routines. Under the same percentage of fare increase, considerably higher percentage of respondents chose to use a different mode or not travel at all in the morning-peak than in the afternoon peak. This might

reflect that passengers felt there were more options available to them in returning home at the end of a work day (such as lifts with colleagues/friends) than in the morning.

That study also found that the impact of price discounts varied by station grouping, whether a passenger travelled from inner, overlap or outer-stations. Passengers travelling from outer-stations were the most sensitive to price changes. Webb et al. (2010) argued that this might reflect that those passengers paid a higher price for travel (and thus, a per cent discount represented a greater dollar value) and/or that these suburbs might have a higher proportion of first home buyers and families suffering a degree of ‘mortgage stress’ which might lead to greater price sensitivity in travel choices.

Combined with price, the impacts of service frequency, crowding, and stopping patterns were also tested. Availability of express and price had the greatest potential to reduce peak demand by improving the relative service levels offered in ‘shoulder’ and ‘off-peak’ time bands, particularly for passengers travelling from outer-stations. Service frequency did not appear to greatly influence passengers’ choices of time of travel. Availability of seats had a greater impact than service frequency on peak demand, especially during the afternoon peak.

### 3.3.4. Stated choice experiment of departure time by train in Sydney, Australia

Douglas et al. (2011) presented a SP experiment as part of a passenger survey carried out during August to December in 2010 across Sydney metropolitan rail network. The survey interviewed 1,119 passengers over off-peak and peak periods. The analysis by Douglas et al. only included data from 786 passengers interviewed in peak periods. Interviewers presented passengers with a series of paired SP choice options and asked passengers which train service they would use out of each pair. The train services varied in terms of departure time, time spent on train, and fare. Figure 5 shows a choice game, by which passengers are effectively asked whether they would be willing to pay \$4 more to avoid a ten minutes longer trip that departs 40 minutes earlier.

Figure 5: Example of choice task of a SP survey in Sydney (source: Douglas et al., 2011)

10	A	B
Depart	Earlier 40 mins than now	as now
On train	10 mins Longer	as now
Fare	as now	Single \$4 Weekly \$44 Conc \$2

Fifty pairs of options were designed to give a statistically controlled experimental design. Each respondent was required to complete a set of eight or nine choices. Five fare levels were included in the experimental design, three levels of a surcharge of \$2, \$3, or \$5 and two levels of a discount of \$2 or \$3. Twenty-five choices featured departing later by 15, 20, 30, 40, or 60 minutes and 25 choices departing earlier. Onboard time varied around the current time with Train B either 5 or 15 minutes faster than now or 10 or 15 minutes quicker.

The findings showed that travelling later than desired had a greater displacement cost than travelling earlier. Passengers were more averse to travelling later than earlier. Travel time displacement was valued lower than onboard train time. Late displacement was valued 93% of onboard time and early displacement, 53%. Averaging the early and late values gave a relative value of displacement of 0.73 of onboard time.

Passengers were less willing to pay more to save time than they were to accept a fare discount for a longer travel time. Passengers were also more sensitive to a fare surcharge than to a discount which resulted in an asymmetry in the value of time. Onboard train time was valued much higher relative to a fare discount than to a surcharge. The value of time was estimated as \$33.80 which was 2.5 times higher than the surcharge value of \$13.56 per hour. The surcharge value was reasonably close to the value of travel time saving (\$12.85 per hour) for Sydney rail passengers in 2010.

Four monetary values of displacement time were derived for the four types of time displacement: discount-early, discount-late, surcharge-early, and surcharge-late. The values were calculated by multiplying the value of onboard time (discount or surcharge) by the value of displacement (early or late). The highest value was the discount value of late displacement, with passengers requiring a fare discount of \$31.43 to travel an hour later. The lowest was the surcharge value of early displacement, with passengers willing to pay \$7.19 to avoid travelling an hour earlier. The other two values were a discount value (\$17.91 per hour) of early displacement and a surcharge value (\$12.61 per hour) of late displacement.

### **3.4. Simulations of peak spreading based on trip scheduling models**

This paper reviewed three studies on simulating the effect of differential fare on peak spreading in the context of urban rail transit. The core of all these simulation models is based on disaggregate choice models of a passenger's travel behaviour. However, they have different assumptions, particularly on two points, the impact of onboard crowding and the response of overall patronage.

#### **3.4.1. PRAISE model in North England, UK**

Whelan & Johnson (2004) redeveloped the Privatised Rail Services (PRAISE) rail operations model to include penalties for overcrowding. The PRAISE model is capable of assessing demand and costs for small networks of stations incorporating the services of up to five operators, each with ten different ticket types. It comprises a demand model, a cost model, and an evaluation model. It was the demand model that was of particular interest to the study by Whelan & Johnson on the demand impacts of differential fare.

The demand model has a bi-level structure and works at the level of the individual traveller. At the lower level, there is a multinomial logit model of a passenger's choice from a number of combinations of different services and ticket types, based on their generalised costs. The generalised cost of each option is composed of the return fare, a crowding penalty, and the value of generalised journey time, which is a function of in-vehicle time, an interchange penalty as time, out of vehicle time, and schedule adjustment time (i.e., the difference between a passenger's desired departure time and the actual time timetabled departure time). When selecting a service on which to travel, a passenger is assumed to select trains from a given time frame around his most desired departure time. The model uses a one-hour window of opportunity to travel in which individuals are prepared to consider alternative options. Opportunities outside this window would have much higher generalised costs (based on a non-linear function of schedule adjustment time) and thus lower probabilities. The upper level of the model is concerned with mode choice and therefore the overall size of the rail market of interest. This mode choice is modelled by an incremental logit model based on the overall attractiveness of rail services relative to other modes and not travelling at all.

The choice modelling hierarchy is repeated for a sample of individuals drawn from known desired departure time profiles. The market share for each option of service and ticket type is taken as the average probability for each option over all individuals in the sample. By assessing the outward and return portions of a journey, together with information on ticketing restrictions (such as departure time, advanced purchase, transferability between operators), the model is able to forecast ticket revenue by operator.

Whelan & Johnson applied the PRAISE model to a line between two regional rail stations in the North of England. Passenger preferences including value of time, value of schedule adjustment time, and crowding penalties were set to be equal to those recommended in the UK Passenger Demand Forecasting Handbook (ATOC, 2002, as cited in Whelan & Johnson, 2004) and the generalised journey time elasticities and desired departure time profiles taken to be equal to those used in the commonly used MOIRA rail demand model in UK (AEAT, 2002, as cited in Whelan & Johnson, 2004).

Scenario simulation was performed to examine how peak/off-peak differential fare should be set to spread demand throughout the day without significantly reducing the overall demand for rail travel. Key findings were as follows:

- Increasing peak fare by 10% reduced peak loading ratio (loads to seat capacity) from 130% to 126%. 30% peak surcharge reduced peak loading ratio from 130% to 119%;
- Discounting off-peak fares by 10% to 30% generated small reductions in peak load ratio. Passenger benefited from fare reduction, but at the cost of operator viability.

