TRC BUSMODEL - AN INTEGRATED MODEL OF URBAN BUS OPERATIONS

Mr Charles Lau
Research Fellow, Transport Research Centre
RMIT University

Prof Tony Richardson
Director, Transport Research Centre, RMIT University

Mr John Tudorovic
Resaerch Assistant, Transport Research Centre
RMIT University

ABSTRACT

Major changes are occurring in the structure of the bus industry in Victoria, with privatisation of the government bus fleet and the restructuring of government contracts with private operators to reflect o more performance-oriented approach These changes require better market information and analysis to enable bus operators to compete more effectively in this new environment. This paper describes the development of an integrated modelling system by the Transport Research Centre (TRC) for the Bus Proprietors' Association (Victoria) to assist in this transition.

The models being developed by the TRC have a number of components. Each component has a stand-alone role as a source of information for the operator, and when taken together create a powerful, but understandable, modelling framework for the analysis of bus routes, and later bus networks. The initial suite of models being developed is centred around a spreadsheet model of bus route operations, know as TRC BusModel. Supporting the TRC BusModel are a wide variety of data sources, covering descriptions of the bus network in GIS format, demographic information in catchment areas, information on bus users from patronage surveys, further information on users and non-users from household travel surveys, plus information on users' preferences from Stated Preference surveys.

All the above information is then used by the TRC BusModel to determine levels of service on the route, operating costs, revenue, profit levels and a range of operating characteristics under a variety of designs and operating conditions. In this way, the model is able to determine what fares would need to be charged under current conditions to maintain a commercially viable service, and what changes would be desirable to improve levels of service to passengers and hence ensure the ongoing commercial viability of the service within the new environment dictated by the transport reform agenda.

Contact Author

Mr Charles Lau
The Transport Research Centre
P O Box 598 Market Street
Melbourne 8007
Australia
Ph: + 61 3 9629 4835 Fax : + 61 3 9629 4839
email: trc@rmit.edu.au

ATRF 96

Introduction

Major changes are occurring in the structure of the bus industry in Victoria, with privatisation of the government bus fleet and the restructuring of government contracts with private operators to reflect a more performance-oriented approach. As described by Wallis (1995), these reforms are part of an overall reform of public transport operations in Australia and New Zealand. Indeed, they are indicative of a much wider reform in the provision of all sorts of "public" services, including transport, water, electricity and waste management services. In the first and last of these areas, there is a strong move towards a system of performance-based contracts whereby private contractors are paid on the basis of their performance for the provision of "public" services.

These changes in regulatory and contractual environments require better market information and analysis to enable bus operators to compete more effectively in this new environment. In recognition of these changes, the Transport Research Centre (TRC) was commissioned, in late 1994, by the Bus Proprietors' Association of Victoria (BPA) to develop a suite of data sources and analytical techniques to assist operators in adapting to the changes occurring in the industry. It was envisaged that as well as being applicable to route services in Victoria, the suite of models would also be applicable to other bus systems where there is an interface between private operators and a government regulator. Therefore, while this paper will refer to the Victorian situation for its examples, the principles and the analytical techniques should be applicable to a far wider audience.

The Bus Proprietors' Association of Victoria has a membership of 709 bus operators running 4,384 buses across the state as of 1994 (BPA, 1994). Of these operators, approximately 50 operate route services in the Melbourne metropolitan area, and it is these operations which are the main focus of the research described in this paper. The main objective of this project is to develop a model of urban bus operations which can be applied to the entire private bus network in Melbourne. The need for this modelling has come about because of proposed changes in the relationships between the private bus industry and the government, whereby private bus operators will now enter into performance-based contracts whereby they will be rewarded for the number of passengers they carry and the distance for which they carry them. This is in contrast to the previous contracts which were based on bus-kilometres travelled, independent of the number of passengers carried on the buses. Clearly, in this new operating environment it is important that operators, and the government, have a much better idea of the demand for their services and of the cost implications of supplying services to cater for this demand.

As part of the study commissioned by the Bus Proprietors' Association (BPA), the Transport Research Centre (TRC) has developed a single-route bus model (TRC BusModel) as a planning tool to assist bus operators to plan for their bus services. The model is built to simulate the results of interactions between the demand and the supply side of a bus route taking into account the physical characteristics of the service. As will be outlined later, however, the model can also be used in a wider context to investigate the implications of various regulatory and contractual situations.

Performance-Based Contracts

As noted above, there is a wide-spread move towards performance-based contracts in a range of fields where private contractors provide services which are perceived by the community to have a "public" service nature to them. In particular, this arrangement is increasingly being adopted for the provision of public transport services and in the provision of waste management services, especially recyclables collection. In both areas, there has been a situation in which there has been little or no incentive for operators to provide any more than a "bare-bones" operation. The current "no incentive" situation is depicted by the payment conditions outlined in Figure 1.

