Benefits and costs of different road expenditure activities

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M Chow and T Chen
HoustonKemp Economists

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NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

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Abbreviations and acronyms

ARTIMIS	Advanced Regional Traffic Interactive Management and Information System
BCR	benefit–cost ratio
CBA	cost-benefit analysis
CEA	cost-effectiveness analysis
DSI	deaths and serious injuries
FHWA	Federal Highway Administration (US)
IRI	International Roughness Index
ITS	intelligent transport systems
LCV	light commercial vehicle
LOS	level of service
MCA	multi-criteria analysis
MCV	medium commercial vehicle
NLTP	National Land Transport Programme
NPV	net present value
PV	present value
RAC	road authority costs
RIT-T	Regulatory Investment Test for Transmission
SCATS	Sydney Coordinated Adaptive Traffic System
TMR	Department of Transport and Main Roads (Queensland)
Transport Agency	New Zealand Transport Agency
US	United States
VKT	vehicle kilometres travelled
VOC	vehicle operating costs

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Executive summary

The importance of the road network and the significant resources involved to operate, maintain and upgrade it every year means a clear and transparent decision-making process and frameworks to determine funding levels and allocation are crucial. Inadequate funding or poor management of the road network can result in adverse effects on social well-being given the central role the road network plays in the everyday life of New Zealanders.

There are a number of existing frameworks that help decision makers prioritise different types of road expenditure activities. However, these frameworks are designed to prioritise opportunities that are of the same activity type (eg capital investments or maintenance and renewal works). It follows that a holistic framework for assessing different activity and investment types does not exist. The purpose of this research project was to address this gap.

The research task

This research report examines how benefit and cost appraisals for road operations activities, maintenance and renewal activities, and minor work improvements could be undertaken in a manner comparable with the current appraisal framework for capital investments. This will provide decision makers with a holistic view across different activity and investment types to identify a portfolio of opportunities that offers value for money and meets its service level targets. In addition, the research sought to answer several related questions, namely:

- What should the target service level for the road network be?
- What are the marginal benefits and costs of changes to the service level target?
- What is the optimal allocation of resources between activities and investments that improve resilience, safety and efficiency outcomes, using minor work improvements as an example.

This research report first explores decision-making frameworks commonly used to assess the merits of different activities. It then explains the purpose of service level targets and trade-offs involved when the target is changed. The report then sets out a proposed framework that helps identify an 'optimal' portfolio, informed by a budget constraint, cost-benefit analysis (CBA) and service level targets. Lastly, fit for purpose CBA frameworks are developed for road operations activities, maintenance and renewal activities and minor work improvements so the proposed framework can be implemented.

Common frameworks used to prioritise activities and investments

Different road activities and investments often help road authorities achieve similar desired outcomes, and so should be assessed against each other on this basis. Decision makers are often required to evaluate competing activities and investments to ensure they provide adequate economic returns and so should be funded. Many overseas countries consider multiple factors when deciding which activities and investments to fund. Common considerations include:

- the strategic fit of the activity or investment, which assesses if they deliver outcomes that are consistent with the objectives of the decision maker
- effectiveness of proposed solution, which examines if all practical options have been given due consideration and the most appropriate option has been put forward
- economic assessment of the activity or investment, which typically involves undertaking a CBA

- financial considerations, such as the funding required for the activity or investment and if it generates revenue
- the associated project risk, such as stakeholder acceptance of the activity or investment, and technical feasibility of its delivery.

While strategic fit, effectiveness, financial and risk considerations are important in the overall decision-making process, a central consideration is whether projects are economically viable and whether they are maximising benefits for each dollar spent. The most commonly used economic assessment framework is CBA, which provides estimated measured social outputs that are more objective and easier to interpret. While there are other frameworks for assessing economic viability of the initiatives, eg multi-criteria analysis and cost-efficiency analysis, these are often considered to be less useful in comparisons between different projects relative to CBA.

Achieving the desired service level

The purpose of undertaking different activities is to ensure the road network delivers the desired service level so it meets the needs of the user and community. To this end, road authorities often set, or are delegated with, outcome performance measures and targets to monitor whether the road network is meeting the needs of end users and the community. A common approach to setting outcome performance measures and targets is through the lens of the end customer or society. In other words, what performance measures best capture outcomes that end users or society want from the road network. Examples of service level targets include reducing the number of fatal and serious crashes by, say, 20% or improving travel time by 10%.

The setting of outcome performance targets is more of ‘an art rather than science’. Although targets could be determined quantitively using frameworks such as CBA, they often reflect aspiration targets of the decision maker. The service level target should reflect the priorities of the users and society, and be measurable so the progress can be monitored over time. The target should also be challenging yet achievable. Put another way, the purpose of setting a target is to motivate road authorities and their delegated agent to achieve a goal they otherwise may not achieve in the absence of the target.

Most road authorities have a fixed budget for the transport or road network. Within this context, aiming for a more ambitious target in one outcome area, say safety, means in theory at least, there would be less focus and available budget to achieve outcomes in other areas, say amenity and mobility. In short, increasing the service level target for one performance area will likely reduce outcomes in other performance areas unless the available budget also increases.

The proposed approach to selecting an ‘optimal’ portfolio of investment opportunities

The portfolio approach selects a collection of investment opportunities that maximises the net present value of benefits less costs of the portfolio given a budget constraint, the service level target, and the CBA of individual activities and investments. This approach provides road authorities with a practical tool in allocating limited funds among investment opportunities that may aim to achieve different specific objectives, within the context of being in the interest of society more generally.

The proposed approach of selecting an ‘optimal’ portfolio of opportunities involves the following process:

1. Rule out activities and investments that are considered too risky, not effective, or do not align with the strategic objectives of the decision maker

2 Estimate the costs and benefits for each activity or investment using consistent assumptions and inputs across all estimates

3 Calculate the net present value of benefits and costs for each activity or investment using a common discount rate

4 Set constraints that reflect an organisation's budgetary constraint and service level targets

5 Select the combination of activities and investments that delivers the highest total net present value given the relevant constraints.

The first step of the process acts as an initial filter to rule out projects that are not ideal candidates for funding. It recognises that undertaking CBA for projects is time consuming and projects that are too risky, ineffective or do not align with the decision maker's strategic objectives should be ruled out in the first instance. The second and third steps of the process involves undertaking a CBA for individual projects, while the fourth and fifth steps involve setting budget constraints and service level targets that feed into identifying an optimal portfolio of activities and investments.

The proposed approach set out above provides a method to systematically align a portfolio of activities and investments with a road authority's organisational objectives. Furthermore, the analysis of portfolios with and without a level of service targets provides an effective way to evaluate the marginal cost (or benefit) of service levels, which can be calculated by taking the difference in net present values between portfolios with differing service level targets.

A proposed CBA framework for road operations activities, maintenance and renewal activities, and minor work improvements was developed so the proposed approach could be implemented. This is further discussed below.

Developing a fit for purpose CBA framework

To implement the proposed framework in obtaining the optimal portfolio, a fit for purpose CBA framework was developed for minor work improvements, road operations activities, and maintenance and renewal activities. The framework and relevant inputs were designed to closely align with current methodology for evaluating capital investments so that results are comparable. The CBA framework was also designed to be fit for purpose to suit the nature of the activity or investment, including the small-scale nature of minor work improvements and operations activities, and the decision-making process.

The framework developed for minor work improvements and operations activities is robust and can be readily applied. The key benefits arising from these activities are mainly improved safety outcomes, improved travel time savings and reduced user costs from using a better route. These benefits are covered by existing literature and evaluation guidelines. The appraisal framework can be applied together with a portfolio approach discussed above where activity and investment NPVs are assessed individually and then selected for inclusion in a portfolio that maximise overall benefits from a set budget.

In contrast, the framework developed for maintenance and renewal works illustrates how a CBA framework can be applied to estimate the marginal benefits and costs of changing the levels of service targets and identifying the appropriate target level of service for a road classification. The framework for maintenance and renewal works focuses on the interaction between the target for road roughness, road authority costs and vehicle operating costs for road users. Existing gaps within the literature meant the framework does not yet capture other benefits associated with maintenance and renewal works, such as safety and amenity benefits, or include other condition measures, such as rutting and skid resistance.

Benefits quantified under the proposed framework are summarised in table ES.1.

Table ES.1 Benefits quantified under the framework

Activity/investment type	Benefits quantified under framework
Minor works – safety	Crash cost savings from reduced crashes
Minor works – efficiency	Travel time savings for new and existing users
Minor works – resilience	Reduced chance of a road closure, resulting in fewer detours for drivers and avoided restoration costs for road authorities
Operations	Benefits quantified include improved safety outcomes, time savings and selecting a better route. We suggest using the same framework as minor works given the similarities in benefits. The specific benefits will depend on the nature of the activity or investment
Maintenance and renewals	The framework quantified the relationship trade-off between vehicle operating cost and road authority costs to illustrate the marginal benefits and costs of changing road roughness service level targets, and appropriate roughness service level targets for different road classifications

Abstract

This research report examines how benefit and cost appraisals for road operations, maintenance and renewal, and minor work improvements could be undertaken in a manner comparable with the appraisal framework for capital investments.

In addition, this research seeks to answer what the target level of service should be for each classification of road across the entire network; what the marginal benefits and costs of changes are to the network-wide target level of service for a classification of road; and what the optimal split is between resilience improvements, safety improvements and operational improvements, particularly for minor work improvements.

1 Introduction

1.1 The need to assess different road expenditure activities

The road network is one of the most crucial pieces of infrastructure in New Zealand. It plays a key role in the movement of goods and people on a daily basis, and its essential importance to our everyday life is reflected in its ubiquitous nature. The road network is also one of New Zealand's most valuable assets, with the state highway network worth $30.2 billion alone (NZ Transport Agency 2015a)[1]. A significant amount is spent on the road network to ensure it is maintained and meets the needs of the community. For example, in 2016/17, the National Land Transport Programme (NLTP) is expected to fund $3.5 billion of transport activities, of which just under $2.8 billion is related directly to road expenditure, including (NZ Transport Agency 2016a):

- $1.5 billion on improvements to state highways and local roads
- $976 million on maintenance of state highways and local roads
- $142 million on emergency works on roads.

Given its importance and the vast amount of annual expenditure, attention naturally turns to ensuring road expenditure delivers the desired performance in a cost-efficient manner.

To this end, a number of frameworks help decision makers prioritise different types of road expenditure activities. For example, there are well-established guidelines that can be used to assess the merits of large capital investments or determine maintenance and renewal activities that should have higher priority for funding. However, these frameworks are designed to prioritise opportunities that are of the same activity type (eg capital investments or maintenance and renewal works). It follows that a holistic framework that assesses different activity types does not exist. The purpose of this research report is to address this gap.

1.2 What have we been asked to do?

This research project examined how benefit and cost appraisals for road operations activities, maintenance and renewal activities, and minor work improvements could be undertaken in a manner comparable with the appraisal framework for capital investments. This will help decision makers with a holistic view across different activity and investment types to identify a portfolio of opportunities that offers value for money and meets its service level targets.

In addition, the research sought to answer a number of related questions, namely:

- What should the target service level for the road network be?
- What are the marginal benefits and costs of changes to the service level target?
- What is the optimal allocation of resources between activities and investments to improve resilience, safety and efficiency outcomes, using minor work improvements as an example?

This report sets out the findings of the project.

[1] Valuation of the state highway network is for the 2014/15 financial year ended 30 June and is based on optimised depreciated replacement cost.

1.3 What you will find in the remainder of this report

The remainder of this report is structured as follows:

- Chapter 2 explores decision-making frameworks commonly used to prioritise investment opportunities and achieve value for money.
- Chapter 3 discusses the purpose of service level targets and the trade-offs involved with setting targets.
- Chapter 4 describes the proposed approach to selecting an ‘optimal’ portfolio of investment opportunities and our approach to developing a fit for purpose cost-benefit analysis (CBA) so the proposed approach can be practically applied.
- Chapter 5 sets out an illustrative framework that examines the marginal benefits and costs of changing intervention levels for maintenance and renewal works, using a change in the roughness intervention level as an example.
- Chapter 6 describes the benefits and costs that arise from minor work improvements and a quantification framework that could be used.
- Chapter 7 explores the nature of operations activities and typical benefits and costs, and a generic quantification framework that could be used.
- Chapter 8 summarises the key conclusions of this project.
- Chapter 9 lists the references used in the report.

Appendix A provides an overview of the toolkit developed for this project and appendix B provides a web link to the toolkit at www.nzta.govt.nz/resources/research/reports/631.

2 Common frameworks used to prioritise investment opportunities

The number of socially desirable potential road investment opportunities will typically exceed a road authority's budgetary and capacity constraints. It follows that a framework to select and prioritise investment opportunities is needed to maximise benefits from public expenditure. This chapter explores common frameworks and tools adopted by other jurisdictions and industries to prioritise potential activities and investments.

2.1 Common factors developed countries use to prioritise activities and investments

Decision makers are often required to evaluate competing activities and investments and decide which activity or investment would provide adequate economic returns and so should be funded. These activities and investments are often diverse in nature and deliver different outcomes. For example, road safety campaigns are aimed at improving safety (and so would reduce road fatalities), whereas highway upgrades would expand the capacity of the network (and so would reduce travel time). To decide which activity or investment should receive funding, decision makers are often required to examine which activity or investment provides the best value for money, eg compare the net benefits (benefits less costs) of reducing fatalities with benefits of improving travel time.

CBA is the most common approach used in developed countries to assess and prioritise different activities and investments. It is extensively used in New Zealand, the US, England, Australia, Singapore, Chile, Ireland and many other countries (World Bank 2016). In brief, a CBA is a 'with and without' assessment that highlights the likely difference an activity or investment will make to societal welfare, and give rise to corresponding benefits and costs. These benefits and costs are converted into a dollar value that permits consistent comparison of benefits of diverse activities and allows decision makers to examine likely rates of return (ie benefit–cost ratio (BCR)) and magnitude of net benefits (ie net present value (NPV)) of the benefits and costs of different activities and investments.

Recently, there has been an emerging trend in many developed countries (examples include the UK, some states in the US, Australia and New Zealand (World Bank 2016) to consider the CBA in conjunction with other factors, such as:[2]

- assessing the strategic fit of an activity or investment
- examining the financial and commercial aspects of the activity or investment
- assessing the deliverability or risk of the activity or investment.

The strategic fit assessment seeks to examine if the activity or investment will likely deliver outcomes that are aligned with the policy objectives of the decision maker. For example, a programme dedicated to improving road safety could rule out activities and investments that primarily delivered travel time savings on the basis of strategic fit.

[2] Government organisations including those in the UK (eg Department for Transport), Australia (eg Infrastructure Australia) and other organisations adopt a similar approach in project appraisals.

The financial aspects are related to the size of funding a proponent is asking for, and whether the activity or investment is desirable and affordable for the decision maker. For activities and investments that can generate revenue, such as a toll road, decision makers also often consider the commercial aspects of an activity or investment, eg whether revenue is sufficient to cover cost, and if not, what is the likely gap. Typical frameworks used to assist in evaluating financial aspects of a potential activity or investment include breakeven or payback period analysis.

Some of the activities and investments can be high risk because of variations in demand for road travel over time, geological uncertainties, their complexity or because of strong objections from key stakeholders as they could affect local amenity. Decision makers often need to consider whether these risks can be reasonably managed.

