

Demonstrating the benefit of network operations activities

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Abstract

The benefits and processes for evaluating economic outcomes of standard transport interventions are well recognised and generally consist of infrastructure improvements, intersection treatments, public transport schemes, safety improvements etc.

Operations activities such as network optimisation, ITS system operation, traffic management, events and traveller information are generally accepted to be beneficial. Compared to other interventions, these activities generally require significantly lower investment and therefore industry practices and views are that any benefits are likely to return high value-for-money outcomes.

Historically there has been limited requirement in New Zealand to carry out in-depth economic assessments of operations activities. The methodologies and approaches for carrying out benefit appraisal of operation activities are not well established.

In line with the NZ Transport Agency business case approach, operations activities need to be considered as part of the potential lifecycle of transport solutions and evaluated alongside, or as part of, the main investment solution options. Parties involved in the implementation of operations, such as the Transport Operations Centres, also have a need to consider the economic impacts, benefits, and balances as part of their day-to-day tasks and processes.

The key purpose of this research is to identify economic approaches, evaluation methodologies, comparison with standard interventions, and develop a feasible framework for the economic assessment of these activities.

1. Introduction

This paper provides an overview of the methodology and outputs of a NZ Transport Agency funded research project into demonstrating the benefits of activities associated with network operations. Network operations activities are playing an increasingly important role in the delivery, management, and optimisation of our transport systems. In the New Zealand (NZ) context, these activities are largely covered by the regional Transport Operations Centres (TOCs) for urban areas for all modes of travel. The TOCs and their activities have been determined to be a reasonable proxy for the scope of this research and, generally, there is a focus towards urban operations covering the whole network and all travel modes.

This research project addresses the economic evaluation of operations activities with a particular focus on the suitability of economic evaluation procedures and the development of a framework to carry out economic assessment of operations activities. These activities relate to the day-to-day management and operation of the transport system - including real time management and operation systems, the management of planned and unplanned events, provision of traveller information, and the collection and utilisation of business

intelligence. The purpose of this project is to investigate and establish economic evaluation principles and techniques for the evaluation of these activities.

This research paper provides a literature review of similar research undertaken in NZ in section 2, and then provides a review of international assessments in section 3. Section 4 provides an overview of the Network Operations in NZ. Section 5 defines the assessment options available for operations activities. Section 6 provides a discussion of the framework that was developed to assist practitioners. Section 7 provides a practical approach to applying the framework within the NZ Transport Agency business case approach. Section 8 then provides a case study example applying the framework. Section 9 then summarises the conclusions of the research.

2. New Zealand Literature Review

Four previous NZ Transport Agency research reports (undertaken over the last 15 years) that appeared to have some relevance for this research were identified and reviewed. These were Raine et al (2014), Chang et al (2013), James (2006) and Dalziel et al (1999).

It was found that the extent of information in these previous NZ reports that was directly relevant and helpful for this research was quite limited.

Probably the most useful previous material is that given in James (2006). This provides information on the benefits and costs of ITS-based projects implemented internationally, arranged under a detailed set of project categories. However, we note that this report is now nine years old and that: (i) technologies and costs for ITS applications will have changed substantially since then; and (ii) methods for estimation of benefits will also have improved, to a large extent related to recent technology developments.

3. International Literature Review

The international review focused on assessments of 24 network operations and related scheme types undertaken and reported internationally over recent years and published in ITS International. A list of the articles that were reviewed and schemes are included in Appendix A.

Of the 24 schemes reviewed, the evaluations for 21 of them were undertaken after the scheme was implemented in the transport system. They were based on data collected both before and after scheme implementation, and estimated the benefit and cost differences between the before situation and the after situation.

In almost all cases where a comprehensive benefit assessment has been undertaken, the following are the main components incorporated:

- Travel time savings
- Vehicle operating cost (fuel) savings
- Accident savings (but not included in many cases)
- Local emissions/health impacts (pm10, nox, hc)
- Global emissions (GHG=CO₂e)

In terms of the relative contribution of these components to overall benefits, the travel time savings component is dominant in almost all cases, accounting typically for 80%-90% of total net benefits.

Typically VoC (principally fuel) savings is the second largest benefit component, accounting for in the order of 10%-20% of total benefits. There seems to be little recognition of VoC benefits apart from fuel savings. In many cases, accident savings are mentioned, but appear

not to have been quantified. Where they are specifically evaluated, they comprise up to 30% of total benefits. Where local emissions have been assessed, the contribution of any changes to total benefits is usually small, less than 10% of total benefits.

Changes in global emissions (GHG) appear not to be mentioned in most cases. Where global emissions impacts have been assessed, their contribution to total benefits appears to be no more than about 5%. It may be that in some cases GHG benefits have been included with the fuel cost savings, but there is no clear evidence of this.

The findings support the use of standard economic evaluation techniques for the evaluation of economic benefits of operations activities. This indicates that typical NZ transport economic principles and approaches involving application of the EEM can also be applied in evaluating the benefits of operations activities on the NZ transport network.

4. Network Operations in NZ

The definition of network operations used by the NZ Transport Agency to seed this research is as follows;

Network operations in this context refers to the day to day operational activities managed by the traffic operations centres and network maintenance contractors, and the soft engineering solutions to manage, monitor, and optimise the road asset, and inform customers.

The above statement excludes maintenance of the road network and the draft 2015-2018 State Highway Activity Management Plan (NZTA, 2014, p.56) provides more refinement around this. It identifies the four main areas of operations activities as;

- Network monitoring: collection of network intelligence
- Traveller information: communication of network intelligence
- Management of events: control and response to events on the network
- Network optimisation: maximising the value of the state highways and our services to customers

These four areas define the core scope of the research.

