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Transport Economics in a Network

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Abstract

It is normal practice in most Australian State Highway Authorities to carry out an economic evaluation to define a Benefit-Cost Ratio (B/C) for any potential highway improvement project as part of their justification for funding. This paper is intended to illustrate that it is not sufficient or correct for the B/C Ratio of any road to be accepted in isolation, if any other link within the network is to be changed or improved within the economic life of that road.

1 Introduction

Australian State Highway Authorities carry out an economic evaluation to obtain a Benefit-Cost Ratio (B/C) for any potential highway improvement project. This forms a part of their business case. Projects are usually evaluated individually and, when there are several, they are ranked in priority with some attention to their economic contribution.

This paper is intended to illustrate that it is not sufficient or correct for the B/C Ratio of any road to be accepted in isolation, even if evaluated in a wide network context, if any other link within the network is to be changed or improved within the economic life of that road because benefits accrue during the whole economic life.

All roads exist in a network and are interdependent with each other. Any road improvement influences the economics of another road and, indeed, all roads in the network. Therefore the economic results for any single road will be changed if any other link in the network is changed or improved within the economic life of that road. Some roads, if evaluated individually, may be satisfactorily economically viable but, when evaluated as part of a road program with other road improvements, they may not measure up. The converse may also be true. It is necessary to examine all combinations of current road improvement proposals to see what combinations provide the best economic returns to the whole network and also to examine the staging program, as this itself may change priorities and economic results.

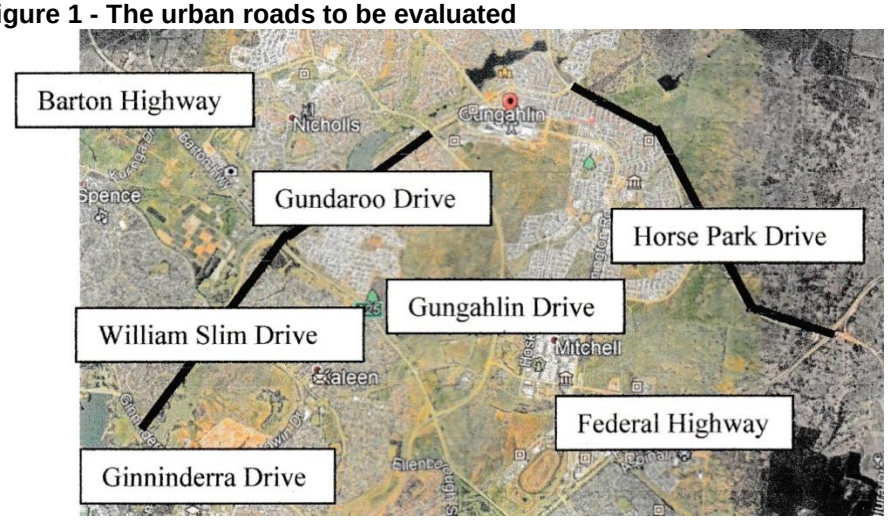
2 An illustrative urban road network case study

2.1 Case study location

The case study relates to three road improvements in the Gungahlin area of Canberra shown in figure 1. The proposed projects are the duplication of:-

- Gundaroo Drive from Gungahlin Drive to the Barton Highway;
- William Slim Drive from the Barton highway to Ginninderra Drive; and
- Horse Park Drive from Gundaroo Drive to the Federal Highway.

Figure 1 - The urban roads to be evaluated



2.2 Economic evaluation of each road link in isolation

Table 1 provides the economic results for each of the three road links when evaluated individually.

Table 1 - The costs[1] and benefits for each road evaluated individually

		Gundaroo Drive	William Slim Drive	Horse Park Drive
Capital Cost		$ 25.4	$ 22.7	$ 32.6
User Savings	Veh Op Costs	$ 61.0	$ 42.0	$ 66.0
	User Time	$ 73.0	$ 53.0	$ 85.0
	Accidents	$ 1.0	$ 1.0	$ 2.0
	Total	$135.0	$ 96.0	$153.0
User Benefits[2]		$ 17.0	$ 15.0	$ 21.0
Total Benefits		$152.0	$111.0	$174.0
B/C Ratio		**5.98**	**4.89**	**5.34**

Source: the TRANSTEP[3] model of Canberra. Present Values discounted @ 7% in Millions

The benefits accrue from induced travel and savings in travel time, accidents and vehicle operating costs (Veh Op Costs). All three projects have minimal effect on transit usage. All three road links have substantial economic merit with B/C Ratios well in excess of that normally required for funding.