Whelan & Johnson concluded that substantial reductions of peak train overcrowding could be achieved by increasing fare differentials between peak and off-peak travel. They argued that it was more efficient to price passengers out of the peak period (i.e., increasing the fare during peak period) than to entice them away by reducing the off-peak fare; and revenue neutral solutions could be obtained using a combination of fare increases in the peak and fare reductions in the off-peak.

### **3.4.2. Equilibrium train assignment model in London, UK**

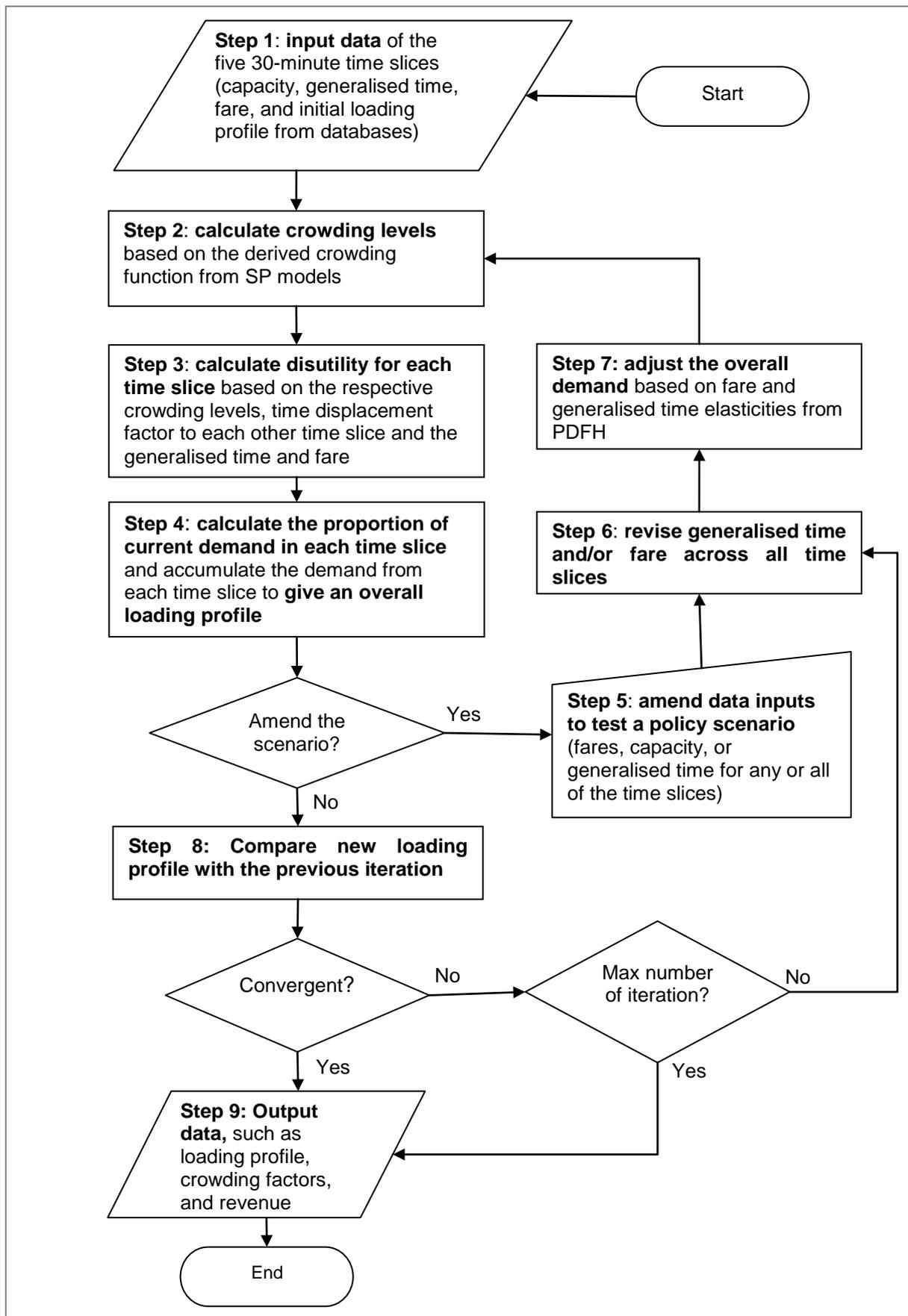
Faber Maunsell (2007) developed a temporal assignment model for trains to investigate the effect of differential fare on peak spreading for London-Birmingham rail transit corridor. The basic premise behind this model is that travellers make decisions as to their time of travel based on the following factors: required arrival time at destination and degree of flexibility; available rail services for the journey in each time period in terms of expected journey time and frequency; fare for travel in each time period; and level of crowding experienced in each time period.

This simulation model splits morning peak (from 7:00am to 9:30am) into five 30-minute time slices, as the SP choice models introduced in Section 3.3.1. Choice among the five time slices is then modelled based on their levels on loadings, capacity, generalised time, and fare. This model can handle multiple service groups and collate together the results of the various service groups into a corridor summary.

Assuming crowding as an important factor in choice of scheduled train (i.e., time of travel), this model therefore has a built-in iterative procedure to reflect how changes in demand or capacity in any one time slice will change its relative disutility due to changes in crowding effects and the subsequent impact on time slice choice. In essence, an equilibrium position is sought where travellers are optimally distributed across the time slices such that they could not improve their disutility by moving to an alternative time period.

The initial actual loading profile is assumed to represent an equilibrium state thus is used to calibrate the scaling parameters of individual time slices and as the starting point for an incremental application of the model in policy testing. Demand elasticities of generalised time and fare are also used to model trip generation and suppression effects of test policy scenarios. The default elasticity values are derived from UK Passenger Demand Forecasting Handbook (ATOC, 2002, as cited in Faber Maunsell, 2007). Elasticity values for different user types are weighted by the proportion of each user type in the peak period market. Figure 6 shows the model structure.