In NZ the various regional Transport Operations Centres (TOCs), currently manage all of the components described above to some degree (the structures and organisation of the geographic TOCs varies mildly). The TOCs are generally structured into three teams;

- Real Time Operations (RTO): monitor the network and responsible for the management and optimisation of ITS systems.
- Traveller Information (TI): provide information and communications to the wider public and stakeholders.
- Traffic Management (TM): supervise, manages, and approves traffic management activities on the network.

4.1 Project types

The following list of the more common project types that each of the TOC teams carry out as part of the day-to-day practices has been developed to provide some reference to practical activities for this research.

- ITS optimisation projects, e.g. SCATS signal optimisation, ramp signalling system operation.
- Incident management, e.g. alteration to ITS systems to prioritise routes.

- ITS network operation and management systems, e.g. speed management, automated safe systems.
- ITS network enforcement and management tools, e.g. Weigh In Motion (WIM), tolling.
- Planned event management, e.g. review and assessment of impacts and options for roadworks and public events.
- Linkage to TI team to provide traveller information about typical and real-time network conditions.

5. Network Operations Assessment

Establishing the benefits of changes to or improvement of the transport network by implementing various operations activities requires some form of assessment. A range of assessment approaches are possible, and these generally fit into two broad categories pre-implementation and post-implementation appraisal.

5.1 Pre-implementation appraisals

The evaluation of many transport interventions will involve a pre-implementation appraisal, i.e. an assessment prior to the implementation of the project. This will include analyses at certain stages of the assessment process. Pre-implementation appraisals usually focus on quantification with and without the intervention scenarios and are likely to include transport modelling, and/or desktop analysis.

The majority of transport interventions are assessed using a pre-implementation appraisal approach. The techniques and methodologies are well established and in NZ this style of economic assessment would follow the standard Economic Evaluation Manual (EEM) procedures.

5.2 Post-implementation evaluations

A post-implementation evaluation assessment involves the collection and comparison of before and after on-road / real-world data measurements. This can include setting up a bespoke data collection exercise around the initiative and/or making use of existing collection systems.

5.3 Practical limitations

Currently in NZ post-implementation reviews (PIR) are carried out on a small selection of standard transport schemes. A key goal of this process is to review, update or refine the EEM procedures in order to inform and improve the pre-implementation appraisal process.

In specific relation to operation activities, generally the opposite of the above historical focus on pre-appraisal is true. There tends to be more of a focus on use of observed real-world data following scheme implementation rather than transport modelling and desktop assessment in assessing the benefits of operations activities.

Ideally both approaches would be applied regularly to both operations activities and more standard transport scheme evaluations. This would have the benefit of informing and improving pre-implementation appraisal methods by checking against real-world outcomes, and providing realistic measures of success. However, rarely are both approaches undertaken either for operations or standard transport schemes. This is generally accepted within the transport industry to be due to practicality and feasibility issues such as;

- If a comprehensive pre-implementation assessment is carried out, there is little appetite to expend further resource in carrying out a post-implementation review

(often on the belief the pre-implementation appraisal was robust and there may be political consequences of challenging this or finding it was not robust, or more simply wasted effort).

- If an activity is implemented on-road without a pre-implementation assessment (common of operations initiatives), this is on the understanding that the initiative is needed, relatively inexpensive and generally beneficial. Post-implementation evaluation can then be carried out to verify this, or estimate the magnitude of benefits.

6. Economic assessment framework for operations activities

The research has developed a framework with the anticipation that it can be applied as a high level guide to practitioners carrying out economic evaluations of operations activities in NZ. It identifies and highlights issues which are specific to operations activities and is designed flexibly so that it can be applied to any form of operational scheme although examples and focus is towards vehicular benefits.

The guidelines have been developed from the perspectives that:

- They focus on quantifying and valuing the benefits within an economic framework of network operation activities and, in particular, identifying aspects that may be unique and specific to these (relative to more typical transport schemes generally involving larger investment).
- They have been designed to cover methodologies which include forecasting savings and/or measurement of before/after on-road data. Before and after observed data measurement is often used to evaluate operations activities for the purposes of investigating economic returns and potentially developing funding cases (sometimes in retrospect, sometimes via live system implementation and measurement). The framework is designed to provide guidance on assessment of operations and the development of a funding case for this style of scheme.
- The categories of economic benefit relevant to network operations activities are essentially the same as those applying to road infrastructure activities (in most cases) or to other types of activities covered in the NZ Transport Agency Economic Evaluation Manual (EEM). Given this, and the desirability of being able to directly compare the economic performance of network operations activities with other transport investments, the EEM provides the base for the economic appraisal of network operations activities.