However it is intended that all three of these roads will be constructed within the next few years. Hence it is necessary to consider the economic effect of each road upon the other two as each will affect the benefit stream of both of the others.

2.3 Testing the effect of one road on another

As William Slim Drive is a continuation of Gundaroo Drive some of the benefits will be mutual although the construction costs will not change.

[1] The costs and benefits shown in this case study are estimates only and should not be quoted
[2] User Benefits are derived user Consumer Surplus methodology as outlined by Neuberger – see reference
[3] See TRANSTEP User Manual – R J Nairn & Partners Pty Ltd

The result of testing the economic merit of William Slim Drive after Gundaroo Drive has already been constructed is shown in Table 2.

Table 2 - The economic effect of building Gunderoo Drive before William Slim Drive

		Gundaroo then William Slim	William Slim Contribution
	Capital Cost	$ 48.1	$ 22.7
User Savings	Veh Op Costs	$ 96.0	$ 35.0
	User Time	$115.0	$ 42.0
	Accidents	$ 2.0	$ 1.0
	Total	$213.0	$ 78.0
User Benefits		$ 24.0	$ 7.0
Total Benefits		$237.0	$ 85.0
B/C Ratio in Network		**4.93**	**3.74**

Source: the TRANSTEP model of Canberra. Present Values discounted @ 7% in Millions

It should be noted that the economic contribution of both roads changes from when it was evaluated by itself although both road projects would still be economically viable.

This illustrates that it is not sufficient or correct for the economic analysis of any road in a network to be accepted in isolation if any other road is improved within the economic life of the road.

A further example is to include Horse Park Drive which is likely to divert benefits from both the other roads. Table 3 lists the effect of building Gundaroo Drive first, then Horse Park Drive and then William Slim Drive, which is in fact the probable staging program.

Table 3 - Economic contribution of the road programme when constructed in a staged sequence

		Gundaroo then Horse Park	Horse Park Contribution	Then William Slim	William Slim Contribution
	Capital Cost	$ 58.0	$ 32.6	$ 80.7	$ 22.7
User Savings	Veh Op Costs	$114.0	$ 53.0	$153.0	$ 26.0
	User Time	$142.0	$ 69.0	$191.0	$ 33.0
	Accidents	$ 3.0	$ 2.0	$ 4.0	$ 1.0
	Total	$259.0	$124.0	$348.0	$ 60.0
User Benefits		$ 36.0	$ 19.0	$ 50.0	$ 12.0
Total Benefits		$295.0	$143.0	$398.0	$ 72.0
B/C Ratio in Network		**5.09**	**4.39**	**4.93**	**3.17**

Source: the TRANSTEP model of Canberra. Present Values discounted @ 7% in Millions

The economic merit of the roads has been reduced although all roads are still viable. Horse Park Drive's Contribution Ratio falls from 5.34 to 4.39 and William Slim Drive's Ratio falls from 4.89 to 3.17.