While other factors are important in the decision-making process (eg they are often used as an initial filter to rule out unsuitable activities and investments), CBA continues to be the key framework used by decision makers to assess which activity or investment provides the best (social) value for money. To ensure CBA results are comparable, decision makers often require proponents to follow guidelines to be eligible for funding.

An example of a clearly defined evaluation process employing CBA is the appraisal of an electricity transmission infrastructure in Australia, which guides the evaluation process to ensure predefined objectives are satisfied. A summary of the process is provided in box 2.1.

Box 2.1 Regulatory Investment Test for Transmission, Australia

Transmission network augmentations costing over $6 million in the national electricity market are required to undergo an appraisal and consultation process. This process is referred to as the Regulatory Investment Test for Transmission (RIT-T), which requires proposed transmission network augmentation projects to achieve at least one of two needs (or objectives):

- market benefits: which relate to reducing network constraints to obtain market benefits from more efficient electricity generation and dispatch. Analysis of this need requires using CBA framework to ensure options considered have positive net market benefits
- meet reliability standards: which relate to augmentation projects that are required to meet jurisdictional reliability standards that ensure electricity customers are supplied with electricity. Analysis of this need utilises the CBA framework to identify the lowest net cost solution to meet reliability standards.

The RIT-T process involves three stages where CBA is built up in increasing detail. Both stage one and stage two are subject to submissions which require the transmission network company to respond as part of the consultation process. Where a project is found to contribute to one of these two needs then the RIT-T process enables the transmission company to undertake these projects, funded through increasing charges on customers.

A key feature that differs from frameworks in transport is that the objectives are clearly defined; meeting reliability standards and achieving market benefits are the only two types of needs that give rise to network augmentation. This avoids the need to evaluate the strategic fit of a project. Further, the RIT-T process does not impose a budget constraint as additional expenditure is recovered from increased user charges. The RIT-T instead looks to meet the identified need using a CBA framework given all the credible options available, including non-infrastructure solutions such as demand management.

At the core of the RIT-T process is a CBA analysis that considers all the costs and benefits of credible options and enables decision makers to identify the option that provides the highest degree of value for money for electricity consumers.

In section 2.2, we explore assessment frameworks commonly used in evaluating value for money that underpins the economic aspects of a business case.

2.2 Value for money assessments

There are a number of assessment frameworks and tools used by decision makers to help identify which activity or investment provides the highest net social benefits and best value for money, including:

- multi-criteria analysis (MCA)
- cost-effectiveness analysis (CEA)
- cost-benefit analysis (CBA).

These are discussed in further detail below.

2.2.1 Multi-criteria analysis

MCA evaluates an activity and investment against a number of criteria. There are a number of methods that MCA can apply. While the details of each method may differ, the key steps involve:

- identifying the key criteria for evaluating activities and investments (eg economic, social or environmental objectives)
- establishing a rating system that would assess how each activity and investment compared with the key criteria (eg rating from 1 to 10, low/medium high)
- calculating an overall rating for each activity and investment, based on rating with the key criteria and weighting of different criteria.

The end output of the MCA is often a qualitative score for each activity and investment. A key strength of MCA as an appraisal framework is that it explicitly recognises both monetary and non-monetary objectives that can influence decision making. In practical terms, MCA can be easy to undertake as it does not require sophisticated analysis or modelling to perform.

MCA also has a number of drawbacks. The rating of activities and investments is subjective and the weighing of criteria in reaching a decision can often be arbitrary. This means that results from MCA are often considered less rigorous and consistency of assessments is an issue. In addition, it is difficult to interpret the results of a MCA, and assess if an activity or investment is expected to provide more benefits than costs. These drawbacks mean MCA is often used as a filtering tool to reduce the number of possible activity and investment options rather than as the end point of the value for money assessment.

2.2.2 Cost-effectiveness analysis

CEA assesses the outcomes or effects achieved by an activity or investment (eg number of lives saved) relative to the activity's cost. CEA is different from CBA, which converts benefit outcomes into a monetary value. Broadly speaking, the two key outputs of a CEA for each activity or investment are:

- cost-efficiency ratio, which represents the unit cost of delivering the desired effects (eg average cost per life saved)
- efficiency-cost ratio, which represents social benefit effects delivered per dollar spent (eg life saved per $ million spent).

An advantage CEA has over CBA is that it is simpler as CEA foregoes converting outcomes into monetary values. Another advantage of CEA is that it is a flexible framework providing decision makers with a robust way to compare activities and investments that deliver the same outcomes. It is often used in industries, such as the health sector, where it can be difficult or inappropriate to monetise outcomes. The key outcomes of a CEA, the cost-efficiency ratio and efficiency-cost ratio, have a clear meaning and are intuitive.

The disadvantage of CEA is that it does not allow decision makers to compare activities and investments that deliver different outcomes. In addition, it does not allow decision makers to examine if activity or investment benefits are expected to exceed associated costs. These disadvantages mean that CEA is typically used to compare activities and investments that are expected to deliver one key primary benefit rather than activities and investments that deliver multiple or different benefits.

2.2.3 Cost-benefit analysis

CBA is a common framework used to assess the merits of different activity or investment types in many sectors including transport. The key steps of a CBA are:

- defining the base case, or the most likely outcomes and problems that would arise if an activity or investment does not proceed[3] (eg worsening congestion or high crash rates)
- identifying activity or investment cases, or describing possible options that could resolve the problems that arise under the base case (eg build additional lanes to reduce congestion or addressing ‘black spots’ on the road network to improve safety outcomes)
- identifying and quantifying the likely benefits and costs from the different activity or investment options with comparison with the base case. In general, this will require monetising identified costs and benefits, which may be informed by using affected parties willingness to pay for the benefits of an investment: which in many cases will be adequately measured by market prices
- calculating the NPV of benefits and costs and the BCR
- undertaking sensitivity analysis.

The key outputs of CBA are the BCR and the NPV for an activity or investment. The BCR represents the ‘rate of return’ of an activity or investment, or the value of benefits achieved (measured in dollars) for each dollar of cost incurred. The NPV presents the magnitude of the net benefit of an activity or investment to society as at the date of the decision, and is calculated as the present value (PV) of benefits minus the PV of costs. NPV is considered to be the most robust measure of incremental social benefits generated by an activity or investment, while BCR is useful in characterising the return of an activity or investment to both the road authority and society more broadly. The key advantage of CBA is its ability to compare activities and investments that deliver different outcomes as it seeks to convert all benefits into a monetary value. In addition, the CBA framework is flexible and can be applied in many different situations and contexts. The end results of a CBA (ie BCR and NPV) have clear meanings and allow decision makers to identify activities and investments where benefits are expected to exceed costs, and assess which activities and investments would deliver the best value for money.

However, CBA also has several disadvantages. First, the CBA framework requires a level of information and analytical maturity that can be significant in terms of costs, time and resources. Second, CBA may exclude cost and benefits that are difficult to monetise. These shortcomings mean CBA is often not applied for activities and investments below a certain size or when there is a short turnaround time for decision making.

[3] For transport projects, this is often the do minimum scenario that reflects business as usual without the project.

Figure 2.1 Benefit- cost analysis framework overview

Step	Description
Identify the base case	Describe the 'do-minimum' case (current/minimum expenditure) and the problems that arise from this
Identify the option cases	Identify the potential options that can address problems under the base case
Identify costs and benefits for base and options	List benefits and costs arising from each option
Develop project life or analysis period	Identify how long the analysis period is for, which can be the life of the project or shorter
Quantify benefits and costs over analysis period	Compare different options' incremental costs and benefits from base case
Calculate economic results of each option	Calculate overall results (eg, benefit cost ratio, NPV) of options to identify preferred option
Perform sensitivity analysis	Change key assumptions in the analysis to assess range of possible outcomes

2.2.4 Conclusion: which framework to use?

Each of the value for money assessment frameworks mentioned in sections 2.2.1 to 2.2.3 has its own advantages and disadvantages. Consequently, deciding which framework to use depends on the context of the decision-making process and the nature of the projects.

A key purpose of the research was to develop a framework that can assess road operations activities, maintenance and renewal activities, and minor work improvements in a manner comparable with the appraisal framework for capital investments. The diverse nature of these projects, further discussed in chapter 3, means the types of benefits that need to be considered are also varied. In addition, capital investments are currently evaluated using CBA.

Given the context above, CBA has been used to assess the value for money of these different activity and project types. Using CBA would be compatible with how capital investments are evaluated and it can compare projects that deliver different types of benefits. Since the NZ Transport Agency (the Transport Agency) currently evaluates the economic case for capital investments using a CBA framework, many of the key benefits and costs have already been quantified. In contrast, CEA is not well suited to evaluating projects that deliver different types of benefits and MCA does not provide meaningful results for use in comparative decision making. Our approach to developing the CBA framework is described in section 4.3.

Table 2.1 Advantages and disadvantages of different value for money assessment frameworks

Assessment framework	Advantages	Disadvantages
Multi-criteria analysis	• Easy to undertake • Can incorporate impacts that cannot be quantified	• Difficult to interpret the results of the analysis • Ratings can be subjective and arbitrary
Cost-efficiency analysis	• Simpler to undertake when compared with CBA • Provides clear and meaningful results	• Cannot be used to compare projects that deliver different outcomes • Does not assess if benefits will likely exceed costs
Cost-benefit analysis	• Can be used to compare projects with different outcomes • Provides clear and meaningful results	• Requires the most amount of time and effort to implement • It may not be possible to quantify important costs and benefits

3 Achieving the desired service level

The purpose of undertaking different activities is to ensure the road network delivers the desired service level to meet the needs of users and the community. For example, the end users and the community commonly want safer roads and improved travel times. To this end, road authorities often have outcome performance measures and service level targets to monitor if the road network is meeting the needs of end users and the community. This chapter discusses outcome performance measures commonly used by road authorities, how investment opportunities help road authorities deliver the required performance measures, and the purpose and trade-offs in setting service level targets.

3.1 Commonly used outcome performance measure and examples of targets

The characteristics of the road network and community needs differ for each road network, eg, congestion would likely be more of a concern to a road authority in an urban area. Naturally road authorities all have different desired objectives they seek to achieve from the road network. However, these objectives would be merely aspirational if there was no way to define and measure performance.

A common approach to setting performance measures is through the lens of the end customer or society. In other words, what performance measures best measure outcomes that end users or society want from the road network, ie, customer performance outcome measures. In contrast, technical output measures, such as skid resistance service levels, focus on the outputs produced by road authorities.

Examples of performance measures used by road authorities are set out in the table below. Examples of service level targets include reducing the number of fatal and serious crashes by, say, 20%, or improving travel time by 10%.

Table 3.1 Examples of outcome performance measures[4] (Source: Transport Canada 2006, pp8, 13, 17–19)

Outcomes desired	Outcome description	Performance measure
Safety	Ensuring the road network is safe for all users	• Total number of road fatalities and injuries • Road fatalities and injuries per kilometre/registered driver
Mobility	Improving the overall performance of the road network from a convenience and travel time perspective	• Average and total travel times • Standard deviation or variation of travel time
Amenity	Providing a pleasant ride experience and road environment to all users	• Quality of the ride for users • User satisfaction index
Environment	Minimising the negative effect road related travel has on the environment	• Vehicle related emissions
Economic	Ensuring road expenditure provides economic returns to users and society	• NPV and BCR • Internal rate of return • Job creation

[4], These elements and outcomes are based on surveys of various provincial and state jurisdictions in several different countries, including Australia, the US, the UK and New Zealand. Consequently, not all outcomes or performance measures are applied in each of the countries.

3.2 How maintenance, operations and minor work improvements help achieve performance outcomes

Road authorities often do not have direct or total control over the outcome performance measures they set. That is, outcome performance measures and targets do not directly determine the activities or level of work road authorities undertake. For example, road authorities do not have control over the number of crashes that occur or how congested a road is for a given day. However, road authorities can undertake activities that help deliver outcomes such as removing safety hazards to reduce the chance of a crash or expanding the highway to improve travel speeds.

The activities and investments road authorities undertake are focused on improving the performance of the road network over time. Many of these activities and investments, such as minor work improvements and capital improvements and road operations activities, are considered on a case-by-case basis. On the other hand, maintenance and renewal activities are undertaken to maintain the quality of the network so it continues to provide the required functionality. This involves setting technical intervention levels for certain condition measures, eg skid resistance and roughness, and undertaking activities when these intervention levels are about to be breached.

All the activities road authorities undertake should contribute to delivering better outcomes from the road network. Capital investments, maintenance and renewal activities, and road operations activities are diverse in nature and so have the potential to contribute to different performance outcome areas. In contrast, minor work improvements are designed to improve particular aspects of road performance.

Table 3.2 below shows how these different road activities and investments contribute to different performance outcomes set out in New Zealand's One Road Classification Network, which cover safety, accessibility/reliability, resilience,[5] cost efficiency and amenity.

Table 3.2 How different road activities and investments contribute to different performance outcome areas

Performance area	Capital investments	Maintenance and renewal activities	Operations activities	Minor work improvements		
				Safety	Efficiency	Resilience
Safety	✓	✓	✓	✓		
Accessibility/travel time reliability	✓		✓		✓	
Resilience	✓	✓	✓			✓
Cost efficiency measures	✓	✓	✓			
Amenity	✓	✓				

3.3 Setting a service level target

Road authorities often set service level targets as a way of monitoring and improving the performance of the road network over time. Road authorities can also use service level targets as a way to delegate responsibilities toward lower level authorities, agents or contractors. The setting of service level targets is more of 'an art rather than science'. The service level target should reflect the priorities of the users and society, and be measurable so the progress can be monitored over time. The target should also be

[5] Resilience refers to preserving and restoring access to the road network in the event of disruptive events such as floods or rockfalls.

challenging yet achievable (Transport and Infrastructure Council 2016, p14). Put another way, the purpose of setting a service level target is to motivate road authorities to achieve a goal they otherwise may not achieve in the absence of a target.

An example of service level target in the road sector is Vision Zero, where the goal is to have zero serious injuries or fatalities on the road network. The target was set at zero because any human loss on the road network is considered unacceptable. Vision Zero originated in Sweden and has since been adopted by several other governments, such as the Victorian and Western Australian state governments in Australia.

3.4 The trade-offs when setting a service level target

A key objective of road authorities is to achieve the service level targets that have been set. Most road authorities have a fixed budget for the transport or road network. Within this context, aiming for a more ambitious target in one outcome area, say road safety, means in theory at least, there would be less focus and resources to achieve outcomes in other areas, say amenity and mobility.

In short, increasing the service level target in a particular area will likely affect outcomes in other performance areas unless there is also a corresponding increase in budget. The likely effects will depend on how the change in target influences the portfolio of investment opportunities that road authorities pursue. These considerations are further discussed in the next section.

4 The proposed decision- making framework

Organisational constraints (eg budget or capacity constraints) give rise to the need for road authorities to prioritise and select investment opportunities they intend to undertake. The decision-making process in selecting investments needs to account for different objectives that different activities and activities and investments aim to satisfy and their own service level targets. Further, the decision-making process should maximise the benefits to stakeholders from undertaking road activities and investments. This section discusses a proposed decision-making framework that could be used to select an 'optimal' portfolio that represents balance for money while balancing service level targets and organisational constraints.

4.1 Proposed approach to selecting an optimal portfolio

4.1.1 Overall framework

Selecting a portfolio of investment opportunities from a set of possible road activities and investments can present challenges as they deliver different types of benefits that may not be immediately comparable with each other. Furthermore, activities and investments will vary in scale in terms of costs and benefits, which adds an extra dimension to consider when determining the group of activities and investments to undertake.

