

PLANNING FOR CHANGE IN PUBLIC TRANSPORT
SYSTEMS: MEASURING IMPACTS WITH 'IMPACTS'

I Wallis
Joint Managing Director

R Bullock
Director

B Hagberg
Senior Consultant
Travers Morgan Pty Ltd
North Sydney

ABSTRACT

In order to provide value for money, public transport operators need to respond to changes in demand patterns. These responses may include changes to timetables, routes and interchange facilities, and sometimes investment in new modes. The planner needs to develop options for change and to evaluate the impacts of those options on operator finances, on demand for services and on user benefits. This paper describes the structure and practical applications of an integrated suite of programs developed by Travers Morgan to measure these impacts in a mutually consistent way. The model is called IMPACTS (Integrated Models for Planning and Costing Transit Systems).

The particular strengths of IMPACTS over other models available include its treatment of market segmentation, particularly in relation to captive and choice public transport users; its mode split model, which enables choice between different public transport modes to be realistically modelled; its direct and precise calculation of user benefits, disaggregated by user groups where appropriate; and its incorporation of a sophisticated costing module to provide good estimates of the incremental costs associated with a wide variety of service changes.

INTRODUCTION

Public transport services are essential to the efficient functioning of major cities; all the evidence suggests that the public is willing through the taxes it pays, as well as through the fare box, to support systems which provide a good and reliable level of service.

The high level of financial support in Australia and many other countries does however create other public interests. Rightly, there is a concern that services should be provided in the most cost-effective manner so that the community's scarce resources are well spent. Australia's urban transit authorities recover about 30 percent of their total operating costs (including debt servicing) through the fare box. This is comparatively low by world standards. The other side of this coin is an annual subsidy bill to the taxpayer of about \$1.7 billion (1987/88 dollars), roughly equivalent to \$320 per year for each household in Australia.

The challenge for the transit planner is to provide services which are not only attractive to the users but which also provide value for the money provided by the taxpayer. This is true both in respect of existing operations and in considering the justification for investment in new or upgraded systems and infrastructure.

The challenge needs to be met by periodic scrutiny of how well matched is the day-to-day supply of transport services to current and latent demand (insofar as it can be discerned); and by development and review of investment programs to ensure that emerging or predicted changes in demand can be adequately met.

Demand is constantly changing in response to demographic and land-use changes as well as to socio-economic forces. Trends are established by a combination of what are individually small and sometimes imperceptible changes. Transit authorities cannot claim that they provide value for money unless they are able to respond to these trends through adjustments to service delivery.

Unfortunately, change is not generally well regarded by transit users. This is reinforced by media approaches to the subject. The introduction of a new bus or railway timetable is treated as entirely unnewsworthy unless, on its first day, at least one passenger misses the service he or she has used for the last thirty years on each third Friday of the month.

It must nevertheless be acknowledged that community familiarity with transit routes and services is an important factor affecting the use which is made of services. Generally, the customers of transit companies and authorities build up their knowledge over many years. On the whole, they do not like changes to the services with which they are familiar. Revisions to routes and timetables are therefore usually met with something less than rapture, no matter how well-intentioned the planner or how well he has deployed his resources to provide the best result for the majority of people. This can be true of even minor timetabling changes. More fundamental route restructuring is a task which is approached with

some trepidation by an experienced transit planner who knows the public exprobration which can follow from getting it wrong

The authors are well seized of the challenge, having been involved in planning and evaluating service changes in a wide range of operating environments found in Australia, New Zealand, Western Europe, China and Singapore. We have found the need to develop computer-based models which can simultaneously, and in a methodologically consistent way:

- assist the planner to identify improvements to networks and services;
- predict the impacts of such changes on the demand for services;
- assess the incremental costs of such changes in a way which enables financial evaluation of alternative plans to be undertaken;
- estimate the economic benefits to passengers, so a social cost-benefit analysis can also be completed.

The need to develop such tools, initially in Australia, arose out of perceived deficiencies in alternative models available from overseas. Some are suitable for detailed service planning but do not have sufficient sophistication in the costing approach or the economic evaluation of passenger benefits properly to assess the relative value-for-money of different plans. Most tend to operate with a fixed origin-destination matrix of passenger trips and do not allow overall demand to respond (as it does in practice) to changes in service attributes. Some cannot distinguish between the intrinsic attraction of different modes (for example as between an exclusive right-of-way mode and one which operates on-street).