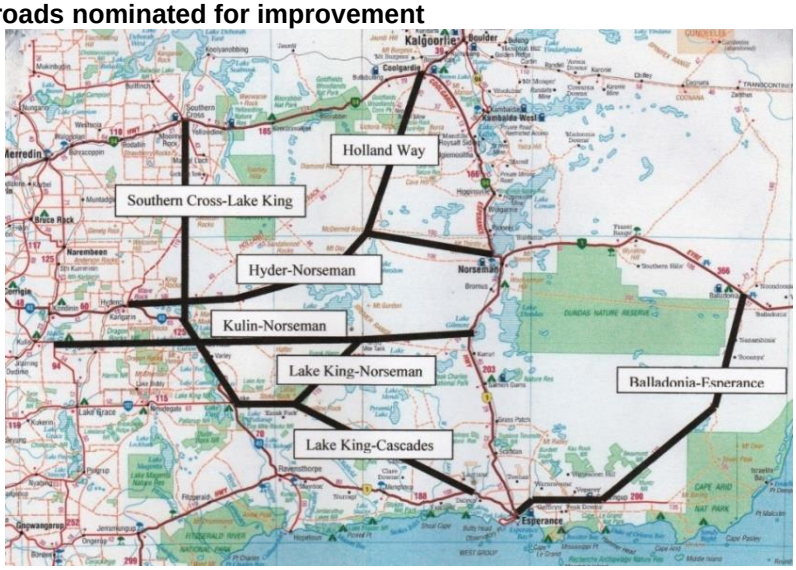
3 Rural case study illustrating staged network economics

3.1 Case study location

A further case study illustrates the building up of the economic value of a rural network of roads in south-eastern Western Australia. Economic growth of this area depends mainly on expansion of the agricultural industry, increased tourism and some mining opportunities.

Few roads in the area were sealed and it was to be expected that road improvements would enhance the economic returns of the area. Figure 2 shows the roads which were to be assessed for possible inclusion in a road program for this area. The objective being to establish which road links should be improved to provide the optimal economic impetus for the area.

Figure 2 - Optional roads nominated for improvement



3.2 Economic evaluation of each road link individually

Each of these road links was initially assessed individually to obtain their B/C Ratio if evaluated alone. They were evaluated using CARTS[4] software in a comprehensive multimodal network which covered all roads in Western Australia and which contained all necessary links into South Australia and the Northern Territory.

It should be noted that it is normal in some Australian highway authorities[5] for a B/C ratio of about 2.5 to be required before any road would be likely to be funded. This is because the costs are accurately known and real but many of the benefits:-

- are estimates; and
- are considered intangible such as consumer surplus (User Benefits), user time savings, vehicle operating costs and environmental impacts; or
- they rely on inter-departmental co-operation, such as savings in road construction or road maintenance by other authorities, or changed bus services, which may or may not eventuate; or
- they relate to road accident probabilities; and

[4] See CARTS User Manual R J Nairn & Partners Pty Ltd
[5] Private correspondence with Western Australia Main Roads and NSW Road Traffic Authority

- the B/C procedure does not, at this stage, consider risks which invariably reduce their economic return; and
- Road investment must compete with education, health and other sectors which also can have high B/C Ratios due to shortages of investment funds.

Table 4 lists the results of the evaluation for the different road links when carried out on each road by itself.

Table 4 - The costs and benefits for each road evaluated individually

Benefits or Costs	Hyden-Norseman	Lake King Norseman	Balladonia Esperance	Lake King Cascades	Southern Cross Lake King	Holland Way	Kulin Norseman
Capital cost	**$36.80**	**$21.50**	**$30.60**	**$24.70**	**$21.60**	**$38.60**	**$57.70**
Cost Savings							
Maintenance	$2.20	$1.40	$1.50	$1.60	$1.30	$2.20	$2.70
Accidents	$9.40	$7.90	$3.40	$16.70	$1.60	$23.10	$20.40
Veh Op Cost	-$18.90	-$32.20	-$16.70	$23.60	$0.00	-$0.80	-$81.40
User Time	-$22.10	-$11.70	$2.20	-$3.50	-$1.70	-$27.00	-$45.40
Total Savings	**-$29.40**	**-$34.60**	**-$9.60**	**$38.40**	**$1.20**	**-$2.50**	**-$103.70**
Benefits							
Travel Benefits	$142.50	$109.70	$31.50	$18.90	$3.00	$128.20	$226.20
Industry Benefits[6]	$2.80	$3.60	$29.80	$3.60	$0.00	$1.50	$1.20
Total Benefits	**$145.30**	**$113.30**	**$61.30**	**$22.50**	**$3.00**	**$129.70**	**$227.40**
Net Benefits	**$79.10**	**$57.20**	**$21.10**	**$36.20**	**-$17.40**	**$88.60**	**$66.00**
B/C Ratio	**3.95**	**5.27**	**2.00**	**0.91**	**0.14**	**3.36**	**3.94**

Source: CARTS model simulations. Present Values in $Millions discounted at 7%

These results suggest that three roads - Southern Cross-Lake King Road, the Balladonia-Esperance Road and the Lake King-Cascades Road - would not gain funding if the cut-off point was set at a B/C Ratio of 2.5. The Lake King-Norseman Road, the Hyden-Norseman Road, the Kulin-Norseman and the Holland Way would all be suitable to be funded. Their economic ranking when assessed alone is shown in Table 5.