For a given budget constraint and service level targets of the road authority, an optimal portfolio of investment opportunities can be selected using the results from CBA, as one of the advantages of applying CBA is it converts benefits and costs into monetary terms, thereby making them comparable.

The CBA framework can be applied to selecting a portfolio of investment opportunities given a set budget by the following process:

1 Rule out opportunities that are considered:
   - a too risky for the road agency to take on
   - b not effective in achieving the objectives of the road agency
   - c outside the road agency's capacity to deliver
   - d not aligned with the strategic objectives of the decision maker.

2 Estimate the costs and benefits for each possible investment opportunity using consistent assumptions and inputs across the different opportunities

3 Calculate the NPV for each opportunity using a common discount rate

4 Set a constraint that reflects an organisation's budgetary constraint and service level requirements

5 Select the combination of opportunities that delivers the highest total NPV given the budget constraint.

The first step of the process acts as an initial filter to rule out projects that are not ideal candidates for funding. It recognises that undertaking a CBA for projects is time consuming; projects that are too risky, ineffective, cannot be delivered, or are not a strategic fit should be ruled out in the first instance. For example, a project could be ruled out because it has significant engineering or environmental risk that cannot be mitigated to a satisfactory level. Projects that require significant resources and budget above the capacity of a road authority could also be ruled out as they cannot be delivered.

The second and third steps of the process involve undertaking a CBA for individual projects. Our approach to developing a CBA framework for road operations activities, maintenance and renewal activities, and minor work improvements is discussed in section 4.3 below. Chapters 5, 6 and 7 have examples of how the CBA framework could be applied.

Steps four and five involve selecting a portfolio of projects that deliver the optimal outcome subject to the constraints identified in step 4. In other words, what is the list of projects that can achieve the highest social net benefit, defined as total benefit minus cost, while still meeting budget constraint and service level targets? An example of how steps four and five could be implemented is presented in section 4.2.

Selecting a portfolio of investment opportunities from a set of possible road activities and investments can present challenges as they deliver different types of benefits that may not be immediately comparable with each other. Furthermore, activities and investments will vary in scale in terms of costs and benefits, which adds an extra dimension to consider when determining the group of activities and investments to undertake.

This process[6] will generate a list of opportunities that maximises the portfolio NPV by choosing an optimal combination of activities and investments given a budget constraint and minimum service level targets. An illustrative example of this process is provided for minor work improvements in section 4.1.2 below.

4.1.2 Further enhancements to the framework

4.1.2.1 Understanding the relationships between projects

Our proposed framework currently assumes all projects are discrete and standalone projects. In practice, the road network is linked and projects could be supplementary or complementary. For example, projects involving works on a particular road could be implemented jointly to minimise disruption to road users or reduce overall project costs. Similarly, a project that could shift road users from road A to road B would also be likely to affect the economic merits of work associated with road A and road B. These effects could be included in the optimal portfolio choice at a cost of complexity.

4.1.2.2 Incorporating risk assessments into the framework

The proposed framework currently provides the expected BCR and NPV benefits and costs of the portfolio. In practice, uncertainty in factors such as future demand and construction costs mean there is risk that actual outcomes could deviate significantly from the expected results. The proposed framework could be extended to provide a range of likely outcomes using sensitivity tests, or through Monte Carlo simulation of the optimal portfolio NPV. However, this would require significant input and effort to implement.

4.2 Illustrative example of the proposed approach

Minor works provide a useful set of investment types (ie safety, efficiency and resilience) to illustrate how a portfolio approach can balance funding demands from different objectives by applying the CBA framework in a portfolio approach. While this framework uses minor work improvements as an example, it could be expanded to include large capital investments, road operations and maintenance and renewal activities.

The illustration is provided for a set of hypothetical minor work improvements that consist of eight safety improvements, eight efficiency improvements and eight resilience improvements. These improvement projects vary in size with an average cost of approximately $347,000 and a range of $516,000 in NPV terms between the smallest and largest improvement projects by cost.[7] The total funding requirement for this set of investments in

[6] Microsoft Excel includes a solver add-in that optimises solutions for linear problems, such as maximising overall NPV given a list of possible activities and investments. A brief discussion of the solver is provided in appendix A.

[7] A simplifying assumption made in constructing these investments for the illustrative example is that each investment is discrete and not scalable. However, the illustrative example does not preclude the inclusion of scaled-up versions of smaller investments in the set of possible investments.

NPV terms is approximately $8.3 million over a period of 10 years. The full set of investments is unable to be funded given a budget constraint of $4 million for the same period in NPV terms. Further, the road authority has set minimum service level targets for safety (reduce fatal/serious crashes by 0.3 occurrences per year), efficiency (reduce 85,000 hours of travel time per year), and resilience (reduce detours by 50,000 kilometres per year).

Consequently, decisions on which investments to progress will need to be made. Details of these investments are contained in the accompanying model located at www.nzta.govt.nz/resources/research/reports/631. The proposed approach to selecting the optimal portfolio seeks to maximise the economic benefits by maximising the overall NPV of a portfolio while meeting the budget constraint and minimum service level targets. It may not be possible to meet the required minimum service level targets given the available investment opportunities and budget. In this case, decision makers will need to consider some combination of lowering the service level targets, increasing the available budget and developing new projects.

Implementing the proposed approach requires estimating the costs and benefits and converting these into a common monetised quantity for each possible investment. The next step involves calculating NPVs for each possible investment, which allows the optimal combination of investments to be determined. Table 4.1 sets out the NPV and BCR results of each of the 24 individual investments noted above.

Table 4.1 Individual investment NPVs and BCRs

Investment number	Investment type	NPV ('000s)	BCR	DSI prevented per year	Detour distance avoided (vkt)	Time saved (hours)
Investment 1	Safety	$1,882	6.2	0.12	-	-
Investment 2	Safety	$297	4.8	0.02	-	-
Investment 3	Safety	$2,477	5.8	0.16	-	-
Investment 4	Safety	$577	4.3	0.04	-	-
Investment 5	Safety	$762	3.1	0.06	-	-
Investment 6	Safety	$3,905	7.6	0.24	-	-
Investment 7	Safety	$3,232	7.3	0.20	-	-
Investment 8	Safety	$3,242	7.5	0.20	-	-
Investment 9	Efficiency	$1,383	9.0	-	-	9,500
Investment 10	Efficiency	$3,796	13.1	-	-	17,500
Investment 11	Efficiency	$4,155	10.6	-	-	20,000
Investment 12	Efficiency	$3,263	8.5	-	-	22,500
Investment 13	Efficiency	$2,757	6.3	-	-	20,000
Investment 14	Efficiency	$1,087	13.5	-	-	5,000
Investment 15	Efficiency	$1,565	11.0	-	-	7,500
Investment 16	Efficiency	$1,517	3.9	-	-	12,400
Investment 17	Resilience	$116	1.5	-	6,475	245
Investment 18	Resilience	$398	2.4	-	51,000	1,367
Investment 19	Resilience	$671	3.1	-	32,000	1,209
Investment 20	Resilience	$2	1.0	-	6,820	158
Investment 21	Resilience	$196	1.4	-	38,800	1,035
Investment 22	Resilience	$734	2.4	-	69,300	2,090
Investment 23	Resilience	$600	2.7	-	34,790	1,270
Investment 24	Resilience	$43	1.2	-	8,250	209

The optimisation process selects four safety investments, two resilience investments and six efficiency investments. These investments require just under $4 million (PV) of funding over 10 years but will provide a NPV of net benefits of over $27.7 million. The portfolio of investments satisfies the $4 million budget constraint and meets the service level targets while maximising-NPV given the constraints. Table 4.2 presents the investments selected for the portfolio.

Not all investments with a high BCR will be selected for the portfolio. This is because the investment selection process optimises the total portfolio NPV given a budget constraint. This causes some investments that might have a high BCR (such as Investment 1) to be rejected from the portfolio as a consequence of the optimisation process trying to make the most of the allowed budget. Put another way, any unspent budget effectively offers zero NPV that reduces overall portfolio NPV. Therefore, it is advantageous to select investments that contribute to the overall portfolio NPV and can fit into the budget, rather than select a few large investments with high BCRs that leave a large amount of unspent budget.

Table 4.2 Investments selected for the portfolio

Investment	Investment type	Funding (‘000s)	NPV (‘000s)	BCR	DSI prevented per year	Detour avoided (VKT)	Time saved (hours)
Investment 6	Safety	$594	$3,905	7.6	0.24	-	-
Investment 8	Safety	$501	$3,242	7.5	0.20	-	-
Investment 7	Safety	$511	$3,232	7.3	0.20	-	-
Investment 18	Resilience	$286	$398	2.4	-	51,000	1,367
Investment 11	Efficiency	$434	$4,155	10.6	-	-	20,000
Investment 10	Efficiency	$312	$3,796	13.1	-	-	17,500
Investment 12	Efficiency	$434	$3,263	8.5	-	-	22,500
Investment 13	Efficiency	$521	$2,757	6.3	-	-	20,000
Investment 15	Efficiency	$156	$1,565	11.0	-	-	7,500
Investment 9	Efficiency	$174	$1,383	9.0	-	-	9,500
Total		$3,924	$27,697	8.1	0.64	51,000	98,367

Overall, the portfolio of activities and investments selected provides an NPV of $27.7 million and a BCR of 8.1. The high-level economic results of the portfolio are presented in table 4.3. The portfolio is also expected to deliver the minimum service level targets the road authority has set.

Table 4.3 Overall portfolio dashboard (money amounts measured as NPV)

Overall results	Amount
Total PV funding required to implement all projects (‘000s)	$8,337
Available funding (‘000s)	$4,000
Funding used (‘000s)	$3,924
Remaining funding (‘000s)	$76
NPV of funded investments (‘000s)	$27,697
BCR of funded investments	8.1
Number of investments funded	10
Number of fatal/serious injury crashes avoided	0.64
Number of hours saved	98,367
Avoided detours (VKT)	51,000

Service level targets have a material effect on the outcome of activity and investment selection that can be used to align portfolios with an organisation's strategic objectives. As an illustration, we undertake activity and investment selection again but without service level targets. The resulting portfolio of activities and investments is shown in table 4.4.

Table 4.4 Investments selected for the portfolio without setting service level targets

Investment number	Investment type	Funding ('000s)	NPV ('000s)	BCR	DSI prevented per year	Detour avoided (VKT)	Time saved (hours)
Investment 6	Safety	$594	$3,905	7.6	0.24	-	-
Investment 8	Safety	$501	$3,242	7.5	0.20	-	-
Investment 7	Safety	$511	$3,232	7.3	0.20	-	-
Investment 4	Safety	$174	$577	4.3	0.04	-	-
Investment 2	Safety	$78	$297	4.8	0.02	-	-
Investment 11	Efficiency	$434	$4,155	10.6	-	-	20,000
Investment 10	Efficiency	$312	$3,796	13.1	-	-	17,500
Investment 12	Efficiency	$434	$3,263	8.5	-	-	22,500
Investment 13	Efficiency	$521	$2,757	6.3	-	-	20,000
Investment 15	Efficiency	$156	$1,565	11.0	-	-	7,500
Investment 9	Efficiency	$174	$1,383	9.0	-	-	9,500
Investment 14	Efficiency	$174	$1,383	9.0	-	-	5,000
Total		$3,976	$29,261	8.4	0.7	-	102,000

Five safety activities and investments are selected in the portfolio without service level targets instead of four at the expense of one resilience investment. This alternative portfolio exclusively optimises activity and investment selection based on the objective of maximising portfolio NPV, which leads to a higher NPV of $29.3 million compared with $27.7 million. However, the higher portfolio NPV comes with no improvements in avoided detour vehicle kilometres due to the absence of service level targets. Stated in another way, the difference in net benefits of approximately $1.6 million in NPV terms between the two portfolios is the marginal cost of service level targets.

In addition to illustrating how road authorities can quantify the marginal cost of service level targets, this example alludes to the fact that ranking activities and investments purely on cost and benefit basis does not necessarily achieve what is 'optimal' from an organisational objectives perspective. The exploration and inclusion of service level targets will sometimes be necessary to align the overall portfolio with operational objectives the road authority wants to achieve; perhaps for reasons of delegating work programmes.

Table 4.5 Overall portfolio dashboard without constraining by service level targets

Overall results	Amount
Total funding required ('000s)	$8,337
Available funding ('000s)	$4,000
Funding used ('000s)	$3,976
Remaining funding ('000s)	$24
NPV of funded investments ('000s)	29,261
BCR of funded investments	8.4

Overall results	Amount
Number of investments funded	12
Number of fatal/serious injury crashes avoided	0.70
Number of hours saved	102,000
Avoided detours (vehicle kilometres)	–

The two portfolios generated with and without a service level target presented above illustrate how service level targets can be used to align activities and investments with a road authority's strategic objectives. Further, the analysis demonstrates that the marginal cost of service level targets (and service levels by extension) can be derived by the difference between portfolios with and without service level targets. This type of analysis can be easily extended to evaluating the marginal cost (or benefit) from increasing or decreasing service level targets.

4.3 Developing an appropriate cost-benefit analysis framework

To implement the proposed framework, we sought to develop a suitable CBA framework that is fit for purpose. CBA is a flexible framework that can be used in many contexts and situations. It allows the user to define the base case and the activity or investment case, determine the benefits and costs that could be included, and how these could be quantified.

However, a CBA framework is only useful for a decision maker if it aligns with the decision-making framework, can be practically applied, and is applied in a consistent manner. We set out three principles that guide our development of a suitable cost-benefit framework that is fit for purpose for application to road activities and investments undertaken by the Transport Agency.

4.3.1 The framework needs to be relevant to decision makers

A CBA framework is only useful if it assists with the decision-making process. This means the cost-benefit framework should be tailored to the activity type and needs to align with the decision that is being made.

For example, different levels of maintenance and renewal works can be directly linked to the required levels of service at a network level (eg a decision maker could set a level of service for roughness and achieve this by customising the forward work programme across the network). In contrast, activities and investments such as minor work improvements are typically considered on a case by case basis rather than from the perspective of achieving network wide service levels.

4.3.2 The framework can be practically applied

Undertaking a comprehensive and detailed CBA can be a time consuming and resource intensive exercise. Given this, it is common for decision makers to introduce threshold values on when CBA should be undertaken, and at what level of detail, eg simplified procedures could be applied to smaller activities and investments.

When designing the framework, we have sought to balance the trade-off between level of detail and the nature of the activity or investment. For example, minor work improvements are typically less than $300,000 and so the framework should not be onerous. Given this, we have sought to use information that is already provided under the current assessment process and thereby limited the additional information that users need to provide to apply the framework.

Another example is operations activities, which can be dynamic in nature in order to deal with changing network conditions (eg traffic management during events, rush hour traffic management, reduce likelihood of crashes in adverse weather conditions). Consequently, operations activities typically have faster turnaround and lower costs. Our framework for operations therefore focuses on the primary benefits (eg time savings and crash cost savings) rather than possible secondary impacts (eg, possible changes in environmental impacts and vehicle operating costs (VOC) due to changes in speed). In addition, our framework does not include travel time reliability benefits because reliability requires significant user analysis before it can be applied. However, the Transport Agency's *Economic evaluation manual* (EEM) could be applied to quantify this benefit if it represents a significant benefit and is justified given the size of the activity or investment.