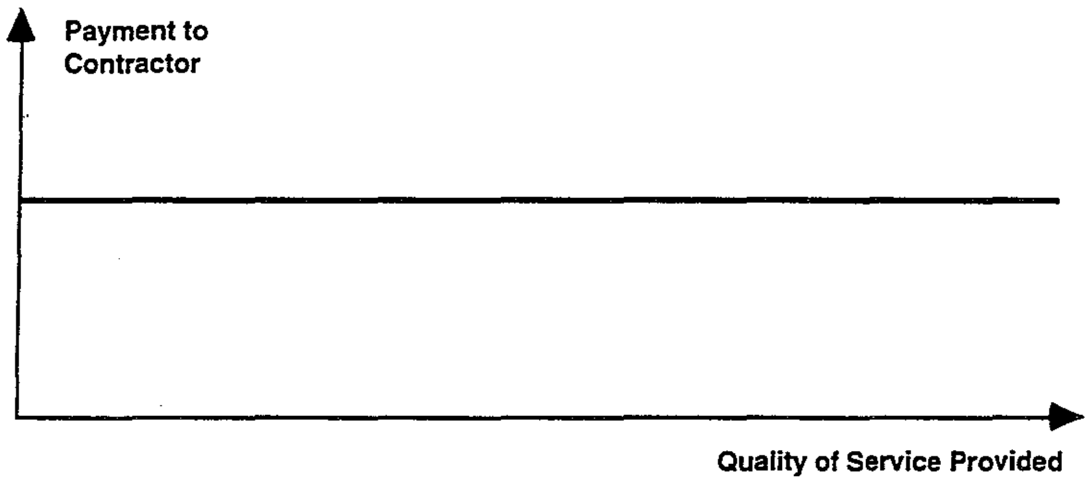

Figure 1 Fixed Payment based on Quantity of Service Provided

In such a situation, a contractor is paid a fixed amount based upon the quantity of service provided, as determined by the Government regulator. In the case of bus services, this may be measured in terms of bus-kilometres run over a fixed set of routes. For recycling services, this may be measured in terms of the number of households serviced on the collection route. Since the cost of providing extra bus services is generally less than the revenue to be earned from these services (or the market price for resale of recyclables is currently less that the full costs of collection), the contractor is losing profit for every extra passenger carried (or every extra tonne of recyclables collected). The more passengers they carry (or recyclables they collect), the less profit they earn. Clearly there is little incentive for contractors to increase the passengers carried (or quantities collected) when working on such a fixed price contract.

In order to provide some positive incentives for the carriage of more passengers (or the collection of more recyclables), there has been a move towards a performance-based contract where the payment to contractors is based on both the amount of service provided and the number of passengers carried (or the number of households serviced and the quantity of recyclables collected). A variety of performance-based contracts have been proposed, as described for recycling services by Manning (1993). One such proposal is for the contactor to be paid a lump sum based on the number of bus-kilometres run (or the number of households serviced) plus a bonus for every passenger carried (or tonne of recyclables collected), up to a maximum lump sum contract amount, as shown in Figure 2.

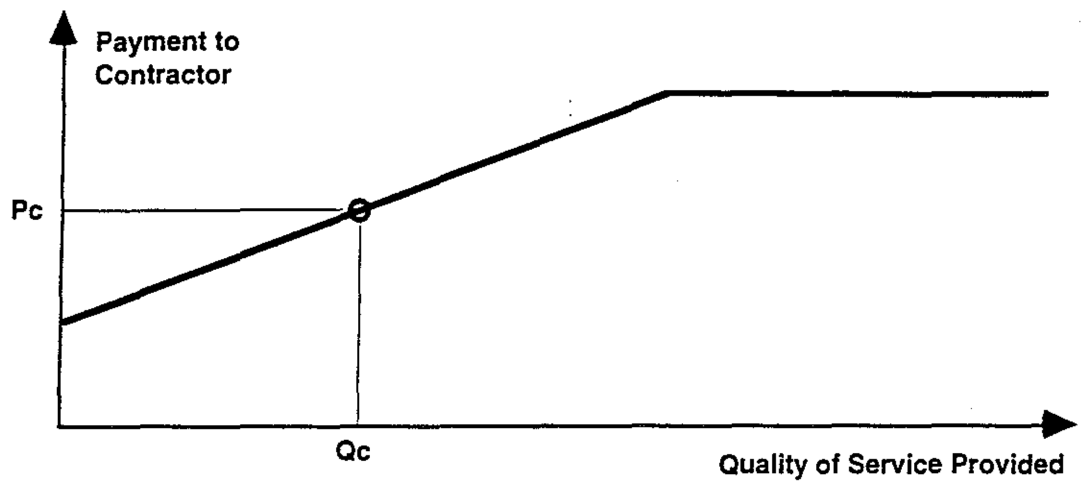

Figure 2 Performance-Based Payment based on Quality of Service

Under these conditions, any equity implications of the performance-based contract may be accommodated by ensuring that the performance-based payment schedule includes the current quality of service provided (Qc) and payment to the contractor (Pc) as one of the possible options under the new contract. Under these conditions, the contractor may choose to continue providing the same level of service for the same payment. However, the new contract is a vast improvement in that it provides a real system of incentives and disincentives for the contractor. By choosing to provide a better quality of service (which will attract new passengers, or increase the yield of recyclables) the contractor can now be rewarded for such entrepreneurship and innovation. On the other hand, if the quality of service is allowed to slip, then a system of financial disincentives comes into force.