Table 5 - Initial economic ranking if evaluated alone

Road	B/C Ranking	B/C Ratio
Lake King to Norseman	1	5.27
Hyden-Norseman	2	3.95
Kulin-Norseman	3	3.94
Holland Way	4	3.36
Balladonia-Esperance	5	2.00
Lake King-Cascades	6	0.91
Southern Cross-Lake King	7	0.14

Under current practice these results would be used to assess the likelihood for funding and the probable priorities for construction within budgeting and political realities.

[6] Industry Benefits are derived using the World Bank's Producer Surplus methodology – see reference

However, as some roads are likely to be constructed within the economic life of others, it is necessary to examine their interacting effects.

3.3 Economic evaluation of these road links in a staged program

It was decided that the Lake King-Cascades Road and the Balladonia-Esperance Road should still be included in the program but that the Southern Cross-Lake King link could be eliminated.

These roads were then evaluated in a staged program containing many combinations of road links staged two years apart. The cumulative economic return of each stage was computed as each road improvement was added.

As some parts of the roads overlapped, some costs were reduced – for instance the Holland Way and Lake King-Cascades.

Many combinations were considered and tested although it was soon obvious that the links with high individual economic returns should be considered early in the program. The resulting program of improvements with the best cumulative economic returns for the whole road program is listed in Table 6.

Table 6 - The cumulative costs and benefits for the optimal staged road program

Benefits and Costs of whole program	Lake King to Norseman	Add Holland Way	Complete Hyden to Norseman	Add Balladonia Esperance	Add Lake King to Cascades	Add Kulin to Norseman
Capital Cost	**$21.50**	**$55.20**	**$64.30**	**$84.70**	**$95.70**	**$118.60**
Cost Savings						
Maintenance	$1.40	$3.40	$3.90	$4.90	$5.60	$6.40
Accidents	$7.90	$20.10	$18.20	$17.40	$28.40	$30.60
Veh Op Costs	-$32.20	-$6.20	-$4.00	-$0.20	$10.40	$0.20
User Time	-$11.70	-$30.00	-$35.90	-$31.70	-$36.40	-$43.50
Total Savings	**-$34.60**	**-$12.70**	**-$17.80**	**-$9.60**	**$8.00**	**-$6.30**
Benefits						
Travel Benefits	$109.80	$145.10	$162.90	$170.80	$176.40	$176.30
Industry Benefits	$3.50	$4.00	$4.00	$28.60	$28.60	$25.50
Total Benefits	**$113.30**	**$149.10**	**$166.90**	**$199.40**	**$205.00**	**$201.80**
Net Benefits	**$57.20**	**$81.20**	**$84.80**	**$105.10**	**$117.30**	**$76.90**
Network BCR	**5.27**	**2.70**	**2.60**	**2.35**	**2.14**	**1.70**

Source: CARTS model simulations. All figures are Present Values in $Millions discounted at 7% after staged construction.

Table 6 shows that while the Net Benefits increase up until the addition of the Lake King-Cascades Road into the staged improvement program, but falls after that and the Network B/C Ratio falls after each road link is added.

This confirms that, after all the multiple options were tested, the listed priority was correct.

This now gives the result that, after the total program economic evaluation, only the Lake King-Norseman Road, the Holland Way, and the Hyden-Norseman Road would be funded if the financial cut- off point for the whole program of roads was a B/C Ratio of 2.5.

The Belladonna-Esperance might still be considered but the Lake King-Cascades Road and the Kulin-Norseman Road would not despite the latter being attractive on initial analysis.

