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**Paper title:** Estimating passenger demand for fast rail services with the Rooftop Model

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**Abstract (200 words):**

The Rooftop Model was developed by British Rail in the 1980s as a technique for estimating passenger demand for individual train services. Given a timetable of train services, the model allocates passengers to services based on the passengers' departure, arrival and travel time preferences. Although the Rooftop Model has not yet had widespread application in Australia, it is a potentially useful tool for measuring network performance (in terms of overall passenger travel time) and optimising rolling stock and timetables.

This paper describes the model and its application to the planning of Victoria's Regional Fast Rail services. The model was calibrated for the Victorian regional rail network using an extensive program of interview and stated-preference surveys. The calibrated model estimated current peak service loads across a typical weekday with a fair degree of accuracy. Future proposed timetables were also tested with the model to estimate the likely effects of the new service patterns.

This paper also describes how the Rooftop Model can be linked to a conventional four-step model to estimate the effects of land use, population and employment on future rail demand.

### Introduction

When timetabling new train services, planners are often interested in how passenger demand will be distributed between available trains. An express train, for example, may attract a higher passenger load than a stopping service. However, if express trains run infrequently, passengers may prefer to take a stopping service to avoid an unreasonably early or late departure time.

This paper describes a technique for estimating the number of passengers travelling on individual train services, given a timetable and a pattern of passenger movements. The technique, often referred to as the ‘Rooftop Model’, has been used by British Rail since the 1970s to assist in the planning of high-speed rail services (Tyler and Hassard 1973, Shilton 1982). The model has not yet had widespread application in Australia, and one of the objectives of this paper is to inform Australian rail planners about the model’s principles.

The Rooftop Model was recently used by consultants Sinclair Knight Merz to estimate the demand for proposed new services delivered as part of the Victorian Regional Fast Rail Project. The paper explains how the model was adapted to the Victorian regional context and developed into a fully-featured tool for testing Fast Rail timetables.

The paper first looks at a hypothetical example of a passenger’s train-selection process, then provides a mathematical description of the Rooftop Model. Later sections of the paper describe practical aspects of the model’s application to Regional Fast Rail planning.

### Passenger Decision-Making: Katy’s Trip to Ballarat

To illustrate the model’s principles, let us consider a hypothetical situation where Katy takes a train from Melbourne to Ballarat. Katy’s preferred departure time is 10:15am.

The available trains between 10:00 and 11:00am are shown in Table 1.

**Table 1** Train timetable for Katy’s trip to Ballarat

Train Number	Departure time (Melbourne)	Arrival time (Ballarat)	Travel time (min)
1	10:00	11:15	75
2	10:30	12:00	90
3	11:00	12:10	70

Katy’s decision-making process may go along the following lines:

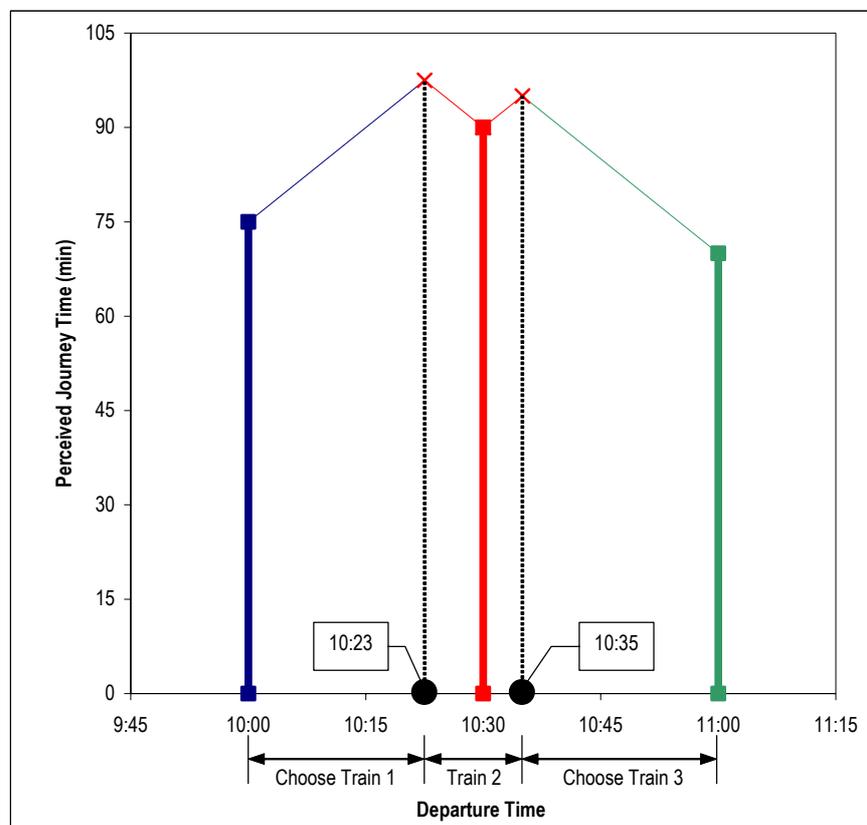
- “Even though Train 3 is the fastest, I would need to wait at the station for 45 minutes (ie. 10:15 until 11:00) if I chose train 3.”
- “Train 2 leaves just after my desired departure time, but takes 20 minutes longer than Train 3 and 15 minutes longer than Train 1.”
- “Train 1 is quicker than Train 2, but leaves 15 minutes before my ideal departure time. I’m prepared to leave home 15 minutes earlier to catch this train and avoid the extra travel and waiting time.”

Assuming that Katy values her travel time, waiting time and her leaving-home-earlier time equally, we can quantify the total ‘perceived’ time (or disutility) for each of her choices as follows:

- Train 1: 15 minute earlier departure + 75 minute travel time = 90 minutes
- Train 2: 15 minute waiting time + 90 minute travel time = 105 minutes
- Train 3: 45 minute waiting time + 70 minute travel time = 115 minutes

Train 1 has the lowest perceived time, and is therefore Katy’s chosen alternative.

To develop a more general rule, let us carry out this perceived time calculation for all possible desired departure times between 10:00 and 11:00am. Plotting the perceived time against desired departure time, we obtain the diagonal 45-degree lines shown along the top of Figure 1.



**Figure 1 Simple graphical construction to estimate train choice based on perceived time**

This graphical construction can be used to determine the threshold times at which Katy would choose Train 2 over Train 1 and Train 3 over Train 2. In this example, Katy would choose Train 1 for a desired departure time earlier than 10:23, Train 2 for a time between 10:23 and 10:35, and Train 3 after 10:35.

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To construct a similar plot for any general train timetable, the analyst would carry out the following steps:

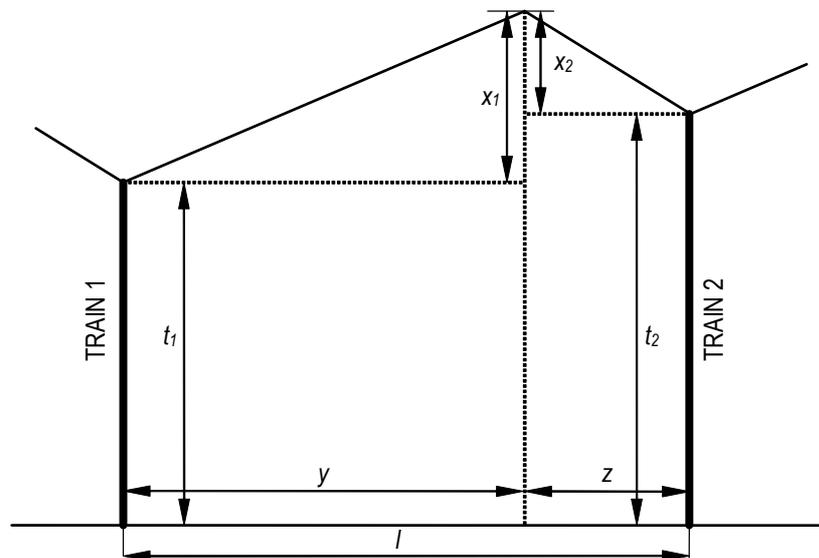
- plot vertical lines at each train departure time, the height of each line being equal to the travel time of the train;
- construct 45-degree rays from the top of each vertical line;
- determine the train choice threshold times by calculating the intersection points of each adjacent pair of 45-degree rays.