One of the major policy questions to be addressed in a system of performance-based contracts is the slope of the line in Figure 2. That is, how much should be paid for every extra passenger carried (or tonne of recyclables collected)? If the slope if high, then the system will provide a strong incentive for contractors to perform better. However, it will also increase the financial risk to the government regulator. If the system is very successful in encouraging contractors to perform better then the payments by government to contractors could become excessive. It is true that the maximum payment can be controlled by the maximum capping payment, but if this cap comes into play too quickly then the government objective of maximising passengers carried (or recyclables collected) may not be achieved. The degree of government risk can be reduced by reducing the slope, but it must not be reduced so far as to remove the incentive for contractors to improve performance. The minimum risk situation is to have a zero slope, as shown in Figure 1, but this is exactly the situation which is to be changed. Clearly, there is a delicate trade-off to be made between contractor incentive and government risk. The mechanics of this trade-off will depend on the objectives of the government regulator, the cost structure of the industry, the interactions inherent in the provision of the services (whether they be bus or recycling services), and the sensitivity of customers to the quality of service provided by the contractor. In such a situation, there is a clear need for analytical techniques to address this trade-off. Such modelling techniques for recycling systems have been described by Richardson and Wang (1994). The current paper describes the development of modelling methods for bus systems.

The General Structure of the TRC BusModel

The TRC BusModel has been based on the conceptual model of bus route operations depicted in Figure 3. This model was used as the basis for the earlier pedagogical version of BusModel (Richardson, 1994), and has since been extended to allow for the customisation of the model for specific bus routes. Because of the transparent nature of the spreadsheet-based BusModel, it was felt that it could provide a useful and understandable platform on which to base more comprehensive modelling efforts.

The pedagogical BusModel made a number of simplifying assumptions to enable relatively quick and data-free analyses to be conducted. For example, the bus route was assumed to service a simple rectangular catchment area divided into equal size zones. The demand matrix for trips between origin and destination zones was completely assumed by the user. The model only allowed for analysis of a single time period. The placement of bus stops and traffic signals was arbitrarily assumed to be evenly spaced along the route at specified densities. Fare structures were assumed to be zonally-based, with no flag fall fare. All passengers were assumed to pay full fares. The model assumed a single value of elasticity of demand with respect to fares, and a single value of elasticity of demand with respect to travel time.

Even given all the above assumptions, the original version of TRC BusModel had real power as a pedagogical device in that it enabled people to develop a real feeling for the counter-intuitive interactions inherent in the design of a real system. When faced with a task such as designing a system which would make a profit, experienced transport professionals found that they were making design decisions which not only moved the system as far as they expected towards their goal, but which were actually taking them in the wrong direction. Even experienced bus operators found that they could learn some things about second-order and third-order interactions between demand and supply which they had not fully appreciated. This was perhaps because it had been so long since they had actually had to make such decisions in the real-world under the current contractual arrangements!

The current version of TRC BusModel relaxes many of the assumptions and constraints inherent in the original version, to enable it to replicate the operations of real bus routes. In particular, the TRC BusModel now allows for:

- design of actual bus routes in GIS formats
- bus stops and traffic signals placed in actual positions along route
- sections based on fare structure requirements
- user demand matrices based on on-board surveys
- user preferences based on Stated Preference surveys
- use of logit choice models to estimate customer sensitivities to change
- section-based fare structures with flag falls
- full fare and concession fare passengers considered separately
- multiple time-period analyses, which can then be aggregated