In addition, some of the models available are not well dimensioned to the situations which occur most commonly, but instead require a level of detail (and hence a volume and cost of input data) which acts as a discouragement to their use. Any model should be used as an aid to professional decision-making, not as a substitute for it. We observe that the greatest modelling need of public transport planners is to be able to develop and assess a number of alternative operating strategies quickly, economically and sufficiently accurately to come to reliable conclusions, rather than to study every individual service component of a single operating pattern to the third decimal point.

The suite of programs which we have developed is known as IMPACTS (Integrated Models for Planning and Costing Transit Systems). It measures the impacts of changes in transit systems: impacts on the operator's operations and costs, on passenger demand and on user benefits (measured by the economic concept of consumers' surplus).

Section 2 of the paper describes the scope and structure of IMPACTS. Attention is drawn to the key areas where methodological integration allows consistency in model application and in the decision-making which follows from the results.

Section 3 gives a brief technical specification of the model.

Section 4 describes and contrasts three studies in which the models have been applied. The first is the restructuring of transit routes and services in the Hutt Valley area of Wellington, New Zealand. The second is the development and evaluation of alternative means of providing rapid transit services in Perth's northern suburbs. The third is a review of bus service levels in Christchurch, New Zealand.

Finally, Section 5 draws more general conclusions as to the range of applications for which IMPACTS is appropriate, and summarises its main features and strengths.

MODEL SCOPE AND STRUCTURE

The key components in the IMPACTS package are:

- .. Passenger Matrix Development
- .. Network Definition
- .. Mode Choice Model
- .. Transit Assignment
- .. Demand and User Benefit Assessment
- .. Operational Assessment
- .. Costing Assessment.

The basic structure is rather different from the 'four-step' model conventionally used in transport planning. This results from the focus of IMPACTS specifically on public transport rather than highway issues. Firstly, considerable emphasis is placed on market segmentation, by specifically identifying and distinguishing between those passengers who are captive to public transport and those who have a choice. This has major implications in dealing with potential park-and-ride (and kiss-and-ride) passengers separately from those who do not have a car available. This is an important feature, as cars are often used more than feeder buses for accessing line haul public transport services.

Secondly, IMPACTS distinguishes between different public transport modes and allows for their different modal characteristics. The normal procedure in other models is to designate a 'generalised public transport' mode and subsequently use assignment techniques to estimate the shares of total trips by the actual public transport modes available. IMPACTS, however estimates shares for the individual public transport modes using a mode split formulation. This greatly increases its realism in allocating public transport trips between modes.

Typically, the package is used first to model the existing (or base) situation in terms of usage levels and patterns, operational requirements, operating costs and fare revenue. Then, in light of the examination of the performance of the base situation, a number of options are developed and then evaluated by comparison with the base system. Figure 1 shows a typical structure of the processes involved in such applications. Some key parts of the process are now described.