Figure 6: Structure of the simulation model as described in Faber Maunsell (2007)



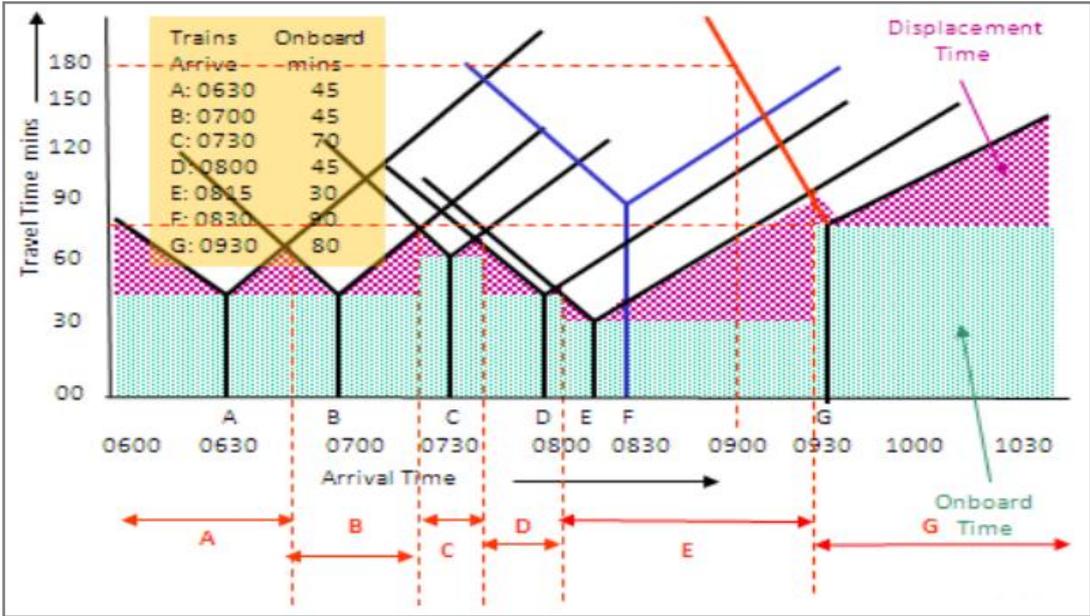
The primary objective of the simulation by Faber Maunsell (2007) was to understand how fare policy could be used as a mechanism to manage rail peak period demand and maximise utilisation of available capacity. The simulation model was used to test a set of fares policy proposals aimed at spreading peak load while minimising impacts on overall rail revenue and average fare. The main results found in these simulations are summarised as follows:

- Many current corridors did not have much spare capacity in the peak period as a whole and as such spreading demand across the peak to take advantage of spare capacity was limited by the lack of spare capacity;
- Fare reductions needed to be large in percentage terms for many corridors due to the relatively low base fares compared to the crowding and time displacement penalties;
- Future year growth would be constrained by capacity limitations as tests had shown that in the future around a third of the underlying demand for rail growth would be suppressed without capacity increases;
- Fare reductions could enable the underlying growth to be accommodated but generally with a resultant loss in revenue. This was achieved by better utilisation of the shoulder of peak;
- Peak period surcharges lead to revenue gain overall but suppress ridership;
- Combinations of peak surcharge, off-peak/peak shoulders discounts, and selective capacity increases could lead to revenue neutral effects while meeting overall passenger demand growth.

**3.4.3. ‘Rooftops’ model in Sydney, Australia**

Douglas et al. (2011) applied the ‘rooftops’ approach, which originated from theoretical work in spatial economics, to model rail passenger choice of scheduled service by ‘temporal catchments’ for trains. Douglas et al. extended the rooftops approach to include fare via values of time so as to study the effect of differential fare such as off-peak discounts and peak surcharges on loading level. The technique is named ‘roof-tops’ because the train choice graph looks like streets of rooftops (Figure 7 shows seven trains: Train A arrives at 06:30am, train B at 07:00am, train C at 07:30am, and so on).

**Figure 7: ‘Rooftops’ train choice graph (source: Douglas et al., 2011)**



The basic rooftops approach compares travel times of different train services to passengers wanting to travel at different times. The vertical axis shows the total travel time which comprises two elements: (1) the time spent on the train and (2) the displacement time, i.e., the difference between when passengers want to arrive and when the timetable allows them to arrive. Passenger's desired arrival time and scheduled train arrival time are measured on the horizontal axis as well. Both vertical and horizontal axes have the same scale. For example, in Figure 7, train E, is an express train taking 30 minutes; there are three limited-stop trains A, B, and D that take 45 minutes; there is also a slower limited-stop train C taking 70 minutes and two all-stop services F and G that take 90 and 80 minutes respectively.

Displacement is shown as the sloping lines that fork in opposite directions from a scheduled train arrival time. The left hand line from each train's arrival time measures late displacement time; the right hand line measures early displacement time. The displacement line at 45 degrees for train A in Figure 7 implies that one minute of displacement is valued equal to a minute of onboard train time. Steeper slopes would weight displacement time more heavily and flatter slopes would weight displacement time relatively less than onboard train time. In essence, the train service offering the lowest total or generalised time (on-board plus displacement) is chosen and this depends on when passenger wants to arrive. Where the displacement slopes for two train services intersect, the two trains have the same generalised time. The intersection points are referred to as thresholds, which are the 'watershed' of adjacent trains' catchments (indicated by the red lines on the horizontal axis in Figure 7). Train F is a slow train and by taking 90 minutes fails to capture any trips since passengers would be better off travelling earlier on train E or later on train G.

Train passenger loads can be calculated by assigning passengers to trains based on their desired travel time profile and trains' temporal catchments. This technique was successful in explaining and predicting passenger choice particularly for irregular services and became the basis for modelling intercity train timetables in UK Passenger Demand Forecasting Handbook (ATOC, 2002, as cited in Douglas et al., 2010). As pointed out by Douglas et al., past rooftops applications had focussed on travel time and frequency, whereas including fare was not difficult requiring 'values of time' to convert fare into minutes. The generalised time was extended to assess the effect of fare discounts on early and late trains and surcharges on peak hour trains. To assess a fare discount, the equivalent travel time reduction was calculated and subtracted from the onboard time of 'valid' services. For a fare surcharge, the equivalent travel time was added. Thus, catchments should widen for trains offering discounts and narrow for trains offering surcharges.

Instead of all-or-nothing (or deterministic) assignment, Douglas et al. (2011) employed a probabilistic assignment approach, whose core was a multinomial logit choice model calculating the chance of a passenger choosing a train based on the relative generalised time to other trains. It needs to be noted that first, this rooftop model assumed that total rail patronage would not be affected, i.e., the fare discounts and surcharges would not generate or suppress rail patronage; second, the train choice model did not consider the impact of onboard crowding thus no integrative assignment procedure was involved.

A busy line with the highest morning peak passenger loading across Sydney rail network was used by Douglas et al. for a case study. Passenger travel time profiles (one for adults, one for school children) were developed based on barrier exit data to describe when passengers want to travel. It is worth noting that barrier data is only a 'proxy profile' for the ideal travel time of passengers. The valuation of displacement times was estimated using SP technique, as introduced in Section 3.3.4. The rooftops model was calibrated using data from passenger count surveys. The calibrated rooftops model was used to predict the effectiveness of fare discounts and fare surcharges (where school children's fare was kept unaffected) in spreading passenger loads across the morning peak. Simulation results of differential fare scenarios suggested that fare discounts on early and late peak trains would be less effective than surcharges imposed on peak hour trains. The spreading of peak loads was maximised when discounts and surcharges were introduced in combination. With a 30% discount

offered on early and late peak trains and a 30% surcharge imposed on peak hour trains, peak hour loads were forecast to reduce by just over 10%.