7. Application in the NZ Transport Agency Business Case Process

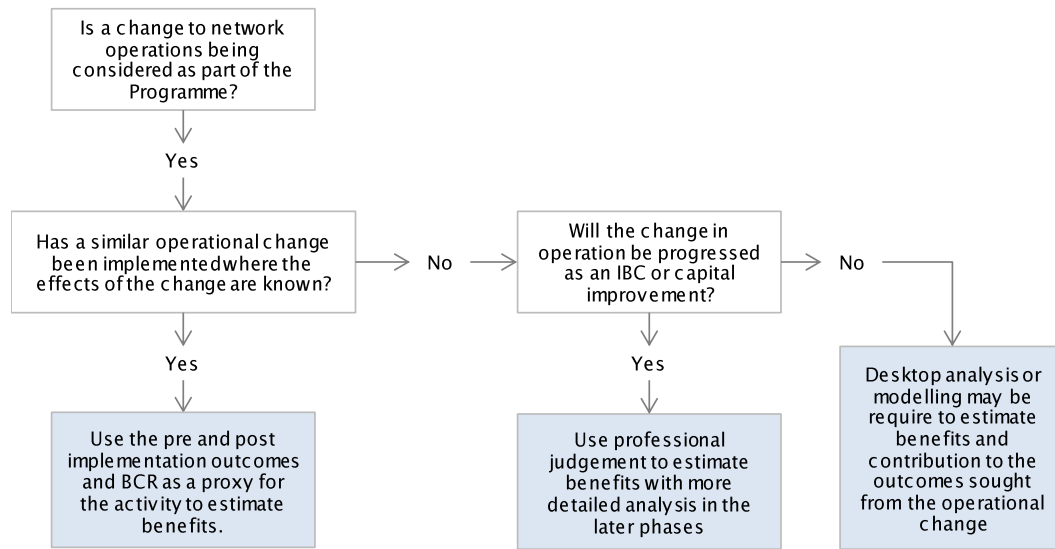
The findings of this research provide a foundation and an evaluation system for carrying out the assessment of operations solutions within the NZ Transport Agency's Business Case assessment. The sections below outline the elements of the research and key decisions as they apply to the Programme and Indicative Business Case stages of the business case process (if operational activity components are progressed to a Detailed Business Case, this would build from the analysis and assessment carried out at the Indicative Business Case stage).

7.1 Programme business case

The Programme Business Case (PBC) stage identifies programmes of work and/or activities that deliver on the strategic case and identifies alternative and options. Data and evidence

gathering is a key step in this stage of the assessment and Figure 1 indicates key decisions on potential methods for carrying out this analysis for operations activities.

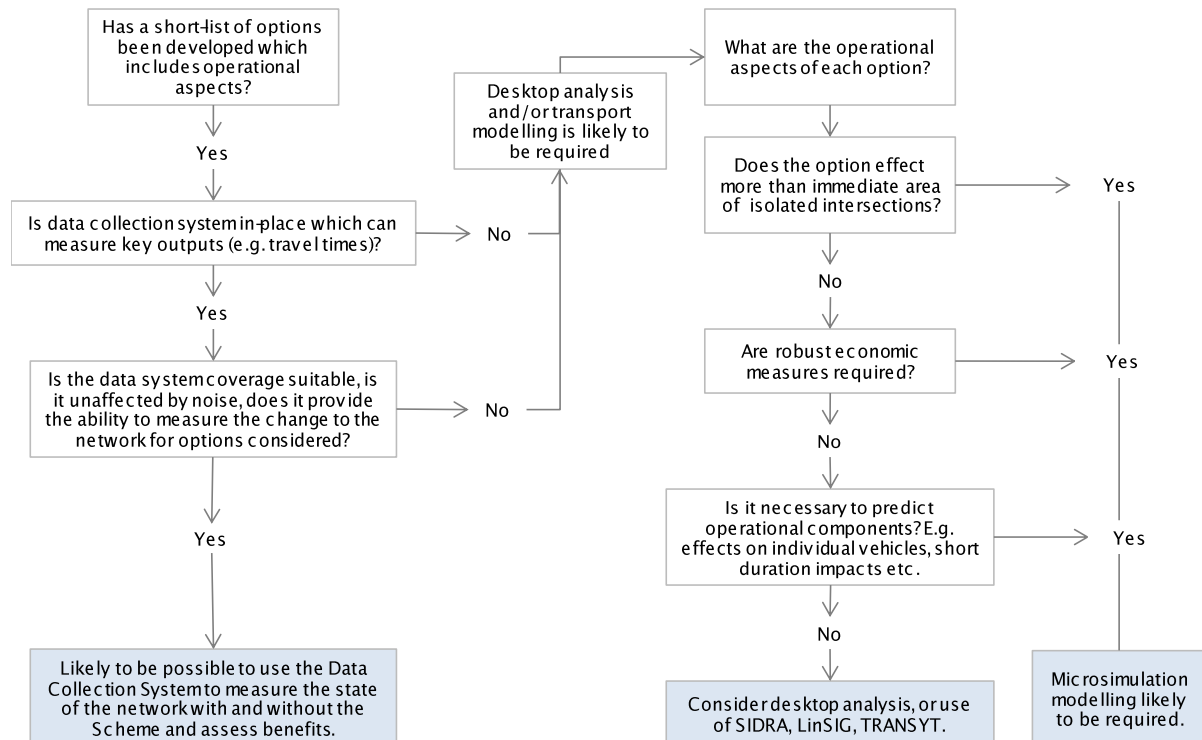
Figure1: PBC key assessment decisions relating to operations activity evaluation



7.2 Indicative Business Case

The Indicative Business Case (IBC) progresses individual activities each of which has an IBC developed where necessary. At this stage a fuller assessment of costs and benefits is required and this will involve a more detailed consideration of the assessment approach. Figure 2 below outlines key decisions relating to the assessment of any operations activities which have IBC's developed

Figure2: IBC key assessment decisions relating to operations activity evaluation



8. Case Study Application

In this section the methodology as described in Section 4 has been applied to a case study in Christchurch, a large city in the South Island of New Zealand.

8.1 Description

The Blenheim Road and Curletts Road intersection is a critical connection in Christchurch's arterial road network. Blenheim Road is a key east-west corridor, linking industrial and commercial areas with the Central City and Curletts Rd is a key section of the inner ring route, linking to the Southern Motorway.

The intersection was selected for a Case Study investigation into SCATs operations options due to the local TOC's desire to investigate optimisation strategies at this intersections and its relative convenience as a test site (isolated, standard layout, peak period delays, and ability to transfer learnings to other sites).