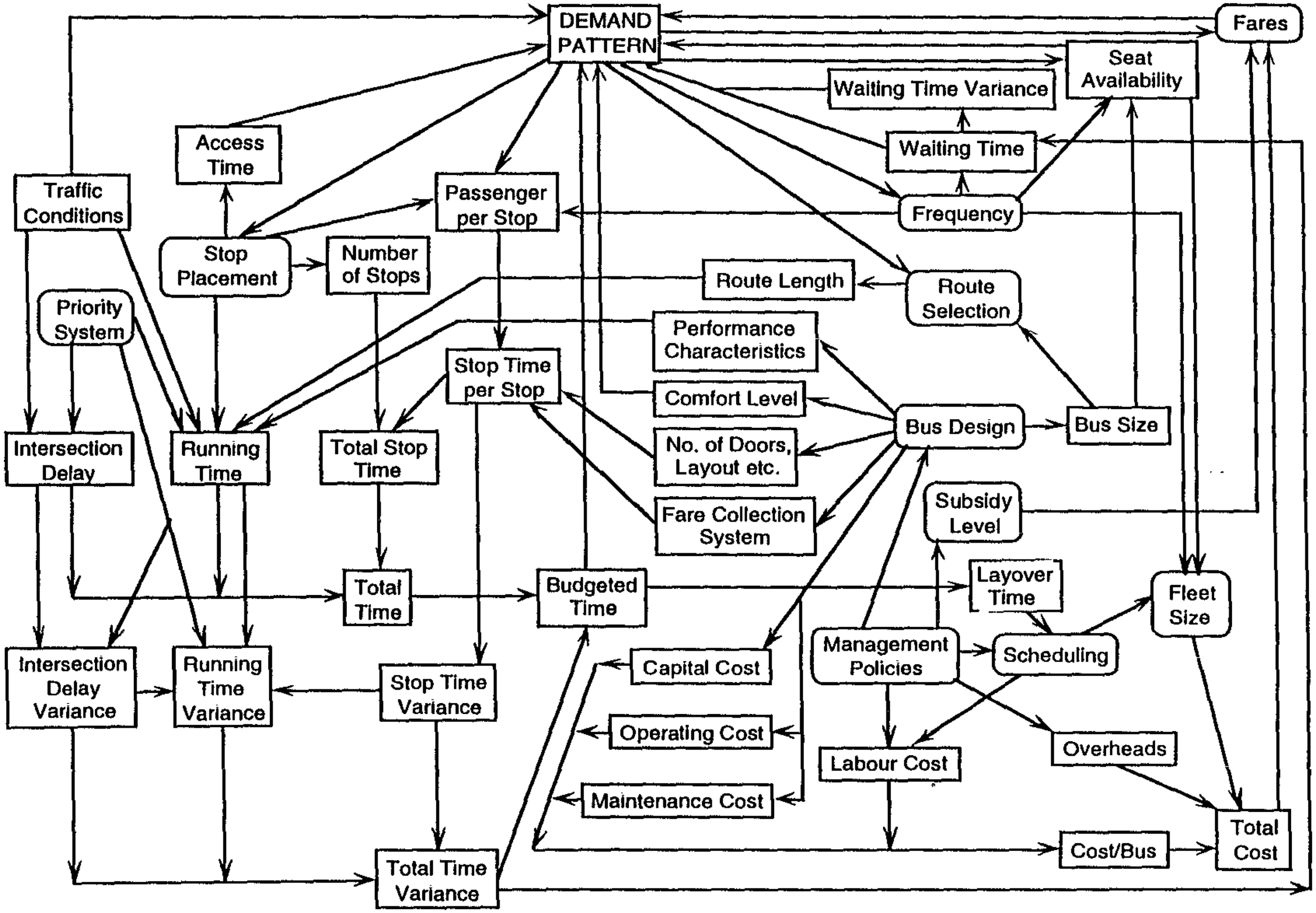

Figure 3 A Conceptual Model of Public Transport Operations

The suite of models being developed by the Transport Research Centre have a number of components and data sources. Each component has a stand-alone role as a source of information for the operator and, when taken together, create a powerful, but understandable, modelling framework for the analysis of bus routes, and later bus networks. Supporting the TRC BusModel are a wide variety of data sources, as shown in Figure 4.