### 3.5. Real-world cases of peak spreading using differential fare

#### 3.5.1. Discounted and free off-peak transit in the US

McCullom & Pratt (2004) presented some early cases of free or discounted off-peak transit in the US, where the provision of free transit service was tested in a number of federally funded demonstrations in the 1970s. A majority of the free transit services involved bus operations in central business districts and universities. However, many transit systems later abandoned thoughts of offering free service due to tight funding. Table 7 shows some early cases in terms of before and after percentages of total ridership occurring in peak and off-peak periods. The lesser percentages in the ‘after’ conditions indicate that reduction in off-peak fares did enhance off-peak usage ‘relative’ to peak riding, though the ‘absolute’ changes of peak ridership were not reported.

**Table 7: Peak ridership as a percent of daily ridership before and after reduction of off-peak fares (McCullom & Pratt, 2004)**

City	Peak/Off-Peak Fare (US Cent)		Peak Ridership (%)		Source (as cited in McCullom & Pratt, 2004)
	Before	After	Before	After	
Denver <sup>a</sup>	35/25	50/free	50 <sup>b</sup>	30	De Leuw, Cather and Company (1979a)
Louisville	50/50	50/25	45	33	Pratt & Copple (1981)
Lowell	25/25	25/10	76	73	Mass Transportation Commission (1964)
Trenton <sup>a, c</sup>	30/15	30/free	68 <sup>d</sup>	55	De Leuw, Cather and Company (1979b)

Notes: a) off-peak free fare demonstration; b) assumed before ratio; c) includes evening service d) estimated before ratio.

The studies of free fare demonstrations during off-peak periods in Denver and Trenton (as presented in Table 7) showed distinct differences in the percentage of new off-peak rides that were diverted from automobile: 46% of the Denver new off-peak rides and 16% of the Trenton new off-peak rides. McCullom & Pratt (2004) noted that this was quite likely due to the socio-economic and structural differences between the two cities: Denver, a new, western city with a diverse economy; Trenton, an old eastern city with a historically industrial base. The full range of prior mode findings is displayed in Table 8. ‘Trips Not Made’ here may reflect either changes in trip destination or in trip frequency, with trip frequency in this case not referring to transit travel per se, but rather to travel by any mode.

**Table 8: Prior mode for new trips in off-peak fare-free demonstrations (McCullom & Pratt, 2004)**

Location	Prior Mode (%)				Source (as cited in McCullom & Pratt, 2004)
	Auto	Walk	Other	Trip not made	
Denver	46	-	22	32	De Leuw, Cather and Company (1979a)
Trenton	16	23	16	45	De Leuw, Cather and Company (1979b)

Data for the off-peak free fare demonstrations in Table 7 were also used by Mayworm et al. (1980, as cited in McCullom & Pratt, 2004) to estimate cross-elasticities of peak demand with respect to off-peak fares (i.e., relative change in peak ridership compared to relative change in off-peak fares). Cross-elasticity values of 0.14 and 0.03 were estimated for Denver and

Trenton, respectively. These low values suggested that most riders in peak periods were travelling to work and had limited flexibility in work starting times and were thus unlikely to shift to travelling in the off-peak (McCollom & Pratt, 2004).

However, McCollom & Pratt (2004) found that a modest shift of elderly riders from the peak to off-peak typically occurs, when reduced fares are offered to the elderly only in off-peak periods. In Pittsburgh, a 45% off-peak fare reduction for the elderly increased off-peak senior citizen riding by an estimated 51%, and decreased peak riding by 19% (Roszner & Hoel, 1971, as cited in McCollom & Pratt, 2004). In Milwaukee, 14% of elderly passengers switched from peak to off-peak riding (Dygert et al., 1977, as cited in McCollom & Pratt, 2004), and in Los Angeles, about 10% shifted (Caruolo & Roess, 1974, as cited in McCollom & Pratt, 2004). The data for the Pittsburgh and Los Angeles senior citizen fare changes were also utilised by Mayworm et al. (1980, as cited in McCollom & Pratt, 2004) to estimate cross-elasticities of peak demand by the elderly with respect to off-peak fares of 0.38 and 0.26, respectively. These cross-elasticities are higher than those calculated for general transit riders in the Denver and Trenton free fare demonstrations, but still suggest that a substantial number of elderly riders in peak periods are unwilling or unable to change their time of travel.

### **3.5.2. 'Early bird free ticket' in Melbourne, Australia**

Melbourne, Australia, like many large cities around the world, experiences significant peak overloading on its public transport. In March 2008, 'early bird free ticket' was introduced to Melbourne metropolitan rail network, which provided free travel to passengers arriving at their destination before 7am on a weekday. Early bird tickets were initially only sold at approximately 30% of all stations where staff members sold tickets. The aim of the program was explicitly set to encourage peak time rail passengers to shift their travel to earlier trains, thus relieving overcrowding pressure (Currie, 2010a).

As reported by Currie (2010a), in September 2008, an intercept survey of 901 rail passengers was undertaken on platforms at selected stations among travellers finishing their trips before 7:00am. The survey had the following findings:

- 23% of early bird ticket holders had shifted trips from the peak to pre-peak times;
- The average time shift was 42 minutes, with a range from 5 to 120 minutes;
- In general, more longer-distance passengers (25%, using Zone 1-2 tickets) made a time shift than shorter-distance passenger (14%, using Zone 1 only tickets);
- 77% of early bird ticket holders had not shifted their time of travel. Among them, 67% had always travelled at this time and another 10% were new passengers. These new passengers could be encouraged by the free fare to start using public transport. However, as noted by Currie, rail patronage had been rising generally, with an increase of 11.8% in 2008 compared with the previous year. Hence, much of this growth might be explained by the background growth.

Currie (2010a) reported the results of the passenger survey's question on reasons for using or not using early bird tickets. Saving money (66%) dominated the reasons for use; however, a small number (13%) also liked using less crowded trains. A mix of reasons for not using the ticket was given. Only approximately 36% suggested that the time was too early (e.g., there was no point arriving early or could not get up that early). Some 23% already had tickets (periodicals or seniors tickets), so they might use early bird later when they renew their tickets. Access to tickets was highlighted by 20% (having to buy another ticket and the station did not sell early bird tickets). Approximately 20% did not know about the ticket despite a reasonable amount of media coverage and promotion. A high share of other reasons was also given (20%), including those who had travel paid by employers, those finding it not convenient, and those being delayed on the day by unexpected events such as sleeping in and bad traffic.

Regarding the early bird free ride program in Melbourne, Currie (2010b) examined two likely seasonal effects on retiming trips to before morning peak, which were suggested by focus groups in London (see Passenger Focus, 2006a) targeting rail commuters who might have the flexibility to retime commuting trips to other time periods:

- 'Medium term growth effect' - there may be time lag effects whereby passengers have to adjust life activities to enable an earlier commute time; therefore, adjustments to pre-peak travel might be larger in the medium-long term than the short term. As stated by Currie (2010b), analysis of early bird ticket usage endorsed this hypothesis because the proportion of all ridership using early bird ticket was increasing by about 1.7% p.a. for the equivalent period of July-November between 2008 and 2009.
- 'Winter dark morning effect' - passengers would be less willing to travel earlier in the dark winter months. According to Currie (2010b), there was not much monthly variation in the share of early bird users (around +/- 5%) and no overall link between darker winter months and lower usage was found. Darker mornings were less of an issue in Melbourne with lighter and milder winter mornings than in London.