In reality, Katy is likely to value her travel time and the inconvenience of leaving earlier or later differently. Therefore, the angled ‘rooftops’ in the graphical construction will not necessarily be at 45-degree angles, nor will the early and late sides of each ‘rooftop’ have equal angles.

The following section provides a more formal derivation of the rooftop function.

#### Derivation of the Rooftop Threshold

Consider the case of two trains with travel times  $t_1$  and  $t_2$  respectively and headway  $l$ . We wish to calculate the threshold desired time offset,  $y$ , at which a passenger may be expected to change their decision between one train and the other. In this derivation, we assume arbitrary angles of the ‘rooftops’ (ie. passengers can value travel time, early departure and late departure time differently). The graphical construction of this situation is shown in Figure 2.



**Figure 2** Graphical construction for derivation of the rooftop function

Let:

$$x_1 = \alpha y$$

$$x_2 = \beta z$$

where  $\alpha$  and  $\beta$  are constants that control the relative weighting of earlier and later departure times respectively.

Then:

$$t_1 + x_1 = t_2 + x_2$$

$$\Rightarrow t_1 + \alpha y = t_2 + \beta z$$

Now:

$$l = y + z \quad (\text{that is, the known headway between trains})$$

So:

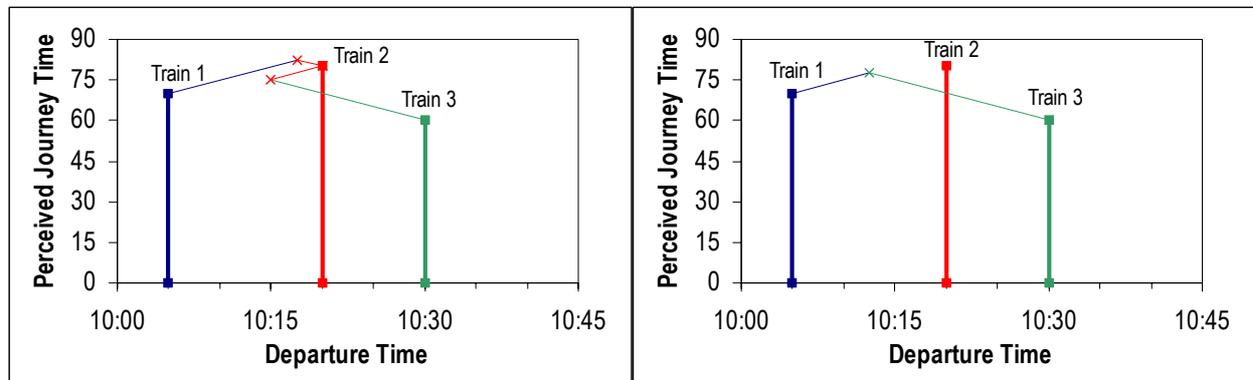
$$\alpha y = t_2 - t_1 + \beta(l - y)$$

$$\Rightarrow \alpha y = t_2 - t_1 + \beta l - \beta y$$

$$\Rightarrow y = \frac{t_2 - t_1 + \beta l}{\alpha + \beta} \quad \dots(1)$$

Therefore, given suitable values of  $\alpha$  and  $\beta$ , we can determine the time offset of the choice threshold between trains.

Note that if  $y < 0$  then the first train attracts no passengers. Similarly, if  $y > l$  then the second train attracts no passengers. Figure 3 (left) shows a graphical construction of the case where  $y < 0$ . In this case, Train 2 (at 10:20) will not attract passengers, as Train 3 leaves later than Train 2 and overtakes it to reach the destination before Train 2. In this case, Train 2 would be excluded from the calculation, and rooftops calculated only for Train 1 and Train 3 (Figure 3 right).