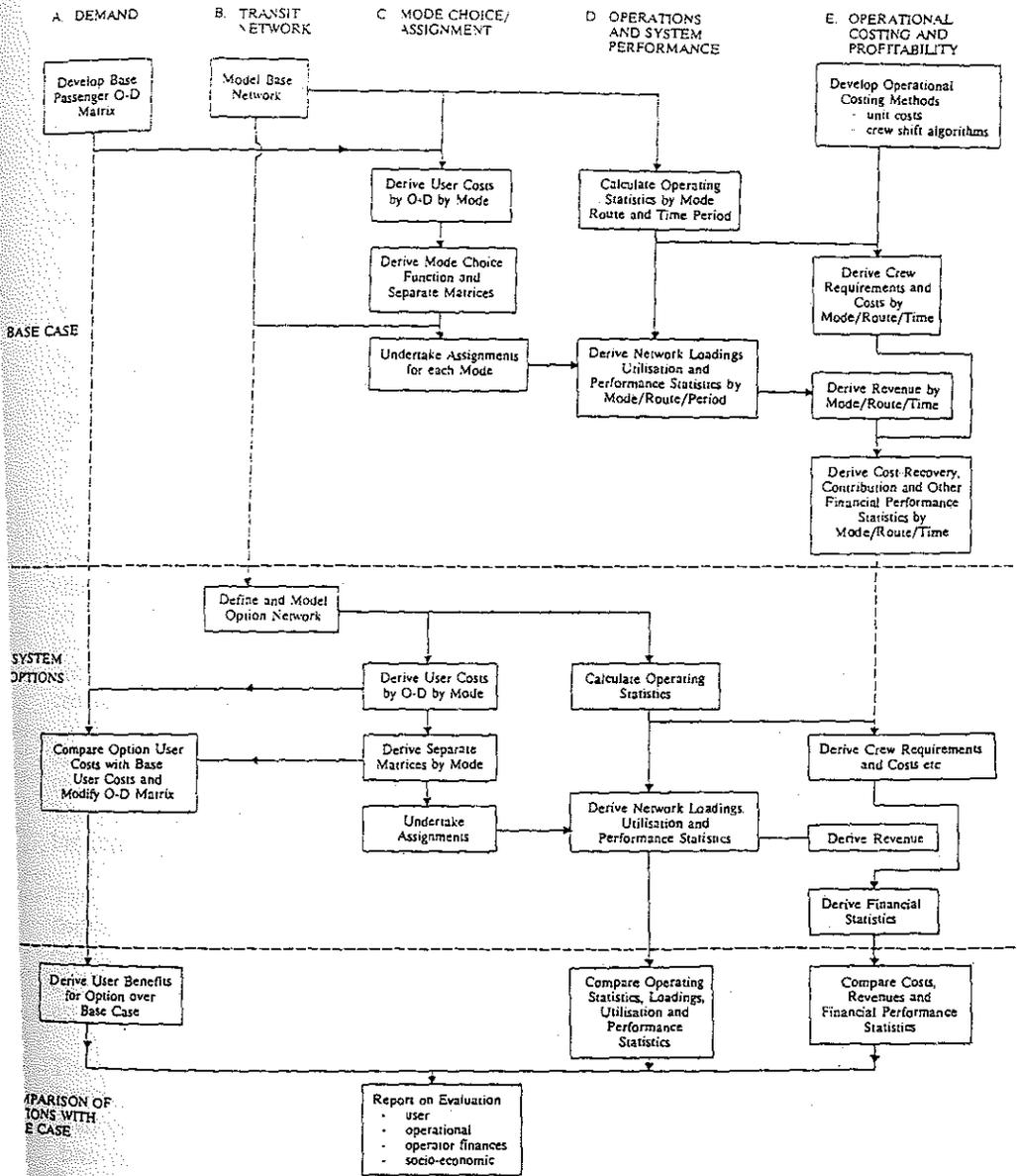


FIGURE 1: FRAMEWORK FOR TYPICAL MODEL APPLICATION

Passenger Matrix Development

The passenger matrix is a base origin-destination (O-D) table of public transport trips. It is generally developed from on-board surveys of users of existing public transport services. The surveys include details of all modes used on each trip, boarding/alighting points, points of transfer, fare/ticket type, journey purpose, access mode, car availability, etc. The length of time that the surveys cover varies with the level of detail required in a specific study and the expected daily variation in patronage.

If it is deemed too expensive to undertake an O-D survey or the time does not allow for it, O-D matrices may be synthesised from other available data sources. One important source is Census data on journey-to-work movements, which often can be successfully used if the study is to address strategic issues with the emphasis on peak periods, rather than detailed route and/or timetable planning issues.

The O-D data is assigned to a system of zones. For detailed route planning a relatively fine zone system is required. The zoning system will be influenced by the existing public transport network, accessibility, land use and so on. It is also desirable to make the zone system compatible with other zoning systems for which data is available (e.g. Census).

Passenger matrices can be developed for different time periods and/or for different trip purposes. Separate AM Peak and Interpeak passenger matrices would normally be used. The AM Peak matrix may be split between work and school demands, depending on the importance of school trips in the total passenger demand. Separate matrices for captive and choice public transport travellers are built for use in the mode split model (a 'captive' public transport user may be defined as a person without access to a car, under driving age, or without a driving licence).

Passenger matrices developed from the survey data are then expanded to give the total demand. Expansion factors are normally based on aggregate loading or revenue data available from public transport operators.

Network Definition

The public transport network describes the existing public transport system. The network components are nodes and links, with each link being defined by two adjacent nodes. The network includes public transport links, transfer links and centroid connectors (walk or car) for access to the public transport system. Each link in the network has an associated time (or speed) and distance. Each node is given a stop type (e.g. pick-up only, set-down only etc.) which defines waiting and transfer time functions. Routes are defined by a specified sequence of nodes. Route headways are used to calculate waiting and transfer time. The route travel times estimated from the network can be checked against timetables to ensure their overall accuracy.