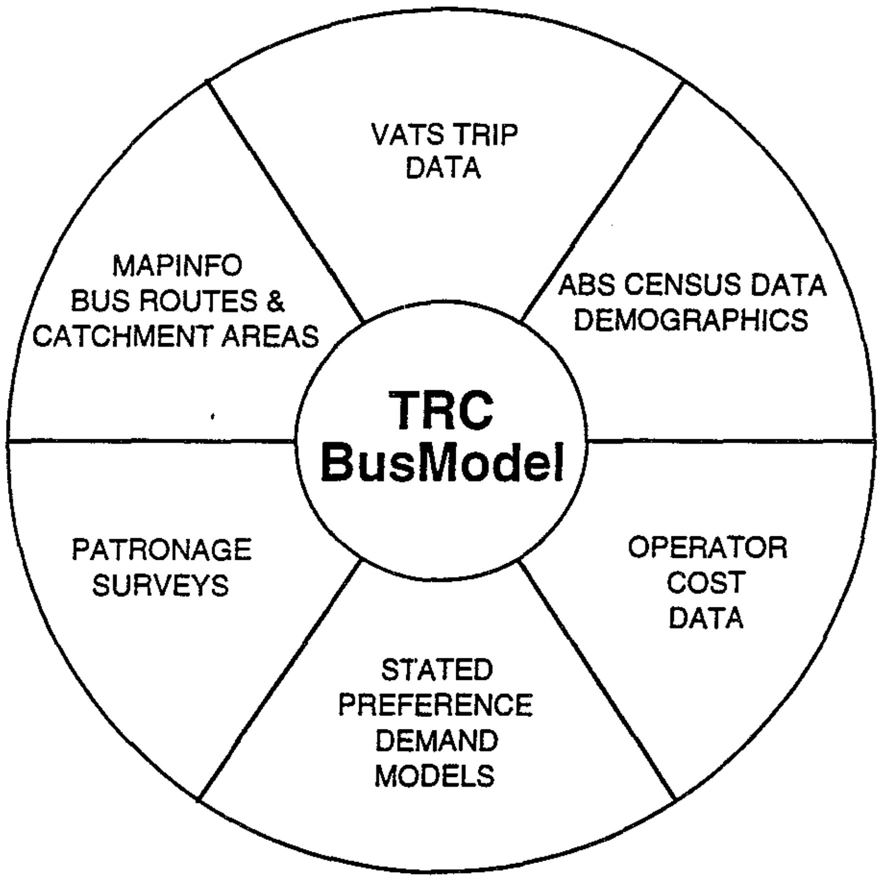

Figure 4 Data Sources Supporting the TRC Bus Model

The information describing all the bus routes in Melbourne is held in MapInfo GIS format. Using GIS functions, catchment areas are then formed around the route and approximated by groupings of Census Collection Districts. This allows demographic data to be extracted from the ABS CDATA91 CD-ROM. Data on bus trips on the selected route, and all trips in the catchment area, are obtainable from the Victorian Activity & Travel Survey (VATS) database. Specific information on trips made on the selected route are also obtained from on-board patronage surveys conducted by the TRC. Information on the costs of operation of the selected route are obtained from the operator through an intensive cost determination process also conducted with the operators by the TRC. Finally, the preferences of the users, and non-users, of the service are obtained through Stated Preference surveys conducted by the TRC. These surveys indicate the sensitivity of customers to variations in a range of service level parameters, such as travel time, waiting time, access and egress time, and fares.

All the above information is then used by the TRC BusModel to determine levels of service on the route, operating costs, revenue, profit levels and a range of operating characteristics under a variety of designs and operating conditions. In this way, the model can be used to determine what fares would need to be charged under current conditions to maintain a commercially viable service, and what changes would be desirable to improve levels of service to passengers and hence ensure the ongoing commercial viability of the service.

Details of the TRC BusModel

The TRC BusModel © 1995 is a spreadsheet model developed in Excel 5.0. It models the changes in demand for a bus service during a certain period of the day by simulating the operation of the bus route and estimating the impact of changes in service details. One model is built for each time period for each bus route. By combining models for different periods of the day, it is possible to generate the demand picture of the bus route for the whole day and hence for the whole season or year.

Geographic Information System (GIS) software, MapInfo, is used to store the physical characteristics of the bus route. The TRC has developed an extensive set of geographic databases of Melbourne's bus routes for this purpose. The route is divided into sections according to the actual operating conditions. For each section, there is a set of data such as route length, number of stops, number of traffic signals, number of priority intersections and length of priority lane, etc. Together with other parameters (e.g. walk speed, catchment area width) and bus type data (e.g. capacity, cruise speed), these data sets are used as inputs of the bus model to simulate the actual operating conditions.

Using MapInfo together with the VATS data, it is possible to estimate the existing market share of a particular bus service. A 400m buffer around the bus route is used to represent the bus catchment area. From the plot of origins and destinations of trips from VATS within the catchment area, trips which are in direct competition with the bus (ie, all trips, excluding walking trips, which travel within the corridor) are used to determine the modal split of travel within the bus corridor. This value is used to show the proportion of trips in the corridor which are made by bus, and hence show the bus market share.

From patronage surveys of the bus service, the boarding and alighting passengers within each section during a particular period of the day are obtained. Using a matrix generation algorithm, the origin-destination matrix of this route is then estimated. The model is able to take into account the different patterns of full-fare and concession-fare passenger demands for this service, and is therefore able to assess the different impacts of fare changes on the two groups of passengers.

Based on the initial fare matrix, the model first generates a travel time matrix using the demand matrix and other parameters. This travel time matrix affects the demand for the service and hence generates a new demand matrix. The model is then run with the revised demand matrix, which will in turn affect the travel time matrix. The iteration process continues until an equilibrium state is reached. Figure 5 shows the basic structure of the bus model.