Currie (2010a) raised two significant questions in assessing the early bird ticket program: 1) is it effective in reducing peak train loads? 2) is it worth the costs associated with it? Currie made the following conclusions regarding this assessment of the impact of the program on reducing peak overcrowding:

- The early bird program was estimated to have encouraged between 2,000 and 2,600 passengers to shift from the peak to pre-peak travel. This shift had reduced demand in the peak by between 1.2% and 1.5% from previous levels and was the equivalent of between 2.5 and five peak trains or 1.5% to 3% of total peak trains.
- However, the demand growth during the study period would have far outweighed the peak speeding effect. Overloading, passenger discomfort, and views on service delivery all declined after the early bird program was introduced. The early bird program reduced the 'scale' of increased overloading, rather than a net reduction.
- Overall it was unclear to what degree the early bird program has acted to reduce overloading problems because, in practice, rising demand had increased the problem. It was clear that this program had more impact in reducing peak travel in the less critical 7:00 to 8:00am peak hour, although this might still be beneficial. Its impact in the critical 8:00 to 9:00am peak hour was less but could still be helpful.

Currie (2010a) compared the distributions of average train loadings on the network by rolling hour over morning peak between October 2007 (before early bird) and October 2008 (after early bird). These loadings were taken at the peak maximum loading point just as trains entered the city. Overall, this comparison supported the view that the early bird ticket had acted to increase ridership before 7:00 a.m. Train loads during the peak had been reduced by the early bird program; however, the dominant shifts in behaviour seemed to be towards earlier peak travel from later peak travel and early bird was unlikely to have been a major influence in this trend.

Currie (2010a; 2010b) provided financial assessment of the early bird program. It was suggested that the program ameliorated at least part of the need to buy new peak trains to cater for overloading problems. The lowest short term estimate of peak trains saved is 2.5 while the highest is 5.0, depending on the assumptions on demand shifted and train loading level. However there is clear evidence of growth in early bird ticket usage. Assuming the share of time shifting passenger remains constant then a low estimate of peak trains saved in 2014 would be 2.8 and a high 5.5. The current capital cost of a new train set is \$20 million and the average annual operating costs of a peak train is at least \$1 million per annum. Fleet savings of this scale are considerable however increased ticket usage will increase the scale of the revenue loss from free fares. The financial costs of the early bird free travel scheme

are the reduced fares, which are approximately \$6 million per annum, with a present value (6% discount rate) over a standard evaluation period of 30 years of \$89 million. Table 9 presents a financial analysis of the program with low and high peak train impacts for a no growth and an average growth scenario for the share of early bird tickets.

**Table 9: Financial assessment of the ‘early bird program’ in Melbourne (source: Currie, 2010b)**

		Net Present Value <sup>a</sup>		Notes
		Low Peak Impact <sup>b</sup>	High Peak Impact <sup>c</sup>	
<b>No Early Bird Ticket Growth</b>				
<b>Program Cost</b>				
Foregone Fare Revenue	\$89M	\$89M	\$6M p.a. in foregone revenue	
<b>Program Benefits</b>				
Reduced Annual Operating Costs	-\$37M	-\$74M	\$1M p.a. reduced operating cost per peak train saved. Low is 2.5 trains; high is 5	
Capital cost Savings	-\$50M	-\$100M	\$20M saving per peak train saved	
Sub-Total	-87M	-\$174M		
<b>Performance</b>				
Net Present Value	-\$2M	+85M		
Benefit Cost Ratio	0.98	1.96		
<b>Average Early Bird Ticket Growth</b>				
<b>Program Cost</b>				
Foregone Fare Revenue	\$107M	\$107M	\$6M p.a. in foregone revenue in 2008 increasing by 1.7% p.a. over 30 years	
<b>Program Benefits</b>				
Reduced Annual Operating Costs	-\$46M	-\$88M	\$1M p.a. reduced operating cost per peak train saved. Low 2.5 trains increasing to 4.4 trains, high 5.0 trains increasing to 8.05, from year 1 to year 30.	
Capital cost Savings	-\$66M	-\$127M	\$20M saving per peak train saved. Marginal savings in capital are applied each year as saved trains increase	
Sub-Total	-111M	-\$214M		
<b>Performance</b>				
Net Present Value	+\$4M	+107M		
Benefit Cost Ratio	1.04	2.0		

Notes: a) discount rate 6%, 30 years, Australian Dollars, \$; b) 2,000 passengers initially time shift from peak – overloading standard of 800 applied to estimate peak train savings; c) 2,500 passengers initially time shift from peak – average load standard of 524 applied to estimate peak train savings.

According to Currie (2010b), overall the financial analysis suggests that savings in peak train capital and operating costs broadly cover lost free fare revenues in financial terms. Without growth in early bird ticket the lowest estimate of peak train savings suggests the cost of lost revenue is almost covered (0.98) by savings in peak train costs. The higher estimate of

impacts on peak trains increases savings considerably; a 1.96 benefit cost ratio (BCR) is achieved in financial terms. The growth in early bird ticket scenario doesn't change this picture much. Although foregone revenues increase (from \$ 6million p.a. in year 1 to \$10 million in year 30, in real 2008 terms) increases in peak train savings keep pace with this. Overall growth in early bird usage slightly improves the net financial benefit but not much. The low peak impact scenario has a BCR of 1.04 while the high 2.0. Since a range of wider economic (rather than financial) benefits might also apply as a result of reducing peak travel (e.g. peak road user travel time benefits and environmental relief) it seems reasonable to assume an economic assessment of the program would be positive even for a low peak demand impact scenario.