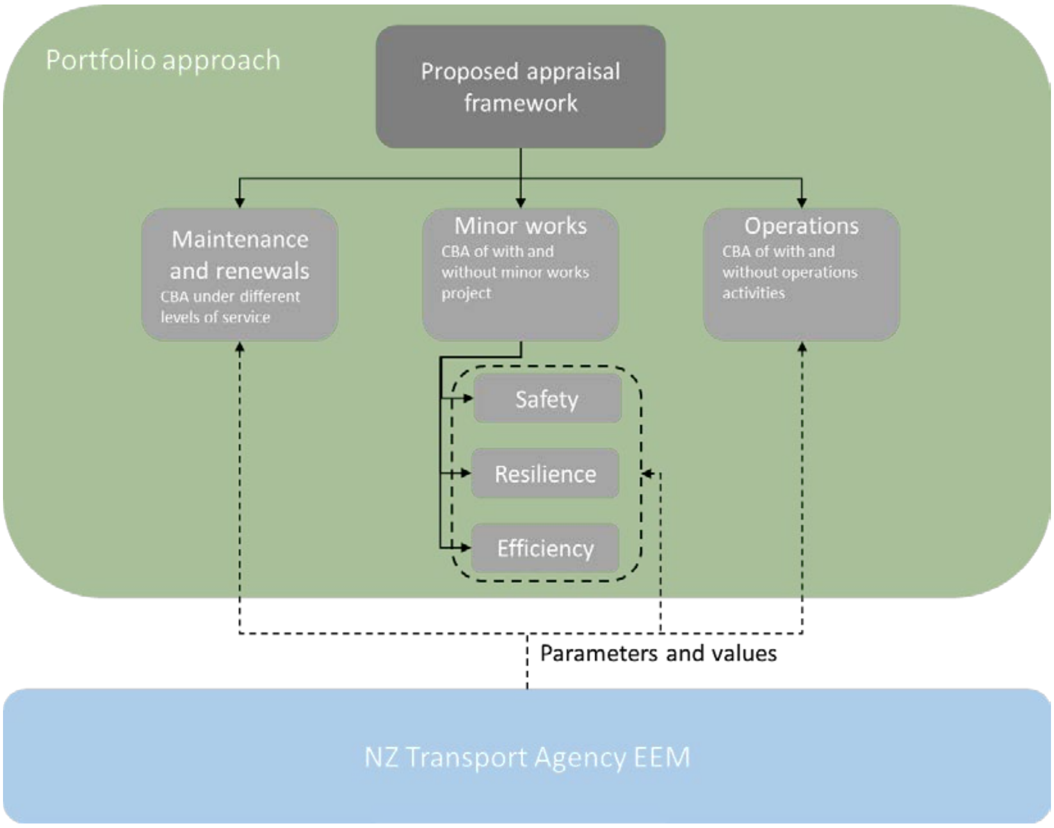
4.3.3 The framework needs to be comparable with the EEM to the extent possible

CBA needs to be conducted in a consistent manner so the results can be used comparatively. To help improve consistency, the EEM contains assumptions and procedures that should be followed when undertaking CBA.

To ensure the framework we have designed is consistent with analysis done for other activity and investment types, we have sought to reference the EEM to the greatest extent possible. In some cases we have not done so as the EEM does not cover the particular subject or it was not practical to do so given the nature of the activity or investment, then we have highlighted this and the potential implications in our discussions. Where appropriate, we highlight how these gaps could be addressed.

Figure 4.1 shows the structure of our proposed framework consists of three parts: maintenance renewals, minor work improvements and operations, each part draws on relevant EEM parameters and values to quantify costs and benefits that is consistent and comparable with existing Transport Agency practice for major capital investments and other activities covered by the proposed framework.

Figure 4.1 Proposed appraisal framework



5 Quantification framework for maintenance and renewal activities

The road network is constantly exposed to both the environment and road users meaning that, over time, the integrity of road assets decay. At some point, this decay in a road asset renders it unable to provide the service level (eg safety and performance outcomes) required, giving the road authority responsible for that asset a choice: rebuild or renew the asset, or accept the lowered safety and performance outcomes.

It is common for road authorities to set a technical minimum service level for a road asset. In other words, allowing the decay of the asset past that minimum is no longer an option, forcing a rebuilding of the asset at substantial cost. However, maintenance and renewal activities allow the road authority to prolong the life of the road asset, or increase the level of service it provides, thereby deferring reconstruction, and meet service obligations in a cost-efficient manner.

5.1 How roads deteriorate over time

Road assets experience deterioration over time. The rate of deterioration depends on a number of factors, such as the original design standard of the asset, level of use and climate of the location. Eventually the asset will need to be replaced or rebuilt because it represents too high a risk to users or no longer provides the functionality required.

There are many ways of defining maintenance and renewal works. For the purpose of this report, we have definitions from the *International infrastructure management manual* (NAMS Group and IPWEA 2015), which has the following definitions:

> *Maintenance: all actions necessary for retaining an asset as near as practicable to its original condition, but excluding rehabilitation or renewal. Maintenance does not increase the service potential of the asset or keep it in its original condition, it slows down deterioration and delays when rehabilitation or replacement is necessary;*
>
> *Rehabilitation: works to rebuild or replace parts or components of an asset, to restore it to a required functional condition and extend its life, which may incorporate some modification. Generally involves repairing the asset to deliver its original level of service (i.e. heavy patching of roads, sliplining of sewer mains, etc.) without resorting to significant upgrading or renewal, using available techniques and standards;*
>
> *Renewals: works to replace existing assets or facilities with assets or facilities of equivalent capacity or performance capability.*

Broadly speaking, maintenance works involve minor activities such as fixing minor defects (eg repairing potholes and fixing damage to a guardrail after a collision) or minor activities that maintain the general condition of the road (eg cleaning the road or mowing grass). In contrast, rehabilitation and renewal works involve replacing the asset to different degrees. These activities are distinct from capital works that improve the capacity or add functionality above the original design.

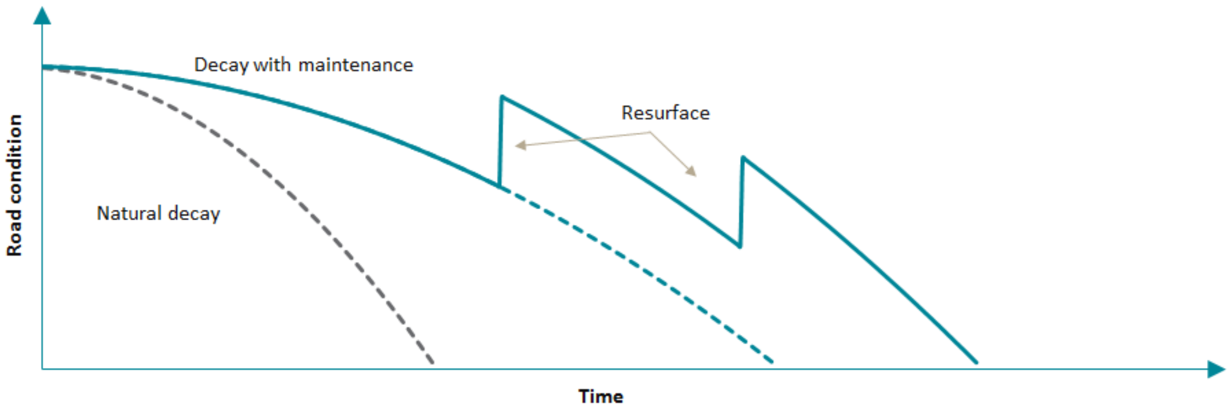
Furthermore, maintenance, rehabilitation and renewal works can often act as substitutes for each other. For example, maintenance involves fixing minor defects, such as potholes and blocked drainage, which can slow the deterioration of the asset, delaying the need for rehabilitation and renewal works. Similarly, resheeting the pavement (ie a rehabilitation activity) could reduce the need for maintenance work (eg crack sealing or repairing potholes) and delay the need for a renewal by providing stronger protection to the base and subgrade. However, as the asset ages over time it will eventually be better and cheaper to renew the asset (ie do a complete rebuild or purchase a new asset).

Once the asset is built, maintenance and renewal works can help road authorities:

- provide the level of service required to meet the needs of road users
- manage risks associated with road infrastructure, including safety risks
- preserve the value of asset to minimise the whole-of-life cost.

An illustrative decay pattern of three roads under different maintenance and renewal work programmes is shown in figure 5.1. One road is allowed to decay without regular maintenance, one is regularly maintained and the last is maintained and rehabilitated. Eventually, a renewal of the road is required once the road reaches its end of life or reaches a certain level of condition. The timing of this differs under the three scenarios and is represented as when the road condition touches the x-axis.

Figure 5.1 The effects of maintenance on road condition and expected life



5.2 Link between maintenance and renewal works and outcomes for road users

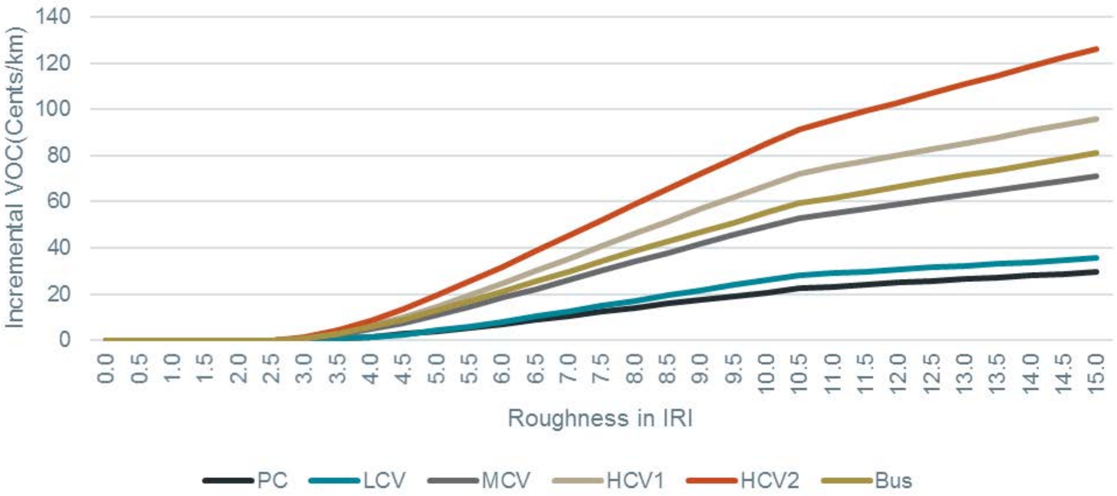
Maintenance and renewal activities have a direct effect on road condition, which influences the level of service enjoyed by road users. Following the One Network Road Classification framework, the road condition directly contributes the following customer levels of service targets (NZ Transport Agency 2016c):

- **Safety**: a better quality road can improve safety outcomes in several ways. For example, it can improve the skid resistance of a road, thereby reducing the stopping distance of vehicles traveling on it. Cut back of vegetation ensures visible signage and stopping line of sight. Maintenance and renewal of safety features, such as guard rails, ensures their effective functioning.
- **Amenity**: a smoother road can lead to improved ride quality and reduced VOC. Well maintained road assets are more aesthetically pleasing than those that have been allowed to decay, improving user satisfaction.
- **Accessibility**: a well maintained road can reduce the chance of unplanned road closures occurring. For example, improved drainage would reduce the chance of flooding in the event of a storm, and a better quality road would be less likely need to close for unplanned maintenance and reactive renewal activities.

- **Mobility**: in the extreme case, roads that are in poor condition may be unsafe to travel at their design speed, requiring road users to travel at slower speeds.

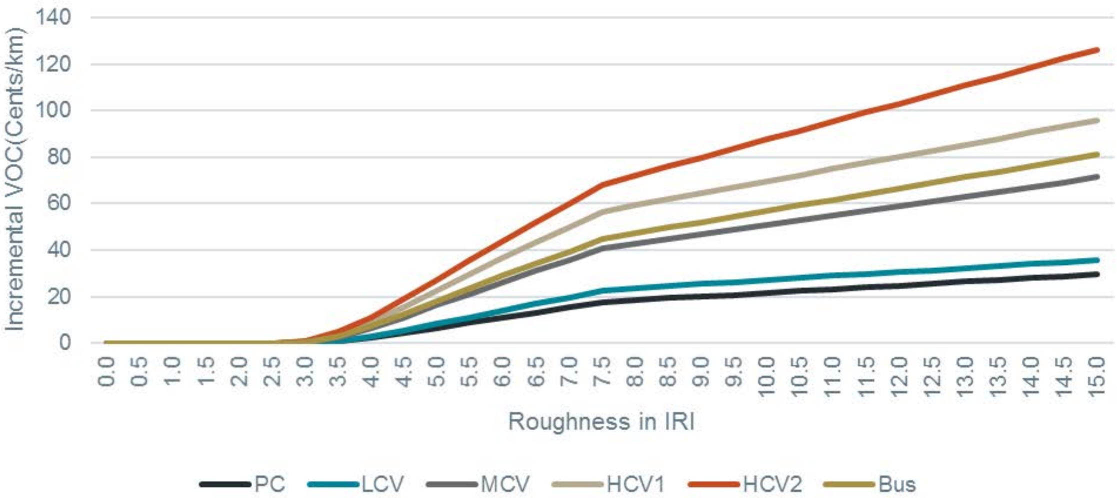
The additional VOC associated with a rougher road, which can be measured using the International Roughness Index (IRI), is the most commonly quantified road user cost that arises from different levels of road condition. The EEM sets out the relationship between the IRI and VOC, which can be seen in figures 5.2 and 5.3 for urban roads and rural roads respectively.

Figure 5.2 Additional VOC due to roughness for urban roads (Source: EEM, table A5.12)



Note: PC = passenger vehicles; LCV = light commercial vehicles; MCV = medium commercial vehicles, HCV1 = heavy commercial vehicle 1 (rigid trucks with or without a trailer, or articulated vehicle with three or four axles in total), HCV2 = heavy commercial vehicle 2 (trucks and trailers and articulated vehicles with or without trailers with five or more axles in total).

Figure 5.3 Additional VOC due to roughness for rural roads (Source: EEM, table A5.13)



The roughness of the road does not influence VOC when the IRI is below 2.5. There is a non-linear and increasing relationship between the IRI and VOC when the IRI is between 3 and 5. The relationship between the IRI and VOC when the IRI is above 5 is relatively linear, with a change after the IRI reaches 10, where the effect of roughness has a diminished effect on VOC.