Mode Choice Model

IMPACTS contains a public transport mode split model, with diversion to or from external modes included in a generation/suppression term. This formulation combines the effects of redistribution between different destinations due to changed service levels with generation/suppression of trips to/from the public transport sub-system. Conventional trip generation, distribution and car/public transport mode split is thus done in one single step in IMPACTS.

The mode split model determines the trips by mode between origin and destination using a logit formulation, in which utility functions covering cost, time and transfer penalties are constructed for each mode. The model is generally estimated using individual choices (disaggregate data) and then applied to groups of trip-makers (aggregate data), with appropriate parameter adjustments for the aggregation process. The principles underlying the use of utility functions are firmly founded in economic theory, in particular individual choice theory. Because of this, there are very strong links and logical consistency between the travel demand model and the evaluation of user benefits.

The utility of a trip by each mode is defined in the model in terms of cost, in-vehicle time, waiting time, walking time, number of transfers and a 'mode-specific' constant. The mode-specific constant represents the mean, over all users, of other factors affecting mode choice. For example, it may represent ease of access (additional to walking time), established operation or safety for the rail mode, or convenience (i.e. closer stops) for the bus mode.

Standard logit functions are applied to allocate public transport users between modes for each origin-destination pair, in proportion to the utilities for the modes. The total number of trips by each mode is then the sum of those using the mode for individual O-D pairs.

The sensitivity (or elasticity) of trip-making to changes in utility is determined by the trip generation/suppression factor. This factor is normally different between captive and choice users as well as between peak and off-peak, reflecting the different service elasticities that are commonly observed for different segments and time periods.

The model is estimated and results calibrated where choices between modes exist. The calibration process enables the calculation of mode-specific constants for use in forecasting demand for the options.

Transit Assignment

The public transport assignment model allows for assignment to different public transport routes that serve the same path. The split between routes is based on the relative in-vehicle travel time and headway of the routes using the same path.

When assigning existing public transport trips to the network, calibration is undertaken by checking the assigned trips against the expanded survey data (i.e. observed trips).

Demand and User Benefit Assessment

The formulation of the mode split model enables more accurate estimation of user benefits than is possible with the traditional approach using the 'rule of a half'. Presuming fare levels remain constant, the user benefits are the difference in utility between the base situation and the option: this is an integral part of the mode split estimation. Where there is more than one public transport mode or the total number of trips changes (i.e. a fixed trip matrix is not used), then the user benefits can be calculated for each trip and summed to give the total user benefits of an option over the base situation. This is of importance where a social cost-benefit analysis of the options under consideration is required. As the user benefits are calculated by O-D pair, user benefits can easily be studied on a zone or area basis. It is also relatively simple to separately identify benefits for captive and choice users. This is very useful for identifying 'winners and losers' from a particular option, and hence progressively refining the option to maximise the 'winners' and minimise the 'losers'.

Operational Assessment

Part of the output from the assignment process is the level of operating resources required to provide public transport services and various measures of service effectiveness. These statistics are output by route and time of day to enable later costing of the base situation and options. The statistics produced by IMPACTS include route kilometres and times (and therefore speeds), bus kilometres and hours, headways, the number of buses required, seat kilometres, passenger numbers and kilometres, and maximum loadings.

These statistics enable identification of routes where the level of service is relatively high or low for the patronage offering. Even if no options are to be assessed, the systematic resource analysis of the base situation often provides indications of areas of potential cost savings.

Costing Assessment

The costing of the base situation and options is undertaken by applying input unit variable cost rates to the relevant resources used. The resources commonly used in costing bus services are bus kilometres, bus hours, number of peak buses and crew hours (or shifts).

The cost allocation and cost modelling procedures used in IMPACTS are based on those developed by Travers Morgan in a number of previous studies, and described elsewhere (Hill, Wallis and Starrs, 1984). These models are particularly appropriate for deriving good cost estimates for a wide variety of service changes.

for buses and other transit modes; they are internationally regarded as being among the most advanced and accurate of their type (Savage, 1989).