3.4 Changed economic contribution from each road in a program

The additional cost and economic value accrued as each road improvement was added to the network provides the incremental value for each added link. Table 7 lists the added costs and benefits as each road link is added and the consequent "Added B/C Ratio".

Table 7 - Incremental costs and benefits as each road is added

Road	Incremental Economic Contribution		
	Added cost	Added Benefit	Added B/C Ratio
Lake King-Norseman	$21.5	$113.3	5.27
Add Holland Way	$33.7	$35.8	1.06
Complete Hyden-Norseman	$9.1	$17.8	1.96
Add Balladonia-Esperance	$20.4	$32.5	1.59
Add Lake King-Cascades	$11.0	$5.6	0.51
Add Kulin-Norseman	$22.9	-$4.2	-0.14

The differences in ratios for each road link when assessed individually and when assessed in a total program are shown in Table 8.

Table 8 – Difference in contributions when assessed individually and in a program

Road	Economic Contribution	
	Initial B/C Ratio	Network B/C Ratio
Lake King to Norseman	5.27	5.27
Hyden to Norseman	3.95	1.96
Kulin to Norseman	3.94	-0.14
Holland Way	3.36	1.06
Balladonia to Esperance	2.00	1.59
Lake King to Cascades	0.91	0.51

The strategic program analysis changed both the priority ranking and viability of the road links from their ranking and viability if assessed in isolation of the other roads.

This rural case study, while it was a real exercise and illustrates the need for network planning, is not necessarily typical of other areas in Australia. A considerable number of roads in one area were candidates for improvement whereas this is not normally the case. The roads concerned were all unsealed and carrying low volumes and were in a relatively remote area of the State. It was therefore an extreme example. Nevertheless the situation is not abnormal – certainly more than one road is normally being improved at any time within any State and the general conclusion holds.

Note that the technology has not been developed to assess "Industry Benefits" in urban networks. Their assessment in rural networks relies on freight cost reductions inducing higher rural industry production. It is much more difficult to assess the effect of freight cost reductions in an urban area where a single freight trip may involve multiple destinations.

3.5 Note on the "network B/C ratio"

It is important to recognise that the Network B/C Ratios shown above are not B/C Ratios for each road. Indeed it is impossible to isolate the B/C Ratio for individual roads in a program of improvements in a network. This is because:-

- Although user time savings, vehicle operating costs, accident costs and environmental impacts could be isolated for each road link;
- Travel Benefits, which are derived mainly from induced travel, cannot be isolated for each link as this would involve multiple counting on several links; and
- Industry Benefits in rural networks, which are derived from Producer Surplus methods, are regional and not linked directly to any specific road link. Indeed they may involve several staged paths – farm-to-market then market-to-city.

It should also be noted that the network B/C ratios listed in Table 7 do not necessarily provide the same priorities as the optimal staging program (see Holland Way).

4. Conclusions

Both case studies illustrate that it is not sufficient or correct for the B/C Ratio of any road in a network to be accepted in isolation if any other road is improved within the economic life of the road.

The case studies also illustrate another reason for setting B/C Ratio cut-off criteria well above unity when single road improvements are being evaluated as the potential network effects alone justify this policy. The same logic applies with other modes for transport in both rural and urban settings.

Attaining the optimal B/C Ratio for the complete network involves testing multiple growth staging sequences.

It appears that there is no option but to carry out periodic long-term whole-of-network planning exercises, similar to that illustrated in the second case study, to establish which of the road links should be improved in a long-term program if it is to be properly based on an economic rationale.

It could be conducted within the framework of a 5-year or 10-year program of road improvements bearing in mind that the economic life of roads is normally assumed to be at least 20-30 years.

The program would, of course, change over time as external circumstances change so that the program would need to be upgraded periodically. However the discounting effect means that changes after say 10 years would have less effect on the benefit stream than changes in earlier years.

It is also clear that the Benefit-to-Cost Ratio should apply only to the total program of roads in a network, not to individual roads, and that a concept such as a Network or Incremental B/C Ratio for a particular road does not necessarily provide the optimal priority for staging the program of road improvements.

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