5.3 Managing the trade-offs between road authority and road user costs

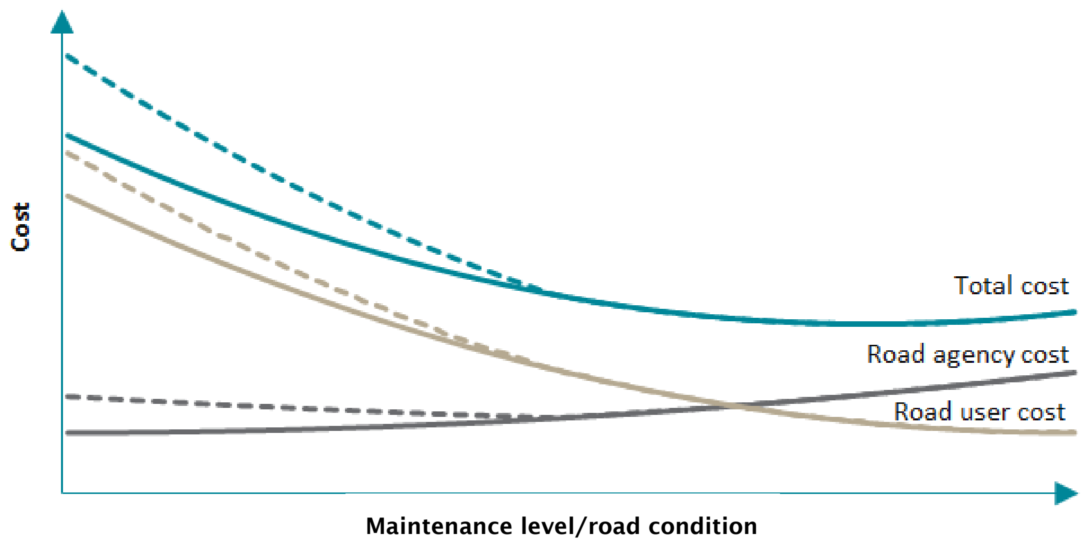
A key question for road authorities is what is the appropriate minimum level of service and how can this be delivered at least total cost. There are a number of considerations pertinent to achieving this goal, and many of them are difficult to quantify.

Broadly speaking, selecting a lower minimum level of services means there is less need to undertake maintenance and renewal works, leading to lower costs for road authorities. However, selecting a minimum level of service that is too low could lead to the premature decay and failure of the road asset, and so higher road authority costs in the long run. For example, maintenance of the road surface protects the subgrade from moisture, decreasing the risk of damage to the road pavement. Choosing a lower minimum service level for the pavement could therefore result in savings in associated maintenance and renewal works, but increases the risk that a road authority will need to reconstruct prematurely. However, it is difficult to quantify the relationship between the targeted minimum service level, the maintenance and renewal works required to maintain this, and the associated risk of premature failure of the asset.

Choosing a lower minimum level service usually leads to lower level of road condition, resulting in higher road user costs. As discussed above, road condition can influence user satisfaction, road safety outcomes, VOC and potential chance of road closures. These relationships are often difficult to quantify and, except for VOC, there is currently a lack of research in this area.

The economically efficient targeted minimum service level will balance road authority cost and road user cost, and risk of premature reconstruction. Figure 5.4 illustrates the trade-off between road authority costs and road user costs in the decision of optimal minimum service level. The risk of selecting a minimum service level that is too low is illustrated with the dotted lines, which shows the outcome of premature failure, resulting in higher costs for road authorities and road users.

Figure 5.4 Cost risks associated with road condition



5.3.1 Examples of quantification frameworks

This section presents two relevant studies that have attempted to quantify the benefits and costs of additional road maintenance. Both studies examine the implications of a change in amount of funding rather than changes in service levels. That said, they still provide a useful demonstration of how CBA could apply to maintenance and renewal activities.

In both studies, VOC represented the key user cost. While the Scotland study included other user outcomes, such as crash cost, VOC represented approximately 85% user costs. Similarly, the second relevant study only examined road user costs as a result of changes in roughness.

Box 5.1 Scotland study (Source: Johnston 2015)

The Scotland study originated from a review by Audit Scotland on how the road network was maintained in Scotland, which included an examination of the wider economic costs and benefits of road maintenance. The examination focused on estimating the economic and social impact of reduced maintenance expenditure on roads over a 10 to 20 year period and involved considering costs and benefits outcomes under three scenarios:

- scenario 1: maintaining 2010/11 spending
- scenario 2: 20% reduction over 10 years, returning to base level over next five years, and then increasing 2.5% in real terms in the next five years
- scenario 3: 40% reduction over 10 years, return to base level over next five years, and then increase of 2.5% over following five years.

The three scenarios were translated into cost and benefits for arterial roads and local roads, which included:

- maintenance costs
- VOC due to surface condition
- travel time costs due to surface condition
- crash costs due to surface condition
- delay costs at roadworks
- crash costs due to reduced lighting
- costs associated with carbon emissions, local air quality and noise.

The CBA indicated that the adverse outcomes in scenario 2 and 3 outweighed the maintenance cost avoided. Table 5.1 sets out a summary of the economic analysis from the case study.

Table 5.1 Quantitative results for all roads under scenario 2 and scenario 3 relative to scenario 1

Cost and benefit	Scenario 2 (£ million, 2002)	Scenario 3 (£ million, 2002)
Maintenance works costs reductions	954	2,027
User costs reductions/(increases)	(1,585)	(3,080)
NPV	(631)	(1,053)

The quantitative results indicate that reducing maintenance spending by £1 generated £1.50 of costs for road users as a result of poor road surfaces. In other words, £1 of maintenance spending saves the road user £1.50 in avoided costs. The results illustrate how trade-offs reducing maintenance can be quantified using a CBA appraisal. While a 40% reduction in maintenance works under scenario 3 produces savings of £2 billion relative to the base case, user costs increase by £3 billion, leaving society worse off by £1 billion. Similarly, we see reduced societal welfare under a 20% decrease in maintenance works in scenario 2, albeit on a smaller scale than in scenario 3.

Box 5.2 Cost of deferring road maintenance expenditure (Source: Harvey 2015)

This study examined how different maintenance options applied to roads in non-urban parts of the national network in Victoria, Australia. The study considers four periodic maintenance treatment types for road surfaces and pavements:

- resurface
- resurface with shape correction
- partial rehabilitation
- full rehabilitation.

Each treatment type has a cost per square metre and varying effect in resetting surface age, cracking, pavement age, pavement age, pavement strength, rut depth and roughness. To examine the cost of deferring maintenance costs, the case study examined the total cost under the optimal strategy under three scenarios:

- without a budget constraint
- with budget constraint of $18.5 million per year in first five years, and then no budget constraint
- with budget constraint of $28.5 million per year in first five years, and then no budget constraint.

These scenarios were assessed using a pavement model that incorporates maintenance treatments, deterioration algorithms, road user cost relationship, technical constraints, and budget constraints, in order to optimise periodic maintenance by minimising total cost. The total cost is defined as the sum of cost incurred by the road agency (ie maintenance cost) and road user cost (ie VOC).

Results of the analysis showed that removing the budget constraints gave rise to marginal NPVs of between $18 million and $140 million or BCR of 1.4 to 4.2 for marginal increases in maintenance expenditure.

5.4 Proposed quantification framework

The complex interaction between the various maintenance and renewal activities and the costs to road authorities and road users makes a comprehensive quantitative decision-making framework difficult to design and implement. The major barriers to quantitative analysis of the benefits of road maintenance and renewal activities are the difficulties in measuring road condition, predicting how roads deteriorate over time, and quantifying the relationship between setting minimum service levels and costs to road users and road authorities.

In trying to measure the effects of a marginal change in minimum service levels the key components are:

- accurately predicting the effects of the change on road maintenance and renewal cost, which requires estimation of the interaction between maintenance and renewal activities and road condition over time
- quantifying and estimating the effects of road condition on road user outcomes such as safety, VOC and user satisfaction.

A change in targeted minimum service levels would change the level of maintenance and renewals required to meet the revised service level. A higher level of service generally requires a road agency to undertake more frequent interventions and incur more cost. On the other hand, an improved service level should deliver benefits to road users.

Quantifying the benefits and costs of changing targeted service levels related to maintenance and renewal works is complex and there is a lack of available data to do so. Future research aimed at understanding of the relationship between user costs (including the drivers giving rise to those costs) and corresponding service levels (defined by measures such as rutting, roughness and cracking) would be useful in closing this knowledge gap and assist in determining a target level of service. Nevertheless, existing research on road condition and road user outcomes, in particular the relationship between the IRI and VOC, allow us to provide an example as a proof of concept.

A case study presented in section 5.5 shows how marginal benefits and costs from changes to the target level of service can be considered. In short, agency costs for maintaining roads to a specific level of service and road user costs driven by the level of service determine total costs to stakeholders. Marginal benefit/cost from changing the level of service for a road classification (and classifications across the network) is the difference in total costs between the different levels of service. It follows that the levels of service should be set to minimise total costs, which is the sum of agency expenditure and road user costs.

5.5 Case study: changing the target minimum service level of roughness for an urban carriageway

The following case study demonstrates how the marginal benefits and costs of changing minimum service level target for roughness can be quantified. We have assumed the road authority sets a targeted minimum service level target for the IRI and undertakes a mill and resheet of asphalt pavement if the service target is to be breached. The mill and resheet brings the IRI back to its original level of 1.5. We have also assumed that IRI deterioration is constant over time and not related to the road authority’s maintenance work program.

5.5.1 Description of the road activity

An urban arterial road with an annual average daily traffic (AADT) of 16,950, comprising 15,000 passenger vehicles and 1,950 commercial and heavy vehicles, has recently undergone reconstruction. The current minimum service level target for roughness is 3.4 IRI (scenario 1) and the road authority is considering changing it to 4 IRI (scenario 2) for a one lane km section.

The IRI is expected to increase over time as road use and climate damages the road. Notably, the rate of increase increases as the road ages over time.[8] To meet its minimum service level target, the road authority renews the road asset with a mill and resheet[9] in the year before it exceeds its IRI target. The road is expected to require a full reconstruction in 40 years when it reaches the end of its useful life.

5.5.2 Quantifying the costs and benefits

Changing the minimum service level target for the IRI has two quantifiable effects over the life time of the road as it changes the:

- timing of when a road authority is required to do a mill and resheet
- roughness of the road, which has an effect on VOC for road users.

For the road authority, increasing the IRI minimum service level target from 3.4 to 4 means the mill and resheet can be delayed. Over the lifetime of the road, the road authority is able to delay the timing of mill and

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[8] We have used Cenek derogation curves sourced from Beca (2016), to model change in roughness over time. The Cenek derogation curves are based on the HDM3 aggregate roughness model that are modified and validated for New Zealand conditions. The Cenek derogation curves used in the model are given below:

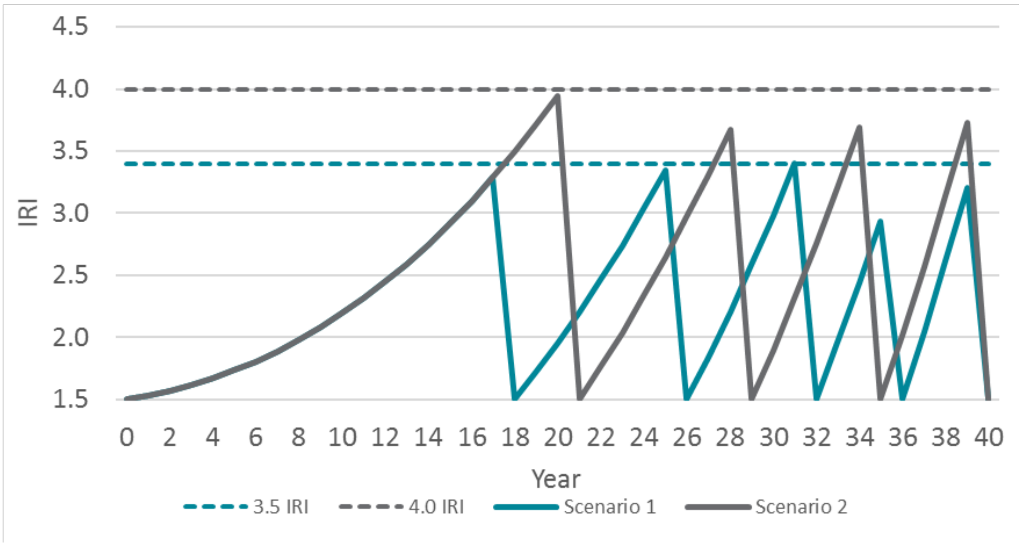
$$r_t = r_{t-1} + \left[m \times r_{t-1} + \left((0.2175 \times (1 + SNP)^{-4.99}\right) \times ESA_t \times (1 + m)\right)\right] \times e^m$$

$r_t = Roughness\ in\ period\ t\ (IRI)$
$m = enviromental\ constant\ calculated\ as\ m = \left((IRI_2/IRI_1) - 1\right)/t$
$ESA_t = cummulative\ equivalent\ standard\ axels\ at\ period\ t$
$SNP = modified\ structural\ number\ (constant)$

[9] Assumed to cost $200,000/km.

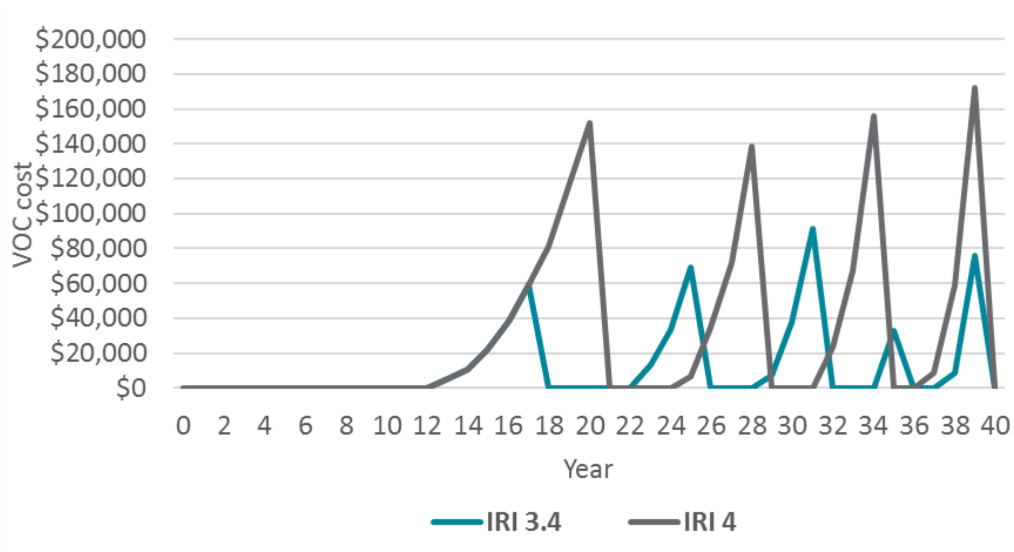
resheet by around three to six years and perform one less mill and resheet (see figure 5.5). The frequency of mill and resheet increases over time as the road decays at a faster rate due to the cumulative damage it has received from road use and the climate.

Figure 5.5 The effects of resurfacing on IRI over time



For road users, the overall roughness of the road is expected to increase if the IRI minimum service level target increases from 3.4 to 4. Initially, road users do not incur additional VOC as the IRI is below 2.5. Over time, additional VOC cost increases as the IRI exceeds 2.5 and then fall backs to zero after a mill and resheet restores the roughness to its original condition of 1.5. The additional VOC incurred by road users is significantly higher when IRI is above 3.4 due to the non-linear, increasing relationship between road user costs and the IRI. Figure 5.6 shows the increase in VOC under the two different IRI targets.

Figure 5.6 Additional vehicle operating costs under the different IRI targets (EEM, table A5.12) [10]



[10] Additional VOC quantified using estimates from EEM.

The total cost profile over the lifetime of the road is shown in figures 5.7 and 5.8. Overall, costs are expected to increase over time as roughness increases and spikes in the years when a mill and resheet is required. However, after the mill and resheet, road users no longer incur additional VOC as the roughness of the road is restored to its original condition. Moving from an IRI target of 3.4 will reduce the cost incurred by the road authority but at the expense of additional VOC for road users.