IMPACTS will also estimate the revenues paid by users of services. This, together with the costs, enables a financial evaluation of existing and proposed services. Similarly, the operator costs and user benefits provide the major inputs to an economic evaluation using social cost-benefit analysis techniques.

TECHNICAL DETAILS

The appropriate size of public transport networks varies considerably between various cities as well as for different applications within the same city. IMPACTS incorporates features which accurately handle smaller networks, where a high level of detail is required, while still being able to deal with large networks where the computing time is of major importance. IMPACTS can handle networks with up to 200 zones, 1000 nodes and 400 one-directional routes. In order to improve user friendliness, IMPACTS allows for external zone and node numbers and route names to be used.

The IMPACTS package consists of about 15 individual programs. The programs are written in standard Fortran, and can be readily used on most micro-computers.

A menu-driven interface for the IMPACTS suite is currently under development. Once this is completed, users will be able to enter full details of networks, routes and stops with the assistance of standard templates and graphics: this should considerably enhance the user friendliness of the system.

APPLICATIONS OF IMPACTS

This section report three applications of the IMPACTS package to demonstrate the type and range of uses to which it can be put. In the first two the total suite was used, but for different purposes. In the third application only some of the components of the suite were used.

Hutt Valley Public Transport Study

The overall objective of the study, undertaken in 1986, was to develop more efficient and cost-effective public transport services for the Hutt Valley, in New Zealand's Greater Wellington region. It has a population of about 130,000, just under half of the region's population. An electrified rail service links the Hutt Valley with the City of Wellington. Three bus operators with about 120 buses provide services within the area, based on a route structure and timetables that have developed historically but are no longer well suited to current movement patterns.

The study required the use of all components of the IMPACTS suite to develop detailed proposals for public transport services within and to/from the Hutt Valley. The procedure adopted was to establish the existing demand for and

supply of public transport services, analyse the performance of the existing system, define options for change, evaluate the options and select the preferred option. A detailed implementation plan including timetables and crew rosters was then developed for the preferred option.

While much of the study work was concerned with bus services, rail service levels and bus-rail integration were also important parts of the study. The most appropriate location for a bus depot, bus parking facilities and the major passenger interchange point between bus and rail services were also addressed.

The preferred option included:

- An increase in the number of peak-period express train services and some increases in off-peak train service frequency. These changes resulted in a reduction in 12 electric rail cars for peak services.
- Changes in bus route structure and peak bus frequencies to better match services to peak period demand patterns. In the off-peak increases in service were recommended ranging from 40% in the weekday interpeak period to 100% on Sundays. These changes resulted in a reduction of 16 buses in peak period service, partly offset by the extra bus kilometres operated in off-peak periods.

The evaluation of the preferred option considered user benefits as well as costs to the operators. The overall user impacts of the recommended bus/rail system changes in the peak were broadly neutral: little net change in travel times, convenience, etc. was expected, although some groups would gain slightly and others lose slightly. Only small changes in peak period patronage were predicted. For off-peak periods on the other hand, substantial user benefits were expected to result from the reduced waiting times and increased convenience: an increase in off-peak patronage of 15% was predicted.

Substantial savings in costs to public transport operators were estimated from the system changes. Major capital cost savings would result from the smaller fleets for both rail and bus services (12 electric railcars and 16 buses). Net operating cost savings of \$530,000 pa were estimated for rail services and \$300,000 pa for bus services (NZ\$1986/87).

The recommendations of the study were fully accepted. The main changes were introduced in early 1989, following construction of the new passenger interchange and bus depot. The changes appear to have been well accepted by users and operators alike.

Public Transport for Perth's Northern Suburbs

This study examined public transport in the northern suburbs of Perth, with particular emphasis on opportunities for implementing a rapid transit system. The study area contains about 300,000 people, 30% of Perth's population, and is the

most rapidly growing residential sector in Perth. A high quality road system and comprehensive bus services cover the area. The study was oriented primarily to selecting the best new mode of transport for the corridor, rather than to making the best use of existing infrastructure (as in the Hutt Valley).

The full IMPACTS package was again used in this study. A preliminary review of route options for the rapid transit facility identified the median of the Mitchell Freeway as the preferred route, the freeway having been designed so as to accommodate such a facility. The study was then concerned with the most suitable technology to use this route (electrified rail, conventional busway, guided busway) and with the associated feeder bus routes to serve the adjacent areas. Extensive public consultations were also carried out.