The intersection is a large signalised intersection with right and left turn bays on all approaches, a double right turn from the west approach towards the Southern Motorway, and two through lanes on all approaches. Figure 3 shows the intersection layout, approach lanes, and turning bays.

Figure 3: Blenheim Rd / Curletts Rd signalised intersection layout

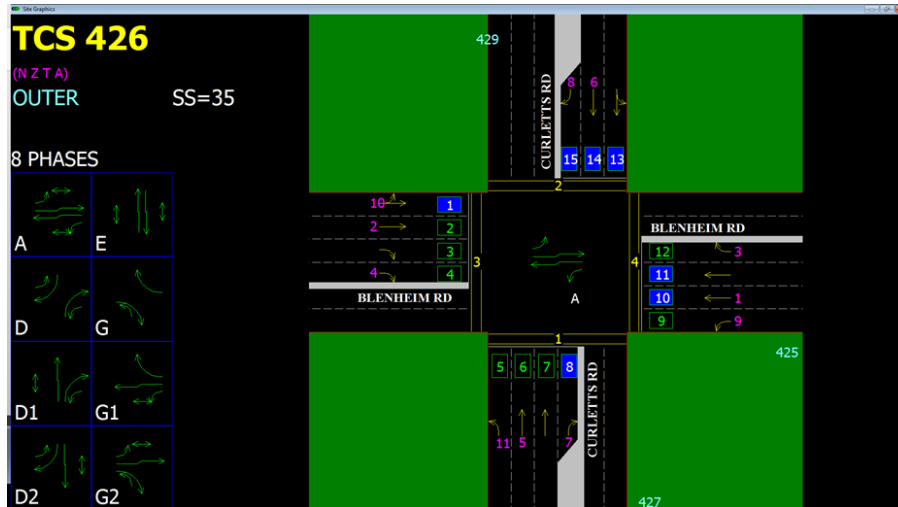


8.1.1 Signal operation

The intersection is largely isolated from the effects of any significant adjacent intersections and coordination with other signalised corridors is not critical on three approaches. To the west is a roundabout, the intersection to the north is a reasonable distance away for this not to be a significant issue, and intersections to the south have significant capacity so that progression is not critical. The exception is to the east to/from the CBD; the Blenheim Rd / Curletts Rd intersection effectively forms the start of Blenheim Rd corridor. Importantly, the Blenheim Rd / Curletts Rd intersection is coordinated with the Hansons Lane / Annex Road offset "T" intersection 500m to the east.

The intersection typically runs the common diamond signal phase arrangement. The phasing and intersection layout is shown in the SCATS graphic below.

Figure 4: Blenheim Rd / Curletts Rd SCATS intersection phasing



8.2 SCATS Option Assessment

8.2.1 SCATS options and alternatives

The SCATS signalised intersection control software has a range of abilities to manipulate and control signal timings and operations. Implementing effective settings requires the Signal Engineer to apply and adjust a range of settings.

Evaluating alternative options and establishing the optimal approach can be difficult due to the need to test settings within the real world where conditions can vary, travel demand may change, and there is the risk of adversely affecting travellers. One option to carrying out testing is linking SCATS with a microsimulation traffic model. This requires either a Signal Engineer with reasonable proficiency in modelling, and/or a close working relationship between the Signal Engineer and Modeller. A modelling approach is likely to be particularly effective to test high risk signal strategies, testing strategies across large areas (corridors, regions, or the whole network), and/or for testing strategies in areas of the network under high pressure, where the risk of significant delays is high. This is effectively a risk trade-off consideration, i.e. the risk of increasing user costs while testing live on-street balanced against the added cost and value of modelling.

For this example, the relatively isolated nature of the intersection meant that a several options could be tested in the real-world without the risk of significant delays through the wider network. Testing strategies at intersections which are within key corridors, influence a number of adjacent network features would carry significant higher risk of adverse effects to travellers. Tests were carried out over a two week period (to allow traffic demand settle in response to any changes and to allow a suitable length of time over which to measure the effects) during non-holiday weekday periods in August – September 2015. The following tests were conducted;

- Baseline (August): Effectively the current base operation; Curletts Rd is the stretch phase (main phase given spare green time) and the west and south right turn movements have calibration factors applied (to reduce the potential for the right turn bays to fill with queued vehicles).
- Test 1: Reduced cycle time, locked at 90 seconds, particularly focussed on the AM peak. Due to the reasonably isolated nature of this intersection, the focus of this test was to investigate more optimal discharge of the approach stacking space and avoid

possible inefficient green-time towards the end of green phases as platoons are more dispersed.

- Test 2: Changed Blenheim Rd to stretch phase (potentially improves coordination to east with Hansons Ln / Annex Rd intersection) and removed right turn calibration factors.

8.2.2 Assessment approach

Approach delays were measured in 15min intervals over the test period from CTOC's Araflow Bluetooth Travel Time monitoring system. The Bluetooth system detects the Bluetooth unique identifier as it passes each detector and provides travel times between detectors. It samples roughly 10% of traffic in the Christchurch network, and the sample rate increases during the AM and PM peaks (12-14%). A Bluetooth detector is located at the Blenheim Rd / Curletts Rd intersection, and the adjacent detectors are located at the major intersections immediately upstream (1-3km away);

- North approach, at the Curletts Rd / Main South Rd / Riccarton Rd intersection
- East approach (and exit), at the Blenheim Rd / Whiteleigh Av / Clarence St intersection. Note, this link includes the Hansons Ln / Annex Rd intersection (the linked intersection immediately to the east) and will measure any associated improvement / detriment from changed coordination with this intersection and the Blenheim Rd corridor to the east.
- South approach, at the Curletts Rd / Southern Motorway interchange and will measure any associated improvement / detriment from changed coordination with the intersections to the south (Parkhouse Road and Lunns Road).
- West approach, at the Sockburn roundabout

The Bluetooth system is ideally suited to robustly measure the approach delays during each phase of the testing.