Figure 5.7 Total costs under the two different IRI targets

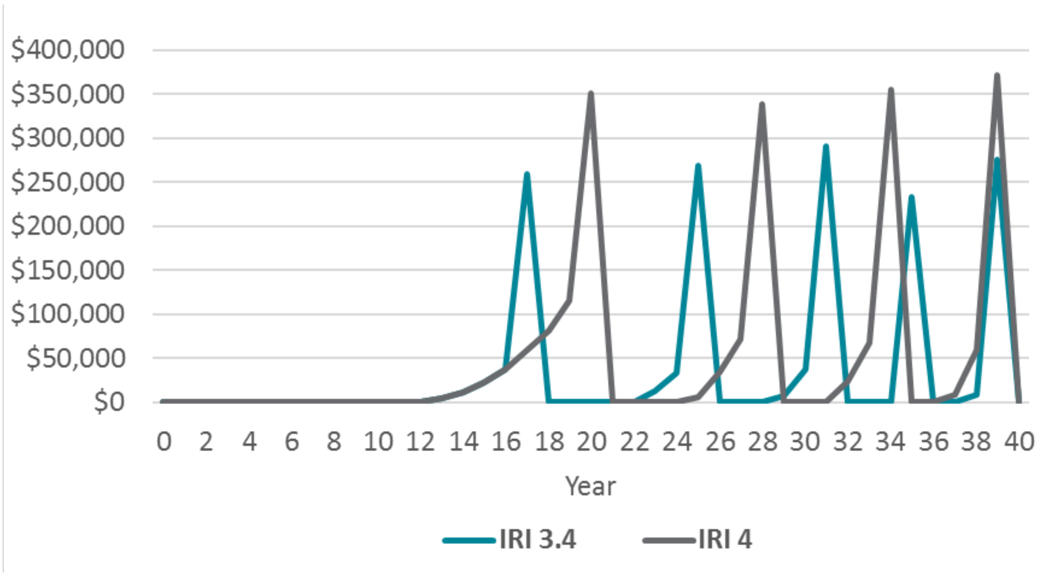
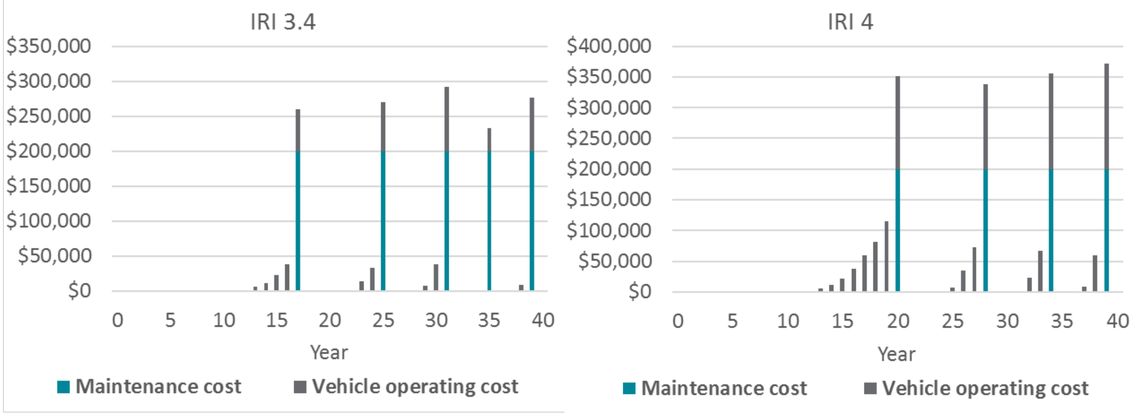


Figure 5.8 Total cost under the different IRI targets by cost type



5.5.3 Results

Using a 6% discount rate, moving the minimum service level target from an IRI of 3.4 to 4.0 saves $51,000 (PV) in road authority costs (RAC) but this is more than offset by the increase in VOC of $162,000 (PV). In total, this means the proposed change in minimum service level target has a negative NPV of $111,000. The results under scenarios 1 and 2 are presented in table 5.2.

Table 5.2 Present value of proposed change in minimum service level (PV, '000s)

Scenario	IRI minimum service level	Vehicle operating costs	Road agency costs	Total costs
Scenario 1	3.4	$118	$200	$318
Scenario 2	4.0	$279	$150	$429
Difference	(0.6)	$(162)	$51	$(111)

5.5.4 Using CBA to determine 'optimal' level of service for roughness

The analysis above can be extended to different IRI targets to determine the optimal level of service for road roughness. The table below presents the corresponding road user costs, road authority costs and total costs under different IRI targets.

Road user costs decrease as an implemented IRI target becomes lower. The savings for road users diminishes as the IRI target becomes lower, eg, moving from 3.2 to 3.0 IRI results in a savings of $19,000 compared with $61,000 saving when moving from 3.4 to 3.2 IRI, reflecting the relationship between IRI and VOC.

The relationship between the IRI target and road authority cost is subtler. IRI target changes change road authority costs because they influence the timing and frequency of mill and resheet activities, which are non-linear in nature. For example, moving from an IRI target of 4 to 3.8 and 3.2 to 3 results in relatedly modest increases in road authority costs of $9,000 and $15,000 respectively. However, a move from 3.4 to 3.2 IRI results in an increase of $46,000.

Timing plays an important role in determining the PV of road authority costs. IRI target changes that result in moving mill and resheet activities forward in earlier years will have a larger increase in road authority costs in PV terms when compared with moving activities forward in later years.

In this illustrative example, an IRI target of 3.0 results in the lowest total costs of $299,000 whereas an IRI target of four results in the highest total cost of $429,000.

Table 5.3 Costs under different levels of roughness targets ('000s)

Cost type	IRI 3.0	IRI 3.2	IRI 3.4	IRI 3.6	IRI 3.8	IRI 4.0
Road user costs, PV	38	57	118	165	218	279
Road authority costs, PV	261	246	200	168	159	150
Total costs, NPV	299	303	318	334	376	429

5.5.5 Extending the analysis to other road types

The analysis above can be extended to determine the optimal roughness target for different road types. We demonstrate how this can be done for four different road types: urban arterial road, rural arterial road, urban other road and rural other road.

Table 5.4 AADT assumptions for different road types

Vehicle type	Urban arterial AADT	Urban other AADT	Rural arterial AADT	Rural other AADT
Passenger cars	15,000	3,000	10,000	1,000
LCV	1,000	600	400	200
MCV	500	75	1,000	100
HCV1	200	100	150	75
HCV2	200	100	150	75
Buses	50	10	40	6

Table 5.5 below sets out maintenance and road user cost results of IRI settings ranging from 3.0 to 4.0 rising in increments of 0.2 for four different road types using the same methodology as above. The costs are broken down into VOC and road agency costs.

Table 5.5 Present values for different levels of roughness targets and road types (PV, '000s)

IRI LoS	Cost type	Urban arterial	Urban other	Rural arterial	Rural other
3.0	VOC	$38	$7	$7	$1
	RAC	$261	$114	$261	$37
	Total	**$299**	$121	$268	$38
3.2	VOC	$57	$10	$24	$2
	RAC	$246	$107	$208	$33
	Total	$303	$117	$232	$35
3.4	VOC	$118	$18	$47	$4
	RAC	$200	$75	$170	$28
	Total	$318	$94	**$217**	$32
3.6	VOC	$165	$23	$71	$6
	RAC	$168	$71	$159	$25
	Total	$334	$95	$229	**$31**
3.8	VOC	$218	$29	$91	$8
	RAC	$159	$67	$153	$23
	Total	$376	$97	$244	$31
4.0	VOC	$279	$50	$126	$12
	RAC	$150	$39	$125	$21
	Total	$429	**$89**	$251	$32

The results above show the optimal service level as follows:

- The urban arterial road is an IRI of 3.0 costing $299,000, comprising $261,000 in VOC and $38,000 in RAC.
- The urban other road is an IRI of 3.4 costing $89,000, comprising $50,000 in VOC and $39,000 in RAC.
- The rural arterial road is an IRI of 3.4 costing $217,000, comprising $47,000 in VOC and $170,000 in RAC.
- The rural other road is an IRI of 3.6 costing $31,000, comprising $6,000 in VOC and $25,000 in RAC.

These optimal service levels represent the lowest total cost level of service setting for stakeholders given cost trade-offs between RAC and VOC. Ideally, the level of service should be set at these levels to minimise overall costs to stakeholders.

The key driver of the different roughness targets for the different road types is AADT and the fact that the relationship between VOC and IRI is different for urban and rural roads. AADT influences the number of users that incur additional costs, which means that changes in RAC have a higher effect on total cost. In addition, AADT, particularly when there is a high proportion of heavy vehicles, also increases the deterioration of the road, thereby influencing road authority costs. According to the EEM, the relationship between VOC and the IRI is stronger in rural roads than in urban roads. In other words, the savings rural road users achieve when there is a reduction in the IRI is higher on a per kilometre basis.

This example illustrates how the CBA framework can be applied to maintenance and renewal works using relationships between VOC and RAC. However, gaps in current literature mean other benefits of maintenance, such as safety and amenity, and other pavement condition measures, such as rutting and skid resistance, cannot be readily incorporated. It follows that the framework and accompanying analysis is a partial one and it is important to recognise setting appropriate level of services likely involves a wider consideration of other factors including amenity, safety, mobility and accessibility.

Future research on these dimensions of service in relation to user costs will allow a more complete analysis of marginal costs and benefits from changes to levels of service and road classifications. Instead of only a single measure of roughness affecting VOC as used in the case study above, composite measures capturing dimensions of amenity, safety, mobility and accessibility would inform road user costs. This would improve the analysis of road user costs with respect to a level of service provided by road agencies and better inform trade-offs between VOC and RAC in determining ideal target service levels.

5.6 What should the target level of service be for each classification of road across the entire network?

The target level of service for a road classification should ideally reflect a setting for which overall costs to stakeholders are minimised, and is absent of other non-economic considerations. The level to which costs are minimised will depend on road characteristics, the composition of traffic and traffic volumes. It follows that each class of road may have level of service target that is different from other road classes so the level of service provided by a road is fit for purpose for the vehicles that use the road. The level of service where stakeholder costs are minimised will balance agency costs and road user costs. Analysis using the proposed framework for maintenance and renewals can be undertaken for each road classification (and sub classification) to determine cost minimising levels of service for roads across the network.

6 Quantification framework for minor improvements

Minor work improvements fall under three main categories, namely:[11]

- safety activities and investments targeted at reducing crashes
- efficiency activities and investments targeted at reducing travel time for road users
- resilience activities and investments aimed at reducing the impact of unplanned events.

While minor work improvements are considered separately from other types of activities and investments, they are not an activity or investment class in their own right. Rather, minor works can involve maintenance and renewal activities, operations activities and capital investments. The distinguishing feature of minor work improvements is they involve relatively small amounts of funding.

The small-scale nature of these minor work improvements means the quantification framework needs to be pragmatic and not impose additional burdens on users. To achieve this, we have sought to develop the framework largely based on information that road authorities already provide under the existing assessment framework, or can be provide with relative ease. This chapter provides an overview of the objective of each minor works category, including the existing assessment framework, the theory underpinning the relevant benefits, and the proposed CBA framework.

6.1 Quantifying minor work safety activities and investments

6.1.1 Objective and current assessment framework

Minor work safety improvements are aimed at reducing the number of crashes, particularly crashes involving deaths and serious injuries. Typical minor work safety improvements include hazard removal, intersection improvements, and improving signage or pavement marking.

Currently the two key metrics used to assess minor work safety improvements are:

- total deaths and serious injuries saved over 10 years
- total deaths and serious injuries saved over 10 years per $100 million invested.

The most challenging part of the existing assessment framework is estimating the expected reduction in deaths and serious injuries. The commonly used approach is to first examine the number of reported crashes, identify the targeted crashes the activity or investment could help reduce, and examine the relevant reduction factors, using information from KiWiRap, EEM and other sources.

6.1.2 Social cost of road crashes

Road crashes represent a significant social cost to New Zealand, with the total social cost of injury and fatality crashes estimated to be $3.5 billion in 2014 (Ministry of Transport 2016). The most significant cost arising from road crashes is the lasting effect it has on the people involved (ie loss of life and permanent disability), representing around 91% of the social cost of injury and fatal crashes. Vehicle damage is the second largest

[11] This refers to projects that are funded under work category 341 of the NLTP. Minor work projects typically cost under $300,000 and are considered low risk.

cost component, representing around 5%, whereas medical, legal and cost fees, and lost work time while recovering from injury make up the remaining 4% of the social cost (Ministry of Transport 2016).

Naturally, the social cost of a crash differs significantly depending on the type of crash. The estimated cost per reported fatality or injury in New Zealand is around (Ministry of Transport 2016)[12]:

- $4.1 million per fatality
- $763,000 per serious injury
- $75,300 per minor injury.

6.1.3 Quantification framework and comparison with EEM

The proposed quantification framework for minor work safety improvements is relatively straightforward and can be calculated based on information that is already currently provided by road authorities. The proposed framework would involve:

- estimating the reduced number of fatalities and serious injuries
- multiplying these figures by the social cost per fatality and serious injury.

6.1.4 Illustrative study: seal widening to prevent unprotected drop-offs

6.1.4.1 Description of the road activity

Currently a key section of an arterial road does not have sealed shoulders to prevent unprotected drop-offs. It also has sub-standard intersection layouts, which further contribute to having more drop-offs. As a result, this section of the road has experienced a higher than normal rate of reported fatal and serious injury crashes in the past five years. To address the safety concerns, the road authority is considering widening the seal on the road and making upgrades to the clear zone and intersections.

6.1.4.2 Quantifying the costs and benefits

The sealing of shoulders and upgrades will cost $210,000 in the first year and then $21,000 in ongoing cost per year over the next 10 years. The activity is expected to reduce annual fatal crashes by 0.06 occurrences, serious injuries by 0.06 occurrences and minor injuries by 0.17 occurrences, after its completion.

The average cost of a reported fatality is around $4.1 million whereas the average cost of a reported serious injury is $763,000. Given this, the total crash cost saving is then estimated to be around $305,000 per year over the next 10 years.

6.1.4.3 Overall results

The benefits and ongoing costs have been modelled to continue for 10 years after the activity is completed. Using a 6% discount rate, the activity has a benefit/cost NPV of around $1.9 million and a BCR of 6.2. The NPV comprises $365,000 in activity (ie roading) costs and $2.2 million in crash cost savings.

[12] Inflated to June 2016 prices. These figures have been scaled up to account for under-reporting of crashes

6.2 Quantifying minor work efficiency improvements

6.2.1 Objective and current assessment framework

Minor work efficiency improvements are aimed at improving the flow of traffic, and delivering reduced travel time for road users. Currently, two key metrics used to assess minor work efficiency improvements are:

- average hours saved per person
- total person hours saved over 10 years per dollar invested.

Under the current framework, road authorities are required to estimate likely time saving per vehicle, the current level of traffic, and the increase in traffic by vehicle type after the activity or investment is implemented. The current framework also incorporates occupancy rate (eg a car is expected to have 1.2 occupants) to work out the total number of people the activity or investment is expected to affect.

6.2.2 Value of time saved and the rule of half

The EEM calculates the total travel time savings as the sum of base travel time benefits, incremental benefits during congested periods and benefits from improved travel time reliability. These concepts are discussed in further detail below.