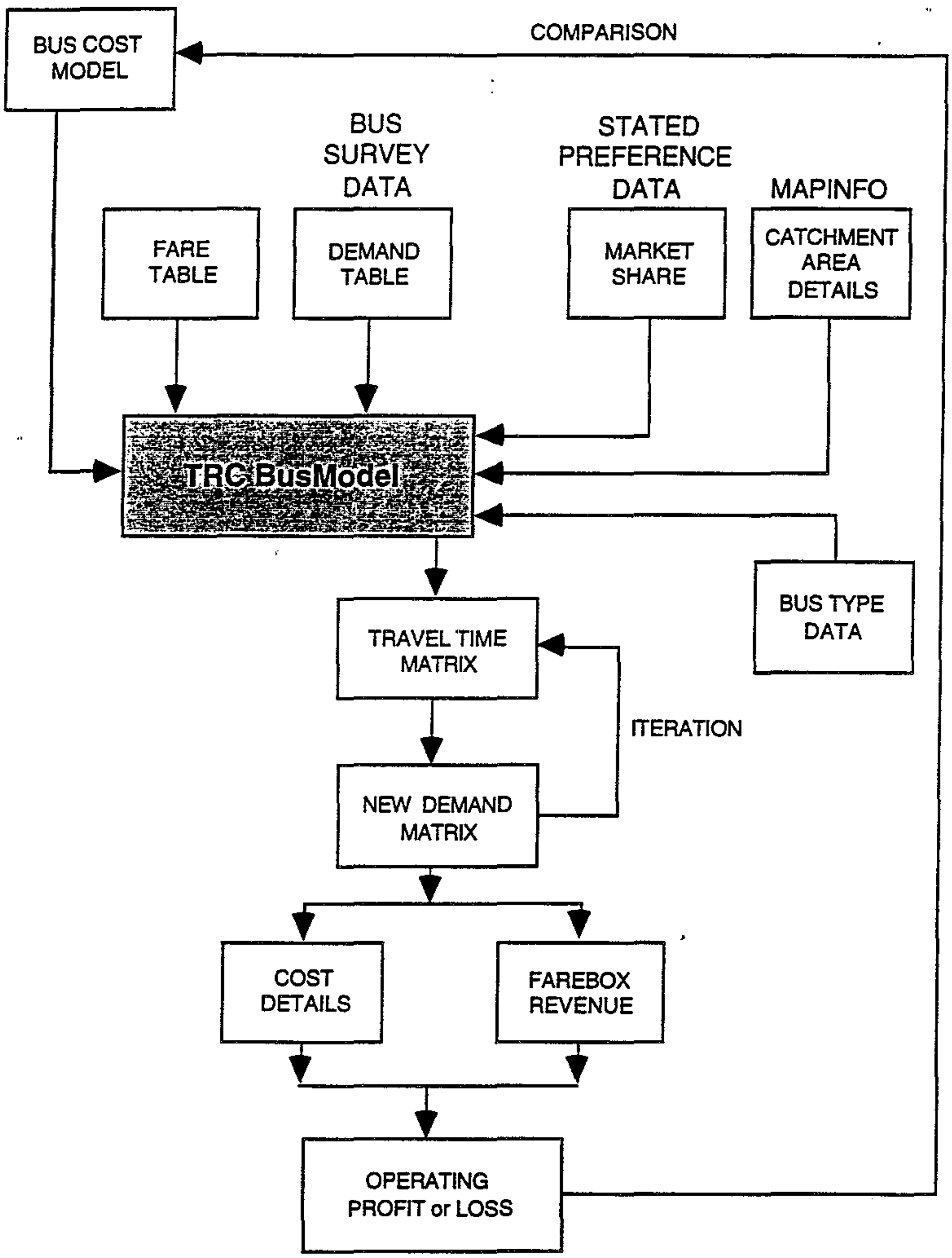

Figure 5 Basic Structure of the TRC BusModel

The TRC BusModel consists of an Excel workbook containing a number of worksheets which hold the inputs and the basic parameters of the model, the sets of equations used to calculate the effects of interactions between the supply and demand sides of the service, the results of the simulation in both numeric and graphic terms, and the macros or programs required to error check the inputs and calibrate the model against the surveyed data, as outlined in Table 1.

Table 1 Worksheets in the TRC BusModel Excel Workbook

Route Map	- Shows the routing, sections, terminal points and stops of the route.
Control Panel	- Shows a summary of the major inputs and outputs on one sheet
Inputs	- Contains all the basic parameters and other data inputs of the model.
Demand	- Shows the base and the projected demand situation of the route.
Supply	- Contains the formulas for calculating the new performance measures.
Outputs	- Displays a summary of results of the calculations in tables.
Graphs	- Displays some of the results in graphical terms.
Error Checking	- A macro sheet to check for errors in data entry

The inputs to the TRC BusModel are grouped into the following major categories:

Sectional Inputs

- Route Length (metres)
- Number of Stops
- Headway (minutes)
- Number of Signals
- Cycle Time (seconds
- Red Phase (seconds)
- Number of Priority Intersections
- Length of Priority Lane (metres)

Sectional Fare Matrices

- Full Fare Matrix
- Concession Fare Matrix

Sectional Demand Data

- Full Fare Boardings and Alightings (existing)
- Concession Fare Boardings and Alightings (existing)