Volumes estimates by approach have been extracted from SCATS detector information to provide an estimate of vehicle demands.

8.2.3 Travel time and volume outcomes

Figure 5 and Figure 6 show the weighted average approach travel time (the average approach travel time from the upstream detector to the intersection detector, weighted by the volume on each approach) and the estimated approach volume across the three test periods.

Figure 5: Weighted average intersection travel time

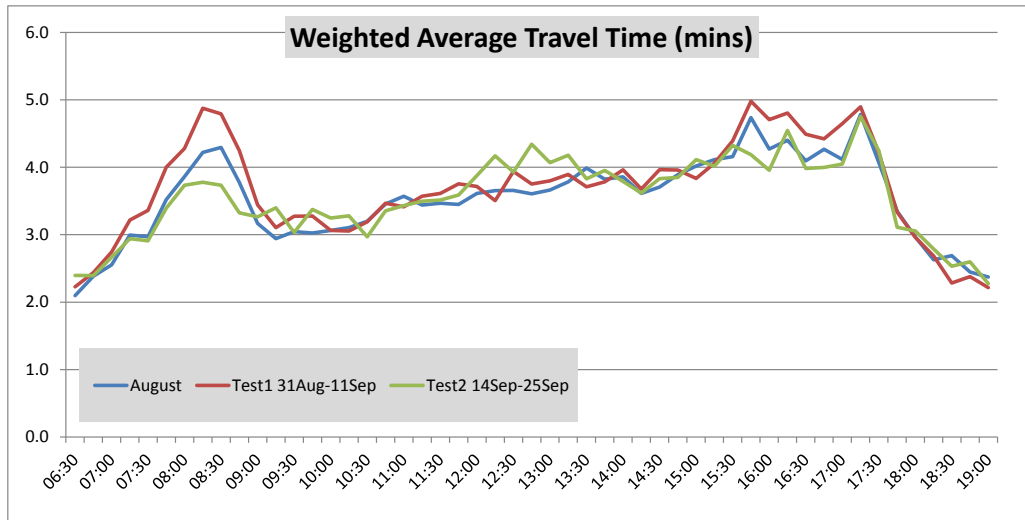
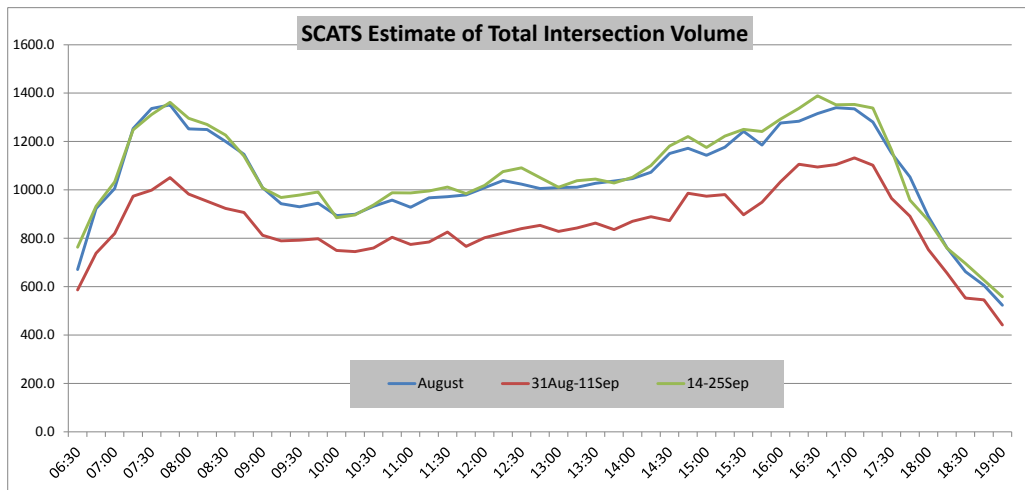


Figure 6: Overall intersection volume estimate (SCATS detector observations)