All options were estimated to increase total public transport patronage in the northern suburbs. The predicted increase was somewhat greater for busway options than for an electrified railway, primarily because fewer users would be required to transfer between modes: the busway options allow pick-up of passengers in the suburbs before joining the rapid transit route to Perth. The increase in patronage due to a rapid transit system (over the base case) was estimated to be 14% for busway options and 12% for an electrified railway in the peak period. Interpeak patronage, which comprises largely captive users, was forecast to increase by about 6% for both busway and electrified railway options.

User benefits were estimated to be slightly higher for the busway options than the electric railway option. This has been criticised by some: it is however a reasonable result given the relative total journey times and convenience of bus and rail modes. Although an electrified railway would achieve higher line-haul speeds than a busway, it would require more passengers to transfer, which adds to total journey time and perceived inconvenience.

In overall economic terms, there was little to choose between the busway and the guided busway options. The rail option had poorer economic performance, largely due to its higher capital cost relative to the busway options.

The study therefore concluded that a busway was currently preferred to an electrified railway on the technical and economic evidence, but that a railway might be justified in the future using the right-of-way established. But the report noted:

"... that pure economic and technical considerations do not always give the best perceived result for the community in general, and that political judgement has an important influence on decisions of this type."

In the event, political judgement did indeed overtake the results of the study with the government announcing that an electrified railway would be constructed, following consideration of the planning and developmental benefits that it felt could be attributed to a railway compared to a busway.

Urban Bus Study, Christchurch

This study was undertaken during 1988 for the New Zealand Urban Transport Council (UTC). The UTC provides subsidy funds to NZ bus operators and so has an interest in ensuring that services are provided efficiently and effectively. The objective of the part of the work described here was to examine peak service levels to determine whether services could be provided more efficiently by better matching of supply to demand. The study thus did not require use of the full IMPACTS package but concentrated on the operational planning and costing modules.

The study started with a review of peak period passenger counts at the maximum load points on each route. These were found to have declined significantly over the previous few years and to be low by comparison with reasonable loading standards and levels for other operators.

Detailed proposals were developed for deletion of certain peak trips and for associated driver re-scheduling. These resulted in a reduction of 15 buses in service in the critical peak times, which represented about 10% of the peak bus requirement, but only about 2% of total bus kilometres. These changes were estimated to reduce operating costs by about \$1 million p.a. (NZ\$1988), based on cost assessments using the IMPACTS costing models.

These proposals were fully accepted by the operator and implemented within a period of a few months, with very little adverse user reaction.

The work had also indicated that there was potential for further rationalisation of peak service levels in the medium term, if more detailed work was undertaken. This suggested policy was taken up by the operator in response to severe budget constraints: work is currently in hand to reduce services by a further 10%-15% in ways which will have least adverse impact on passengers.

CONCLUSIONS

This paper has described the IMPACTS package developed by Travers Morgan for the planning of urban public transport services, and has reported three successful applications. The package has been developed incrementally and its development will continue in the future.

The major strengths of IMPACTS are:

- its treatment of market segmentation, particularly in relation to captive and choice public transport users;
- the mode split model, which enables choice between public transport sub-modes to be realistically modelled;
- the formulation of the mode split model which enables accurate calculation of user benefits when a choice between public transport modes occurs or the total number of trips changes;

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- the production of operating statistics by route to assist assessment of the effectiveness of the public transport system; and
- the incorporation of a relatively sophisticated costing module which can be used to provide good estimates of the incremental costs associated with a wide variety of service changes.

The IMPACTS package has been developed as other available software was not suitable for many applications. The package provides the normal network planning functions of most similar packages. But it also provides the outputs to enable operational, financial and economic assessments to be readily made of any proposed changes. Either the full package or selected modules can be used depending on the objectives of a particular study.

The three examples of the application of IMPACTS indicate that relatively large savings in both capital and operating costs can be made as a result of its use by skilled professionals. In the Hutt Valley, IMPACTS was used to identify means of providing more effective and efficient services by revamping the bus route structure and revising bus and train service frequencies. In the northern suburbs of Perth, IMPACTS was used to determine the best technical and economic option for a new rapid transit system in a major corridor. In Christchurch, parts of IMPACTS were used to identify resource and cost savings that could be achieved by adjusting peak period service levels to better match existing demands. In addition to these three examples, the package has also been used successfully in a number of other planning studies over the last few years.

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