

This is author version of article published as:

Johnston, Katherine A. and Ferreira, Luis and Bunker, Jonathan M. (2006) Using Risk Analysis to Prioritize Intelligent Transport Systems: Variable Message Sign Case Study in Gold Coast City, Australia. *Transportation Research Record: Journal of the Transportation Research Board* 1959:pp. 28-36.

Copyright 2006 Transportation Research Board

Using risk analysis to prioritise intelligent transport systems: a variable message sign case study in Gold Coast City, Australia

Kath Johnston (formally Marschke) (corresponding author)
Senior Engineer (Traffic Management)
Queensland Department of Main Roads AND
Queensland University of Technology
GPO Box 1412
Brisbane Qld 4001
AUSTRALIA
Ph: 61 4 3834 9438
Fax: 61 7 3834 9401
katherine.a.johnston@mainroads.qld.gov.au

Professor Luis Ferreira
School of Urban Development
Queensland University of Technology
PO Box 2434
Brisbane Qld 4001
AUSTRALIA
Ph: 61 7 3864 1542
Fax: 61 7 3864 1515
l.ferreira@qut.edu.au

Dr Jonathan Bunker
School of Urban Development
Queensland University of Technology
PO Box 2434
Brisbane Qld 4001
AUSTRALIA
Ph: 61 7 3864 5086
Fax: 61 7 3864 1515
j.bunker@qut.edu.au

Submission date: 31 March 2006

Word count: 7500 (including 13 tables/figures @ 250 each)

ABSTRACT

With perpetual strains on resources, road agencies need to develop network-level decision-making frameworks to ensure optimum resource allocation. This is especially true for intelligent transport systems (ITS), and in particular, variable message signs (VMS), a key component of incident management services. The objective of VMS is to minimise the safety, efficiency, reliability and environmental impacts of incidents on the operations of the transport system. This may be achieved by informing travellers of the incidents so they can adapt their behaviour in a manner that reduces community impacts, such as lateness and the associated vehicle emissions, unreliability of travel times, as well as secondary accidents due to incidents.

Generally, road authorities do carry out needs assessments, but qualitatively in many cases. Therefore, this paper presents a framework that is systematic, quantitative and relatively easy to implement. A risk management approach which focuses on minimising the impacts on, and costs to, the community, was taken to prioritise VMS infrastructure deployment. In the framework and case study presented in this paper, safety, efficiency, reliability and environmental impacts are quantified using an economic risk management approach to determine an overall risk score. This score can be used to rank road sections within the network, indicating the road sections with the highest risk of incident network impacts and therefore the road sections with the highest need for intervention. A cost-effectiveness based risk-reduction ranking can then be determined for VMS, comparing the net risk with treatment to that without treatment, and dividing by the net present value of deployment. The two types of ranking, pure risk and cost-effectiveness based risk reduction, will help to minimise the network impacts on the community and optimise resources allocation.

1. INTRODUCTION

Transport agencies around the world are shifting focus from conventional road engineering construction to traffic management and enhancing existing road networks. Variable message signs (VMS) are part of an overall suite of deployment transport options called Intelligent Transport Systems (ITS), distinct from major road construction projects. The objective of VMS is to minimise the safety, reliability and environmental impacts of incidents on the operations of the transport system. This may be achieved by informing travellers of the incident so they can adapt their behaviour in a manner that reduces individual and community impacts, such as lateness and the associated vehicle emissions, unreliability of travel times, as well as secondary accidents due to incidents.

The aim of evaluating ITS treatments is four fold (1). Firstly, ITS is evaluated to understand the social, economic and environmental impacts on the transportation system and its users. By understanding the impacts, the benefits can be quantified. Both of these elements help transport agencies to optimise public sector investments by making future investment decisions. Finally, ITS evaluations help to identify areas of improvement for existing operations or systems. With perpetual strains on resources and traffic increasing at a steady rate, transport agencies need to evaluate the road network and make informed decisions to determine which road sections have the greatest risk of adverse incident impacts and therefore identify the road sections that have the greatest case for intervention. This is the case for ITS and in this case, VMS, but what is the optimal evaluation method?

As with conventional transportation infrastructure projects, the most common way to evaluate VMS is using economic analyses, such as benefit-cost. Unfortunately, VMS impacts are difficult to monetise for a number of reasons. Historical information for VMS impacts is not always readily available and impacts are generally not transferable. In contrast to conventional projects, VMS impacts are incremental to the individual user, but usually have a much wider area of impact. Incremental changes to each individual user and project take-up-rate depend on behavioural responses. To overcome these issues, VMS impacts are usually determined using stated preference surveys and modelling tools. Moreover, the costs to quantify the impacts of VMS projects have the potential to exceed the benefits of the project outcomes.

To overcome the problems with monetising ITS impacts, agencies are increasingly applying multi-criteria analyses to evaluate ITS. The approach involves the decision-maker(s) to score and weight each criterion. A benefit cost ratio can be included as a criterion thereby combining both quantitative with qualitative criteria. There are two fundamental shortfalls of multi-criteria analyses (2). There is no single solution optimising all criteria, so the decision-maker must compromise between solutions. As such, the method is not well structured mathematically. Further, optimising one criterion often reduces the value of another criterion; therefore many solutions cannot be compared in terms of dominance.

The two common evaluation tools are insufficient for VMS evaluation. Therefore, a new network evaluation framework is presented in this paper for ITS and in particular VMS deployment. The framework aims to analyse the road network and prioritise roads with respect to two factors: the historical risk associated with incidents; and the cost effectiveness of implementation. To assess the historical risk, the framework initially converts social, economic and environmental impacts to a common monetary base, enabling the addition of the incident impacts. The economic impact values must be treated as relative values of measurement, not absolute costs. The second part of the framework assesses the historical risk, taking into account both the consequence of an event, measured in economic terms described above, and the probability of an event occurring based on historical information.