Constants

- Walk Speed (metres/second)
- Catchment Area Width (metres)
- Levels of Congestion
- Days Per Year
- Length of Period (hours)
- Priority Lane Cost ($/metres)
- Priority Lane Economic Life (years)
- Priority Signal Cost ($/signal)

- Priority Signal Economic Life (years)
- Driver Award Rates ($/hour)
- Driver Cost Penalty for this Period
- Fixed Overhead Cost ($/hour)
- Dead-heading Distance and Time

Bus Type Data

- Capacity (seated and total)
- Number of Doors
- Purchase Price ($)
- Operating Cost ($/km)
- Acceleration/Deceleration Rate (kph/sec)
- Cruise Speed (kph)
- Bus Life (years)
- Passenger Loading Constant (seconds)
- Passenger Unloading Constant (seconds)
- Loading Rate (seconds/passenger)
- Unloading Rate (seconds/passenger)

The sectional inputs in the Inputs worksheet, such as the number of stops and the number of traffic signals, are used to calculate the bus travel time and stopping time in each section and hence the total bus trip time of the route. The original demand matrices are used to determine the passenger travel time matrices which in turn generate the new demand matrices. Numeric constants such as walking time and waiting factors are used in some of the formulas to calculate passenger travel time, passenger demands and operating costs of the bus service. Finally, bus type data such as passenger loading rates, bus cruise speed and acceleration rates help determine the bus trip time by calculating the loading and unloading time and the travel time of the bus.

The Demand worksheet summarises the original demand situation and the new situation after changes in fare and other parameters e.g. headway. It contains tables showing the original fare, demand, and passenger door-to-door travel time matrices as well as tables showing the new situation. A logit model to calculate the new market share of the bus service upon changes in fare or other parameters is incorporated at the end of this spreadsheet. It replaces the use of simple demand elasticities and provides more flexibility by taking into account the preferences of the users as reflected in the stated preference survey. The model takes into account the changes in fare and door-to-door travel time to calculate the new probabilities of using this service for both full-fare and concession passengers. From these probabilities, the new demand matrices are generated.

The Supply worksheet contains most of the formulas used in the model for the calculation of performance measures for the bus route. The calculations can be grouped into five major categories:

Bus Service Calculations

- Access and Egress Walk Times
- Waiting Time

- Passengers Per Stop Per Run
- Average Stop Time Per Run
- Maximum Load Per Run
- Acceleration/Deceleration Times and Distances
- Bus Running Time
- Signal Delay

Round-Trip Bus Travel Time

- Takes account of bus travel times in each direction plus the layover times at the end of each run to calculate the total turnaround time

Fleet Requirements

- Takes account of the total turnaround time and the desired headway to calculate the minimum number of buses required to service this route

Financial Evaluation

- Calculates the costs of providing the route service, and compares this with the fare-box revenue from the route to calculate the profitability of the route

Passenger Door-to-Door Weighted Budgeted Times

- Takes account of waiting, walking and travel times, and the variability of these times, to calculate the estimated time that a passenger must budget for completion of the trip

Application of the Model

The TRC BusModel may be used at a number of levels of analysis, such as:

- analysing the effect of changes in a route design for a specific time period
- estimating the annualised effect of a change in the design of a route
- analysing the effect of a company-wide change in policy or operations
- analysing the effect of government policies on the industry

As shown in Figure 6, the Bus Industry is broken up into separate Companies which each operate a number of different Routes. For modelling purposes, each route is modelled in six discrete periods: four weekday periods, plus one each for Saturday and Sunday. While the model was originally designed to operate at the route level, it can be used, with appropriate recognition of limitations, at the more aggregated levels. For example, an operator may wish to examine changes to the operation of a specific route at a certain time (such as using smaller buses in off-peaks or at weekends, or changing frequencies in peak periods) and for this type of application, the model can be run at the left-most side of Figure 6. Alternatively, the operator may wish to evaluate a route-level change such as a change in route structure which will remain in force at all times. For this type of application, the model can be run at the second level shown in Figure 6. If the operator, wishes to examine a company-wide change, such as a change in award rates for drivers, then the model can be run at a company level, affecting all routes and all times of the week.