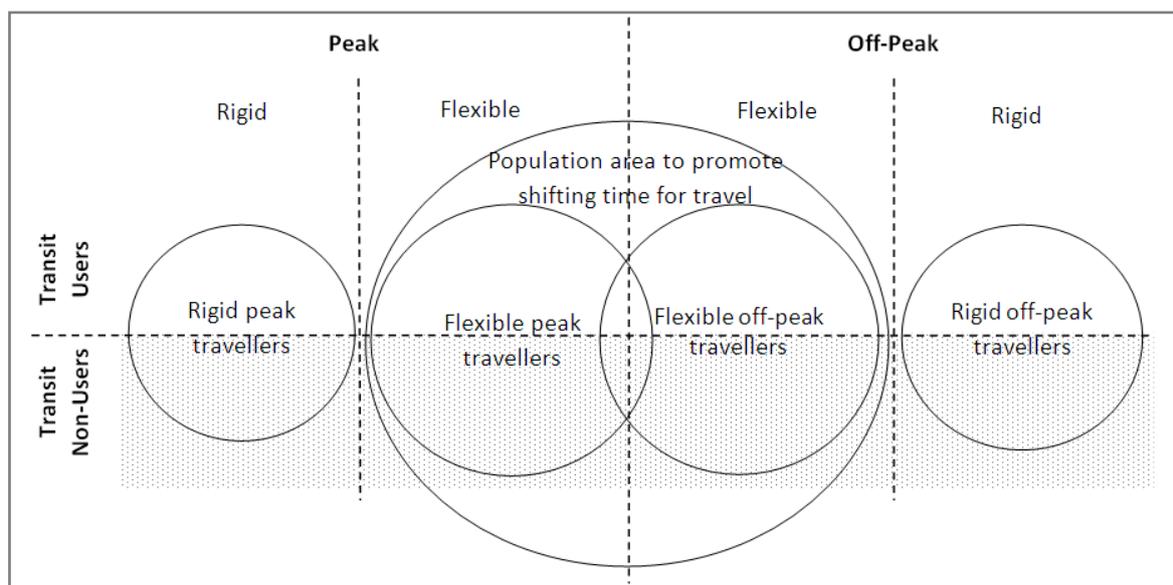
Moreover, Currie (2010a; 2010b) pointed out another perspective on the value of early bird ticket program, i.e., it is the only 'quick' way of dealing with peak overloading. In this context, no other alternative means of addressing overloading was possible within the timeframe available. Where line capacity is available, procuring new trains would have taken 3 to 5 years; where line capacity is not available, provision of new lines would have taken approximately a decade or more.

## 4. Advice to Policy Prescription

### 4.1. Flexibility or rigidity in time for travel

To be willing to re-schedule his/her trip, a traveller must have the flexibility in choosing time for travel. In reality, many travelers don't have this time flexibility due to work and family commitments and have to travel during certain time periods. Therefore, it is illogic to include these time rigid travellers in departure/arrival time choice models, since they have no choice. Transit market can be segmented by traveller's rigidity/flexibility in time for travel (Figure 8). This segmentation is comparable to the mode captivity issue in mode choice modeling. For example, a traveller can be car captive because there is no public transport available; or, s/he can be transit captive due to no access to a car. The original mode captivity version of Figure 8 was put forward by Krizek & El-Geneidy (2007).

**Figure 8: Transit market segmentation by travel time flexibility**



Beimborn et al. (2004) noted that the existence of mode captivity constrains the variation of mode split. They modified mode choice models between car and transit by adding mode captivity factors representing the probabilities of a traveller being transit and car captives. Given the dependencies on car and transit, a traveller's transit ridership can be estimated by Equation 1:

$$Pr(T) = Pr(TCaptive) + Pr(TChoice) * [1 - Pr(ACaptive) - Pr(TCaptive)] \quad (1)$$

where,

$Pr(T)$  = probability of selecting transit compared with car;

$Pr(TCaptive)$  = probability of user being a transit captive;

$Pr(ACaptive)$  = probability of user being an automobile captive; and

$Pr(TChoice)$  = probability of user choosing transit, as a mode choice user.

The same logic applies to time choice modelling. A time choice model applied to a population including time rigid travellers will overestimate the variation of choices between peak and off-peak (Figure 9). Therefore, time rigidities can be added into the model of choosing to travel in off-peak period, as shown in Equation 2:

$$Pr(O) = Pr(ORigid) + Pr(OFlexi) * [1 - Pr(PRigid) - Pr(ORigid)] \quad (2)$$

where,

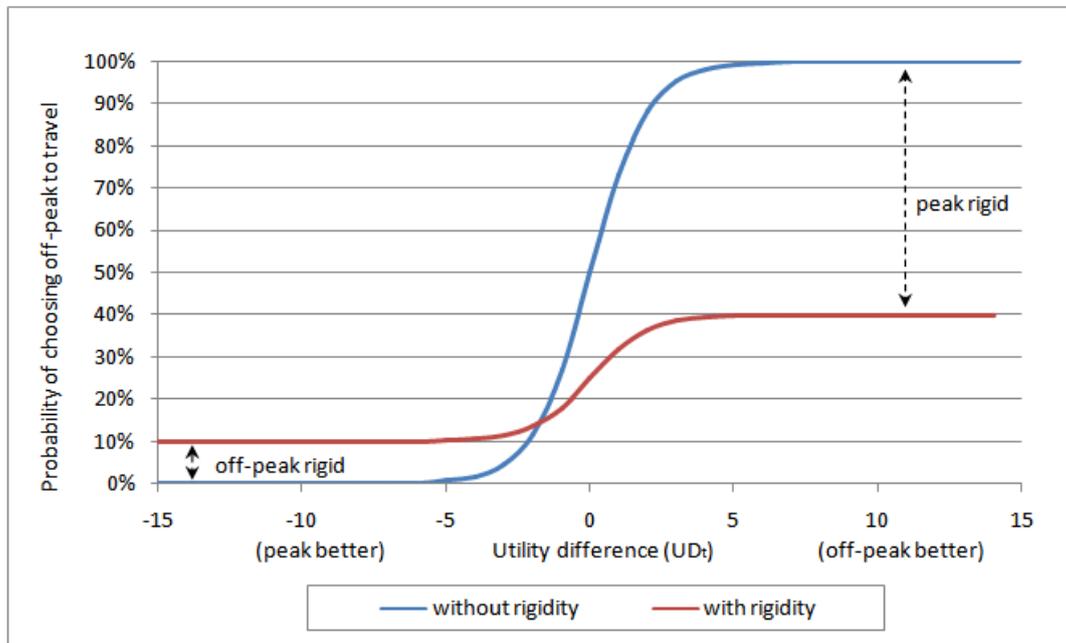
$Pr(O)$  = probability of selecting to travel in off-peak compared with peak;

$Pr(ORigid)$  = probability of user being a rigid off-peak traveller;

$Pr(PRigid)$  = probability of user being a rigid peak traveller; and

$Pr(OFlexi)$  = probability of user choosing to travel in off-peak, as a traveller being flexible in time for travel.