The third uses a cost-effectiveness based ratio comparing the reduced impacts with the project costs.

To test this model, 2002 traffic count and incident log data from the Gold Coast region in Australia was collected and processed using the framework. The Gold Coast region has a land area of 5,734 square kilometres (2,214 square miles) and a population of 425,400 (as at June 1997).

The economic risk analysis presented below integrates safety, reliability and environmental impacts, providing an integrated decision-making tool for proactive VMS deployment decision-making. It is an improvement on the benefit cost analysis and multi-criteria analysis methodologies, but does not overcome all the deficiencies.

2. ITS EVALUATION: STATE-OF-PRACTICE

There are two significantly different views of how Intelligent Transport Systems (ITS), and hence Variable Message Signs (VMS), should be evaluated. One opinion is that a completely new framework should be developed to evaluate ITS; whilst the other view is that the existing road evaluation procedures should be used but the methods of measuring and valuing the impacts be adapted to ITS. Some authors agree that there is little difference between ITS and conventional road projects and that it is sufficient in most cases to apply existing evaluation methods to assess ITS projects (3). Gillen and Li recognise that the problem lies in the measurement and valuation of cost and benefits with the lack of historical data (4). In contrast, Bristow et al. suggest that current evaluation procedures are not suited to measuring or valuing many of the impacts that form the rationale for some ITS projects (5).

2.1 Why ITS differs from conventional road engineering

ITS projects may have new impacts beyond those included in the evaluation of traditional road infrastructure projects. Depending on the type of ITS project, these new impacts may include:

- ◆ Travel time reliability improvements;
- ◆ Improved control over travel choices;
- ◆ Travellers' 'peace of mind' and enhanced comfort;
- ◆ Privacy compromise due to surveillance nature of some ITS applications leading to higher levels of take-up rate uncertainty; and
- ◆ Greater risk in implementation due to greater technological content and uncertainty in predictions of the project's impact.

Conversely, some common impacts are generated by different mechanisms or with varying elasticities. For example, a traditional road project may effect changes in vehicle operating costs by improving the road surface or changing the average speed whereas an ITS project may affect the vehicle operating costs by changing number of stops a vehicle makes.

The main problem with ITS evaluation is that all evaluation methods require qualitative and/or quantitative data, both types being relatively sparse due to the evolving nature of ITS projects. For this reason the availability of data may be a constraint in conducting an ITS evaluation.

The success of some ITS applications depends on the behavioural response of travellers (5). For example, alternate route recommendation displayed on a VMS will have no effect of alleviating congestion if travellers do not comprehend and act upon the message. Traveller behaviour is influenced by prior personal experience, knowledge of the network and

the behaviour of other drivers, as well as the availability of the ITS system in the case of in-car ITS applications (3).

It has been stated that ITS projects are more complex than conventional road projects, that is, the impacts of the interactions and synergy between components are often more significant than the effects of any individual component (6). To account for this complexity, an ITS evaluation methodology must be capable of evaluating the impacts of individual components of the project, as well as the resultant impacts of various combinations of components.

2.2 ITS evaluation methods

Although benefit cost analysis (BCA) is the most commonly used method of evaluation for ITS projects, the single output benefit cost ratio (BCR) is based on many assumptions about the monetary values of benefits. This problem could be overcome by incorporating a BCR as one of many evaluation indicators into a goals based evaluation framework such as multi-criteria analysis (MCA) (1). While this solution will avoid exclusion of project impacts, it may lead to double counting of certain impacts that could be included in both the BCR and the MCA. Baum and Schultz recommend the use of either BCA or cost effectiveness analysis in ITS project evaluation (7). Similarly, Bristow et al. recommend that cost-effectiveness analysis be used when benefits are difficult to measure or in addition to BCA as a means of sensitivity analysis (5).

Cost-effectiveness compares alternative projects on the basis of the project cost and a single measurable project impact. The European Union EVA ITS evaluation manual recommends the use of BCA where standard monetary values of measurable impacts are available, MCA where monetary values are not available for measurable impacts and cost effectiveness analysis where monetary values are available only for costs and a specified impact level is achieved (5).

The use of risk analysis techniques has increased in the areas of transport safety and infrastructure maintenance and takes into account not only the consequences of failure, but also the probability of a failure occurring. This statistical analysis makes risk analysis unique. This form of analysis has benefits in the evaluation of ITS projects and network evaluations. Dalziell et al. use risk analysis to evaluate the risk of a road closure occurring due to random events such as accidents or bad weather (8). Hence mitigation options can be assessed and an optimal distribution of incident management resources determined.

Performance indicators tell an organisation a great deal about the system, but are just an isolated representation of data. The data needs to be compared against a benchmark; a standard of some sort. A gap or deficiency analysis can be used to identify large gaps between performance and standards and be used to systematically manage and monitor the problem areas of a network (9).

Gap and system analysis techniques are well advanced in the area of maintenance. For example, Hunt and Bunker developed a model combining both cumulative and probability density functions forming a frequency network profile of pavement performance (10). A set of descriptive pavement performance categories (good/fair/poor) was developed using roughness progression and high maintenance expenditure pavement ratings. The categories provide a method of combining a number of performance indicators into one measure of 'absolute' performance. From the network profile, Hunt and Bunker were able to predict the percentage of roads requiring maintenance over a 10-year period. A similar technique could be used for ITS evaluation as a tool to evaluate the network.