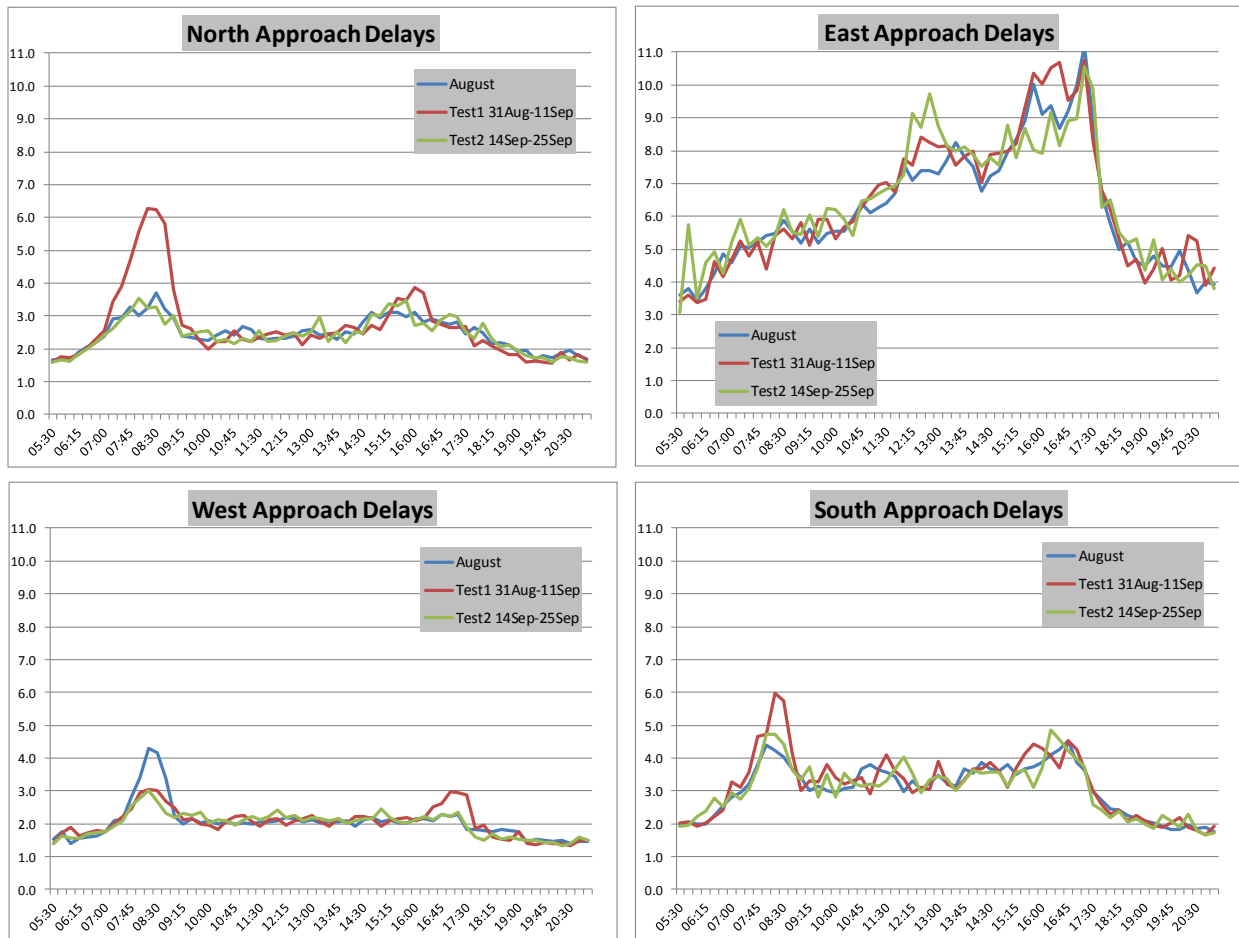
The above graphs show that the shorter cycle time test (31 August - 11 September) deteriorated performance relative to the base and other test.

The SCATS volume estimate shows a significant drop in volumes during the shorter cycle testing (31Aug – 11 Sep). Volume reductions were unlikely to have been as significant as shown in this figure. The effect is likely to be due to the reduced cycle time affecting the SCATS detection algorithms. It should be emphasised that SCATS volume information is only an estimate.

Delays were higher particularly in the AM peak. Figure 7 below shows the delays by approach. This demonstrates that the shorter cycle test was particularly problematic on the North and South approaches, but reduced delays reasonably significantly on the west approach in the AM peak.

The recalibration test (14 September - 25 September) produced notably lower delays in the AM and PM peak periods. This is largely due to improvements on the West approach. The results on the other approaches are similar to the August baseline. The eastbound exit link from the intersection towards the CBD also demonstrated some minor peak period travel time savings, which are likely to be from improved coordination through the intersections to the east (Hansons Ln, Annex Rd, and further east).

Figure 7: Approach delays by direction



8.3 Economic assessment

8.3.1 SCATS and Staff costs

Economic assessment needs to consider both the benefits and costs of implementing schemes. Although the cost component of this work is potentially small, it should not be discounted from any economic assessment. The costs have been calculating assuming that this exercise could be carried out roughly once per year for intersections of this nature to verify the optimal operation strategy. There are three cost components to include;

- SCATS Software annual maintenance cost to enable options and optimisation: \$700-900 (per intersection)
- Signal Engineer Time to develop options, programme SCATS, and monitor:\$2,700
- Analyst Time to analyse SCATs and Bluetooth data and assess optimal strategy:\$1,500

The total cost of assessing and developing optimisation options for an intersection of this nature is approximately \$5,000 annually. The cost of collecting the Bluetooth data has not been included in this assessment as the Bluetooth system exists in-situ in the Christchurch network and is generally used for other purposes.