**Figure 3 (Left) Overlap condition where Train 2 does not attract passengers. (Right) Train 2 excluded from rooftop calculation.**

So far in this paper, the rooftop method has been applied to a passenger's choice of train based on a desired *departure* time. For some trip purposes, the *arrival* time will be more critical for the passenger. For example, when commuting to work, a passenger may choose the latest train that will get him to work on time. In this case, the rooftop calculation (Equation 1) would be performed using train arrival times and headways at the destination.

## **Application of the Rooftop Model to the Victorian Regional Fast Rail Project**

### Background

The Regional Fast Rail Project (RFRP) is a Victorian State Government initiative to introduce improved rail services between Melbourne and the regional cities of Geelong, Ballarat, Bendigo and Traralgon. As well as upgrades to rail infrastructure, the project will introduce new higher-speed rolling stock to improve travel times in the non-metropolitan sections of the lines.

In designing the new service patterns and timetables for the upgraded lines, RFRP planners required estimates of the number of passengers on each service. This information was important in optimising the timetable so that most passengers gain benefit from the faster trains and to ensure that trains have sufficient seating capacity to serve the anticipated demand.

### Model Structure

To estimate the demand for individual services, consultants Sinclair Knight Merz developed a service planning model to carry out rooftop calculations for each Fast Rail line (Sinclair Knight Merz 2004a). Figure 4 shows the structure of the model.

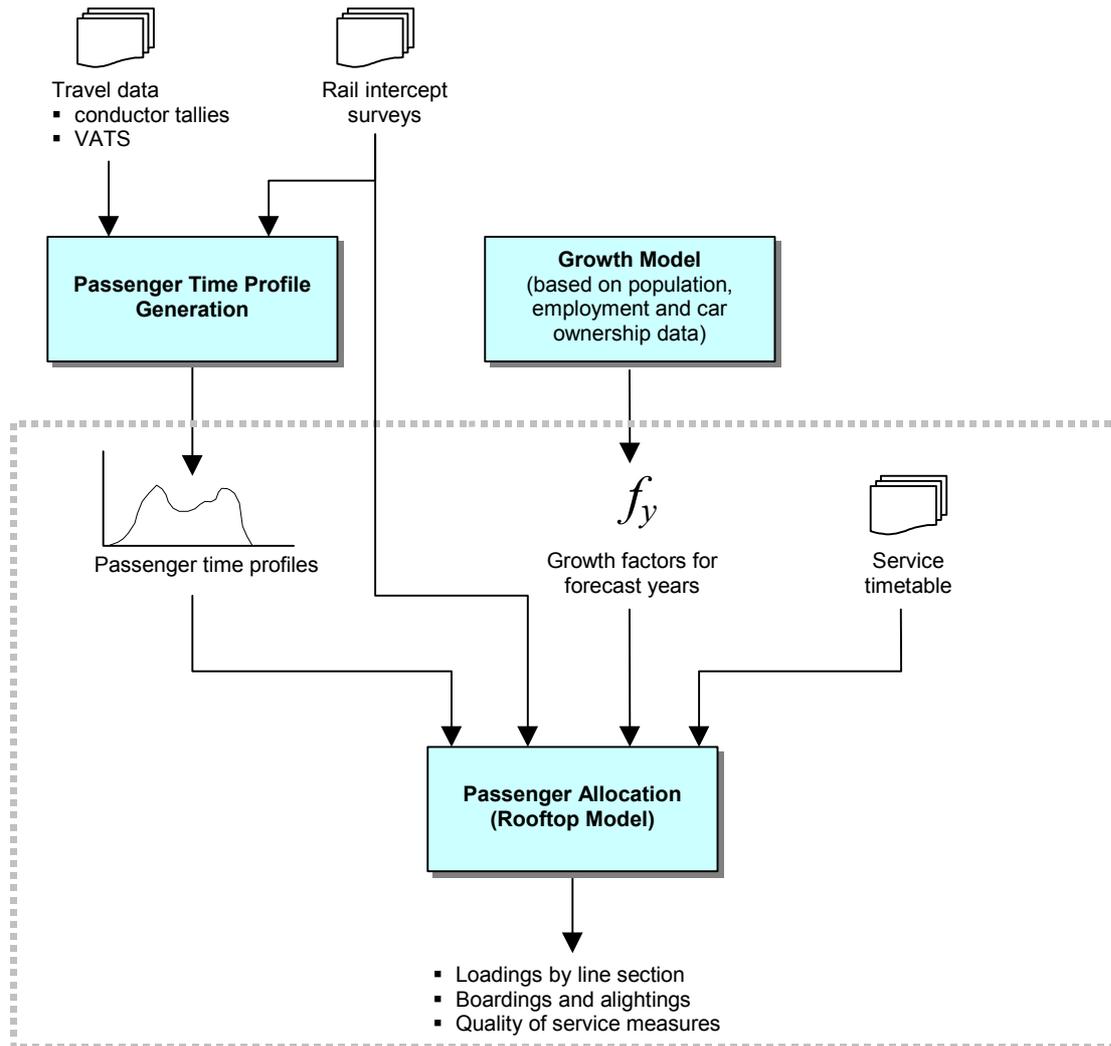
The key inputs to the model were:

- *a passenger origin-destination station matrix* derived from an intercept survey of existing passengers on each rail line;
- *passenger time profiles* specifying the number of passengers desiring to travel between each pair of stations at different times across the day (with different profiles for work, education and other trip purposes);
- *growth factors* for each origin-destination station pair specifying the overall anticipated growth in each forecast year for each Fast Rail scenario;
- *timetables* of Fast Rail services for each scenario with an ability for these to be taken directly from the RailSys (SIMU++) rail simulation model operated by the Victorian Department of Infrastructure (RMCon 2004).

As well as intercept surveys of rail passengers and car drivers along each rail corridor, stated preference (SP) surveys were carried out by Halcrow to calculate appropriate values for the  $\alpha$  and  $\beta$  displacement weights for the Rooftop Model. The final weights adopted in the model are shown in Table 2.

When processing the SP survey results, Halcrow combined education and ‘other’ trips to provide a sufficiently large statistical sample. The displacement weights used for these trip purposes are therefore the same (0.57).

The analysts also found that there was no statistically significant difference between the  $\alpha$  and  $\beta$  values for any single trip purpose. In other words, passengers tended to view the inconvenience of an early train as being similar to that of a later train. The  $\alpha$  and  $\beta$  values were therefore taken to be the same for each purpose.



**Figure 4** Structure of the Regional Fast Rail service planning model

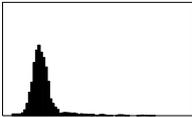
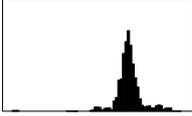
#### Calculating rooftop thresholds

With all these inputs assembled, the model calculated the rooftop thresholds for each station origin-destination pair and trip purpose. Trips *to* work and education were constrained by the arrival time of the train, that is, the model assessed the arrival time of the train in relation to when people wanted to arrive at their workplace or school.

Conversely, trips *from* work and education were constrained by the departure time of the train, as were all other purpose trips.

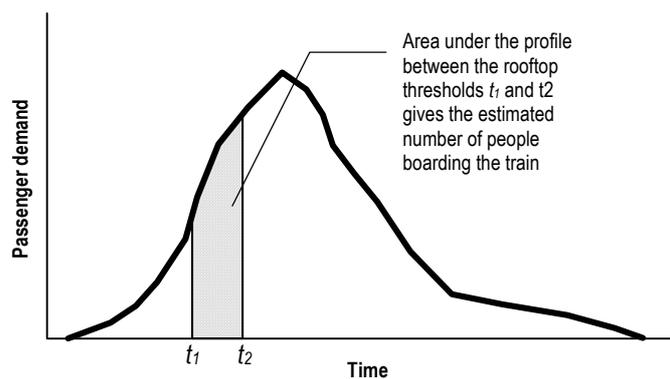
Table 2 summarises the arrival and departure constraints and provides thumbnail plots of the demand profiles adopted for each trip purpose. In each thumbnail, the horizontal axis specifies the time of day (4am-12 midnight) and the vertical axis specifies the proportion of passengers travelling during the period. The demand profiles were derived from the rail intercept surveys carried out as part of the project, taking into account the difference between passengers' desired departure times and the departure times dictated by the timetable.