6.2.2.1 Base value of time

The demand for travel generally arises from the need to go from one place to another. In other words, it is an activity that generally does not provide value itself and so travel time is assumed to be a cost. Given this, consumers are generally willing to pay for shorter travel times.

The willingness to pay for a travel time saving will depend on the nature of the traveller, the nature of the trip and the mode. For example, time saved could either mean more time for working, which would provide a monetary benefit to either the traveller or their employer, or more time for recreation activities, which delivers benefits to the traveller. Another relevant factor is how comfortable the trip is, eg, the more crowded or uncomfortable is trip is, the more willing a traveller is willing to pay for shorter travel times.

Given the above, it is common for transport economic evaluation guidelines to develop value of time estimates that vary depending on the mode of transport, the purpose of the trip and vehicle type etc. By way of example, the EEM (table A4.1) estimates the value of time for a car driver to be[13]:

- $32.9 per hour for trips related to work travel
- $10.4 per hour when commuting to/from work
- $9.2 per hour for other non-work travel purposes.

While value of time varies depending on a number of factors, it is common for economic guidelines to provide a value of time that represents a composite value of time that could be applied more generally. The composite value would typically reflect vehicle mixes and trip purposes etc to reflect the standard traffic composition of the road network. The most generic composite value of travel time provided in the EEM, section A4.4, is by road type, where the recommended values are around:[14]

- $22 per hour for urban roads
- $31 per hour rural roads.

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[13] Value of time estimates from the EEM and inflated to July 2016 values.

[14] Value of time estimates from the EEM and inflated to July 2016 values.

6.2.2.2 Incremental benefits during congested periods

As discussed above, the willingness to pay for travel time savings is linked to how comfortable the trip is. Given this, road users are generally willing to pay an incremental amount above the base value for time travel saved during congested periods.

Minor work efficiency improvements can deliver travel time benefits during congested periods and the EEM has developed a framework for estimating these benefits. However, the framework requires road authorities to provide conducted detailed analysis, such as of peak traffic intensity and volume to capacity ratio, before the incremental benefits can be estimated. The additional effort involved in estimating incremental benefits during congestion is unlikely to be justified given the small-scale nature of minor work improvements.[15]

6.2.2.3 Value from improved travel time reliability

Travel time reliability is a related but distinctly different concept to travel time savings. Road users typically include a ‘buffer’ by leaving earlier than usual when there is uncertainty around the travel time required. Often this means road users will arrive earlier than the required time but occasionally later than required. The required buffer is linked to the variability in travel time. Variability can be measured in many ways, including as the standard deviation of trip time, and the difference between the 90th percentile trip time and the average time.

Activities and investments that deliver travel time savings do not necessarily always improve travel time reliability (however they may do so). Estimating the benefits of travel time reliability is also significantly more complicated than estimated travel time saving since it requires knowledge of not just the change in average speed but also the change in the distribution of travel speed. We have not included improved travel time reliability in our framework given the small-scale nature of minor work efficiency improvements.

6.2.2.4 Rule of half of new users

It is common to apply the rule of half to calculate benefits that accrue to new users after the improvement (Litman 2017, p18). The rule of half assumes there will be new users who were just marginally discouraged from using a road before the improvement (and so would receive close to the full benefit) and there will be new users that are just marginally better off after the improvement (and so receiving nearly no benefits). Hence, on average it is assumed new users will receive half of the benefits.

We have included the rule of half in a framework given its potential effect on the size of benefits. Current information provided by road authorities can be used to separately calculate hours saved by new users and existing users so the rule of half can be applied.

6.2.3 Benefit quantification framework and comparison with EEM

The proposed framework and approach to quantify benefits for minor work efficiency improvements is as follows:

- Road authorities estimate the likely time savings for existing users and new users separately.
- The time savings is multiplied by the relevant composite value of time estimates based on the relevant road type for the activity or investment.
- The rule of half is applied for new users.

[15] An example of such an operations activity is changing the phasing of a set of traffic lights at a particularly problematic intersection. This project would not require significant resources, but would deliver reduced travel time benefits. Measurement and analysis of the activity’s effect on congestion would likely take more resources than the initial activity itself.

The framework does not require road authorities to provide any additional input other than specifying the relevant road type for the activity or investment. However, it does require adjustments to the existing assessment spreadsheet so time saved by users can be generated automatically.

The use of composite values represents a simplified approach when compared with full procedures under the EEM. However, this should provide a reasonable approximation that is appropriate for the small-scale nature of minor work improvements. Excluding incremental benefits during congested periods and travel time reliability benefits means the the framework is conservative when compared with evaluations that include these benefits.

6.2.4 Illustrative efficiency activity: reprioritisation of traffic

6.2.4.1 Description of the road activity

An urban primary collector road merges with a local access road to form one road. Currently, the local access road, with an AADT of 500, has lower traffic volumes but has priority over the primary collector road, which has an AADT of 2,500. The activity involves remarking and redesigning the layout so the primary collector road has priority access instead.

6.2.4.2 Quantifying the costs and benefits

The activity is expected to cost $100,000 in the first year with $10,000 ongoing costs in following year.

It is anticipated the change in priority will result in an approximate 40 second time saving for vehicles travelling on the primary collector road, at the expense of a 40 second delay for vehicles travelling on the local access road. It is also expected the AADT on the primary collector would increase by 100, to 2,600 after undertaking the activity. In total, the total time saving benefit is estimated to be around $212,000 per year, as follows:[16]

- Existing users of the primary collector are expected to save 11,900 hours per year, which equates to time saving benefits of $259,000 per year.
- New users of the primary collector are expected to save 475 hours per year, which equates to time savings benefits of around $5,000 per year after the rule of half is applied.
- Existing users of the access road are expected to continue their use of the road and incur an additional 2,400 hours per year, which equates to time cost of around $52,000 per year.

6.2.4.3 Overall results

The benefits and ongoing costs have been modelled for 10 years after the activity is completed. Using a 6% discount rate, the activity has an NPV of around $1.4 million and a CBR of 9.0. The NPV comprises $174,000 in costs and $1.6 million in time saving benefits.

[16] Time savings/delays in seconds are calculated as relevant AADT x 365 (days) x 40 (seconds) x 1.2 (average occupancy of a vehicle). This is then converted to hours saved and multiplied by the composite value of travel time for an urban other road. The analysis implicitly assumes that only passenger vehicles use the road but can easily be expanded to incorporate other vehicle types. The cost estimates have also been inflated to 2016 dollars, which has been done using CPI series from Statistics New Zealand.

6.3 Quantifying minor work resilience activities and investments

6.3.1 Objective and current assessment framework

Minor work resilience improvements are aimed at reducing the impact of a road closure due to unplanned events. This can be done by either reducing the duration or effect of a closure or reducing the chance that a closure occurs. An example of a resilience activity or investment includes preventing rocks falling on to the road or bridge scour.

The Transport Agency currently assesses minor work resilience improvements using two metrics:

- a maintenance priority index, which compares the expected cost of the do-nothing option with the cost of the project [17]
- a security factor, which is based on the expected additional travel that would result from an adverse event[18].

To calculate the measures above, road agencies are required to assess the probability of the unplanned event occurring, identify the alternative route, examine the likely number of vehicles that would be affected and the cost of reinstating the road in the event of a closure.

6.3.2 International literature

In contrast to the benefits of safety and time savings, the benefits of resilience are not directly covered by EEM and associated literature is less common. However, literature discussing how adverse events are costed can inform us on how resilience metrics currently used to assess minor resilience works can be adapted into a CBA measure.

A practical example can be found in the Queensland Department of Transport and Main Roads' (TMR 2011, pp2.22–2.23) CBA manual, which among other things provides guidance to measuring the cost and benefits of flood proofing projects. The approach adopted by TMR compares the avoided costs of traffic delay or diversion due to flooding. Diversion and delay costs that would be saved by improving access are then estimated. The delay or diversion costs saved represent the benefits from flood proofing works.

6.3.3 The economic cost of a road closure

The economic cost of a road closure depends on how the behaviour of drivers would change as a result of the closure. The possible reactions of a road closure are the driver:

- uses an alternative route to get to the destination, which most likely involves additional travel time and distance travelled
- waits until the road closure finishes and then travels to the destination
- no longer travels to the destination.

Where there is a viable alternative route, the most likely driver reaction is to use the alternative route since additional costs are likely to be small, especially if the driver has already commenced the trip. Waiting until road

[17] More specifically, the maintenance priority index is calculated as the ratio of the expected cost of the do-nothing option to the cost of the option.

[18] Security factor is calculated as the product of the probability of the event occurring, the probable number of days of full road closure, the detour length and the amount of disrupted traffic.

closure finishes or no longer travelling are likely to be higher cost options but would be relevant if the road closure is widespread or there is no viable alternative, eg, detour is too long or does not exist.

Given the above, it is common for CBAs to assume the base case is a driver who uses an alternative route. It is also easier to understand the implications of using an alternative route, and so calculate the additional cost associated with a road closure. The two main costs of using an alternative route are the additional travel time and VOC that would be incurred as a function of the road service on the alternative route.

Table 6.1 Costs caused by flood disruption dependent on traffic behaviour

Road user behaviour	Flood impact/cost
Divert The user utilises an alternative route around the flood affected area.	Increase in travel time costs Increase in VOC Increase in crash exposure costs Increase in external costs
Wait The user remains at the flood site and waits for waters to subside.	Incur waiting cost
Does not travel	Cost of not undertaking the trip

6.3.4 Quantification framework and comparison with EEM

The proposed CBA framework for minor work resilience improvements is similar to the current assessment metrics. It involves examining:

- the additional economic cost of detours, which can be calculated using:
  - the number of trips affected
  - the reduced probability of a road outage occurring and the length of outage
  - the additional travel time and VOC per trip.[19]
- the expected avoidable cost associated with reinstating the road, which can be calculated using:
  - the reduced probability of a road outage occurring
  - the cost of reinstating the road in the event of an outage.

The above framework can be largely implemented using information that users currently provide under the existing assessment framework. The only additional information required is the road type and average speed of the original route and the alternative route, which should be relatively easy for road authorities to provide.

6.3.5 Illustrative resilience investment: constructing a fence to prevent rock fall

The investment involves an urban arterial road with an AADT of 3,700. A 10 km section of this road is sometimes closed because of rock falls. Past history suggests there is an 80% chance of a road closure due to rock fall each year. In the event of a rock fall, the road is closed for one day and it costs the road authority $110,000 to reinstate the road. The alternative route is 14 km along a local urban road.

6.3.5.1 Quantifying the costs and benefits of constructing a fence

[19] These could be estimated by using parameters in the EEM and specifying the road type, travel speed and length of trip for the original and alternative trip.

With the fence in place, closures due to rock falls will no longer occur. The investment involves $125,000 costs in the first year to build the fence and $12,500 ongoing cost per year to maintain the fence and clear any build-up of rocks over time.

The two key savings from the investment are the avoided cost from reinstating the road when a rock fall occurs and avoided cost of detours for road users. The avoided cost of reinstating the road can be calculated as $88,000 per year ($110,000 x 80%).

The expected number of trips affected each year from outages is 2,960[20]. In the event of a road closure, road users will need to use an alternative urban local road (which involves a 14 km trip at an average speed of 50 km/h) instead of the original route (which is 10 km trip at a speed of 90 km/h). Given this, the cost per trip is[21]:

- $5.31 dollars for the original route, comprising $2.89 of VOC and $2.42 of time costs
- $10.56 dollars for the alternative route, comprising $4.02 of VOC and $6.53 of time costs.

In other words, the additional cost arising from using the alternative route is $5.24 per trip, which is the difference between the cost of the alternative route ($10.56) less the cost of the original route ($5.31). This means the expected cost of detours each year is nearly $7,000 each year (1,295 trips multiple by $5.24).

6.3.5.2 Overall results

The investment is expected to take one year to complete. The benefits and ongoing costs are expected to continue for 10 years after the investment is made. Using a 6% discount rate, the investment has a NPV of around $116,000 and a BCR of 1.5. The NPV of $116,000 comprises (all in PV terms):

- $217,000 in total costs, consisting of $125,000 of upfront costs and $92,000 (set aside upfront at 6%) for ongoing costs (all expressed in NPV terms)
- road user savings of around $50,000, including $11,000 of VOC savings and $39,000 of travel time savings
- $283,000 of avoided reinstatement costs.

Table 6.2 Cost- benefit analysis for resilience investment

Benefit cost category	NPV over 10 years
Vehicle operating cost savings	$11,000
Time savings	$39,000
Avoided reinstatement costs	$283,000
Total benefits	**$333,000**
Total costs	**$217,000**
NPV	$116,000
BCR	1.5

[20] This is calculated as the product of the average number of closures each year (0.80), AADT (3,700) and the average days of closure (1 day).

[21] This is calculated using the length of the trip, the average speed, and the composite value of time and vehicle operating cost for the relevant road type. EEM provides vehicle operating costs per km estimates for urban arterial and other urban roads for different average speeds and gradients. We have assumed an average gradient of 3 for both roads. The cost estimates have also been inflated to 2016 dollars.

7 Quantification framework for operations activities

This section sets out the nature of operations activities, the proposed quantification framework and a case study that uses the proposed framework. It also draws upon the findings of our stage 1 research.

7.1 The nature of operations activities

Operations activities related to the day-to-day management and operation of the transport system play an increasingly important role as technology continues to improve. The broad nature of operations activities means they encompass a wide variety of potential activities. In New Zealand, regional transport operations centres are primarily responsible for operations activities in major urban areas. Examples of typical operations activities include:

- ITS optimisation activities (eg SCATS signal optimisation, ramp signalling system operation)
- incident management (eg alteration to ITS systems to prioritise routes)
- ITS network operation and management systems (eg speed management, automated safe systems)
- providing travellers better information (eg website mapping, travel time information, network status information and updates).

Assessment of operations activities in New Zealand and overseas tend to be post-implementation evaluations (Wilmshurst and Wallis 2016, p8). This reflects the agile environment that transport operations centres work in and the fact that operations activities are often perceived to have low costs and a high BCR.

7.2 International assessments of operations activities

As noted above, international assessments of operations activities tend to be post-implementation rather than pre-implementation. However, pre-implementation appraisals are more common where they are required as part of a funding process. To ensure operations activities are not disadvantaged in funding allocation decisions, the US Federal Highway Administration has two publications to assist road authorities when applying CBA to operations activities:

- FHWA (2012) *Operations benefit/cost analysis desk reference*: while this publication does not provide detailed procedures like those in the EEM, the desk reference does provide a discussion of what costs and benefits might be considered when undertaking a CBA appraisal of operations activities.
- FHWA (2015) *Transportation systems management and operations benefit-cost analysis compendium*: this publication provides examples of CBA appraisals across several operations activities.

The literature review identified that the benefits arising from operations activities can vary significantly depending on the nature of the activity. That said, the typical objectives for road operations activities are:

- improving the flow of traffic, leading to travel time savings (eg signal optimisation)
- improving road safety outcomes (eg, speed management and automated safety systems)
- encouraging road users to use the best alternative route, either because an unplanned event has occurred (eg incident on a highway) or a section of a road is particularly congested.

We present two US case studies in box 7.1 and box 7.2, which use the CBA framework for evaluating operations activities.