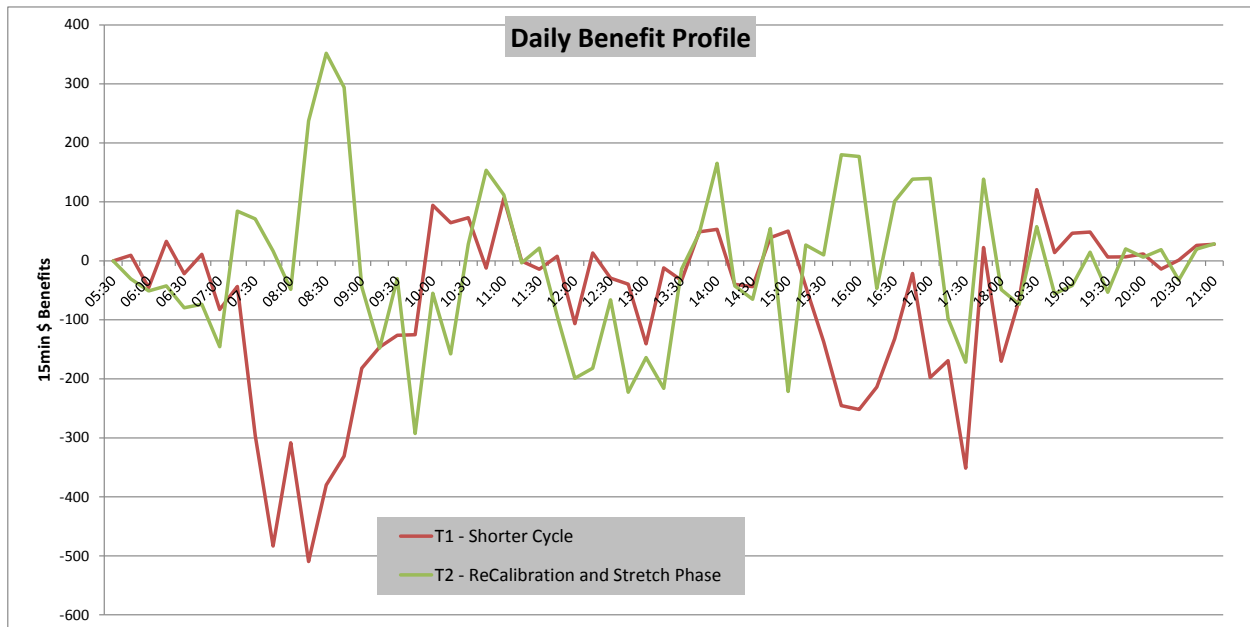
The infrastructure costs associated with physically running the traffic signals have not been included in this assessment. These are part of the existing infrastructure, and costs would have been evaluated when the signals were installed, rather than being part of this project to optimise the infrastructure.

8.3.2 Benefit calculation

The economic benefits of the two test options have been calculated from the 15min travel demand estimate and delay saving (difference between the baseline and test option). The EEM (2014) Values of Time for the AM, IP, PM and Night, including the congestion increment, have been applied to the 15min time saving per vehicle to calculate the benefit stream through the day.

Small operational changes to a single intersection are unlikely to significantly affect the total travel demand and vehicle distance travelled. Therefore Vehicle Operating Costs and Environmental benefits have not been assessed. It is possible that travel time reliability and frustration benefits could accrue from improved signal settings and reduced peak period delays. These have not been evaluated in this assessment as the value of time savings significantly outweigh the costs and therefore the return from the effort of carrying out this analysis is limited. Figure 8 below shows the daily benefit profile from VOT savings. A positive \$ value indicates a benefit saving of the option and a negative a disbenefit.

Figure 8: Daily benefit profile of SCATS options



The lower cycle time test generates disbenefits through the majority of the day. These daily disbenefits have been annualised across non-holiday weekdays, giving a total annual disbenefit of \$1,000,000 – 1,100,000. This is an important result; it demonstrates that if sub-optimal or untested signal settings are implemented over a long period there can be significant economic detriment. This emphasises the usefulness of analysing data (or modelling) to check and confirm optimal approaches and the work of the Signal Engineer / SCATS system to develop signal options.

The second test option demonstrates reasonably significant benefits in the AM and PM peak periods, but disbenefits in the inter-peak and shoulder periods. This suggests that the optimal approach is to implement the baseline settings in the shoulder periods and interpeak, i.e. apply the baseline before 7am, 9am – 3:30pm, after 6pm, and the test 2 settings during the peaks. If this approach was employed, the shoulder and inter-peak disbenefits would not occur and the additional benefits from employing Test 2 would be approximately \$320,000 - \$340,000 annually.

The total disbenefits (delay to travellers) from carrying out the 4 weeks of testing was \$40,000 - \$50,000, which could arguably be taken from the annual benefits noted at the end of the paragraph above. However this cost is common to all options assessed and therefore

can be cancelled from the BCR evaluation. It is also more likely that the optimal settings will be in place for a period of greater than a year and returns will be greater than these figures.

8.3.3 Cost / Benefit assessment and potential extrapolations

The assessment outlined above demonstrates potentially high returns from small investments of staff time and short periods of on-street testing to develop optimal signal strategies. The benefit cost ratio from the above work is estimated at around 65.

In the Canterbury region there are around 330 signalised intersections. Assuming conservatively that 5% of these intersections have similar characteristics, then carrying out a similar exercise across the Christchurch network has the potential to save very roughly \$4,500,000 annually.

9. Conclusion

The background research investigation reached a number of conclusions which form the basis of the development of the economic assessment framework. The key conclusions from this project were;

- Key outcomes established through this project form principles which underpin the transport economic value of day-to-day Transport Operation Centres and operations activities.
- This research project and economic framework provides a practical tool for Business Case assessments where solutions may, and should often, consider operations treatments to extend the lifespan of existing infrastructure and potentially delay more costly capital expenditure.
- The economic framework for evaluating the benefits of operations activities is practical, flexible and not onerous to apply and therefore fits with the agile TOC approach.
- The operations economic framework fits within the overall NZ Transport Agency assessment framework, and notably can be included within Business Case assessments.
- A key consideration in assessing the benefits of operations is the assessment approach adopted, notably whether pre-implementation appraisal or post-implementation evaluation is carried out. The framework is applicable to both approaches.
- Social cost-benefit analysis is an appropriate framework for assessing the economic benefits of operation activities with the main ranking criterion being the benefit: cost ratio (BCR).
- The economic impacts that are relevant to operations are all covered by the NZ Transport Agency Economic Evaluation Manual (EEM).
- It is appropriate to adopt the EEM procedures and parameters for the economic evaluation of operations activities (unless there are good reasons to the contrary in any particular case).