3. THEORETICAL BASIS OF ECONOMIC RISK MODEL

Risk is defined as the product of the likelihood of an event and the consequence of the event (11). Conventional engineering risk analysis has focused on equipment failure such as bridge and pavement failures. In the case of Variable Message Signs (VMS) in particular, the risk is of an incident event impacting upon a traffic network. Therefore, an “impact event” may be defined as any incident that reduces the ability of a section of infrastructure to offer a safe and reliable means of travel.

Applying this general risk theory to incident management deployment is summarized in the flowchart in Figure 1.

(insert Figure 1 about here)

Incident events can be categorized as safety, reliability and environmental. Table 1 describes examples for each category for illustration.

(insert Table 1 about here)

Vehicle operating costs such as fuel, tire and oil costs are not included in the framework due to the limited accurate data available. If speed data is recorded for all incidents, it should be included in future frameworks.

Annual incident consequences are determined by summing the consequence categories for each incident then summing the total incident consequences for the year. Furthermore, the average consequence for a road segment can be considered as the annual incident consequences, divided by the number of incidents. To complete the risk valuation, the probability or likelihood of an impact event occurring is equal to the number of times an event occurs, divided by the total sample size, for example, the total number of significant days in a year (12). A significant day is one in which an incident will have a considerable impact on the network. Therefore, the risk score can be expressed as the total annual consequence for the road segment, divided by the number of significant days in the year, which depends on road type (see Table 2).

(insert Table 2 about here)

Using the risk score, the pure risk of each road segment can be used to rank roads from the highest risk, to the lowest risk. This provides the decision-maker with important information regarding roads with the highest incident impacts on users.

Australian Road Research Board (ARRB) have developed a road safety risk management methodology and software for Austroads. The work provides a decision making tool to evaluate the benefits associated with a wide range of road safety engineering treatments. The tool takes account of the road safety risk before a treatment, as measured by exposure likelihood and severity outcomes of road crashes and uses research data to estimate the reduction in risk after treatment. Incorporating the treatment cost provides a Risk Reduction Cost Ratio that allows for prioritization of different projects across the network (13). A similar approach has been used here, however the reduction is determined in terms of cost of consequences. Therefore the reduced cost of consequences for a road segment can be expressed as the cost of consequences before treatment minus the cost of consequences after treatment.

The consequence reduction calculation can be used to determine the impact reduction if VMS is deployed. From the consequence cost reduction, a cost-effectiveness ratio can be calculated, by converting the consequence cost reduction to present value terms and dividing by the net present value of treatment. Similar to a benefit cost ration, this ratio can be used to distribute resources in the most cost-effective manner, assuming that treatment costs are well within the resources available.

Ranking the roads from highest cost effectiveness ratio to the lowest enables a systematic and justifiable method of prioritizing incident management deployment. This is the second type of ranking: cost-effective consequence reduction. Both methods of ranking allow us to both minimize the incident network impacts on the community and maximize resource effectiveness together.

Following the network-level prioritization, more detailed project-level analyses are required to evaluate incremental costs of implementation to an area irrespective of ranking. For example, it may be feasible to implement ITS in a low priority roadway section that is between two high priority sections to ensure complete system coverage and user system confidence.

4. MONETISING INCIDENT IMPACTS

The consequence of a traffic incident can be considered as the collective severity of an event upon the individuals exposed to the event. This may be broken into two parts. Firstly, the number of individuals exposed over the duration of the impact event; and secondly, the severity of the impact event upon each individual exposed to it. The severity or impact of an event can be expressed in economic terms.

Each impact event can be monetized using the available routine data from the road network. This is described in more detail in the following sections.

4.1 Safety impacts

The safety impacts of incidents include secondary accidents. A secondary accident can be defined as an accident that occurs within half an hour of the initial accident along the same road segment. Half an hour was believed as a reasonable timeframe for a secondary accident to be related to a primary accident. The initial accident is not included in this analysis since the focus of this research is related to reducing the impacts of incidents, rather than reducing incidents in the first place.

The safety impact values in Table 3 are measured in crash costs by severity categories: fatalities; serious injuries; minor injuries; and property damage taken directly from Section 4.2 in Austroads' "Guide to Project Evaluation Part 4: Project Evaluation Data" (14). These values are state averages for Queensland and relate to the total community costs associated with road crashes. Austroads recommend that the values are suitable for general road project evaluation where precise definitions of crash types are not required. Property damage (PDO) is included in the analysis since this type of damage also has community impacts and can be improved by incident management services. At the time of writing, AU\$1.00 was worth approximately US\$0.75.

(insert Table 3 about here)

4.2 Reliability impacts

The reliability impact of incidents is defined here as lateness. That is, travel time greater than the average expected travel time, taking into account the time of day. Therefore reliability is measured with respect to the unpredictable travel time for drivers and passengers in both private and commercial vehicles. The cost of lateness depends on the following exposure and severity factors: volume of traffic exposed to the incident; average occupancy of vehicles (i.e. the number of occupants of each vehicle); distribution of vehicle types; duration of the

incident; lateness caused by the incident; and the percentage of road blocked to traffic. Therefore, the reliability impacts can be expressed as:

$$C_{Rx} = \sum_{j=1}^9 DL' D' K' V_j T_j \quad \text{Equation 4.1}$$

Where C_{Rx} = cost of lateness for incident x in dollars

D = estimated lateness caused by incident x in hours

L' = percentage of road closure/blocked factor for incident x

D' = directional distribution factor of carriageway impacted upon by impact event for incident x

K' = proportion of AADT occurring during incident x

j = vehicle type

V_j = average daily volume of vehicle type j

T_j = average travel time value for vehicle type j (see Table 4) in Australian dollars
(insert Table 4 about here)

Austrroads have developed values of travel time for vehicle types based on surveys and occupancy values for each vehicle type (14). This information has been averaged and adopted to suit the count data collected (see Table 4). However, since there is a considerable difference between the private and business passenger car values in the original Austrroads table and the trip purpose cannot be measured by traffic count analyses, the values in Table 5 are based on the split of business and private trips from the 2004 South East Queensland (SEQ) Travel Survey. Table 5 below indicates the values used, which are averaged over a 24 hour period.