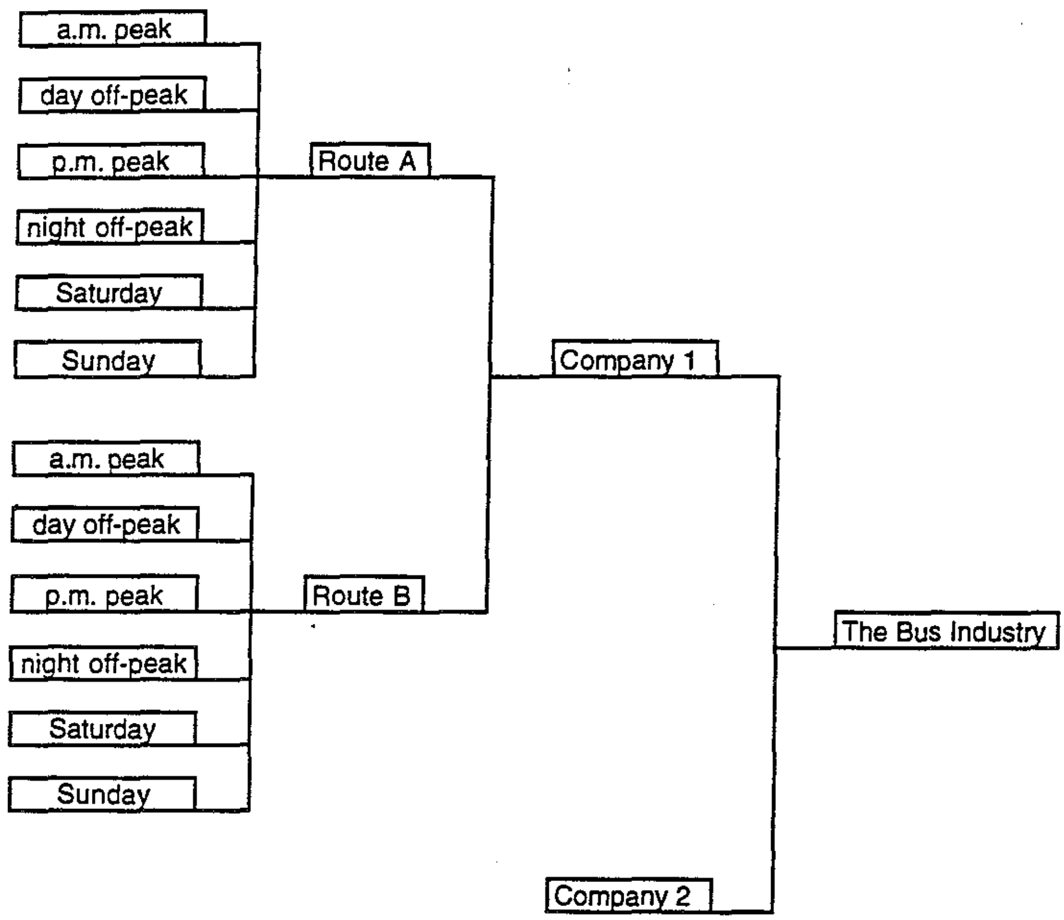

Figure 6 Operating Levels of the TRC BusModel

A more recent application of the model has been running the model at an industry-wide level to identify an appropriate structure for "commercial fare" structures. That is, what are the parameters of a distance-based fare structure which would enable the industry to operate in a commercially viable manner under current conditions of service provision and patronage. To do this, a macro has been written to control the operation of the model as it tests the effects of various fare structures (combinations of flag falls and section fare increments) for all companies, all routes and all time periods. This is a non-trivial application of the model, involving approximately 50,000 different runs of the basic model (a far cry from the pedagogical model presented at the 19th ATRF).

Conclusion

The TRC BusModel started life as a simulation model for a single bus route. It uses data from bus surveys and other sources such as the ABS Census and the Victorian Activity & Travel Survey (VATS) to replicate the real world situation and simulate the operation of a bus service. Once calibrated with survey data, the model can be used as a simple-to-understand planning tool for the bus operator to assess the impact of changes in fare or other service parameters on the service. It can also be used at a meta-level to assess commercial fare structures for the bus industry as a whole. The use of Excel 5.0 to build the model allows a high degree of transparency and flexibility of model modifications. It also allows the model to be a user-friendly tool which does not require extensive computer experience from the user. The TRC BusModel also serves as a way of introducing bus operators the importance of up-to-date market information and systematic use of analytical tools in order to compete more effectively in the new environment directed by the transport reform agenda.

References

Bus Proprietors' Associations' Association (Victoria) Inc., (1994). *Annual Report 1994*.

Manning, I. (1993). *Performance-Based Contracts for Recycling Services*. Report prepared for Recycling and Resource Recovery Council, Victoria.

Richardson, A.J. and Wang, F.S. (1994). "Domestic Solid Waste Management: the Forgotten End of the Urban Goods Movement Chain". *19th Australasian Transport Research Forum Conference.*, Lorne, Victoria, pp 583-601.

Richardson, A.J., (1994). "Operator and Customer Trade-offs in Public Transport Route Design", *19th Australasian Transport Research Forum Conference.*, Lorne, Victoria, pp 603-622.

Richardson, A.J., Lau, C., Tudorovic, J. and Wilson, D.I. (1996). *The TRC BusModel - v95.1 Documentation*. Report prepared for the Bus Proprietors' Association, Victoria.

Wallis, I.(1995). "Urban Bus Reform 'Down Under': Six Years of Words, Actions and Achievements." *4th International Conference on Competition & Ownership in Land Passenger Transport,* Rotorua, NZ, July, pp. 64-96.

13