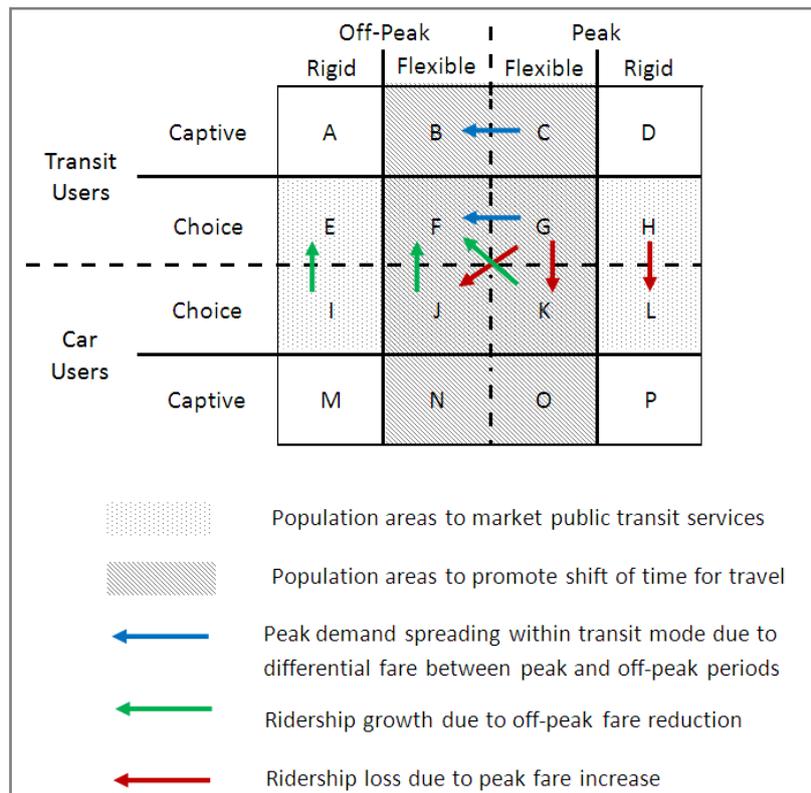
**Figure 9: Choice of time for travel with and without travel time rigidity (assuming 10% chance of being rigid in off-peak and 60% in peak)**



## 4.2. Mode shifting and peak spreading

Peak fare surcharge could drive some peak transit users to shift to private cars rather than to off-peak or peak shoulders, which would be counter-productive for fare revenue and for broader sustainability objectives. Therefore, a fare differentiation policy should be assessed by its impacts on both mode shifting and peak spreading. Considering mode captivity and time rigidity, Figure 10 visualises a conceptual segmentation of travellers with choices between off-peak vs. peak and between transit vs. car.

**Figure 10: Segmentation of transit users by time-for-travel rigidity and mode captivity**



In Figure 10, solid boundaries indicate clear segmentations; while dashed boundaries mean obscure ones. Thus, demand can only shift across the dashed lines. For example, a traveller can only be either mode captive or mode choice; however, a flexible off-peak traveller can sometimes travel during peak. Population areas to market public transit services include both choice transit and choice car users (i.e., Segments E, F, G, H, I, J, K, and L). Among them, choice car users are potential transit users (i.e., Segments I, J, K, and L), as noted by Krizek & El-Geneidy (2007). Similarly, population areas to promote peak spreading include both flexible off-peak and flexible peak travellers (i.e., Segments B, F, J, N, C, G, K, and O). Flexible peak travellers (i.e., Segments C, G, K, and O) are potential off-peak travellers.

The coloured arrows in Figure 10 indicate the potential impacts of peak/off-peak differential fare on transit peak spreading and mode shifting, Increasing peak fare could encourage travel time shifts within transit mode (blue arrows) from C to B and from G to F, as well as ridership loss (red arrows) from H to L, from G to K, and from G to J. Reducing off-peak fare could also result in travel time shifts within transit mode (blue arrows) from C to B and from G to F, plus ridership growth (green arrows) from I to E, from J to F, and from K to F.

For a transit agency, the preferred results of differential fare for peak spreading is to achieve demand shifts represented by the blue arrows and ideally also the green arrows but to avoid the red arrows in Figure 10. By introducing peak surcharge and off-peak discount within the same time frame, a transit agency can expect to double the effects of peak spreading within transit mode but also needs to trade off between potential ridership loss and ridership growth. According to the market segmentation in Figure 10, off-peak transit market share (i.e., Segments A, B, E, and F) can be estimated by Equation 3:

$$Pr(OT) = Pr(A) + Pr(B) + Pr(E) + Pr(F) \tag{3}$$

where,

$Pr(OT)$  = probability of selecting off-peak travel by transit;

$Pr(A) = Pr(ORigid) * Pr(TCaptive)$ , probability of user being a rigid off-peak and captive transit user;

$Pr(B) = Pr(OFlexi) * Pr(TCaptive) * [1 - Pr(PRigid) - Pr(ORigid)]$ , probability of user being a flexible off-peak and captive transit user;

$Pr(E) = Pr(TChoice) * Pr(ORigid) * [1 - Pr(ACaptive) - Pr(TCaptive)]$ , probability of user being a rigid off-peak and choice transit user; and

$Pr(F) = Pr(OFlexi) * Pr(TChoice) * [1 - Pr(PRigid) - Pr(ORigid)] * [1 - Pr(ACaptive) - Pr(TCaptive)]$ , probability of user being a flexible off-peak and choice transit user.

When mode captivities and time rigidities are zero, Equation 3 collapses down to Equation 4:

$$Pr(OT) = Pr(TChoice) * Pr(OFlexi) \quad (4)$$

The existence of mode captivity and/or time rigidity can significantly constrain demand's sensitivity to policy changes such as peak/off-peak differential fare.

### 4.3. Requirements for transit service provision

The spare capacity in off-peak or peak shoulders is critical for peak spreading. Currie (2010b) emphasised this as the first key condition underpinning the success of initiatives seeking to shift rail passengers out of peak periods. Faber Maunsell (2007) also noted it as an absolutely critical element for differential fare policy to achieve its peak spreading objective.

A successful introduction of peak/off-peak differential fare may need to be linked with the roll-out of smart card technology. As noted by McCollom & Pratt (2004), fare differentiation can be complicated in practice because of multiple fare categories offered. Currie (2010b) suggested that peak/off-peak differential fare would require a sophisticated electronic ticketing system capable of recording actual journey details.

Peak spreading through pricing is a short-term strategy to deal with peak overloading. As pointed out by Faber Maunsell (2007), the potential long-term solution is to adopt a strategy of judicious and achievable capacity increases combined with a balanced set of pricing differentials to achieve the desired objective of increased overall rail passenger growth and maximisation of the peak period capacity. Meanwhile, an unequivocal message from Faber Maunsell is that increasing capacity to address peak overcrowding will not in itself enable future growth to be fully accommodated as the first reaction to improved peak conditions will be, for those travellers who have already shifted time to avoid overcrowding, to return to the now 'uncrowded' peak and within a short time frame the same issues will arise again.

Enough time should be allowed for fare adjustments to take effect. It should be remembered that trip rescheduling should not be expected overnight, as passengers are more likely to respond to fare changes in the medium to long term after allowing for lifestyle changes to take effect. Moreover, this paper is relatively narrow in its focus on fare differentiation for peak spreading on its own. However, peak/off-peak differential fare can be combined with other service changes (e.g., frequency, routing, etc.) in the same timeframe.