(insert Table 5 about here)

Most project evaluation methodologies recommend the use of a single value of time for all levels of delay or lateness. In addition to this method, we have tested the impact on the results of adopting a different approach where short delays (up to 20 minutes) are valued differently from longer delays (over 1 hour), as shown in Figure 2. It was assumed that travellers experienced 30% of travel time values in the first 20 minutes of delay indicating that a shorter delay is less inconvenient. Delays between 20 minutes and one hour were valued at the Austrroads' travel time value, while delays longer than an hour were valued at double the published value. For reference, the evaluation guidelines developed by the UK Department of Transport has valued unexpected delays or lateness at up to five times in-vehicle time (15).

(insert Figure 25 about here)

Average daily volume data (V_j) can be obtained directly from traffic count data. These volumes, by vehicle type, must be converted into the volume of vehicles exposed to the incident. This is achieved through the K' and D' factors. K' is the proportion of the daily volume occurring during the incident. D' is the directional distribution factor and represents the proportion of vehicles traveling in the direction affected by the incident.

The percentage of road closed or blocked is represented by L' . This factor represents reduced capacity caused by the incident. Table 6 indicates the values used in this analysis.

(insert Table 6 about here)

4.3 Environmental impacts

Tables 7 and 8 below summarize externality costs based on Tables 5.3 and 5.4 in Austrroads' "Guide to Project Evaluation Part 4: Project Evaluation Data" (14). The monetizing of environmental and other externalities is relatively immature in Australia. The values shown

below are based on research by environmental authorities, Bureau of Transport and Regional Economics (BTRE) and universities and require updating as research becomes available.

Noise, water pollution, urban separation, and nature and landscape are environmental impacts included in Austroad's evaluation data, but have not been included in this model. Vehicular noise does not increase with incident congestion. Factors such as terrain and vehicle types affect noise. Similarly, water pollution does not increase with incident congestion. Both urban separation, and nature and landscape impacts are related to road construction rather than incident management.

(insert Table 7 about here)

(insert Table 8 about here)

5. GOLD COAST CASE STUDY RESULTS

The framework described in sections 3 and 4 was tested using data from the Queensland Department of Main Roads South Coast Hinterland District. The district encompasses the Gold Coast and surrounding regions and has a land area of 5,734 square kilometres (2,214 square miles) and a population of 425,400 (as at June 1997).

5.1 Data

The following data was used to test the framework:

- ◆ 2002 incident data from the traffic management centre incident logs and traffic count information;
- ◆ Tonne-kilometre data from Main Roads' head office;
- ◆ 2002 classification data and road lengths from the district office; and
- ◆ The percentage split of business and personal trips was obtained from the Brisbane 2004 travel survey.

Since the case study location is in a strong tourist area, the number of significant days for the risk analysis was considered 365 for all road types. Large volumes of tourist traffic on weekends and commuter traffic on weekdays imply that an incident on any day of the year will cause a significant impact.

5.2 Variable Message Signs (VMS)

VMS displaying incident information has been used as an example of the application of the risk framework. To determine the risk reduction of installing a VMS, the following benefits were assumed:

- ◆ 10-20% reduction in the probability of secondary crashes;
- ◆ 2-5% reduction in travel time or lateness; and
- ◆ 0.5-1% reduction in vehicle emissions.

This information is based on the results found in the literature. Although ITS benefits generally are non-transferable, this information is considered adequate at this stage of research. Following local before-and-after studies of VMS deployment, these values can be updated in the framework.

Similarly, to calculate the net present cost (NPC) of the VMS, the following values were assumed and can be updated in the future:

- ◆ Capital cost of AU\$150,000;
- ◆ Ongoing maintenance cost of AU\$7,5000 per annum;

- ◆ Life of five years;
- ◆ Discount rate of 5%; and
- ◆ One VMS every 5 kilometres (3.1 miles) of road.

5.3 Rankings and discussion

In this research, there are two methods for ranking road segments for risk. Tables 9 and 10 rank road segments by pure risk and cost-effectiveness respectively.

(insert Table 9 about here)

The road segments in each table are state-controlled roads in the South Coast Hinterland District, Queensland, Australia. The results shown are based on data for one year and therefore they should be considered as an illustration of the methodology only. For a full analysis it would be necessary to use significantly more data. To illustrate, only one secondary accident was recorded in the district during the analysis period. Therefore, safety benefits of VMS have not been included in the analysis. If the analysis was conducted using average values over a 5-year period, a more accurate safety impact would be demonstrated.

(insert Table 10 about here)

The ranges of values in Table 10 are due to the uncertainty of VMS benefits, as discussed in Section 5.2. The roads with cost effectiveness ratios (CER) of zero indicate that deploying VMS will have minimal impacts on travel times and secondary accidents. It is important to note that the CER is not a benefit cost ratio. The analysis period considered was a conservative 5 years, due to the relatively short life span of technology. Also, many VMS impacts were not easily monetised and hence not included. Drivers who are exposed to VMS incident messages experience a level of comfort and convenience that is difficult to measure. VMS have the potential to be used for other information applications and the community expect VMS information services from the agency. For these reasons the CER values are used as a network analysis and ranking methodology not for project justification.