**Table 2** Arrival and departure constraints, displacement weights and travel profiles for each trip purpose

Trip Purpose	Constraint	$\alpha$	$\beta$	Profile Thumbnail
To Work	Arrival	1.29	1.29	
From Work	Departure	1.29	1.29	
To Education	Arrival	0.57	0.57	
From Education	Departure	0.57	0.57	
To/From Other	Departure	0.57	0.57	

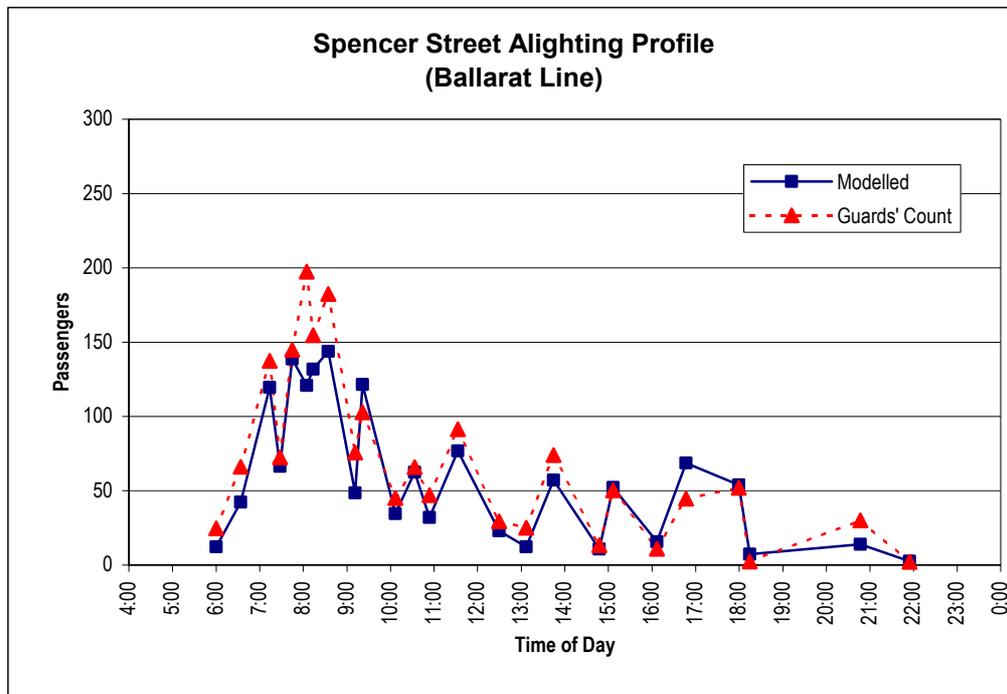
### Allocating passengers to trains

Once the model had calculated the rooftop thresholds for each origin, destination and trip purpose, it then allocated passengers to individual trains. The model determined the passenger allocation for a train by calculating the area under the demand profile between the rooftop threshold times for that train (see Figure 5). The allocation process was carried out separately for each trip purpose and the contributions from each purpose summed to determine total passenger loads on each train.

**Figure 5** Calculating the passenger allocation for a train

## Model validation

The model was validated by comparing the modelled number of boardings and alightings for each train (using the current timetable) with those counted by train conductors. Figure 6 shows one such validation plot for trains arriving at Spencer Street Station in Melbourne from Ballarat.



**Figure 6** Validation of the model at Spencer Street Station for the Ballarat line

In this situation, the model correctly picks up the peaks and troughs of demand, although there is some under-representation of passenger loads in the morning peak. The jagged ‘sawtooth’ pattern is caused by the interleaving of express services (which attract higher demand) and slower stopping services (which attract lower numbers of passengers). It should be noted that the train conductor tallies are subject to significant day-to-day variability and error, sometimes by as much as  $\pm 40\%$ .