The development and application of the framework to the case study has identified the following key outcomes from the research;

- Definition of the Do Minimum and development of option costs are key components of economic assessment of operations.

- Considering and evaluating the lifespan of the activity is often a critical aspect of an operations economic assessment.
- Before and after data measurement can be an effective technique for measuring the benefits of operations activities. This needs to be balanced against the risk of this approach and the robustness of measurements from the data collection system.
- Microsimulation transport modelling is an effective mechanism for evaluating the economic benefits of the majority of operations activities, either alongside on-street data measurement or as a stand-alone approach. This needs to consider the added-value and potential risk reduction of this approach.
- It is relatively straightforward to include operations activities within the suite of potential solutions to identify problems and to assess the economic returns of these options within NZ Transport Agency policy and economic evaluation frameworks.
- Generally operations activities are highly cost-effective transport treatments.

10. Disclaimer

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an efficient, effective and safe land transport system in the public interest. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

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Appendix A

Schemes reviewed through ITS International publications.

#	Cat 1	Cat 2	ITS Article Title	Publ date	Scheme Title/Agency	Benefit Framework	BCR / Net
1	NM		Cost saving multi-agency transportation and emergency management	01-Apr-10	Houston TranStar (multi-jurisdiction transport & emergency management agency).	CBA	11.4
2	RTO	IM	Reducing incident clear-up times, saving money	01-Oct-11	Towing and recovery incentive programme (TRIP).	CBA	11
3	RTO	IM	Integrating traffic systems improves management and control	01-Apr-12	STREAMS Motorway traffic management and control system (Transmax). VicRoads, Aust.	CBA	>\$1M per day
4	RTO	SE	Automatic speed enforcement in Finland	01-Jun-10	Ext. of automatic speed enforcement cameras. Finland.	CBA (partial)	c4.0
5	RTO	TC	Wireless traffic management reduces costs and commute times	01-Feb-10	Wireless traffic monitoring and management system. LA County Department of Public Works.	No formal CBA.	
6	RTO	TC	Signal optimisation reduces congestion, improves travel times	01-Apr-09	Traffic signal optimisation, Metro Nashville, Tennessee USA.	CBA	21
7	RTO	TC	Adaptive control reduces travel time, cuts congestion	01-Aug-11	Reduce arterial congestion (adaptive control software). San Diego County, USA	CBA	8
8	RTO	TC	Benefits of traffic light synchronisation	01-Jun-11	Alicia Parkway signal synch. (11 mile corridor, 41 signalised intersections). Orange County Tptn Authority, CA, USA	CBA	
9	RTO	TC	Adaptive traffic control drives financial benefits	01-Oct-09	Adaptive traffic control system (52 intersections). City of Cartagena, Columbia.	CBA	
10	RTO	TC	Cost benefits of LED traffic signals	01-Jun-09	Kentucky statewide replacement of incandescent traffic signals with LED modules. USA	CBA (financial only)	>5.0
11	RTO	TC	Re-timing traffic signals delivers cost benefits	01-Apr-09	Commentary on experience and benefits from re-timing traffic signals (no specific project covered). USA.	CBA (advocate d)	
12	RTO	TC	Real time traffic control aids travel time reduction	01-Dec-12	Movement-based adaptive control improves intersection performance. TNO (Netherlands).	TT savings	

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13	RTO	TC	TfL expands SCOOT adaptive traffic management	01-Dec-12	Modelling the impacts of SCOOT adaptive controls on intersection performance. London, UK.	Annual benefits	
14	RTO	TC	SCATS study shows significant savings	01-Dec-13	Quantification of the benefits of SCATS. Roads and Maritime Services, NSW, Australia	Annual benefits	
15	RTO	TC	Benefits of Florida's traffic signal retiming	01-Oct-12	Traffic signal retiming and installation of advanced monitoring. Lee County Dept of Tptn, Florida, USA.	CBA	>120
16	RTO	TO	Mounting benefits of dynamic tolling project	01-Feb-10	SR167 HOV to HOT lanes conversion pilot project.	No formal CBA.	
17	TI	SC	Barcelona finds speed cameras save money and lives	01-Feb-12	Speed cameras on Barcelona's beltways: cost benefit analysis. Agencia de Salut Publica de	CBA (partial)	c1.5
18	TI	SC	Study finds speed cameras cut fatal accidents	01-Feb-12	Speed camera deployment in Qatar. Supreme Council of Health, Qatar.	Accident reductions	
19	TI	VMS	Refurbishing ageing VMS with new technology	01-Dec-11	Variable message sign retrofitting programme. Virginia DoT, USA	Cost impacts	c\$300kpa
20	TI	VMS?	Upgrading Koblenz's traffic information system	01-Feb-13	Koblenz traffic information system upgrade	No formal.	
21	TTM	DLC	Road space utilisation improves travel times, reduces costs	01-Jun-10	DRUM (Dynamic Roadspace Utilisation Manager) – dynamic lane closures during roadworks (based on RTI methods).	Cost reductions for roadworks	c4.5
22	TTM	DLC	Dynamic lane closures cuts time, cost and congestion on motorway roadworks	01-Feb-14	Application of DRUM to optimise lane closures for road works. Highways Agency, UK.	Cost reductions for roadworks	
23	TTM	DLC	Moveable barriers improve workzone safety, reduce costs	01-Apr-11	Use of movable barrier on reconstruction of route 3500 South, Salt Lake City,	CBA	c4.0
24	TTM	VMS	Workzone safety can be economically viable	01-Oct-14	Safelane project, 2012–14: Improvements to workzone safety. EC project (4 countries, 8 partners).	Cost reductions for roadworks	