## 5. Conclusions

Urban rail transit systems in many large cities in Australia and around the world have significant loading variability, with morning and/or evening peak demand stressing system capacity and affecting service levels. Addressing these problems solely through investment to increase capacity is not always possible due to financial, technical, and time constraints. Spreading peak demand through differential pricing provides a plausible solution in a quick and cost efficient manner. Although peak surcharge and/or off-peak discount are implemented by many transit agencies for various management purposes, not much research has been conducted specifically to examine the effects on peak spreading.

This paper has reviewed recent empirical studies on fare differentiation to spread peak demand for urban public transport, particularly for rail transit. It is found that shifting demand out of peak is possible as long as peak/off-peak fare differentials are significant; free or discounted off-peak pricing is more welcomed by passengers than peak surcharges; peak surcharges are more effective than off-peak discounts in shifting time for travel; people are more willing to change time for travel to before-peak rather than after-peak periods in the morning; and passengers travelling longer distances and those with time flexibility are more sensitive to differential fare.

Besides passengers' willingness and flexibility to reschedule their trips, the success factors for peak spreading suggested in the past studies include adequate spare capacity in shoulders of peak, a sophisticated electronic ticketing system, and combination of pricing and capacity investment in the long term. It also requires careful application to avoid negative knock-on effects such as peak ridership loss to private automobile. This paper focuses on urban rail and is relevant to public transport in general, providing researchers and practitioners in transport policy with an informative and in-depth reference.

## **Acknowledgements**

This study is funded by Australian Cooperative Research Centre (CRC) for Rail Innovation project, R1.131 Strategies to Address Future Urban Passenger Rail Growth.

## Appendices

**Table A: Primary studies reviewed as empirical evidence of using differential fare to spread daily peak demand for urban rail transit**

Study category	Location	Year of data	Sample size, approach	Respondents	Methodology	Reference
Passenger opinions on willingness to change time for travel	London, UK	2006	173 passengers, intercept interview	passengers arriving between 8.00am and 9.00am	indicative statistics of answers to questions	Passenger Focus (2006a)
	London, UK	2006	5 focus groups	peak time passengers, grouped by travel time, income, and work/study as trip purpose	analysis of comments by attendees of focus groups	Passenger Focus (2006a)
	Great Britain	2006	1123 commuters, questionnaire	commuters across Great Britain travelling during peak periods	likelihood of time shifting under status quo, 10% or 20% reduction in travel cost	Passenger Focus (2006b)
	London & Birmingham, UK	2007	6 focus groups	both users and non-users of train	analysis of comments by attendees of focus groups	Faber Maunsell (2007)
	London & Birmingham, UK	2007	2360 passengers, questionnaire	Passengers making a trip into London/Birmingham between 7:45am and 9:15am.	statistics of answers to questions	Faber Maunsell (2007)
	Melbourne, Australia	2009	942 passengers, online questionnaire	peak period adult train passengers commuting for work on a busy rail line in Melbourne	statistics of answers to questions	Webb et al. (2010)
	Sydney, Australia	2009	1807 passengers, questionnaire	passengers except school children and RailCorp employees surveyed from 43 train services	statistics of answers to questions, e.g., the willingness to travel earlier or later in morning peak for hypothetical fare discount or less time on train	Henn et al. (2011)

**Table A (continued)**

<b>Study category</b>	<b>Location</b>	<b>Year of data</b>	<b>Sample size, approach</b>	<b>Respondents</b>	<b>Methodology</b>	<b>Reference</b>
Valuations of displacement time using stated preference technique	London & Birmingham, UK	2007	2360 passengers, SP experiments (arrival time, crowding, fare)	Passengers making a trip into London/Birmingham between 7:45am and 9:15am.	multinomial logit models based on the overall sample and segments stratified by location, arrival time flexibility, trip distance	Faber Maunsell (2007)
	The Netherlands	2009	1,421 passengers, online SP experiments (fare, off-peak pass)	passengers holding a pass for a specific route between 30-70 kilometres and recently had commuted on average a minimal of three times a week during morning peak hours (7:00 - 9:00 am)	combining RP and SP data, multinomial logit, cross-nested logit, and mixed logit models, with three specifications of utility functions.	Bakens et al. (2010)
	Melbourne, Australia	2009	942 passengers, two online SP experiments (arrival time, fare, travel time, crowding, train frequency)	peak period adult train passengers commuting for work on a busy rail line in Melbourne	sensitivity tests of impacts of service attributes on displacement time choice based on results from discrete choice modeling (no specific model was reported)	Webb et al. (2010)
	Sydney, Australia	2010	786 passengers, SP experiments (departure time, time on train, fare)	peak period passengers across Sydney metropolitan rail network	values of displacement time based on parameter estimates from an unlabelled binary logit model	Douglas et al. (2011)
Simulation of peak spreading based on trip scheduling models	North England, UK	2002	case study of a line between two regional rail stations in the North of England	Passenger preferences parameters were following UK Passenger Demand Forecasting Handbook (ATOC, 2002, as cited in Whelan & Johnson, 2004 )	a MNL model of train choice based on return fare, crowding, in-vehicle time, interchange, out-of-vehicle time, and schedule adjustment time; an incremental logit model of mode choice	Whelan & Johnson (2004)

Table A (continued)

Study category	Location	Year of data	Sample size, approach	Respondents	Methodology	Reference
Simulation of peak spreading based on trip scheduling models	London & Birmingham, UK	2007	London-Birmingham rail transit corridor, populated with data on loadings, capacity, generalised time and fare for each of the five time slices (i.e., every 30 minutes, in the period from 7:30am to 9:30am).	<ul style="list-style-type: none"> <li>proportion of travellers selecting to travel in a time slice was derived using the multinomial logit model (as introduced in the SP studies)</li> <li>The overall demand elasticities to generalised time and fare changes following defaults values in UK Passenger Demand Forecasting Handbook (ATOC, as cited in Faber Maunsell, 2007), weighted by the proportion of each type of user in the peak period markets.</li> </ul>	<ul style="list-style-type: none"> <li>crowding taken as an important factor in choice of train</li> <li>an iterative procedure built into the model to reflect how changes in demand in any one time slice would change the relative disutilities due to changes in crowding effects</li> <li>an equilibrium sought where travellers were optimally distributed across the time slices</li> </ul>	Faber Maunsell (2007)
	Sydney, Australia	2010	A busy line in Sydney rail network as a case study. Passenger travel time profiles for adults and for school children were developed based on barrier exit data	probabilistic assignment based on a multinomial logit model calculating the chance of a passenger choosing a train based on the relative generalised time to other trains (as introduced in the SP studies)	<ul style="list-style-type: none"> <li>extended rooftops approach to include fare via values of time so as to study effect of differential fares</li> <li>total rail patronage assumed not be affected by fare changes</li> <li>train choice assumed not to be impacted by crowding, no integrative assignment procedure</li> </ul>	Douglas et al. (2011)
Real-world case	Melbourne, Australia	2008	901 passengers, intercept survey	passengers finishing their trips before 7:00am	statistics of answers to questions; cost benefit analysis	Currie (2010a, 2010b)

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