## Software implementation

The Rooftop Model and passenger allocation procedure were computationally intensive. For example, on the Ballarat line with 15 stations and 51 train services per day, there were approximately 5,700 individual rooftop passenger allocations. To handle this volume of data, a relational database was set up in Microsoft Access that incorporated the following information:

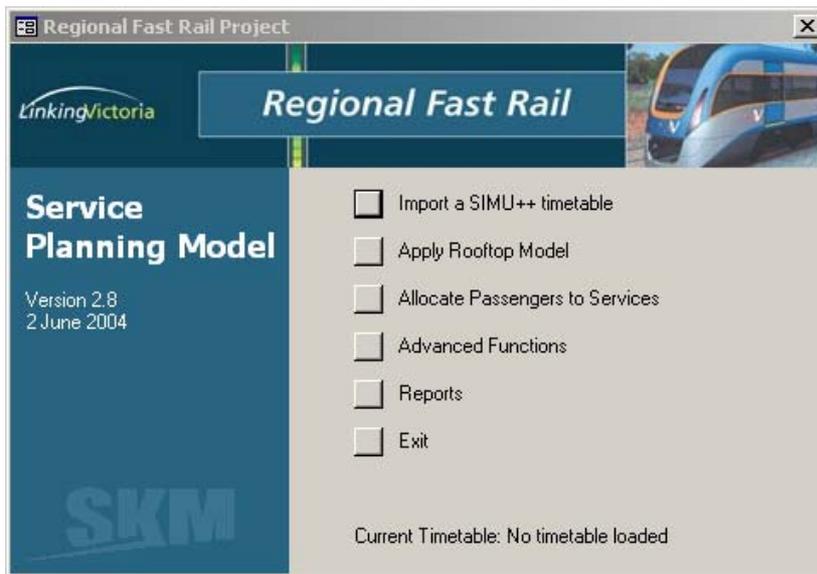
- passenger origin-destination flows;
- train arrival and departure times at each station;
- growth factors for each station pair (for testing future scenarios with the model);

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- station definitions (including names and lines);
- demand profiles

The database was programmed with all of the logic needed to process timetables and growth data, calculate rooftop thresholds and passenger allocations.

A customised interface was developed to automate many of the data processing tasks, and to provide a more user-friendly way of manipulating timetables and generating reports. Figure 7 shows the main interface, Figure 8 shows the range of reports available, and Figure 9 shows a typical report generated by the model. For further examples of the user interface, see Sinclair Knight Merz (2004b).



**Figure 7** Main model interface



**Figure 8** Reports available from the model

4	Boardings (Up)									
5	Station	Total Boardings	8102 Bacchus Marsh 05:08	8104 Bacchus Marsh 05:43	8106 Bacchus Marsh 06:23	8108 Ballarat 06:00	8112 Bacchus Marsh 06:51	8114 Bacchus Marsh 07:12	8116 Ballarat 06:48	8118 Bacchus Marsh 07:00
6	Ballarat	607				71			117	
7	Ballan	92				26			34	
8	Bacchus Marsh	406	5	17	51		55	1	84	
9	Melton	1227	18	54	149		187	174		
10	Rockbank	12	0	1	2		2	4		
11	Deer Park	37	1	2	4		6	6		
12	Ardeer	36	1	2	4		6	6		
13	Sunshine	0	0	0	0	0	0	0	0	
14	Footscray	0	0	0	0		0	0		
15	North Melbourne	0	0	0	0	0	0	0	0	
16										

**Figure 9** Portion of a typical boarding report generated by the model

## Conclusion

When carrying out demand forecasting for rail services, planners often deal with aggregate forecasts of daily passenger flows in a rail corridor. The Rooftop Model provides a simple method for breaking down daily passenger flows into the estimated number of passengers travelling on individual trains. This paper has provided details of the model's derivation and discussed the practical considerations of how the model can be implemented.

In its application to the Victorian Regional Fast Rail Project, the Rooftop Model was shown to match observed passenger boardings and alightings reasonably well. The relational database implementation of the model enabled testing of various timetables and the straightforward generation of reports.

The technique shows promise as a useful tool in public transport forecasting, particularly at the detailed service planning level.

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