The ranking in Table 9 is independent of implementation costs while Table 10 takes into account the cost of deploying VMS. Both ranking methods are important, as public agencies must consider the risks to the community, independently and depending on cost-effectiveness. Eleven of the road segments moved up a few rankings when considering implementation costs. This is not a significant change, but it is important to note that by taking into account cost-effectiveness of implementation, the ranking differs from the pure risk.

Table 11 below indicates the change in cost effectiveness rankings, for the same road segments, using the same data, but making a different assumption about the valuation of lateness. The travel time value changes depending on the delay or lateness, as described in Section 4.2 above. Again, many of the road segments changed in the ranking, reinforcing that the decision-maker(s) must be careful of assumptions.

(insert Table 11 about here)

6. CONCLUSIONS

There is an urgent need for network analysis tools to prioritise and rank ITS and in particular VMS. The risk analysis framework presented in this paper forms a basis for VMS network prioritisation enabling the agency to make informed decisions. The decision-maker(s) can determine which roads require further, project-level analysis using budget information and both ranking methods: pure risk and cost-effectiveness. Using the two ranking methods is vital to ensure both community and cost-effective needs are met. The example shown in the

South Coast Hinterland District case study indicates that the method is sound, but each agency must be careful of the assumptions of network impacts, for example the value of travel time. The economic risk analysis provides results that ensure the optimum use of agency resources across the road network.

7. ACKNOWLEDGEMENTS

This research was conducted under the Memorandum of Understanding (MOU) between the Queensland Department of Main Roads and the Queensland University of Technology in Brisbane, Australia.

REFERENCES

1. Turner, S., Stockton, W.R., James, S., Rother, T., Walter, C.M., *ITS benefits: review of evaluation methods and reported benefits*. Texas Department of Transportation, Austin, Texas, 1998.
2. Tsamboulas, D., Yiotis, G.S., and Panou, K.D., Use of multicriteria methods for assessment of transport projects. *Journal of Transportation Engineering*, Vol. 125 No. 5, 1999, pp. 407-414.
3. Underwood, S.E., and Gehring, S.G., Framework for evaluating intelligent vehicle highway systems. *Transportation Research Record*. Vol. 1453, 1994, pp. 16-22.
4. Gillen, D., Li, J., Evaluation methodologies for ITS applications, California Path Program report UCB-ITS-PWP-99-2, Institute of Transportation Studies, University of California, Berkeley, 1999.
5. Bristow, A.L., Pearman, A.D., and Shires, J.D., An assessment of advanced transport telematics evaluation procedures. *Transport Reviews*, Vol. 17 No. 3, 1997, pp.177-205.
6. Harris, R., Staats, R., and Bailey, R., ITS evaluation: A new framework. *29th International Symposium on Automotive Technology and Automation*, Florence, 1996.
7. Baum, H., and Schulz, W.H., Economic evaluation of chauffer. *4th World Congress on Intelligent Transport Systems*, Berlin, Germany, 1997.
8. Dalziell, E.P., Nicholson, A.J., Wilkinson D.L., *Risk assessment methods in road network evaluation*, Report by Transfund New Zealand, Wellington, 1999.
9. Ogard, E., Pagano, A.M., et al., A model process for linking asset management to strategic planning. *Transportation Research Board Annual Meeting*, 2004.
10. Hunt, P.D., and Bunker, J., Study of sire specific roughness progression for a bitumen-sealed unbound granular pavement network, *Transportation Research Record*, Vol. 1819, 2003, pp. 273-281.
11. Standards Australia and Standards New Zealand, *Risk management*, Sydney, 2004.
12. Smith, P.J., *Into statistics: A guide to understand statistical concepts in engineering and sciences*. 2nd edition, Springer, Berlin, 1998.
13. Austroads, *The road safety risk manager software tool: Background research*. Austroads report AP-R222, Sydney, 2003.
14. Austroads, *Guide to project evaluation part 4: Project evaluation data*. Austroads report, Sydney, 2004.
15. UK Department for Transport, *Transport Analysis Guidance*, <http://www.webtag.org.uk/>, updated: 05/01/05, accessed: 29/07/05.
16. Stockton, W.R., Walton, C.M., and Goodin, G.D., *Estimating ITS benefits: Guidelines for evaluating ITS projects*, report by Texas Department of Transportation, Texas, 2003.

LIST OF FIGURES

FIGURE 1 Economic risk analysis for road segments

FIGURE 2 Example of relationship between lateness and travel time

LIST OF TABLES

TABLE 1 Consequence impact categories for incident management

TABLE 2 Number of significant days for each road type

TABLE 3 Safety Impact Values, based on (14)

TABLE 4 Reliability Impact Values (I_E)

TABLE 5 Proportion of total passenger car trips by purpose

TABLE 6 Percentage of road closed/blocked factor (L' factor)

TABLE 7 Environmental Impact Values (I_G) for passenger vehicles

TABLE 8 Environmental Impact Values (I_G) for freight vehicles

TABLE 9 Pure Risk Ranking for state-controlled roads in the South Coast Hinterland District
using 2002 data

TABLE 10 Cost Effectiveness Ranking for state-controlled roads in the South Coast Hinterland District
using 2002 data

TABLE 11 Cost Effectiveness Ranking for state-controlled roads in the South Coast Hinterland District
using 2002 data with constant values of travel time