Box 7.1 Case study 1: Cincinnati Region ARTIMIS Study (FHWA 2012, pp22–24)

The Ohio-Kentucky-Indiana Regional Council of Governments (OKI)[22] performed a pre-implementation appraisal of the benefits of their regional traffic management and traveller information program, known as ARTIMIS to justify funding for the program's expansion. The ARTIMIS program consists of transportation system management and operation strategies in the region, including:

- regional traffic operations centre
- traffic surveillance
- Incident management and freeway service patrols
- traveller information
- dynamic messaging sign and highway advisory radio among other applications.

OKI undertook a CBA of the program to justify funding under the regional transport plan and compare it to a more traditional capacity improvement project of adding a lane. Comparability to traditional capacity improvement projects was an important factor in identifying benefits generated by the ARTIMIS program, which included improvements in travel time, travel time reliability, safety, fuel use and emissions. A combination of OKI's regional travel demand model and ITS Deployment Analysis System software was used to assist with quantifying costs and benefits of the ARTIMIS program.

Table 7.1 Comparison of ARTIMIS operational projects with a traditional roadway widening project

Selected measure	ARTIMIS	Added lane project
Miles of improvements	88	10
Fatal crashes	Decrease of 3.2%	Increase of 0.3%
Time saving	500 hours	800 hours
Travel time reliability saving	6,900 hours	5,800 hours
Emissions	Decrease of between 3.6% to 4.5%	Increase of 0.3% to 1.4%
Estimated annual benefit	$53 million	$35 million
Total project cost	$40 million	$800 million
Benefit-cost ratio	12	1.1

The CBA results showed that, when compared with adding a lane, the ARTIMIS program provided higher economic benefits ($53 million of annual benefits compared with $35 million) at a fraction of the cost (total project cost of $40 million compared with $800 million). The CBA analysis helped identify the program as a high priority project in the region's transport plan and provided ancillary information about the net benefit of deferment of costly road network expansions.

[22] Ohio-Kentucky-Indiana Regional Council of Governments is the Metropolitan Planning Organization (MPO) for the Cincinnati, Ohio region.

Box 7.2 Case study 2: Oregon's automated wind warning system (FHWA 2015, pp170–176)

Oregon and California departments of transport (ODOT and Caltrans, respectively) deployed ITS installations called automated wind warning systems (AWWS) on South Coast and Yaquina Bay Bridge systems along US Route 101. The objective of AWWS was to alert motorists of dangerously windy conditions, which was expected to reduce crashes and improve efficiency.

To demonstrate the economic case for the system, the ODOT undertook a CBA of the project. The appraisal was informed by analysed crash data, motorist survey results, operational cost assessments and implementation costs. Table 7.2 shows the results from the CBA appraisal of installing AWWS at the two locations on Route 101.

Table 7.2 Annual costs benefits for automated wind warning systems

	South Coast	Yaquina Bay Bridge
Benefits		
Direct savings from non-closure of bridges	$5,135	$11,940
Delay reductions from non-closure of bridges	$41,715	$242,570
Delay reductions from quick deactivation	$2,980	$18,960
Costs		
Initial installation cost (non-recurring)	$90,000	$90,000
Power, communications, maintenance (recurring)	$3,000	$3,500
Benefit- cost ratios		
Direct benefits alone	0.87	1.46
Direct and indirect benefits	4.13	22.8

ODOT's CBA appraisal of AWWS and found BCRs of between 4.13 and 22.8 depending on the section of Route 101 considered, indicating AWWS offered significant cost savings to drivers as well as to ODOT.

7.3 Proposed framework for operations activities

In many ways, these objectives are similar to objectives of minor work improvements. Minor work efficiency improvements are aimed at improving flow of traffic, and so reducing travel time for road users. Minor work safety improvements are aimed at addressing safety issues on the road network, and so improving road safety outcomes. Minor work resilience improvements are aimed at reducing the impact of road closures, so road users can travel on the best available route.

In addition, the framework for operations activities needs to be implemented to fit the agile and low-cost nature of operations activities, also a relevant consideration for minor work improvements. Operations activities are considered on a case-by-case basis rather than from a service level perspective, which is also similar to minor work improvements.

Consequently, we propose to use the same quantification framework developed for minor works for operations activities. The proposed framework for operations activities depends on the objective, or objectives, of the activity. For activities that:

- improve road safety outcomes, road authorities will need to estimate the reduced number of reported fatalities and serious injuries, which can then be used to quantify the benefits using available information on the average social costs of these crashes
- improve traffic flow, road authorities will need to estimate the travel timed saved for existing and new users, which can then be quantified using value of time estimates in the EEM

- encourage the use of the best alternative route, road authorities will need to estimate the number of vehicles that are likely to switch, the characteristics of the original and best alternative route (ie length of trip, road type and average speed), which can be quantified using value of time and VOC estimates in the EEM.

Adopting the framework above would ensure the economic evaluation for road operations and minor work improvements are consistent. Road authorities can potentially use relevant tools and guidelines developed for minor work improvements to help with estimating the required input needed to apply the framework. However, we note that evaluating the benefits of providing travellers with better information will be particularly challenging given the difficulties in estimating the number of vehicles that would change behaviour and defining what the original or best alternative route is.

8 Conclusions

This research report examined how benefit and cost appraisals for road operations activities, maintenance and renewal activities, and minor work improvements could be undertaken in a manner comparable with the appraisal framework for capital investments. This provides decision makers with a holistic view across different activity and investment types to identify a portfolio of opportunities that offers value for money and meets its service level targets. In addition, the research answers several related questions, namely:

- What should the target service level for the road network be?
- What are the marginal benefits and costs of changes to the service level target?
- What is the optimal allocation of resources between activities and investments that improve resilience, safety, and efficiency outcomes, using minor work improvements as an example.

8.1 Setting the desired target service level

Road authorities often set or are delegated with target service levels in the form of outcome performance measures and targets to monitor whether the road network is meeting the needs of end users and the community. The setting of outcome performance targets is more of 'an art rather than science'. Although targets could be determined quantitively using frameworks such as CBA, they often reflect aspiration targets of the decision maker. The service level target should reflect the priorities of the users and society, and be measurable so the progress can be monitored over time. The target should also be challenging yet achievable. Put another way, the purpose of setting a target is to motivate road authorities and their delegated agent to achieve a goal they otherwise may not achieve in the absence of the target.

Most road authorities have a fixed budget for the transport or road network. Within this context, aiming for a more ambitious target in one outcome area, say safety, means, in theory at least, there would be less focus and available budget to achieve outcomes in other areas, say amenity and mobility. In short, increasing the service level target for one performance area will likely reduce outcomes in other performance areas unless the available budget also increases.

8.2 The proposed approach to selecting an 'optimal' portfolio of investment opportunities and the marginal benefits and costs of changes to the service level target

The portfolio approach selects a collection of investment opportunities that maximises the NPV of benefits less costs of the portfolio given a budget constraint, the service level target, and the CBA of individual activities and investments. This approach provides road authorities with a practical tool for allocating limited funds among investment opportunities that may aim to achieve different specific objectives, within the context of being in the interest of society more generally.

The proposed approach involves a five-step process that first rules out activities and investments considered too risky, not effective, or do not align with the strategic objectives of the decision maker. It then requires undertaking costs and benefits for each activity or investment using consistent assumptions and inputs across all estimates that generate the NPV of benefits and costs for each activity or investment. Parameters are set to reflect budget constraints and desired service levels, which feed into determining the optimal portfolio of investment opportunities.

This proposed approach provides a method to systematically align a portfolio of activities and investments with a road authority's organisational objectives. Furthermore, the analysis of portfolios with and without level of service targets provides an effective way to evaluate the marginal cost (or benefit) of service levels, which can be calculated by taking the difference in NPVs between portfolios with differing service level targets.

8.3 Developing a fit for purpose CBA framework

To implement the proposed framework in obtaining the optimal portfolio, a fit for purpose CBA framework was developed for minor work improvements, road operations activities, and maintenance and renewal activities. The framework and relevant inputs were designed to closely align with current methodology for evaluating capital investments so that results are comparable

The framework developed for minor work improvements and operations activities is robust and could be readily applied. The key benefits arising from these activities are mainly improved safety outcomes, improved travel time savings, and reduced user costs from using a better route. These benefits are covered by existing literature and evaluation guidelines. In contrast, the framework developed for maintenance and renewal works illustrates how a CBA framework could be applied to estimate the marginal benefits and costs of changing the levels of service targets and identifying the appropriate target level of service for a road classification. The framework for maintenance and renewal works focused on the interaction between the target for road roughness, road authority costs, and vehicle operating costs for road users. Existing gaps within the literature meant the framework does not yet capture other benefits associated with maintenance and renewal works, such as safety and amenity benefits, or include other condition measures, such as rutting and skid resistance.

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Appendix A: Overview of the CBA toolkit

This appendix provides a brief overview of the CBA toolkit and optimisation features adopted to implement the portfolio approach. A more complete description of how the CBA toolkit should be used can be found in the CBA toolkit itself, which is attached separately as appendix B at www.nzta.govt.nz/resources/research/reports/631.

A1 Structure of the toolkit

The CBA toolkit is structured in two main sections: inputs tabs and calculation tabs. Input tabs enable the user to enter relevant inputs and parameters into the toolkit, while calculation tabs cover inputs and parameters entered by the user into CBA results. The minor works and operations tabs and maintenance tabs demonstrate how the CBA works for an individual project. The portfolio tabs demonstrate how the portfolio approach could work, using minor works and operations activities as an example.

Table A.1 Key user input tabs in the tool kit

Activity or investment type	Input tabs	Tab colour	Tab description and key user inputs required
Minor works & operations – individual improvements	I1 Minor works and operations	Yellow	Inputs and parameters for minor works. For safety related activities or investments, inputs relate to timing, cost and death/injury avoided assumptions. For resilience related activities or investments, inputs relate to timing, cost, route length and speed assumptions. For efficiency related activities or investments, inputs relate to timing, cost and hours saved assumptions.
Maintenance	I2 Maintenance	Yellow	This tab set out required inputs for maintenance CBAs including: • traffic profiles and road types • service level scenarios.
Minor works and operations portfolio	I3 Portfolio	Yellow	This tab enables the user to input the same parameters as those in the I1 Minor works & operations tab but for 40 different projects.

In addition to these input tabs listed above in table A.1, the user can input discount rate and escalation factors common to all calculations into the I0 Overall tab. I4 Detailed VOC assumptions contains the detailed VOC assumptions that are used in the CBA and portfolio calculations.

Information from the input tabs are used for calculating costs and benefits from various types of activities and investments. There are described in table A.2.

Table A.2 Calculation tabs in the tool kit

Activity or investment type	Calculation tabs	Tab colour	Tab description
Minor works and operations	C1 Minor works and operations	Blue	Calculates individual CBA results for safety, resilience and efficiency related activities and investments including benefits, costs, NPVs and BCRs.
Maintenance	C2 Maintenance	Blue	Calculates road authority costs and road user costs under different scenarios and IRI profiles.
Minor works and operations portfolio	C3 Portfolio	Blue	Calculates CBA results for 40 activities and investments and selects the 'optimal' mix of activities and investments given a budget constraint and level of service improvement requirements. Optimisation of the portfolio utilises the Solver function, described in the next section. Outputs are also presented here in a dashboard that describes portfolio NPV, BCR, projects funded and funds used/remaining.

A2 Optimising a portfolio using the Solver function

The C3 Portfolio tab utilises the Solver function that comes with Microsoft Excel. The Solver function is contained in an add-in called Solver that can be used to optimise a set of projects in order to maximise overall NPV given constraints. The Solver add-in can be found in the 'Data' ribbon under 'Analysis' once it has been installed. The solver requires three main inputs:

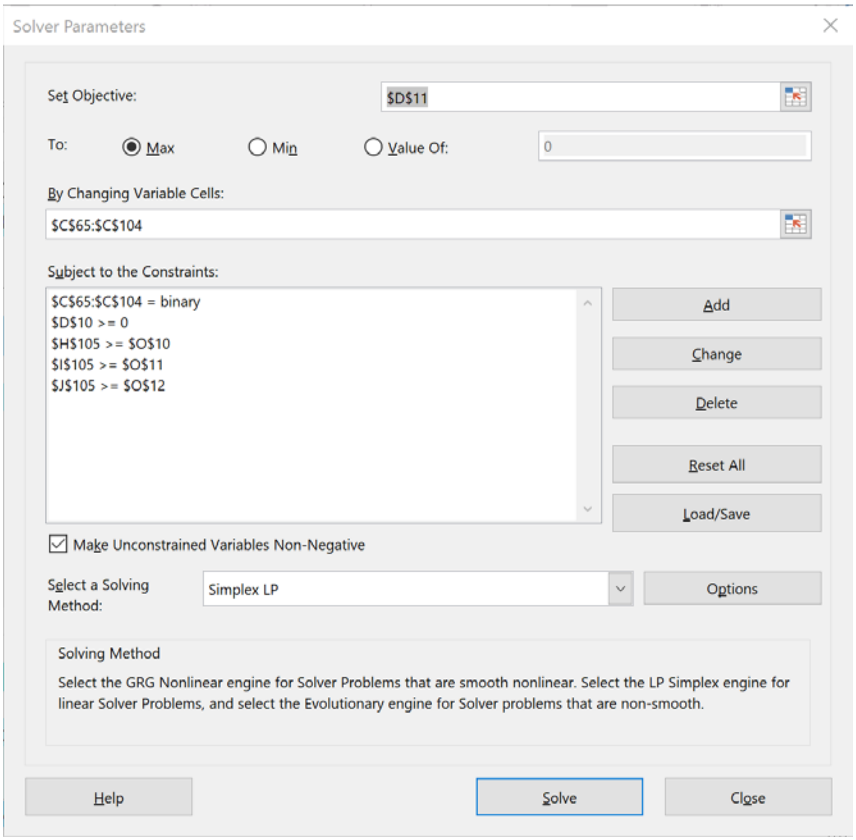
1 **The objective**: this instructs the Solver what needs to be minimised or maximised. In the case of solving for the optimal portfolio of projects, the objective is to maximise portfolio NPV.

2 **Variable to change**: this instructs the Solver what it can change in order to undertake its optimisation process. The CBA tool sets this to '0/1' or 'on/off' switches that enable the Solver to include or exclude any individual project.

3 **Constraints**: one constraint required for the optimisation sets the boundaries within which the Solver is required to operate the optimisation process. The two key constraints are the amount of funds available for the portfolio (ie, budget constraint) and the service improvement target. Another constraint required for the optimisation is concerned with the values the Solver is able to use for the 'variable to change'. The CBA tool sets this constraint to require the solver to use only binary values (ie 0 or 1), which has the effect of excluding or including individual projects.

Figure A.1 shows the Solver interface with each of the above three elements.

Figure A.1 Solver interface



The Solver finds the optimal combination of projects by testing different combinations of individual projects in order to maximise portfolio NPV. The CBA tool has the inputs for the Solver set up in a way that allows users to input the relevant parameters on road characteristics and traffic profiles then run the Solver by using the 'Optimise portfolio' button labelled 'Start'.

If the Solver is unable to produce the optimal portfolio using all possible inputs, an error message will occur. There are two situations where this might occur:

- insufficient funds (ie budget constraint is set too low) to achieve the required service level targets, or alternatively stated, service level targets are too high given the budget constraint
- the set of possible activities and investments is not able to deliver the required service level target.

Where one of these situations apply, the user may wish to re-evaluate inputs for the budget constraint, service level targets or assumptions for individual activities and investments.

Appendix B: Cost- benefit analysis tool

Appendix B can be accessed at www.nzta.govt.nz/resources/research/reports/631.