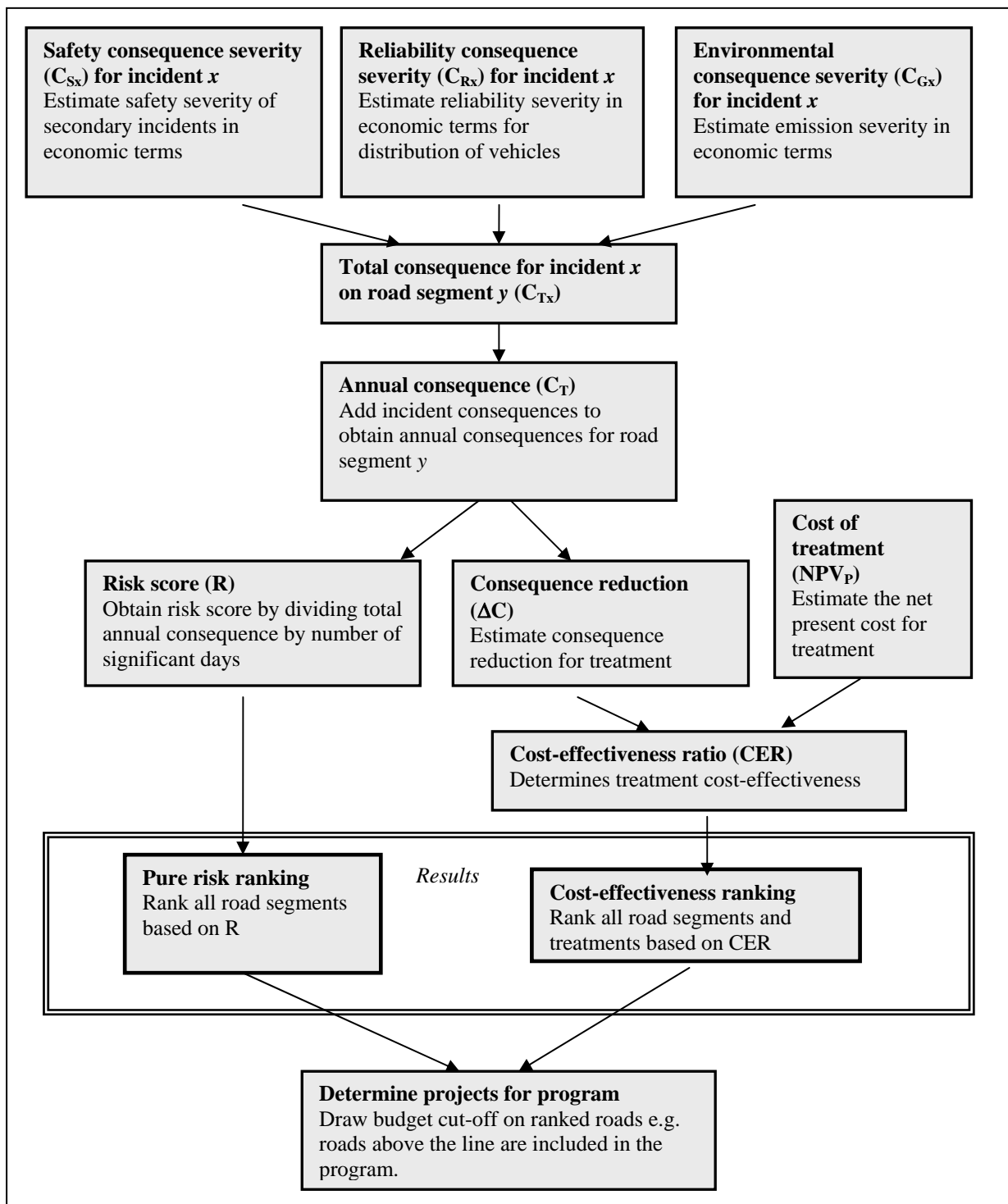


FIGURE 1 Economic risk analysis for road segments

TABLE 1 Consequence impact categories for incident management

Impact category	Description	Examples
Safety (S)	Impact event leading to secondary accidents.	Nose-to-tail accidents due to congestion. Vehicles swept while crossing flooded roads.
Reliability (R)	Impact event causing drivers' excessive lateness leading to diminished user confidence.	Travel time impacts from incident congestion. Road flooded causing road closure.
Environmental (G)	Impact event causing environmental impacts.	Idling vehicles caught in congestion cause additional vehicle emissions. Local air quality may impact health and greenhouse gases may impact global warming.

TABLE 2 Number of significant days for each road type

Road type	Number of significant days per year (N)
Urban arterial	250
Urban freeway / motorway	250
Rural	365

TABLE 3 Safety Impact Values, based on (14)

Secondary Accident Type	Non-urban AU\$	Urban AU\$
Fatal	1,687,600	1,584,500
Serious injury	411,600	387,700
Minor injury	17,100	16,600
PDO	6,500	6,500

**TABLE 4 Reliability Impact Values (I_E)
Based on Table 3.9 (14)**

Vehicle types (j)	Austroads classification	Average travel time value (AU\$/person/hour) (T _j)	
		Non-urban	Urban
1. Passenger cars	1, 2	22.38	22.60
2. Light and medium rigid trucks	3	25.33	27.22
3. Heavy rigid trucks	4, 6	24.95	29.53
4. 4 axle articulated trucks	5, 7	31.12	40.99
5. 5 axle articulated trucks	8	33.92	46.51
6. 6 axle articulated trucks and rigid (3 axle) plus dog trailer (5 axle)	9	37.95	48.51
7. B-double, twin steer (4 axle) plus dog trailer (4 and 5 axle)	10	41.48	39.91
8. Double road train, B triple combination, A B combination and double B-double combination	11	54.54	-
9. Triple road train	12	62.62	-

NB: In this table, '-' means not applicable

TABLE 5 Proportion of total passenger car trips by purpose

Passenger car trip purpose	Proportion of total trips (%)
Business (work-based)	29.5
Private (home-based)	70.5

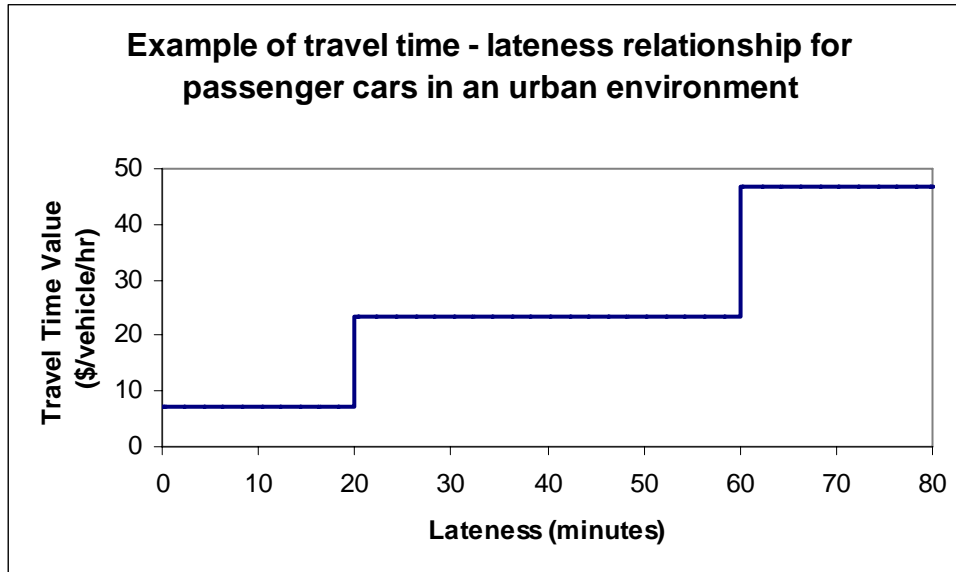


FIGURE 2 Example of relationship between lateness and travel time

TABLE 6 Percentage of road closed/blocked factor (L' factor)

Based on Table A-10 in Stockton et al. (16)

Number of lanes in each direction	Shoulder disablement	Shoulder accident	Lanes blocked		
			One	Two	Three
2	0.05	0.19	0.65	1	-
3	0.01	0.17	0.51	0.83	-
4	0.01	0.15	0.42	0.75	0.87
5	0.01	0.13	0.35	0.6	0.8
6	0.01	0.11	0.29	0.5	0.75
7	0.01	0.09	0.25	0.43	0.64
8	0.01	0.07	0.22	0.37	0.59

NB: In this table, '-' means not applicable

TABLE 7 Environmental Impact Values (I_G) for passenger vehicles

Externality	Unit Cost (AU\$ per vehicle kilometer)	
	Urban	Rural
Air pollution	0.021	0.000
Greenhouse / climate	0.014	0.014
Total	0.038	0.014

TABLE 8 Environmental Impact Values (I_G) for freight vehicles

Externality	Unit Cost (AU\$/'000 tonne-km)			
	Urban		Rural	
	Light Commercial Vehicle	Rigid/ Articulated Vehicle	Light Commercial Vehicle	Rigid/ Articulated Vehicle
Air pollution	100	22.0	1.00	0.22
Greenhouse / climate	42	4.0	42	4.0
Total	142	26	43	4.22

TABLE 9 Pure Risk Ranking for state-controlled roads in the South Coast Hinterland District using 2002 data

Ranking	Road number	Road name	Functional description	Pure risk score (AU\$/day)
1	103	Southport – Burleigh Road	4 lane urban arterial	1169
2	11B	Gold Coast Highway (Broadbeach – Coolangatta)	4 lane urban arterial	605
4	206	Tamborine – Oxenford Road	2 lane regional distributor/collector	603
3	11A	Gold Coast Highway (Helensvale – Southport)	4 lane urban arterial	476
5	106	Southport – Nerang Road	4 lane urban sub-arterial	350
6	105	Nerang – Broadbeach Road	4 lane urban arterial	253
8	2020	Beechmont Road	2 lane regional distributor/collector	180
7	101	Smith Street Connection	4 lane urban arterial	176
9	104	Gold Coast – Springbrook Road	2 lane regional distributor/collector	98
10	202	Beaudesert – Nerang Road	2 lane regional distributor/collector	87
11	116	Labrador – Carrara Road	4 lane urban sub-arterial	58
12	208	Beenleigh Connection Road	2 lane urban sub-arterial	35
13	201	Nerang – Murwillumbah Road	2 lane regional distributor/collector	26
14	102	Burleigh Connection Road	4 lane urban arterial	16
15	114	Hope Island Road	2 lane urban sub-arterial	8
17	2013	Tallebudgera Connection Road	2 lane urban sub-arterial	5
16	2003	Tallebudgera Creek Road	2 lane urban sub-arterial	3
18	2001	Currumbin Creek Road	2 lane urban sub-arterial	3
19	204	Brisbane – Beenleigh Road	4 lane urban arterial	1
20	117	Nerang Connection Road	2 lane urban sub-arterial	1
21	2029	Oxenford – Coomera Gorge Road	2 lane regional distributor/collector	0
22	1003	Staplyton – Jacobs Well Road	2 lane regional distributor/collector	0
23	2041	Advancetown – Mudgeeraba Road	2 lane regional distributor/collector	0
24	2050	Tamborine – Nerang Road	2 lane regional distributor/collector	0

TABLE 10 Cost Effectiveness Ranking for state-controlled roads in the South Coast Hinterland District using 2002 data

Ranking	Road number	Road name	Functional description	Range of cost effectiveness ratio	
				Lower	Upper
1	11A	Gold Coast Highway (Helensvale – Southport)	4 lane urban arterial	0.11	0.23
2	103	Southport – Burleigh Road	4 lane urban arterial	0.06	0.14
3	106	Southport – Nerang Road	4 lane urban sub-arterial	0.05	0.14
4	11B	Gold Coast Highway (Broadbeach – Coolangatta)	4 lane urban arterial	0.03	0.07
5	105	Nerang – Broadbeach Road	4 lane urban arterial	0.03	0.07
6	206	Tamborine – Oxenford Road	2 lane regional distributor/collector	0.02	0.05
7	101	Smith Street Connection	4 lane urban arterial	0.02	0.05
8	2020	Beechmont Road	2 lane regional distributor/collector	0.01	0.04
9	116	Labrador – Carrara Road	4 lane urban sub-arterial	0.00	0.01
10	208	Beenleigh Connection Road	2 lane urban sub-arterial	0.00	0.01
11	104	Gold Coast – Springbrook Road	2 lane regional distributor/collector	0.00	0.01
12	102	Burleigh Connection Road	4 lane urban arterial	0.00	0.00
13	202	Beaudesert – Nerang Road	2 lane regional distributor/collector	0.00	0.00
14	114	Hope Island Road	2 lane urban sub-arterial	0.00	0.00
15	2013	Tallebudgera Connection Road	2 lane urban sub-arterial	0.00	0.00
16	201	Nerang – Murwillumbah Road	2 lane regional distributor/collector	0.00	0.00
17	2003	Tallebudgera Creek Road	2 lane urban sub-arterial	0.00	0.00
18	2001	Currumbin Creek Road	2 lane urban sub-arterial	0.00	0.00
19	117	Nerang Connection Road	2 lane urban sub-arterial	0.00	0.00
20	204	Brisbane – Beenleigh Road	4 lane urban arterial	0.00	0.00
21	2029	Oxenford – Coomera Gorge Road	2 lane regional distributor/collector	0.00	0.00
22	2041	Advancetown – Mudgeeraba Road	2 lane regional distributor/collector	0.00	0.00
23	1003	Staplyton – Jacobs Well Road	2 lane regional distributor/collector	0.00	0.00
24	2050	Tamborine – Nerang Road	2 lane regional distributor/collector	0.00	0.00

NB: Shading denotes roads that have moved up the ranking (compared with Table 9) with the cost effective analysis

TABLE 11 Cost Effectiveness Ranking for state-controlled roads in the South Coast Hinterland District using 2002 data with constant values of travel time

Ranking	Road number	Road name	Functional description	Range of cost effectiveness ratio (x10 ³)	
				Lower	Upper
1	11A	Gold Coast Highway (Helensvale – Southport)	4 lane urban arterial	0.15	0.33
2	103	Southport – Burleigh Road	4 lane urban arterial	0.11	0.28
3	206	Tamborine – Oxenford Road	2 lane regional distributor/collector	0.07	0.17
4	106	Southport – Nerang Road	4 lane urban sub-arterial	0.05	0.13
5	105	Nerang – Broadbeach Road	4 lane urban arterial	0.05	0.12
6	11B	Gold Coast Highway (Broadbeach – Coolangatta)	4 lane urban arterial	0.04	0.10
7	2020	Beechmont Road	2 lane regional distributor/collector	0.03	0.09
8	101	Smith Street Connection	4 lane urban arterial	0.02	0.05
9	116	Labrador – Carrara Road	4 lane urban sub-arterial	0.01	0.03
10	104	Gold Coast – Springbrook Road	2 lane regional distributor/collector	0.01	0.02
11	208	Beenleigh Connection Road	2 lane urban sub-arterial	0.00	0.01
12	202	Beaudesert – Nerang Road	2 lane regional distributor/collector	0.00	0.01
13	102	Burleigh Connection Road	4 lane urban arterial	0.00	0.00
14	114	Hope Island Road	2 lane urban sub-arterial	0.00	0.00
15	2001	Currumbin Creek Road	2 lane urban sub-arterial	0.00	0.00
16	201	Nerang – Murwillumbah Road	2 lane regional distributor/collector	0.00	0.00
17	2013	Tallebudgera Connection Road	2 lane urban sub-arterial	0.00	0.00
18	2003	Tallebudgera Creek Road	2 lane urban sub-arterial	0.00	0.00
19	117	Nerang Connection Road	2 lane urban sub-arterial	0.00	0.00
20	204	Brisbane – Beenleigh Road	4 lane urban arterial	0.00	0.00
21	2029	Oxenford – Coomera Gorge Road	2 lane regional distributor/collector	0.00	0.00
22	2041	Advancetown – Mudgeeraba Road	2 lane regional distributor/collector	0.00	0.00
23	1003	Staplyton – Jacobs Well Road	2 lane regional distributor/collector	0.00	0.00
24	2050	Tamborine – Nerang Road	2 lane regional distributor/collector	0.00	0.00

NB: Shading denotes roads that have moved up the ranking (compared with Table 10) with the value of travel time varying